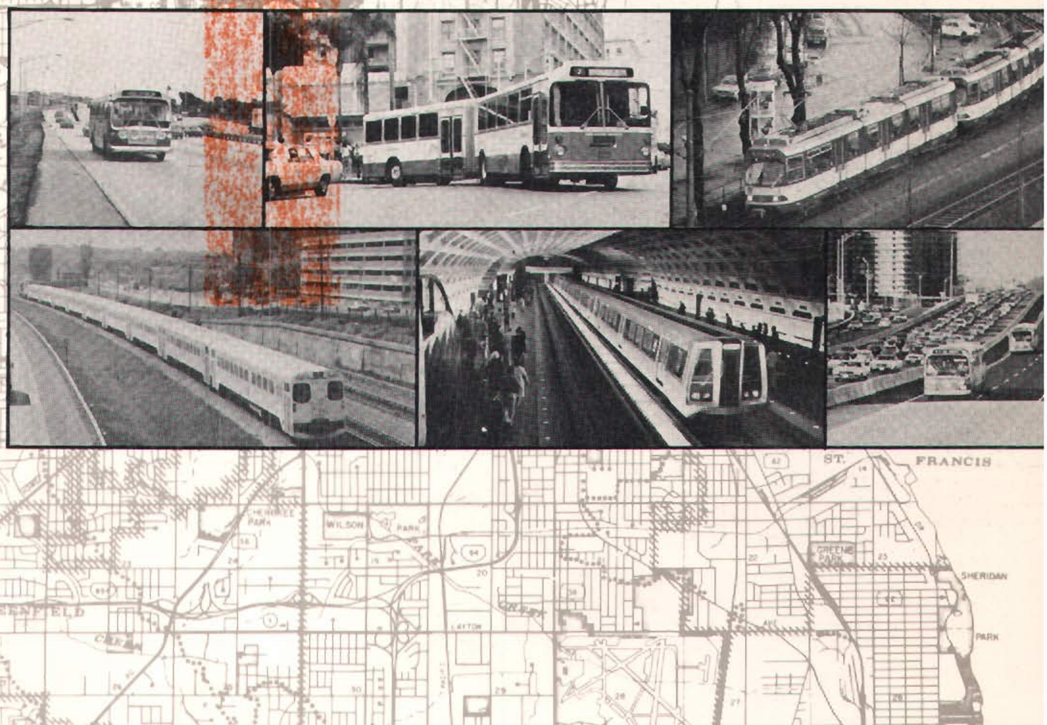
TECHNICAL REPORT NUMBER 24

STATE-OF-THE-ART OF PRIMARY TRANSIT SYSTEM TECHNOLOGY



SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

Special acknowledgement is due Mr. Otto P. Dobnick, SEWRPC Senior Planner, for his contribution to the preparation of this report.

Cover photographs courtesy of City of Milwaukee, Bureau of Traffic Engineering; San Diego Transit; Siemens Corporation; Otto P. Dobnick; Washington Metropolitan Area Transit Authority; and Northern Virginia Transportation Commission.

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STATE-OF-THE-ART OF PRIMARY TRANSIT SYSTEM TECHNOLOGY

Prepared by the
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SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

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STATEMENT OF THE EXECUTIVE DIRECTOR

At the request of Milwaukee County, the Southeastern Wisconsin Regional Planning Commission in March of 1979 undertook a study to determine the best means of providing rapid transit service within the greater Milwaukee area. The objectives of the study—termed in federal planning jargon a primary transit system alternatives analysis—were: 1) to identify those corridors within the greater Milwaukee area which can support fixed guideway transit facility development; and 2) to identify those transit modes which can best provide such service within those corridors. These objectives required the Commission to reevaluate the feasibility of providing rapid transit service within the greater Milwaukee area by bus on freeway, bus on metered freeway, bus on reserved freeway lanes, bus on busway, and heavy rail rapid transit, as well as by light rail transit and commuter rail.

Urban transportation systems, by their very nature, consist of large physical plants. Whether already existing or newly constructed or acquired, the components of such physical plants include vehicles, guideways, stations, propulsion subsystems, traffic control subsystems, provision for the maintenance and repair of the vehicles and fixed plant, and methods of fare collection. In any long-range primary, or rapid, transit system planning process, it is not only necessary to have definitive knowledge of the physical characteristics of each of the primary transit modes which may be potentially utilized, but it is also necessary to have an understanding of the performance capabilities, operating and capital costs, and potential impacts on the surrounding environment of each mode. This knowledge is vital to the formulation of alternative primary transit system plans and to their test and evaluation, so that a final system plan can be selected that will best serve the area.

Accordingly, this technical report presents the findings of an inventory of the state-of-the-art of primary transit technology as applicable to the Milwaukee area. This inventory identifies those public transit modes considered to have potential for the provision of primary transit service in the Milwaukee area within the next two decades. In all, a total of eight different transit modes have been identified under the major categories of motor bus technology, rail transit technology, and electric trolley bus technology as being proven and readily available for application. Also identified and described are those technologies considered to be inappropriate for reasons of obsolescence or lack of sufficient demonstrated performance. Each of the potentially applicable modes is defined and described in terms of the physical characteristics of vehicles, guideways, stations, and support facility requirements. Each mode is also addressed in terms of its performance attributes and capabilities, economic characteristics such as capital and operating costs, and energy consumption.

This technical report thus provides all the primary transit technology-related information required for systems-level plan design, test, and evaluation in the Milwaukee area. The substantial body of information contained in this report represents the contribution of a large number of knowledgeable people affiliated with the planning, design, manufacture, construction, and operation of primary transit systems and components around the world. The Regional Planning Commission is particularly appreciative of the assistance provided by these people in affording a better understanding of the available alternatives for the provision of primary transit service in the Milwaukee area.

Respectfully submitted,

Kurt W. Bauer
Executive Director

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Chapter I

INTRODUCTION

When considering the potential application of primary transit facilities in an urban area, definitive knowledge of the physical, operational, and economic characteristics of available alternative primary transit technologies is required. The physical characteristics of a primary transit system relate to the vehicles, guideways, stations, and other attendant support facilities; the operational characteristics relate to system performance and capacity; and the cost characteristics relate to capital and operating costs. This report presents definitive data on these characteristics for the various primary transit technologies considered applicable to the Milwaukee area. These data are presented in sufficient detail for system planning purposes. The data are derived from existing primary transit systems in other urban areas, primarily of the United States and Canada, and, to the maximum extent possible, are based upon information documented in published reports.

DEFINITION OF TERMS AND SCOPE OF TECHNICAL REPORT

Only the technology of primary transit systems is addressed within this report. Public transit modes that function principally in local and in collection and distribution service and that are characterized by relatively low operating speeds and high passenger accessibility are not addressed except insofar as interface with the primary transit system may be involved.

Primary public transit service is defined as that component of the urban public transit system that provides relatively high-capacity, high-speed service in the most heavily traveled corridors of a transit system service area. The operating speeds provided are the highest of those provided by the public transit system concerned; the trip lengths served are the longest; and the distance between stops is the farthest. The basic purpose of primary transit service is to facilitate intercommunity travel by providing a network of relatively high-speed facilities that link major regional activity centers—commercial, industrial, institutional, and recreational—to each other, as well as to major concentrations of residential development. Primary transit is that component of the public transit system particularly directed toward alleviating peak-hour loadings on major highway facilities and reducing parking demand in major activity centers.

The specific primary transit modes addressed in this report include: motor bus operation on exclusive busways, on reserved freeway lanes, in mixed traffic on freeways, and on reserved arterial street lanes; light rail transit; heavy rail rapid transit; commuter rail service; and electric trolley bus systems. Appropriate vehicles for each of the modes are discussed, including currently available motor coaches, electric trolley buses, light and heavy rail vehicles, and commuter rail rolling stock. Other modes that either are as yet still in an experimental stage, such as automated guideway systems and personal rapid transit systems, or have limited applicability, such as monorail systems, are also addressed but in less detail than the more conventional and proven modes. Also to be included in the discussion of experimental technologies are propulsion systems, or modifications of systems, not yet in wide use in the United States, such as flywheel energy storage systems.

This report also necessarily limits the range of consideration of each primary transit mode to the characteristics of its current "state-of-the-art"; that is, to the characteristics of the mode as actually recently constructed, improved, or expanded in other urban areas. Because the modes considered must be implementable within a period of 10 to 15 years, the data presented herein, in addition to excluding characteristics of systems constructed to obsolete or outmoded standards, exclude characteristics that may be attributed to unproven modes still in the experimental stage.

A large number of primary transit systems are in existence and under construction throughout the world today. In this report, each mode is described in terms of the range of characteristics displayed by a limited number of recently completed systems or systems under construction. This limited number of systems was selected to best typify that mode, particularly as it might be applied in the Milwaukee urban area. Thus, the systems from which the data herein presented were derived are believed to best represent the current state-of-the-art of primary transit technology as applicable to the Milwaukee area.

SCHEME OF PRESENTATION

This report is divided into six chapters. Chapter II, "Motor Bus Technology," and Chapter III, "Rail Transit Technology," provide the data on the physical, operational, and economic characteristics of these two transit technologies as required for systems planning. These two chapters begin with a discussion of each technology's current application, including a description of the technology's most important attributes, its evolutionary development, and its current role. The first section of each chapter specifically addresses the physical characteristics of the vehicles, guideways, stations, and attendant support facilities. The presentations on the physical characteristics of the vehicles include descriptions of the pertinent dimensions, weights, means of passenger access, capacity, suspension, maximum speed, acceleration and deceleration characteristics, noise and pollutant emissions, fuel efficiency, and useful life. The sections on guideways include information on cross-sectional dimensions, vertical and horizontal alignment and clearances, signalization or other traffic control systems, route flexibility, and useful life. With respect to station and support facility requirements, information on dimensions, spacing, fare collection, and interface with other modes is presented, along with information on vehicle storage and maintenance facility requirements, guideway and station maintenance requirements, and power supply requirements.

The next section of Chapters II and III documents the performance characteristics of each primary transit technology, including vehicle operating and system average speeds, headways, station dwell times, and system capacity. The performance of each technology is discussed in the context of the overall system or facility performance.

The last section of Chapters II and III presents data on the economic characteristics of the technologies, including initial capital costs of right-of-way, guideway, vehicles, stations, and support facilities, and system operating costs.

Chapter IV, "Electric Trolley Bus Technology," provides the data on the electric trolley bus pertinent to primary transit systems planning in the Milwaukee area. This chapter includes a discussion of the application of this mode and presents data on the technical, performance, and economic characteristics of electric trolley bus systems. The chapter is arranged in a format similar to that of Chapters II and III.

In Chapter V, "Other Transit Technology," other primary transit technologies are considered. Because these technologies are not suited for implementation within the Milwaukee area within the next 15 years, the discussions on them are not as detailed as the discussions on the motor bus and conventional rail technologies.

Chapter VI summarizes the findings of the inventory of the state-of-the-art of primary transit technologies as presented in the report, compares the principal applicable technologies, and high lights similarities and differences between these technologies.

This technical report is the second of two such reports that present the major findings of the inventory phase of the Milwaukee area primary transit system alternatives analysis. The first of these two technical reports presented data on the demographic and economic characteristics of the Milwaukee area, on land use development within that area, on the travel habits and patterns and public financial resources of the area, on existing and proposed transportation facilities in the area, and on the potential for existing rights-of-way to accommodate primary transit fixed guideway alignments. These data were also presented for the Southeastern Wisconsin Region, of which the Milwaukee urbanized area is an integral part. This technical report, together with its companion documents, SEWRPC Technical Report No. 23, <u>Transit-Related Socioeconomic, Land Use, and Transportation Conditions and Trends in the Milwaukee Area</u>, SEWRPC Technical Report No. 25, <u>Alternatives Futures for Southeastern Wisconsin</u>, and SEWRPC Technical Report No. 26, <u>Milwaukee Area Alternative Primary Transit System Plan Preparation, Test, and Evaluation</u>, is intended to document the procedures and data used, the alternatives developed and evaluated, and the decisions reached in the first phase of the primary transit system alternatives analysis for the Milwaukee area. The findings and recommendations of that analysis are presented in SEWRPC Planning Report No. 33, <u>A Primary Transit System Plan for the Milwaukee Area</u>, which serves as the principal product of the first phase of the alternatives analysis. Chapter III of that report contains in summary form the findings presented in greater detail in this technical report.

SUMMARY

The definitive information required for a thorough understanding and description of all primary transit technologies applicable to the Milwaukee area is presented within this technical report. The intent of this report is to objectively set forth the current characteristics of such technologies through appropriate text, tables, and figures. The technologies examined are limited to those considered proven and ready for implementation in the Milwaukee area within the next 10 to 15 years. The data presented are drawn from existing systems, primarily in the United States and Canada, that either have been recently implemented or are currently under actual construction. Information is provided on the current extent of application of each technology considered, as well as on the physical, operational, and economic characteristics as required for systems planning purposes. The technical report concludes with a chapter comparing the technologies considered, and highlighting the similarities and differences between these technologies.

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Chapter II

MOTOR BUS TECHNOLOGY

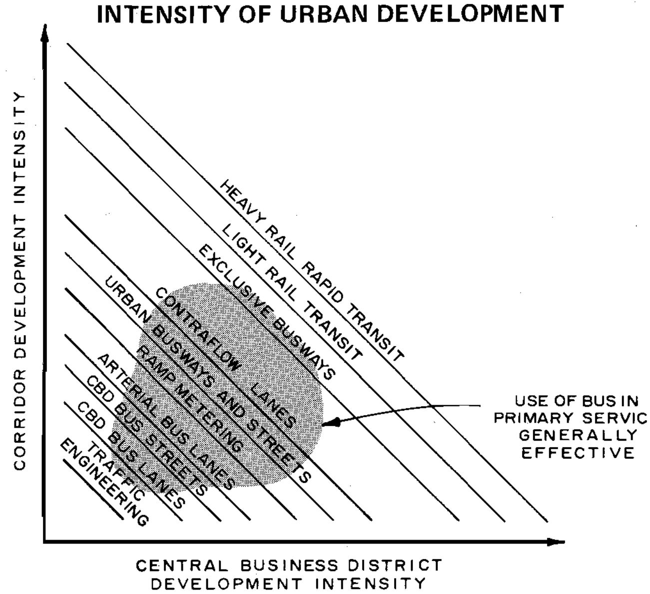
INTRODUCTION

Within the context of this technical report, motor bus technology is examined only to the extent of applications for primary transit service. Existing arterial streets and freeways are utilized to a large extent in the implementation of primary motor bus service since, unlike rail transit modes, an individual guideway that separates the vehicles from other traffic is not required.

In urban areas, motor bus services are subject to delays which can significantly affect the level of transit service offered. Accordingly, various techniques may be used either to permit the bus movements to be expedited through intensely traveled corridors or to circumvent bottleneck areas. Such techniques, listed in order of increasing complexity and passenger volumes necessary for successful implementation, include: 1) optimization of existing highway use through transportation systems management (TSM) actions; 2) metered freeway ramps, with bypass lanes for buses; 3) reserved normal flow or contraflow lanes for buses on arterial streets or freeways; 4) short exclusive busway segments that bypass congested locations or provide access to terminals; and 5) full-scale exclusive busways with or without stations.

Figure 1

RELATIONSHIP OF TRANSIT IMPROVEMENT ALTERNATIVES TO INTENSITY OF URBAN DEVELOPMENT



Source: U. S. Department of Transportation.

It is apparent that the application of the motor bus to primary transit service can involve noncapital-intensive operational measures, as opposed to measures requiring massive fixed plant construction. The traditional hierarchy of travel demand/capital investment generally limits the application of capital-intensive measures to the heaviest traveled corridors in the largest urbanized areas. Bus priority techniques tend to occupy the middle of a hierarchy of possible transportation improvements, relative to other alternatives, as shown in Figure 1.

Four specific modes of bus operation may be used to provide high-speed primary transit service: operation in mixed traffic on freeways, operation over reserved lanes on freeways, operation over exclusive busways, and preferential operation on surface arterials. Unlike the various rail transit modes discussed in Chapter III of this report, these modes of operation need not comprise self-contained systems since any primary transit service that utilizes motor buses can also use the local arterial street network for collection, distribution, and terminal access. Indeed, one of the major assets of the motor bus is its ability to operate in a variety of modes, varying from high-speed line-haul service over exclusive busways to collection and distribution service in mixed traffic on surface arterials. It should be recognized, therefore, that the various motor bus modes considered herein constitute only the high-service-level segments of a complete transit network, and that the motor bus, unlike rail transit, can provide its own collection and distribution service.

When used for primary transit applications, all four of these modes of operation are typically designed to serve the travel demands of home-to-work trips and are focused on a single major traffic generator such as the central business district. Unlike rail transit, however, the motor bus permits the same set of vehicles to be used to serve a number of widely dispersed traffic generators without the need to connect all of the locations by fixed guideways.

The inherent ability of motor bus modes to utilize such a variety of roadway surfaces suggests that implementation of service improvements on an incremental basis can be readily accomplished, with capital-intensive improvements being immediately programmed for only the system segments located in the most critical areas. Rail transit modes do not lend themselves as well to this type of implementation strategy because initial facilities must, at a minimum, be opened as a complete route in order to be operational.

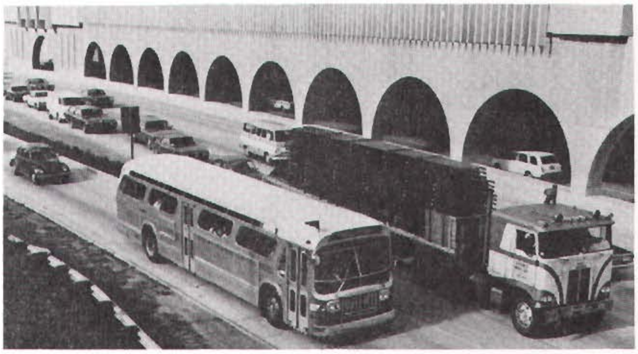
MIXED TRAFFIC OPERATION ON FREEWAYS

Description

Operation in mixed traffic on freeways is probably the most common type of primary transit service provided by bus, as well as the least intensive type of service in terms of new facility development. Motor buses can utilize existing freeways for the express or "line-haul" portion of each trip, usually entering and exiting over existing ramps. The line-haul service can be provided with or without intermediate stops either on or off the freeway. Collection and/or distribution service can be readily provided over surface streets (see Figure 2).

Figure 2

EXPRESS BUS OPERATION IN MIXED TRAFFIC ON FREEWAYS



Operation in mixed traffic on freeways is probably the most common type of primary transit service provided by bus. During 1979, such "Freeway Flyer" service was provided in the Milwaukee area between 12 outlying terminals and the Milwaukee central business district. In addition, "UBUS Flyer" service was provided between three outlying terminals and the University of Wisconsin-Milwaukee campus. In 1979 ridership on the Freeway Flyer bus service in the Milwaukee area totaled about 1,524,600 passengers, an average of 5,979 riders per weekday, or about 3 percent of the total revenue passengers carried by the entire system. Ridership on the UBUS Flyer service totaled an additional 133,300 passengers, or less than 1 percent of the total system ridership.

Photo courtesy of the City of Milwaukee, Bureau of Traffic Engineering.

Collection and distribution service is facilitated by either a series of stops on surface streets, similar to the service provided by local buses, or arrival at and departure from stations, sometimes fed by feeder bus routes, and provided with park-ride and kiss-and-ride facilities as necessary (see Figure 3). Collection and distribution service in the central business district may be furnished by local stops throughout the area, although special terminals are sometimes employed. Regardless, surface streets are almost always used at least at one end of the primary service route in order to facilitate operations.

As an alternative mixed traffic operational scheme, a freeway operational control system could be installed which constrains access to the freeway network during peak traffic hours, ensuring high rates of traffic flow at reasonable operating speeds. Such a system consists of interconnected demand-responsive ramp meters; priority access lanes for high-occupancy vehicles at freeway entrance ramps; and improved driver information and incident management procedures. There are several objectives which can be served by such a system, including the achievement of higher operating speeds on the freeways; the achievement of higher capacities on the freeways; and fuller utilization of existing arterial street and freeway capacity through redirection of some traffic currently using the freeway network. A freeway traffic management system, however, particularly if operated with the objective of maximizing operating speed, and not capacity, would have the potential to negatively impact surface arterial streets parallel or connecting to the freeway. Nevertheless, the most important objective relative to the provision of primary transit service is the operation of high-occupancy vehicles—that is, buses and vanpool and carpool vehicles—at reasonable speeds on the freeways. This objective is achieved by providing preferential access to high-occupancy vehicles via special bypasses at selected freeway entrance ramps (see Figure 4), as well as by operating ramp meters to ensure freeway traffic flows at the desired speeds.

Figure 3

MILWAUKEE COUNTY TRANSIT SYSTEM OUTLYING "FREEWAY FLYER" SERVICE TERMINALS

Of the 12 outlying "Freeway Flyer" terminals in the Milwaukee area, six are located in shopping center parking lots, and six are located at special publicly constructed park-ride facilities near important freeway interchanges. Such facilities, such as at W. College Avenue (left) and W. Brown Deer Road (right), generally consist of between 100 and 425 parking spaces, automobile access roadways, a bus shelter and waiting area, and, in some instances, direct entrance ramps to the freeway system for the exclusive use of motor buses.

Photos courtesy of the Wisconsin Department of Transportation, District 2.

A freeway control system is intended to continuously measure traffic volumes on the freeway network through an interconnected series of traffic-sensing devices. As traffic volumes approach the level beyond which the operation of the freeways would deteriorate, fewer low-occupancy automobiles and trucks are permitted on the system. At times, some ramps may be closed entirely. To ensure the proper functioning of such a system, ramp meters must be provided throughout the metropolitan area. In addition to the provision of bypasses for transit vehicles at metered ramps, exclusive high-occupancy vehicle ramps may be provided at locations where several primary transit routes utilize an identical routing, usually to enter or leave a downtown area (see Figure 5).

Definition

Bus operation in mixed traffic on freeways can be defined simply as the operation of conventional rubber-tired transit buses over conventional freeway lanes that are open to all motor vehicle traffic for the line-haul portion of the trip. The collection and distribution portions of the trip can utilize surface streets and highways. The transit vehicles may be provided preferential access to the freeway network at entrance ramps, or may be provided such access over ramps designated for the exclusive use of transit vehicles. The freeway itself may be operationally controlled or access uncontrolled.

Figure 4

SPECIALIZED BYPASS LANE FOR HIGH-OCCUPANCY VEHICLES AT METERED FREEWAY RAMPS

Bypass lanes which are located on existing freeway entrance ramps are designed to provide preferential access for high-occupancy vehicles, including motor buses, at congested locations. Such lanes enable high-occupancy vehicles to bypass automobile traffic stopped at ramp meters which constrain access to the freeway network during peak traffic hours. In addition to the two bypass lanes located in the Milwaukee area, metered ramp bypass lanes are in service in the Cities of Los Angeles, Minneapolis, Dallas, San Francisco, and San Diego.

Photo courtesy of U. S. Department of Transportation.

For a transit service to be considered a mixed traffic on freeways operation, one or more of the following conditions must be met:

Figure 5

EXCLUSIVE HIGH-OCCUPANCY VEHICLE RAMP

Exclusive high-occupancy vehicle ramps may be provided at locations where several primary transit routes utilize the same segment of roadway, usually upon entering or leaving a downtown area or outlying terminal, as shown here at the W. Holt Avenue park-ride lot in Milwaukee. Exclusive access ramps for motor buses and, in some cases, carpools and vanpools have been constructed in the Seattle, Pittsburgh, San Diego, Chicago, and Miami metropolitan areas, as well as in the Milwaukee metropolitan area.

Photo courtesy of Wisconsin Department of Transportation, District 2.

1. Conventional diesel-powered transit buses, either standard single-level design, double-deck design, or articulated design, are used as the vehicles.

2. The entire operation is in mixed traffic, the line-haul portion being over a divided, limited-access, fully grade-separated roadway.

3. Preferential treatment is granted at freeway entrance locations.

4. Fares are collected on-board.

Attributes

Bus operation in mixed traffic on freeway possesses certain attributes that require consideration in any system planning effort. Such attributes include:

1. Because existing fixed facilities are utilized for the fixed guideway, initial capital costs are limited to vehicle acquisition, provision of maintenance and storage facilities, and minor operational changes. If priority access at freeway entrance ramps is desired, then the ramp modification and necessary traffic control apparatus represent a capital item—an item, however, that is very low in cost relative to that of fixed guideway installations.

2. Because there is no need for major fixed facility construction, the implementation period is relatively short.

3. Since motor buses can be physically operated wherever paved roadways exist, a no-transfer ride can be offered between a large number of origins and destinations, and the same vehicle can perform collection and distribution functions in addition to providing high-speed line-haul service.

4. The institution of this service involves no community disruption.

5. Operating speeds are limited by the traffic conditions on the freeway utilized.

Generic Application of Mixed Traffic Freeway Operation

As already mentioned, operation in mixed traffic on freeways is the most widely used of all modes of operation available for providing primary transit service by motor bus. As major expressways, parkways, and freeways were completed in and through urban areas during the 1950's and 1960's, certain bus route segments were operated over freeways in order to afford those routes a high overall average speed.

Past and current applications of this mode are almost entirely limited to peak-period service between outlying residential areas or stations and a central business district. This mode, however, need not be limited to a central business district orientation in that any major traffic generator which can support such a specialized express bus service can be readily interconnected. Such major traffic generators might include major industrial as well as commercial employment centers, major shopping and service centers, and universities.

Since the motor bus can operate both over freeways and over surface streets, the line-haul portion of the existing services tend to be provided either as nonstop or very limited stop service, and before entering and after leaving the freeway, the buses provide their own feeder service, many times making frequent stops. Existing systems utilizing this mode are generally radial in nature, with the focal point being the central business district.

Table 1

SELECTED CHARACTERISTICS OF EXISTING PRIMARY TRANSIT MOTOR BUS SERVICES OPERATED IN MIXED TRAFFIC OVER FREEWAYS IN THE UNITED STATES: 1972

Characteristic	Atlanta	Baltimore	Cleveland	Dallas	Detroit	Milwaukee	Minneapolis	Oakland	St. Louis	Seattle
Route Designation	29	None	39	55	None	42	6	B	16R	5
Route Title	Lenox Limited	Towson-Metro Flyer	Lake Shore	None	Imperial Express	Bayshore Freeway Flyer	Southdale Red Ball Express	None	Ramona Rapid	Blue Streak
Freeway Utilized	IH 75-85	Jones Falls Expressway	IH 90	Thornton Freeway East	John Lodge Freeway	USH 141	IH 35W	Bay Bridge	Mark Twain Freeway	IH 5
Length of Route (miles)	11.5	15.3	12.0	10.5	19.6	7.0	10.2	10.2	13.4	14.7
Percent of Route on Freeway	43.0	72.0	68.0	20.9	41.0	60.0	75.0	85.0	67.3	39.4
Peak-Period Headway (minutes)	20	20	2.5	12	3	10-15	35	15	34	10
Peak-Period Average Speed	16.3	26.0	26.0	15.7	18.7	19.8[a]	22.7	28.0	19.6	25.0
Year of Survey	1967	1971	1972	1972	1972	1970[b]	1971	1970	1972	1971
Intermediate Stops	--	--	--	--	--	--	1	--	4	--

NOTE: *The 10 primary transit bus routes shown in this table are representative of approximately 250 such routes known to be in service during 1972. Since these data were compiled, such service has been initiated in many more United States cities, greatly increasing the total number of these routes now in service. The Route 42-Bayshore "Freeway Flyer" service described above was one of six Freeway Flyer routes operated in and around the City of Milwaukee during 1970. The total number of such routes in the Milwaukee urbanized area has since increased to 10.*

[a] *During the same time period, other Freeway Flyer routes in the Milwaukee area had average terminal-to-terminal speeds during the peak period ranging from 17.1 miles per hour to 25.3 miles per hour.*

[b] *Average speeds during 1980 have typically changed by less than one mile per hour.*

Source: *Highway Research Board, Bus Use on Highways: State of the Art, NCHRP Report 143; and SEWRPC.*

Geographic Extent of Mixed Traffic Freeway Operation

Given that the operation of buses in mixed traffic over freeways is the easiest of all express bus modes to implement since no fixed facility construction of any kind is required, it is not surprising that there is widespread application of this mode in the United States. In 1973 at least 18 major metropolitan areas were served by express bus service in mixed traffic over freeways. Selected characteristics for these areas are shown in Table 1. Since 1973 numerous other urban areas have initiated express bus service over existing freeways as a low-cost approach to providing primary transit service.

Systems providing preferential access to buses at freeway entrance locations are operated in only a small number of metropolitan areas. Metered freeway entrance ramps have been modified with bypass lanes for high-occupancy vehicles in Dallas, Los Angeles, Milwaukee, Minneapolis, San Diego, and San Francisco. These systems are briefly described in Table 2. Table 3 lists areas providing freeway access ramp facilities for the exclusive use of transit vehicles, these being Chicago, Miami, Milwaukee, Pittsburgh, San Diego, and Seattle. While the operation of express buses in mixed traffic over freeways is common in foreign cities, examples of preferential treatment at freeway entrance ramps appear to be rare outside the United States.

Table 2

FREEWAY SYSTEMS WITH PREFERENTIAL ACCESS FOR HIGH-OCCUPANCY VEHICLES IN THE UNITED STATES: 1978

Urbanized Area	Number of Existing Bypass Lanes at Metered Freeway Ramps	Number of Planned Bypass Lanes at Metered Freeway Ramps
Dallas	1	1 in 1979
Los Angeles	53	47 in 1978 111 in 1979 21 in 1980 22 in 1983
Milwaukee	2	--
Minneapolis	9	--
San Diego	--	4 in 1980
San Francisco	1	--

Source: *Priority Treatment for High Occupancy Vehicles in the United States: A Review of Recent and Forthcoming Projects. U. S. Department of Transportation Final Report, August 1978; and SEWRPC.*

Potential Application in Southeastern Wisconsin

Motor bus operation in mixed traffic on freeways is obviously limited to either existing or planned freeways within the Milwaukee urbanized area (see Map 1). In 1980, the Milwaukee County Transit System operated 10 "Freeway Flyer" express routes

Table 3

FREEWAY SYSTEMS WITH RAMPS USED EXCLUSIVELY FOR TRANSIT VEHICLES IN THE UNITED STATES: 1978

Urbanized Area	Number of Exclusive Ramps	Location	Year of Implementation	Facility Purpose	Number of Buses per Peak Hour
Chicago.	1	O'Hare Airport Access Highway	1975	Connects terminal area to access highway	40-90 per Day
Miami.	1	IH 95	1977	Connects park-ride lots to freeway	26
Milwaukee . . .	2	IH 94 and USH 45	1975 1976	Connects park-ride lots to freeways	12 7
Pittsburgh . . .	1	Braddock Avenue—Parkway East	1971	Inbound ramp onto parkway	10
San Diego . . .	1	Route 163	1974	Outbound ramp in CBD	22
Seattle	1	IH 5	1970	Reversible ramp in CBD	50

Source: U. S. Department of Transportation and SEWRPC.

from 12 outlying park-ride lots to the Milwaukee central business district. The park-ride lots are located throughout Milwaukee County, frequently utilizing existing shopping center parking lots. With one exception, all routes operate only during weekday morning and afternoon peak travel periods. All routes carry revenue passengers, both with and against the direction of peak-period travel, thus serving travel from outlying areas to the central business district and from and around that district to outlying areas during all hours of operation. Not all vehicle trips on all routes are operated over the entire length of their routes.

In addition, the Milwaukee County Transit System operates specialized express bus routes—known as UBUS routes—to the University of Wisconsin-Milwaukee from various areas of Milwaukee County. Four of these routes use the freeway system to provide high-speed service to the campus. Three routes originate at park-ride lots, while the fourth is operated in an arterial express mode before entering the freeway. These routes operate only on days when school is in session during the fall and spring semesters. The location and configuration of both the UBUS and Freeway Flyer routes and the location of the attendant park-ride lots is shown on Map 2. There are also two metered freeway entrance ramps at which special bypass lanes for buses are provided and two exclusive bus ramps leading onto the freeway system from park-ride lots in the Milwaukee urbanized area. The locations of these facilities are also shown on Map 2.

The regional transportation system plan adopted by the Regional Planning Commission envisions the provision of primary transit service throughout the Milwaukee urbanized area using buses operating in mixed traffic over an operationally access-controlled freeway system. This service would receive preferential treatment over other motor vehicles at some freeway entrances, and the freeway traffic management system would be designed to maximize the operating speeds on the freeways. Under this recommendation, access of low-occupancy automobiles to the freeway would be constrained to ensure high-speed traffic flows.

RESERVED FREEWAY BUS LANE SYSTEMS

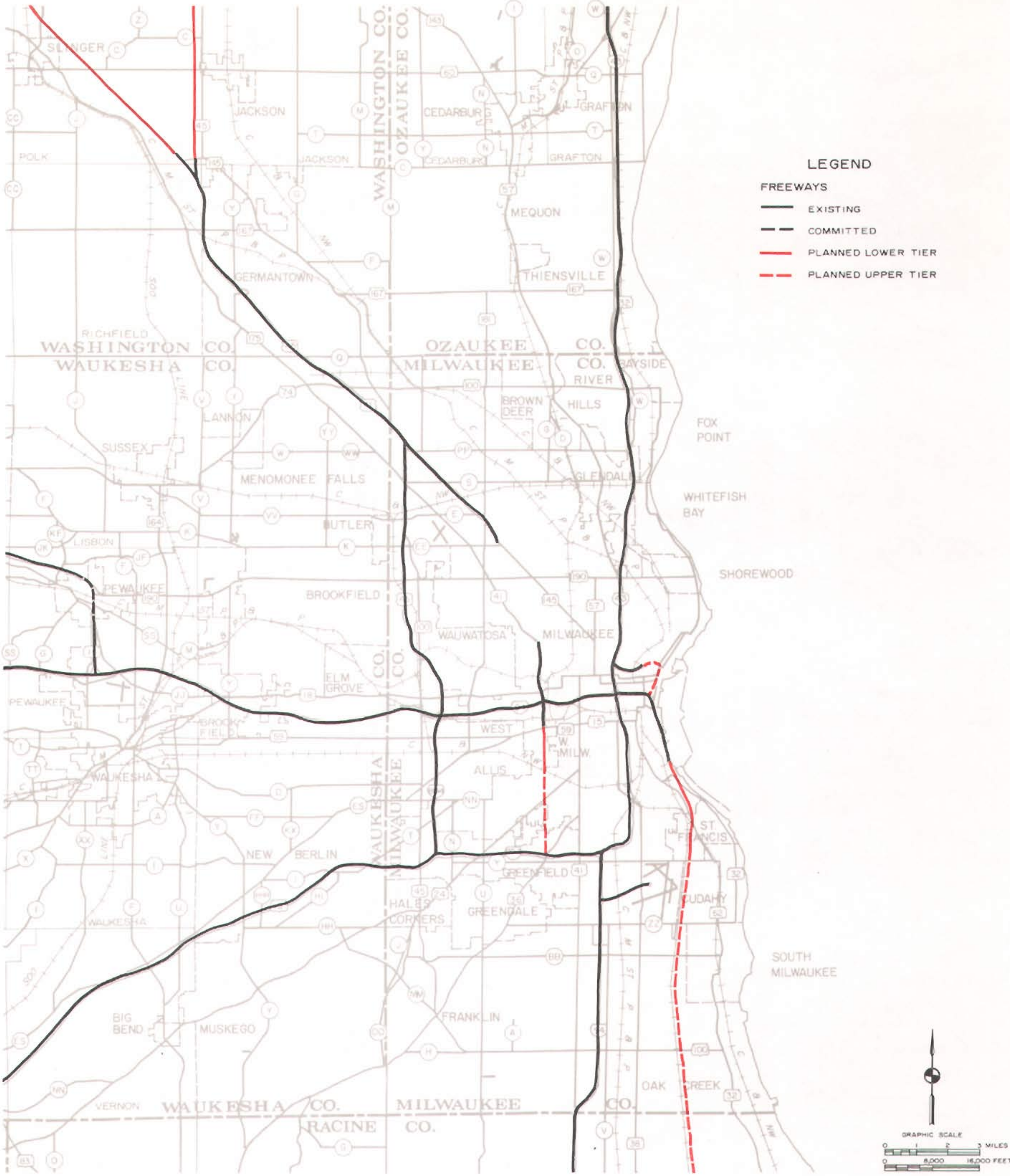
Description

Reserved freeway bus lane systems require either the dedication of existing traffic lanes to transit vehicle use, or the installation of additional lanes either in a median area, adjacent to the outside shoulder, or in one of the shoulder areas. The buses are generally operated nonstop over the line-haul portion, with collection and distribution service provided on surface streets. In some cases, an off-freeway terminal may be used with interconnecting feeder bus service. Also, part of primary transit routes utilizing reserved lanes may operate in mixed traffic over freeways, with reserved lanes being provided only in the most congested segments.

There are a number of ways to provide reserved lanes within freeway rights-of-way. The most obvious way is to reserve one traffic lane in a

Map 1

EXISTING OR PLANNED FREEWAYS IN THE MILWAUKEE AREA

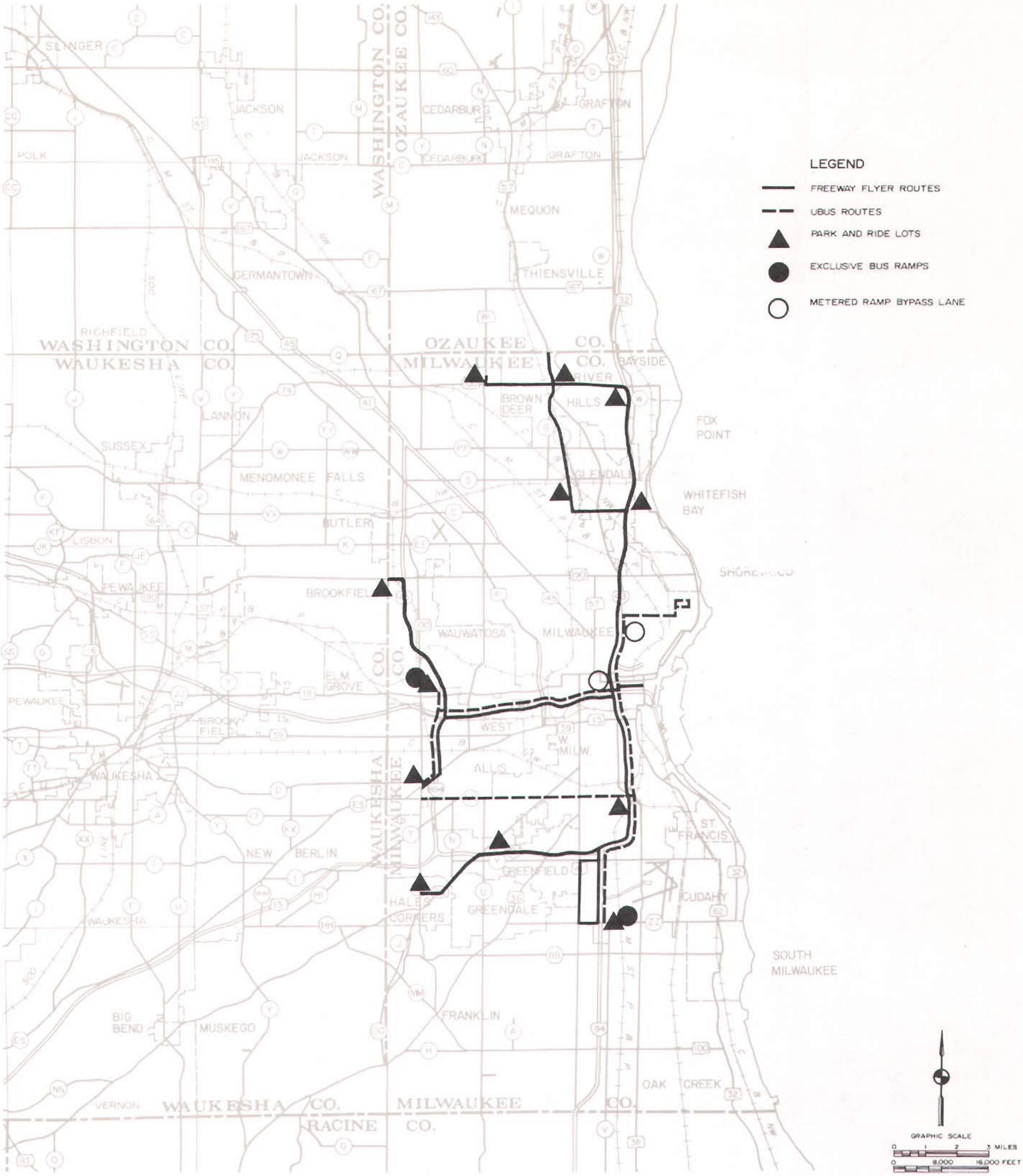


The freeway system proposed for the Milwaukee urbanized area under the adopted transportation system plan for the year 2000 consists of about 120 miles of facilities. As of January 1980, about 103 miles, or about 86 percent of the proposed freeway system, was open to traffic. Under the adopted plan, the remaining 17 miles of proposed freeways are classified into one of two categories: lower-tier facilities, for which implementation should proceed immediately; and upper-tier facilities, for which implementation should not proceed beyond the phase of right-of-way preservation for at least a decade, or until the effectiveness of low-capital-intensive improvements proposed in the adopted plan in lieu of these freeways has been determined. Within the Milwaukee urbanized area, the proposed lower-tier facilities total about 4 miles in length, or about 3 percent of the total planned freeway system; while the upper-tier facilities total about 13 miles in length, or about 11 percent of the total freeway system.

Source: SEWRPC.

Map 2

EXTENT OF FREEWAY UTILIZATION OF MOTOR BUS ROUTES IN THE MILWAUKEE AREA



As of January 1980, primary transit service operating over freeways in the Milwaukee urbanized area was comprised of two distinct forms of primary service, each oriented to a particular major traffic generator. The first form of service was comprised of 10 "Freeway Flyer" routes over which essentially nonstop service is provided between the Milwaukee central business district and 12 outlying park-ride lots. Some of the routes use exclusive bus freeway entrance ramps and metered freeway entrance ramp bypass lanes to gain access to the partially metered freeway system in the Milwaukee area. The second form of service was comprised of five specialized bus routes operating between the University of Wisconsin-Milwaukee and residential areas of the Milwaukee area. Four of these so-called UBUS routes utilize the freeway system to provide high-speed line-haul service to the campus.

Source: SEWRPC.

normal flow configuration so that the motor buses travel in the same direction as does the other traffic. The designation of the reserved, normal flow lane can be accomplished simply by signing and appropriate pavement markings or by more intensive traffic engineering measures, including the use of traffic cones, posts, or barriers (see Figures 6 and 7). Reserved normal flow lanes are typically installed on the inside of the roadway, adjacent to the median area. This prevents automobile and truck movements from having to cross the bus lane when entering from right-hand entrance ramps.[1]

Reserved lanes can also be operated as contraflow lanes within freeway rights-of-way. Where a large imbalance exists between opposing traffic movements during peak periods, a portion of the roadway which serves the relatively light traffic demand can be reserved for the movement of buses in the opposite and high-demand direction of travel. Reservation of the contraflow lanes is accomplished through traffic engineering measures, ranging from the use of traffic cones to full barriers. Contraflow lane operation on freeways is a logical extension of the reversible lane concept which has been in use for more than 30 years (see Figures 8 and 9). Like normal flow reserved lanes, contraflow lanes are located on the inside lanes so that there is no interference from right-hand entrance ramps.

Reserved freeway bus lanes may be operated either as a single-lane facility—applicable to either normal or contraflow—or as a double-lane facility with one lane provided in each direction—applicable only to normal flow. Although some existing reserved lanes are in operation throughout the day, the majority are in operation only during morning and/or afternoon weekday peak travel periods. When these facilities are in operation, high-occupancy vehicles, including carpools and vanpools, may also be allowed to use the reserved lanes. Other possible users include emergency vehicles, suburban buses, and intercity buses. During off-peak times, the lanes are opened to mixed traffic.

Figure 6

IH 95 RESERVED NORMAL FLOW LANES IN MIAMI, FLORIDA

North of the Miami central business district, the median area of IH 95 is used to provide a 7.5-mile-long normal flow bus and carpool lane in each direction. At the north end of the facility, which is in service only during the morning and afternoon peak periods, the priority lanes are connected to the Golden Glades park-ride lot by an exclusive access ramp. Opened in 1976, this facility represented the second phase of a priority treatment project in the IH 95/N. W. Seventh Avenue corridor of Miami. The reserved lanes are separated from mixed traffic lanes by signing and striping.

Photo courtesy of Florida Department of Transportation.

Figure 7

ROUTE 163 RESERVED NORMAL FLOW LANE IN SAN DIEGO, CALIFORNIA

Since 1974, a one-half-mile-long lane adjacent to the outside shoulder has been reserved on State Route 163 during the afternoon peak period for the exclusive use of transit buses. The lane is delineated solely by signing and pavement markings, with no significant rate of violations being reported.

Photo courtesy of San Diego Transit.

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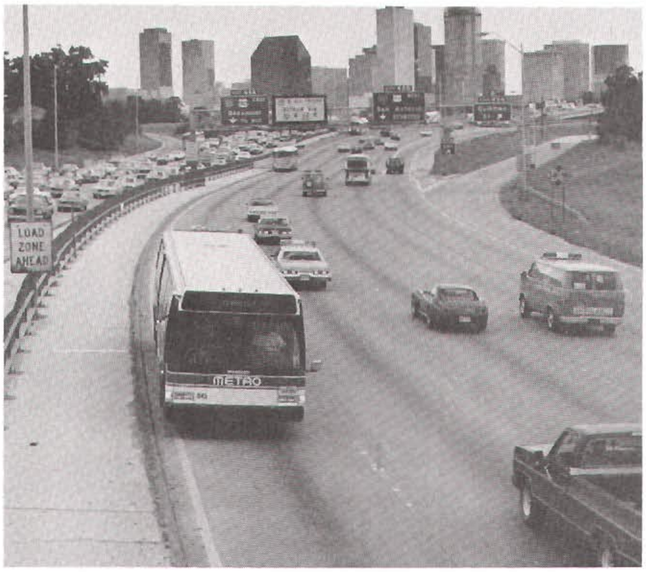
[1] *Some right-hand normal flow lanes are in service. These facilities, however, are short freeway segments—usually under one mile in length—that have no right-hand entrance ramps.*

Figure 8

NORTH FREEWAY RESERVED CONTRAFLOW LANE IN HOUSTON, TEXAS



The Metropolitan Transit Authority of Harris County, Texas (METRO), opened the longest contraflow lane in the United States during 1979 along 9.6 miles of IH 45. METRO's North Freeway contraflow lane creates an express lane for authorized vehicles, which include vanpools in addition to motor buses, by using a lane of the off-peak flow side of the freeway to carry peak-hour transit and vanpool vehicles. The lane is used in conjunction with several new park-ride lots and is delineated by signing, overhead signals, safety posts, gates, and special ramps.

Photo courtesy of Metropolitan Transit Authority of Harris County.

Figure 9

SOUTHEAST EXPRESSWAY RESERVED CONTRAFLOW LANE IN BOSTON, MASSACHUSETTS

In the Boston, Massachusetts, area, an 8.4-mile-long contraflow lane was in morning rush-hour operation between 1971 and 1975, from April through October only. The facility was restricted to motor buses, with operating speeds in the contraflow lane being limited to 40 miles per hour. The lane was designated primarily by signing and traffic cones which were in place only during the hours the contraflow lane was in operation. Operation of the lane was eventually discontinued because of safety considerations plus the implementation of an experimental normal flow lane along the same segment of expressway.

Photo courtesy of Milwaukee County Department of Public Works.

Primary transit buses that utilize reserved freeway lanes otherwise operate in mixed traffic over other segments of the route. Like the typical mixed traffic express bus route, the reserved bus route performs collection and distribution functions on surface streets and highways. Special ramps or priority treatments may be used to gain access to the reserved lane. In instances where reserved lanes merge with mixed traffic lanes on freeways, special control devices are required including, but not limited to, signs, flashing lights, lighted arrows, and gates.

Definition

Reserved freeway bus lane systems can be defined as the operation of conventional rubber-tired transit buses over either normal-flow or contraflow reserved lanes located on freeway rights-of-way. This type of guideway is used for the line-haul portion of the trip, while passenger collection and distribution service is provided over surface streets and highways.

For a transit service to be considered a reserved freeway lane operation, one or more of the following conditions must be met:

1. Conventional diesel-powered transit buses, either standard single-level design, double-deck design, or articulated design, are used.

2. The line-haul portion of the operation is over a reserved lane on a divided, limited-access, fully grade-separated roadway.

3. The reserved lane or lanes can operate either with the peak-flow direction of traffic movement, or against such movement, separated from other lanes by traffic engineering techniques.

4. Preferential treatment is granted at freeway entrance locations.

5. Fares are collected on-board.

Attributes

Bus operation over reserved freeway lanes possesses certain attributes that require consideration in any system planning effort. Such attributes include:

1. Because existing freeway facilities are utilized together with relatively simple non-capital-intensive traffic control measures, such as signing and lighting, initial capital costs are limited to vehicle acquisition, provision of maintenance and storage facilities, and minor operational changes. If priority access at freeway entrances is desired, then ramp modification and necessary traffic control apparatus represent a capital item—an item, however, that is very low in cost relative to that of fixed guideway installation.

2. Because there is no need for major fixed facility construction, the implementation period is relatively short.

3. Since motor buses can be physically operated wherever paved roadways exist, a no-transfer ride can be offered between a large number of origins and destinations, and the same vehicle can perform collection and distribution functions in addition to providing high-speed line-haul service.

4. Reserved bus lanes are typically implemented on an already existing lane. Thus, the capacity for automobiles and trucks is reduced. Therefore, such lanes should be initiated only where the total number of bus passengers in the predominant direction is equal to or greater than the passenger capacity of a lane with automobiles.

5. The successful application of contraflow lanes depends upon a high directional imbalance in peak-hour traffic flows. If such an imbalance does not exist, dedication of a mixed traffic lane to a reserved lane and the subsequent reduction in available capacity in that direction will result in an aggregate time loss for the remaining mixed traffic. The volume of transit ridership on the newly created contraflow lane must be large enough to result in an overall time savings that would offset this loss.

6. Because the physical separation of traffic using the reserved lanes from traffic using the regular mixed lanes is frequently minimal, it is not considered safe to stop buses for passenger pickup or discharge. This, plus the fact that ample space for station turnouts is usually not available, can serve to preclude the installation of bus stops or stations on reserved lane systems.

7. The institution of this service involves little community disruption.

8. While operating speeds are not limited by traffic conditions on the freeways utilized, safety considerations limit the maximum speeds that can be used.

Generic Application of Reserved Freeway Bus Lanes

Reserved freeway bus lanes are a relatively recent phenomenon, the first facilities becoming operative in 1970, with others being implemented throughout the 1970's. This timing corresponds to the recent interest in transportation systems management techniques.

Application of this mode is generally limited to improvement of peak-period travel between outlying and central business districts of major cities. Major traffic generators and corridors of high travel demand, both of which produce sufficient volumes of trips, may also provide an opportunity for successful reserved lane operation. Like express bus service in mixed traffic on freeways, reserved lane services tend to operate nonstop while on the freeway rights-of-way, but provide their own feeder service before entering or after leaving the freeway. Systems utilizing this mode are generally radial in nature, having the central business district as the focal point.

Geographic Extent of Reserved Freeway Bus Lanes

In the United States, reserved freeway bus lanes are in service only in a few of the largest metropolitan areas. Normal flow, reserved freeway lanes are provided in Boston, Honolulu, Los Angeles, Miami, northern New Jersey, New York City, Portland, San Diego, and San Francisco. Select characteristics of these operations are presented in Table 4. Extensions are planned for two of these facilities.

Contraflow reserved freeway lanes are provided in Boston, Houston, northern New Jersey, New York City, and San Francisco. Houston's facility deserves particular note because it is the most recently

Table 4

SELECTED CHARACTERISTICS OF NORMAL FLOW RESERVED FREEWAY LANES IN THE UNITED STATES: 1978

Characteristic	Boston	Boston	Honolulu	Los Angeles	Miami	Northern New Jersey	New York City	Portland	San Diego	San Francisco	San Francisco	San Francisco
Freeway Utilized	IH 93	Southeast Expressway	Moanalua Freeway	Santa Monica Freeway	IH 95	IH 95	Gowanus Freeway	Banfield Freeway	Route 163	Bay Bridge	IH 580	IH 280
Length of Reserved Lane (miles)	1.0	8.0	2.7[a]/1.4[b]	12.9	7.5	2.0	1.0	3.3	0.5	0.5	3.5	2.0
Hours of Operation	A.M. peak	A.M. peak	24 hours	*Both* peak periods	Both peak periods	A.M. peak	A.M. *peak*	Both peak periods[e]	P.M. peak	Both peak periods	24 hours	24 hours
Year of Implementation	1974	1977[c]	1974	1976[d]	1976	1976	1976	1975	1974	1970	1976	1975
Traffic Control Measures	Lane markings, signing, and portable barriers	Plastic inserts	Signing and striping	Signing and striping	Signing and striping	Signing	Signing and striping	Signing and striping	N/A	Toll plaza bypass	Signing and buffer lane	Signing
Number of Buses per Peak Hour	24 in peak period	55	11 in peak period	74	26	400	120	20	22	330	10	15

NOTE: N/A indicates data not available.

[a] *Inbound.*

[b] *Outbound.*

[c] *Discontinued in 1977.*

[d] *Discontinued in 1976.*

[e] *Originally 24 hours.*

Source: U. S. Department of Transportation and SEWRPC.

implemented, and incorporates successful features from other contraflow projects. Selected characteristics of these facilities are presented in Table 5.

There are no known reserved freeway bus lane installations outside the United States.

Potential Application in Southeastern Wisconsin

Application of reserved freeway bus lanes is obviously limited to existing or planned freeways within the Milwaukee urbanized area (see Map 1). Detailed facility design would be dependent upon the location of the proposed reserved lanes. The extensive left-hand merge lanes at major interchanges on the existing Milwaukee freeway system place special constraints upon widespread use of reserved lanes. Also, the use of contraflow lane operation requires highly unbalanced peak-hour traffic flows, a phenomenon that does not exist in the Milwaukee area to the extent that it does in some other urbanized areas of the nation.

There are no normal or contraflow reserved freeway bus lanes in operation or currently planned in the Milwaukee urbanized area.

BUSWAY SYSTEMS

Description

Busways are exclusive roadways designed, constructed, and operated specifically for motor buses. These facilities can be constructed on an existing freeway right-of-way, on other existing rights-of-way, or on a newly acquired right-of-way. Busway facilities are the only type of bus operational mode that can utilize a right-of-way located specifically to provide the desired primary transit service. This method of separation of buses from other traffic is the most positive, and therefore is able to provide the highest quality primary transit service of all of the motor bus modes. Busways can also be used for the movement of carpools and vanpool vehicles, emergency vehicles and suburban and intercity motor coaches.

Most busway designs provide for simultaneous operation in both directions, with the notable exception of one existing and one proposed facility that serve peak-period demand only, with all lanes operating inbound in the morning and outbound in the afternoon. Access to and egress from the busway facility is provided by exclusive ramps which connect with the surface arterial street or freeway systems. Contemporary busways generally have ramps located between the facility endpoints to provide access to other routes or terminals.

Busway facilities can have on-line stations, and such stations can range in complexity from simple turnout bays with shelters to elaborate intermodal transfer facilities. Vehicle operation on the exclu-

Table 5

SELECTED CHARACTERISTICS OF CONTRAFLOW RESERVED FREEWAY LANES IN THE UNITED STATES: 1979

Characteristic	Boston	Houston	New York City	Northern New Jersey	San Francisco
Freeway Utilized	Southeast Expressway	IH 45	Long Island Expressway	IH 495	USH 101
Length of Reserved Lane (miles)	8.4	9.6	2.0	2.5	5.0
Hours of Operation	A.M. peak[a]	Both peak periods	A.M. peak	A.M. peak	P.M. peak
Year of Implementation	1972	1979	1971	1970	1972
Traffic Control Measures	Traffic cones and signing	Traffic posts, signing, and signals	Traffic cones and signing	Traffic signs and directional signals	Signs and traffic posts
Number of Buses per Peak Hour	65	30 in peak period	100	490	150 in peak period

[a] *Operated during both peak periods in 1971.*

Source: U. S. Department of Transportation and SEWRPC.

sive guideway may therefore be nonstop or may include stops. Collection and distribution service is provided off the guideway either at terminal facilities or over connecting surface streets. In most cases, the busway is designed to act as an exclusive line-haul facility for many routes going into the central business district which bypasses locations of serious peak-period traffic congestion. The buses operated in the line-haul service can provide their own collection and distribution service. Separate feeder bus service can also be provided to stations along the busway.

Definition

Busways can be defined as special-purpose roadways designed for the exclusive or predominant use of motor buses in order to improve vehicle movement and passenger travel times. A busway facility may be constructed at, above, or below grade and may be located on separate rights-of-way or within freeway corridors.

For a primary transit service to be considered a busway service, one or more of the following conditions must be met:

1. Conventional diesel-powered motor buses, either standard single-level design, double-deck design, or articulated design, are used.

2. The line-haul portion of the operation is over an exclusive guideway which is located on either a freeway, other existing right-of-way, or new right-of-way. The guideway may be wholly or partially grade-separated at intersections, and may consist of a roadway of one or more lanes.

3. Stations are located along the busway, providing intermediate stops.

4. Entrance and exit ramps are located along the busway, providing access for motor buses at intermediate points as well as at the endpoints.

5. Fares are collected on-board.

Attributes

Busways possess certain attributes which require consideration in any systems level planning effort. Such attributes include:

1. The implementation of busways involves major facility construction, and therefore may take a relatively long time compared with that required to institute other bus transit operational modes.

2. Capital costs are high relative to other bus modes. The capital cost of facilities may approach that of light and heavy rail transit facilities.

3. Implementation may result in some community disruption.

4. Very high vehicle operating speeds are attainable, equaling or exceeding those of rail systems.

5. Even when located within an existing freeway right-of-way, the busway generally does not reduce the capacity of that right-of-way.

6. Since motor buses can physically be operated wherever paved roadways exist, a no-transfer ride can be offered between a large number of origins and destinations, and the same vehicle can perform collection and distribution functions in addition to providing high-speed line-haul service.

Generic Application of Busways

The concept of the exclusive busway became popular in the 1960's as mass transportation facilities that would be less expensive than contemporary rail rapid transit systems were sought. Although many proposals were made, actual implementation of busways in the United States has occurred mostly in the late 1970's.

Busway service is generally implemented to serve travel to the central business district. Busways serve to collect various bus routes at the outlying and intermediate ramps and to provide a high-speed entry into the central business district. Like most other North American primary transit networks, busway facilities tend to have a radial pattern.

Busways, however, are not limited to serving trips to the central business district. There is no reason why such facilities cannot serve other major traffic generators, should demand warrant it. Exclusive busways can also serve as feeders to heavy rail rapid transit lines, and as special facilities for moving transit vehicles efficiently through congested areas. Exclusive busways have also been constructed in new town developments in foreign countries solely to provide for internal circulation.

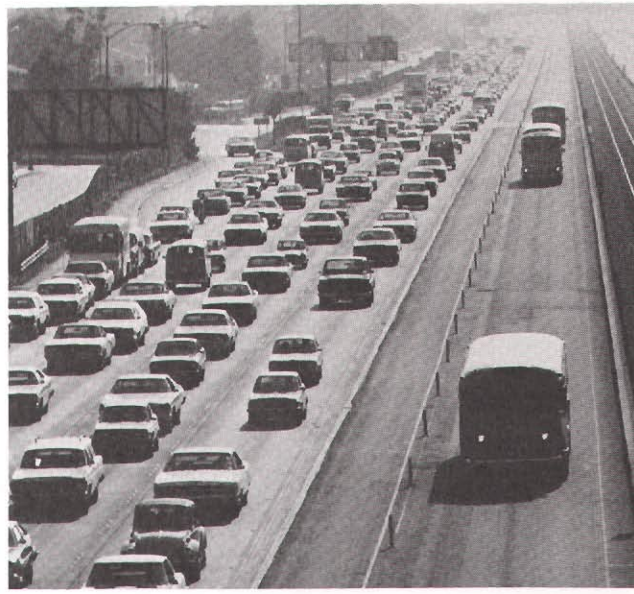
Geographic Extent of Busways

Like other modes of bus operation, busways exist or have been proposed only in the largest urban areas of the United States. Existing exclusive busway facilities are in service in and around the urbanized areas of Los Angeles, Philadelphia, Pittsburgh, Providence, and Washington, D. C. (see Figures 10 through 14). Selected characteristics of these facilities are given in Table 6. Exclusive busways have been proposed for the urbanized areas of Atlanta, Chicago, Dallas, Dayton, Kansas City, Los Angeles, New Haven, Pittsburgh, St. Louis, Washington, D. C., and, importantly, Milwaukee. Selected characteristics of these proposed systems are given in Table 7.

There are two known exclusive busways outside the United States. The first is the local busway in Runcorn, England, built in concert with a new town development. Seven miles of the 12-mile system were opened in 1971, consisting of an elevated guideway in the central shopping area and surface guideways with highway grade crossings in outlying areas. Stops are located approximately one-quarter mile apart. The new town and busway are planned for minimal use of the private automobile, and represent an effort to eliminate the need for a second family auto.

Figure 10

THE SAN BERNARDINO FREEWAY EXPRESS BUSWAY



The San Bernardino Freeway Express Busway is an 11-mile-long busway between downtown Los Angeles and the El Monte bus terminal in the central San Gabriel Valley, and is an example of a Class A busway. Utilized by 20 different Rapid Transit District (RTD) bus routes, the facility offers a travel time savings during rush hours of 15 to 20 minutes over automobile travel time on the parallel San Bernardino Freeway. Other features of this facility include two major intermediate stations, operation of double-deck bus vehicles, and a busway specially designed for relatively easy conversion to rail transit. Construction on the facility was begun in 1972 and completed in 1974, and the estimated daily ridership in 1979 was 25,000 people.

Photo courtesy of Southern California Rapid Transit District.

Figure 11

THE RED ARROW ARDMORE BUSWAY

The Ardmore busway, a 1.5-mile-long two-lane facility operated as part of the Southeastern Pennsylvania Transportation Authority, Red Arrow Suburban Division, is an example of a Class B busway. Constructed in 1967 on the right-of-way of a former surface streetcar line, the busway incorporates at-grade crossings with arterial streets. Such crossings with arterial streets were originally guarded by crossing gates which were activated by the bus driver, but have since been removed.

Photo courtesy of Philadelphia Suburban Transportation Company.

Figure 12

THE PITTSBURGH SOUTH BUSWAY

The Port Authority of Allegheny County's South Busway is a 4.5-mile-long two-lane roadway for transit vehicles extending through the congested South Hills area south of downtown Pittsburgh. On certain portions of the busway, both light rail vehicles and motor buses operate on the same guideway. The facility is utilized by nine different bus routes and three light rail transit routes and includes three intermediate access ramps and 11 intermediate stations. The combined motor bus and light rail transit average weekday ridership is approximately 43,000 people.

Photo courtesy of Port Authority of Allegheny County.

To similarly minimize auto use, planners for the new town of Redditch, England incorporated a local busway. One of 16 projected miles were open as of 1972. Stations are one-third mile apart, and some busway segments are open to mixed traffic.

During the 1970's, the Cities of Perth, Australia and Dublin, Ireland proposed regional busway systems totaling 65 miles and 40 miles, respectively.

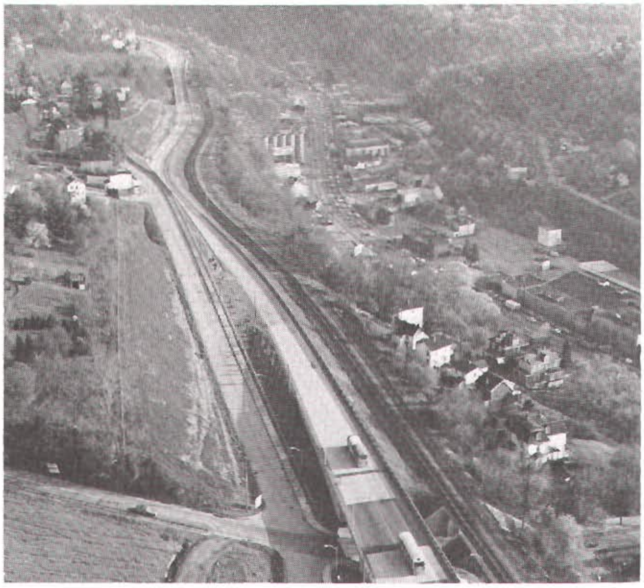
Potential Application in Southeastern Wisconsin

The nature of exclusive busways permits them to utilize new as well as existing rights-of-way, placing few limits on where the facilities may be located other than minimum horizontal and vertical guideway alignment design criteria. Utility and inactive transportation rights-of-way deserve special consideration for such location. Although there are no exclusive busways in the Milwaukee urbanized area at the present time, it is important to recognize that this type of facility was recommended for primary level transit service in the initial regional transportation system plan adopted in 1966.

In this plan, the design year 1990 regional transportation system plan, an exclusive busway was proposed in the travel corridor along the East-West Freeway. As part of an areawide rapid transit and modified rapid system designed around the use of the motor coach, the busway was to parallel the East-West Freeway for a distance of about 4.3 miles from the vicinity of the central business district of Milwaukee to the vicinity of the Zoo Interchange. This facility was proposed to consist of two fully grade-separated lanes for the exclusive operation of motor buses during peak periods of demand, and possibly school, charter, and intercity buses and

Figure 13

LOCATION OF SOUTH BUSWAY WITHIN PITTSBURGH'S SOUTH HILLS CORRIDOR

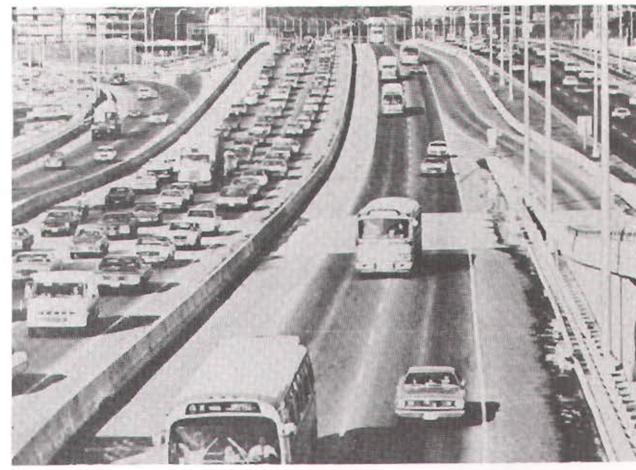


Open for service in December of 1977, Pittsburgh's South Busway is the first busway facility to be constructed in the United States entirely on its own right-of-way and not in conjunction with or as part of another highway project. Designed to allow motor buses to bypass the extremely congested Saw Mill Run Boulevard, one of only a limited number of available routes through the hilly terrain of Pittsburgh's South Hills, the system is available for emergency use by ambulances and police and fire vehicles.

Photo courtesy of Port Authority of Allegheny County.

Figure 14

THE WASHINGTON SHIRLEY BUSWAY



The Shirley Busway is a nine-mile-long, two-lane roadway located in the median area of the Shirley Highway, a congested freeway in northern Virginia which feeds into the Washington, D. C., area. Opened in stages between 1969 and 1975, the Shirley Busway was the first busway in the United States specifically constructed for high-speed motor bus operation. A notable feature of the facility is that the roadway is reversible, both lanes accommodating inbound traffic in the morning peak period and outbound traffic in the afternoon peak period. The Shirley Busway handles approximately 34,000 people per weekday in motor buses and nearly 24,000 people per weekday in carpools, with half of these people traveling in the peak direction during each of the peak periods. This compares with approximately 92,000 people per weekday traveling in all vehicles on the Shirley Highway during both peak periods in the peak direction.

Photo courtesy of Washington Metropolitan Area Transit Authority.

truck traffic during other times. It was estimated that the guideway, including right-of-way acquisition, would cost $12,470,000, or about $2 million per mile in 1966 dollars. In 1978 dollars, the guideway would cost $7,470,000 per mile. It was indicated that this cost could be reduced through utilization of existing rights-of-way such as the former electric interurban railway alignment, portions of which were still intact between approximately N. 27th Street and the Zoo Freeway. Much of the original earthwork could serve as the busway grade, and full grade separations with intersecting surface streets could be readily effected by reconstructing bridges at former abutment openings.[2]

This recommendation provided a basis for the preparation of preliminary engineering plans for the proposed busway under the Milwaukee Area Transit Plan, prepared by the Milwaukee County Expressway and Transportation Commission in 1971. Known as the East-West Transitway, the proposed facility was to extend a distance of 8.0 miles from N. Tenth Street and W. Wisconsin Avenue to a connection with the East-West Freeway near the Waukesha County line. Connecting ramps were proposed to be constructed between the transitway

[2] *See SEWRPC Planning Report No. 7, Land Use-Transportation Study, Volume Three, Recommended Regional Land Use and Transportation Plans: 1990, adopted on December 1, 1966; and Metro-Mode: A New Approach to Rapid Transit, prepared by the General Motors Corporation in collaboration with the Southeastern Wisconsin Regional Planning Commission.*

Table 6

SELECTED CHARACTERISTICS OF EXISTING BUSWAYS WITHIN THE UNITED STATES: 1978

Characteristic	Los Angeles	Philadelphia	Pittsburgh	Providence	Washington, D. C.
Facility Title	San Bernardino Freeway Express Busway	Ardmore Busway	South Busway	None	Shirley Busway
Length of Facility (miles)	11.0	1.5	4.5	0.5	9.0
Type or Location of Right-of-Way	Adjacent to and in median of freeway	Former surface streetcar line	New and existing, including light rail transit	Former street railway tunnel	Freeway median
Intermediate Access	At four locations	None[a]	At three locations	None	At three locations
Intermediate Stations	3	4	9	None	None
Hours of Operation	24 hours	6 a.m. to 10 p.m.	24 hours	24 hours	A.M. peak period and p.m. peak period
Remarks	- -	- -	Guideway partially shared with light rail transit	- -	Reversible
Year of Implementation	1973-1976[b]	1967	1977	1948	1969-1975[b]
Number of Buses per Peak Hour	132 per peak period	4	500 per weekday	20	300 per weekday

[a] *However, this system does have grade crossings with arterial streets.*

[b] *Busway segments and attendant facilities were opened in stages.*

Source: SEWRPC.

Table 7

SELECTED CHARACTERISTICS OF PROPOSED BUSWAYS WITHIN THE UNITED STATES: 1972

Characteristic	Atlanta	Chicago	Dallas	Dayton	Kansas City	Los Angeles	Milwaukee	New Haven	Pittsburgh	St. Louis	Washington, D.C.
Facility Title	North Atlanta and East Atlanta Busways	Crosstown Busway	North-South Central Expressway Busway	Multi-Use Penn-Central Busway	KCI-Airport Bus Rapid Transitway	Century Freeway Busway	East-West Transitway	Canal Line Busway	East Busway	None	Georgetown Busway
Length of Facility (miles)	8.0	20.0	10.0	7.5	19.0	22.0	8.0	13.3	8.0	42.0	12.0
Type or Location of Right-of-Way	In freeway medians	In median and adjacent to freeway	Elevated over railroad	Shared with railroad on surface	Special surface	Freeway median	New and shared with railroad	Shared with railroad	Shared with railroad	Special or in freeway median	Shared with railroad
Intermediate Access Points	2 each	None	4	16	None	N/A	2	Yes	7	*Undetermined*	Undetermined
Intermediate Stations	2 each	Approximately 35	9	3	None	7-22	4	6	11	37	N/A
Hours of Operation	24 hours	24 hours	24 hours	24 hours	24 hours	24 hours	24 hours	6 a.m. to 10 p.m.	24 hours	24 hours	Peak periods only
Remarks	- -	Designed for potential heavy rail rapid transit	- -	- -	- -	- -	Refer to text	Freight train operation at night	Under construction, scheduled completion—1982	- -	Rail operation in off-peak periods single land only
Year Proposed	Approved 1971	Approved 1971	1971-1972	1971	1968	1972	1966	1971	Approved 1970	1959	1969
Number of Bases per Peak Hour	N/A	120-150	90-110	20-30	30-40	N/A	175-250	10-15	120-140	N/A	N/A

NOTE: N/A indicates data not available.

Source: Highway Research Board, Bus Use on Highways: State of the Art, NCHRP Report 143; and SEWRPC.

and the Stadium and Zoo Freeways. The busway was to have been located on existing freeway rights-of-way and the Milwaukee Road's "Elm Grove Line"—an industrial switching line running through West Allis and West Milwaukee south of IH 94. Stations were proposed to be located at Marquette University, the U. S. Veteran's Administration Center, the Wisconsin State Fair Park, and Curtis Road, near the Waukesha County line. The transitway, including right-of-way acquisition, was estimated to cost $40,150,000, or slightly more than $5 million per mile in 1970 dollars. In 1978 dollars this transitway would cost $10,012,000 per mile. The proposed transitway location is shown on Map 3.[3]

Following completion of the preliminary engineering study, the Milwaukee County Board refused to proceed with construction of the proposed busway, acting in 1973 to adopt the Milwaukee Area Transit Plan, but deleting from this plan the busway proposal. Accordingly, when the Regional Planning Commission adopted a new design year 2000 regional transportation system plan in 1978, that plan did not include the busway. The new regional transportation system plan calls for all primary transit service to be of the modified rapid transit type, provided by motor coaches operating in mixed traffic on operationally controlled freeways and on connecting surface arterial streets.[4]

ARTERIAL EXPRESS BUS SYSTEMS

Description

By a strict definition of the terms "primary," "secondary," and "tertiary" transit service, express buses operating over arterial streets offer a secondary level of service, a discussion of which is outside the scope of this report.

It must be recognized, however, that just as light rail transit sometimes occupies a "gray area" between primary and secondary service because of the ability of this mode to be operated under a wide variety of conditions, express bus systems are also difficult to strictly classify because of the intrinsic flexibility of the motor bus which allows it to operate on freeways in mixed traffic, on freeways over reserved lanes, on exclusive busways, and on surface streets. Because of this, the arterial express bus mode is included insofar as it can be applied to fulfill high-quality, line-haul public transportation needs.

Arterial express bus systems operate on arterial and other local streets, with some sort of operational priority provided over other motor vehicle traffic. The level of service provided by express bus routes can be increased over that of ordinary local bus routes operating over surface streets through the use of skip-stop service, normal flow and contraflow reserved lanes, and priority operation at traffic signals. Otherwise, arterial express buses use the same vehicles, stops, and public streets as do local buses.

Skip-stop service is defined as a transit service in which vehicles load and discharge passengers only at certain select stops along a particular route. These stops are generally located at major traffic generators and at route-to-route transfer points. Buses operating in this type of service usually augment local bus service over the same streets. Such service typically operates only during weekday peak travel periods.

Arterial street, reserved lane operation may be implemented in a variety of ways. The most common are normal flow and contraflow reserved bus lanes located adjacent to one of the curbs. These can be either lanes permanently reserved for all-day service or lanes activated only during peak travel periods (see Figures 15 and 16). A variation of the normal flow scheme is a scheme whereby median lanes are located in the middle of a one-way or two-way street. Compared with the more typically used curb lanes, median lanes require a safety island at each stop for passenger shelter, but eliminate traffic conflicts with right-turn movements in the curb lane (see Figure 17). However, this benefit is offset by a need to control or restrict left-turn movements if initiated on a two-way street. In

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[3] *See Milwaukee Area Transit Plan, prepared by the Milwaukee County Expressway and Transportation Commission in cooperation with the Southeastern Wisconsin Regional Planning Commission, and formally adopted by the Commission on March 2, 1972. Also, see An Evaluation of Alternative Transit Equipment Systems for Milwaukee County, prepared for the Milwaukee County Mass Transit Technical Planning Study by Barton-Aschman Associates, Inc.*

[4] *See SEWRPC Planning Report No. 25, A Regional Land Use Plan and a Regional Transportation Plan for Southeastern Wisconsin: 2000, Volume Two, Alternative and Recommended Plans, adopted on June 1, 1978.*

Map 3

PROPOSED LOCATION OF THE EAST-WEST TRANSITWAY

Under the initial regional transportation system plan adopted in 1966, an exclusive busway facility was proposed to provide primary transit service in the important east-west travel corridor extending in a westerly direction from the Milwaukee central business district. This recommendation provided a basis for preparation by Milwaukee County of preliminary engineering plans for the proposed busway. The proposed facility was to extend a distance of about eight miles from N. 10th Street and W. Wisconsin Avenue to a connection with the East-West Freeway near the Waukesha County line. Connecting ramps were to be constructed between the transitway and the Stadium and Zoo Freeways, and four on-line stations were to be included. The transitway was estimated to cost a total of $40 million, or slightly more than $5 million per mile, in 1970 dollars ($10.9 million per mile in 1979 dollars). Following completion of the preliminary engineering plans, the Milwaukee County Board refused to proceed with construction of the proposed busway, apparently preferring to continue to provide the service concerned in mixed traffic over the existing freeway in the corridor.

Source: Milwaukee County Expressway and Transportation Commission, *Milwaukee Area Transit Plan.*

Figure 15

RESERVED LANES ON ARTERIAL STREETS

A common priority measure utilized to provide express bus service on arterial streets is the reservation of a curb lane. Although some reserved lanes are in effect continuously, most are generally in effect only during peak periods, with the separation from other traffic being provided by signing, pavement striping, and temporary barriers such as barricades, flexible safety posts, or traffic cones. This view illustrates a contraflow reserved lane on South Dixie Highway (USH 1) in Miami, Florida. Note the prohibition of left turns during hours in which the reserved lane is in use.

Photo courtesy of Florida Department of Transportation.

Figure 16

RESERVED LANES ON CENTRAL BUSINESS DISTRICT STREETS

The implementation of reserved lanes as a means of providing preferential treatment for motor buses in downtown areas is becoming a popular low-cost option for transit operators. In many cases, the dedication of reserved lanes is typically accomplished by reserving one lane of a multiple-lane one-way arterial street, as shown above in downtown Los Angeles.

Photo courtesy of Southern California Rapid Transit Authority.

Figure 17

RESERVED ARTERIAL STREET MEDIAN LANE

Reserved arterial street median lanes located in the middle of a roadway serve to eliminate traffic conflicts in the curb lanes and conflicts in making right turns. The establishment of lanes in the median area, or what would normally be the median area of a street, however, may require the provision of suitable waiting areas for passengers who must cross traffic to board the transit vehicles. A single lane in the median area, or in the center of the street, can be made reversible, depending upon the direction of peak traffic flow. This view shows the reversible lane along N. W. Seventh Avenue in Miami, Florida, a recent demonstration project which also assessed the benefits of bus-actuated traffic signal preemption.

Photo courtesy of Florida Department of Transportation.

some situations, it may be desirable to reverse the direction of the reserved lane depending upon the peak-period directional demand.

Most reserved bus lanes located on arterial streets consist of a single lane. Double, dual-directional lanes are possible, however. While such reserved express bus lanes have been proposed as a transit alternative several times, there is only one known example of such dual lanes on an arterial street—that in the City of New Orleans. Double, dual-directional lanes probably have not been widely used because they require an extra wide right-of-way (see Figure 18).

An extension of the arterial busway concept is the transit mall, typically found only in central business districts. The establishment of transit malls involves the widening of sidewalks, the installation of other pedestrian amenities, and the redesigning of the street for the exclusive operation of transit and emergency vehicles. Constructed on major shopping streets, transit malls are developed

Figure 18

EXCLUSIVE SURFACE BUSWAY WITHIN ARTERIAL STREET RIGHT-OF-WAY

Most reserved bus lanes located on arterial streets consist of a single lane. Double lanes, however, are possible, such as on Canal Street in New Orleans, Louisiana, as shown in the photograph on the left. When two reserved lanes are located in the median area of an arterial street, a Class B surface busway is, in effect, created. An extension of the arterial busway concept is the establishment of bus streets, or transit malls. As shown in the photograph on the right of the Woodward Avenue transit mall in Detroit, Michigan, the creation of a transit mall is usually accompanied by the addition of pedestrian amenities, such as shelters, landscaping, and widened sidewalks.

Photo (left) by Russell E. Schultz.
Photo (right) by Otto P. Dobnick.

primarily to create an appealing pedestrian environment, usually in concert with districtwide redevelopment. The exclusion of nontransit traffic, of course, aids overall bus travel time.

Priority operation at traffic signals may involve a system that detects the presence of a bus and subsequently modifies the green phase time at upcoming intersections so that the bus is not stopped. The objective of such detection devices is a reduction in overall motor bus travel time. Another option is the provision of special traffic signal phases for transit movements at critical intersections. And yet another option is the utilization of traffic signal progression, phasing the green cycles to facilitate bus movements.

The above alternative motor bus priority measures may be implemented singly or in combination. There is an obvious similarity between the measures outlined above and those outlined for buses operating on freeway rights-of-way. An important distinction, however, is the fact that express buses operating on arterial streets are subject to more interference by mixed traffic, especially cross traffic. Many of these priority measures are applied only in central city and downtown areas.

Definition

Arterial express bus operation can be defined simply as the operation of conventional rubber-tired transit buses over arterial streets to provide some form of preferential operation for express buses. This type of service may be operated in mixed traffic or in reserved lanes on arterial streets. Priority at traffic signals may be used to enhance the average speed and therefore the level of service.

For a transit service to be considered an express service on arterial streets, one or more of the following conditions must be met:

1. Conventional diesel-powered transit buses, either standard single-level design, double-deck design, or articulated design, are used.

2. Some degree of priority is granted for bus movements over other motor vehicle traffic, the options including normal flow, contra-flow, or median reserved lanes, or priority operation at traffic signals.

3. Fares are collected on-board.

Attributes

Arterial express bus service possesses certain attributes that require consideration in any system planning effort. Such attributes include:

1. Because existing fixed facilities are utilized, initial capital costs are limited to those for vehicle acquisition, the provision of maintenance and storage facilities, and minor operational changes. If traffic signal preemption or lane reservation is involved, minor capital outlay is required.

2. Because there is no need for major fixed facility construction, the implementation period is relatively short.

3. No community disruption is involved in instituting service.

4. The level of service afforded by this mode will be adversely affected to some degree by cross traffic at intersections and parallel traffic on the same street regardless of the priority measures utilized.

5. The capacity of the streets on which reserved lanes are operated will be constrained by the elimination of one or more mixed traffic lanes. Priority at signalized intersections, on the other hand, will constrain the capacity of cross streets.

6. Unlike operation on exclusive guideways, maximum transit vehicle speeds will be limited by safety considerations to the posted speed limits.

7. Motor bus vehicles can be physically operated wherever paved roadways exist; a no-transfer ride can be offered between a large number of origins and destinations; and the same vehicle can perform collection and distribution functions in addition to providing line-haul service.

Generic Application of Arterial Express Bus Systems

Some of the priority measures for express bus service on arterial streets have been actively in service in United States cities, as well as in foreign cities, for many years. Normal flow and contraflow curb lanes reserved specifically for the use of buses were implemented in large numbers during the late 1960's and early 1970's. Reserved median lanes, while being proposed as an alternative in various cities, are rare and have usually been implemented on former street railway zones following bus substitution. Signalized installations giving transit vehicles priority at intersections have been common in Europe for many years. Such installations have been demonstrated in the United States only since 1972.

Like the bus transit modes discussed earlier, arterial express bus schemes are designed primarily to increase the average speeds of bus trips destined for major traffic generators—usually the central business district. The routes normally have a radial configuration, although this type of service may also be applicable for certain crosstown and feeder routes.

Reserved arterial bus lanes are generally constructed in or near the central business district. The individual lanes are used for several routes, the high vehicle frequency justifying dedication of such lanes in areas that are otherwise congested during peak periods. Most existing reserved lanes, whether normal or contraflow, are less than one mile in length, thus being limited to serving directly a particular activity center. However, a few existing lanes, as well as many proposed lanes, within the United States are several miles or more in length. Although implemented for the purpose of facilitating improved transit vehicle flow to the downtown area, some of these facilities of greater length may act to serve local trips and trips oriented outside the central business district.

Typically, signal priority techniques are also designed to increase the average speeds of arterial express bus operation on reserved lanes. There is no reason, however, why signal priority for buses could not be implemented at intersections which do not involve reserved lanes.

Geographic Extent of Arterial Express Bus Systems

Express buses operating on arterial streets are common in most large metropolitan areas. The degree to which these services are "express" depends upon the localized practices. This means that the individual service may be considered "express" because it makes only a limited number of stops, because it stops only to pick up or discharge passengers, or because it employs any or all of the priority measures described above.

There are three types of reserved bus lanes on arterial streets: normal flow lanes, contraflow lanes, and median lanes. Normal flow reserved bus lanes are in service in the urbanized areas of Arlington, Baltimore, Birmingham, Boston, Buffalo, Chicago, Dallas, Denver, Houston, Nashville, Miami, New York City, Newark, Philadelphia, Pittsburgh, Portland, Providence, Rochester, St. Louis, San Francisco, Seattle, and Washington. Selected characteristics of some of these facilities are given in Table 8. Normal flow reserved lanes are also widely used in Western Europe, with such lanes being in service in the Cities of Brussels, Hamburg, London, Madrid, Milan, Paris, and Stockholm, among others.

Contraflow reserved bus lanes are in service in the urbanized areas of Chicago, Harrisburg, Honolulu, Indianapolis, Los Angeles, Louisville, Madison, Miami, Minneapolis, Pittsburgh, San Antonio, San Juan, and Seattle. Selected characteristics of some of these facilities are given in Table 9. Contraflow bus lane operation appears to be rare outside the United States.

Median reserved bus lanes are in service within the urbanized areas of Atlanta, Chicago, Miami, New Orleans, Philadelphia, and Pittsburgh. Selected characteristics of some of these facilities are given in Table 10. There is at least one median reserved lane operation in a foreign city—that in Milan.

Transit malls that are reserved for the exclusive use of transit vehicles are a relatively recent development in the United States. Existing transit malls of this type can be found in the Cities of Chicago, Detroit, Los Angeles, Madison, Minneapolis, Philadelphia, and Portland. Similar facilities have been proposed for the Cities of Buffalo, Cleveland, Denver, New York City, and St. Louis. Many such malls also exist in smaller cities outside metropolitan areas. These malls are patterned after many successful applications in Western Europe.

Bus priority signal systems on arterial streets are also a relatively recent development, both in North America and in Western Europe. Signal priority measures at intersections are in existence in the United States Cities of Concord, Dallas, Houston, Louisville, Memphis, Miami, Minneapolis, Portland, Sacramento, Santa Clara, Santa Cruz, and Washington. Characteristics of these facilities are given in Table 11. Priority signal systems are planned for Boston, Minneapolis, and Philadelphia.

<u>Potential Application in Southeastern Wisconsin</u>

Arterial express bus services utilize the surface arterial street system for route location. The potential application of this mode, therefore, is limited only by the extent of the existing network of arterial streets and proposed extensions to that network.

At present, there are three bus routes within the Milwaukee urbanized area having segments providing arterial express service. These routes are Route 5—Oklahoma Avenue UBUS, Route 30—Sherman-Wisconsin, and Route 66—Cudahy-South Milwaukee, as shown on Map 4.

The adopted regional transportation system plan calls for the provision of greatly expanded secondary or arterial express bus service on 14 individual transit routes. Reserved transit lanes would be provided during certain hours of the day on portions of 8 of these 14 routes. One of the reserved lane facilities would be operated as a contraflow lane, while the remaining lanes would be operated as normal flow lanes. The configuration of the proposed express bus services is shown on Map 5.

In addition, a recent study[5] recommends the development of a transportation center in downtown Milwaukee. Such a center would include a transit mall on Wisconsin Avenue from N. 6th Street to N. Water Street, with an option for extension to N. Jackson Street. West of N. Water Street, the mall would have one travel lane in each direction plus staggered bus stop bays on each side of the street. The estimated capital cost for the transit mall element of the plan is $2,715,000, expressed in 1978 dollars.

TECHNICAL CHARACTERISTICS

Unlike the three rail transit modes discussed in Chapter III of this report, the four motor bus modes applicable to primary transit service have several common technical characteristics. A common vehicle type is used in all four modes, and all of the bus modes are capable of operating with other highway vehicles on the same street and highway system. Therefore, the ensuing discussion of certain technical characteristics will pertain not just to a single motor bus mode, but to all four of the motor bus modes considered.

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[5] *See <u>Downtown Transportation Center Study: Milwaukee, Wisconsin</u>, prepared for Milwaukee County by W. C. Gilman & Co., Evanston, Illinois, and published in May 1978.*

Table 8

SELECTED CHARACTERISTICS OF ARTERIAL STREET NORMAL FLOW RESERVED LANES IN THE UNITED STATES: 1975

Characteristic	Arlington	Baltimore	Birmingham	Buffalo	Houston	Nashville	Rochester	Rochester
Street Name	Arlington Boulevard	York Road	19th Street North	Main Street	Main Street	4th Avenue	Main Street	Lake Avenue
Length of Reserved Lane	4.5 miles	6.5 miles	5 blocks	4 blocks	14 blocks	0.4 mile	1.5 miles	2.0 miles
Hours of Operation	A.M./p.m. peak periods	A.M./p.m. peak periods	A.M./p.m. peak periods	P.M. peak period	7:00 a.m. to 6:00 p.m.	A.M./p.m. peak periods	24 hours	A.M./p.m. peak periods
Number of Buses per Peak Hour	40	20	33	50	65	60	100-150	8
Year of Implementation	1974	1958	1973	1964	1971	1956	1957	1970

NOTE: The eight normal flow reserved lanes shown in this table are representative of the more than 50 such facilities currently in operation both within and outside United States central business districts.

Source: U. S. Department of Transportation and SEWRPC.

Table 9

SELECTED CHARACTERISTICS OF ARTERIAL STREET CONTRAFLOW RESERVED LANES IN THE UNITED STATES: 1975

Characteristic	Chicago	Harrisburg	Indianapolis	Louisville	Madison	Miami	San Antonio	San Juan
Street Name	N. Sheridan Road	Market Street	College Avenue	Third Street	University Avenue	South Dixie Highway	Alamo Plaza	Ponce de Leon and Fernandez Juncos
Length of Reserved Lane (miles)	1.2	0.3	2.9	1.5	0.9	5.5	0.2	11.0
Hours of Operation	A.M./p.m. peak periods	24 hours	24 hours	A.M. peak period	24 hours	A.M./p.m. peak periods	24 hours	24 hours
Number of Buses per Peak Hour	32	37	10	12	23	54	30	40-70
Year of Implementation	1939	1958	1969	1971	1966	1974	1968	1971

NOTE: The eight contraflow reserved lanes shown in this table are representative of the more than 20 such facilities currently in operation both within and outside United States central business districts.

Source: Highway Research Board, Bus Use on Highways: State of the Art, NCHRP Report 143; U. S. Department of Transportation; and SEWRPC.

Table 10

SELECTED CHARACTERISTICS OF ARTERIAL STREET MEDIAN LANES IN THE UNITED STATES: 1978

Characteristic	Atlanta	Chicago	Miami	New Orleans	Philadelphia
Street Name	Walton Street	Washington Street	N. W. Seventh Avenue	Canal Street	Market Street
Length of Lane (miles)	0.1	0.6	9.9	1.5	0.6
Hours of Operation	A.M./p.m. peak periods	24 hours	A.M./p.m. peak periods	24 hours	24 hours
Number of Buses per Peak Hour	30	110	52 per day	375 round trips per day	120
Year of Implementation	1958	1956[a]	1974	1964	1956
Remarks	- -	Normal flow or one-way street	Reversible	Two lanes	Two-way

[a] *Operation of this priority lane was discontinued during 1980 following the implementation of a pair of reserved contraflow lanes on adjacent one-way streets.*

Source: U. S. Department of Transportation and SEWRPC.

Table 11

EXISTING BUS PRIORITY SIGNAL SYSTEMS ON ARTERIAL STREETS IN THE UNITED STATES: 1979

City	Type of Signal Priority	Extent of Application	Year of Implementation
Concord	Preemption	12 intersections	1977
Dallas.	Preemption	61 intersections	1978
Houston	Preemption	24 intersections	1978
Louisville. . . .	Preemption	12 intersections	1972
Memphis	Preemption	22 intersections	1978
Miami.	Preemption and Progression	Both tested on *N. W. Seventh Avenue* but discontinued	1974-1975
Minneapolis . .	Preemption	25 blocks plus 21 other intersections	1979
Portland	Preemption	Approximately 6 miles	1978
Sacramento . .	Preemption	3 intersections	1976
Santa Clara. . .	Preemption	12 intersections	1978
Santa Cruz . . .	Preemption	10 intersections	1977
Washington . .	Preemption	Added to computerized traffic control system but discontinued	1972

Source: U. S. Department of Transportation and SEWRPC.

Vehicle Technology

The nature of motor bus transit enables the same rubber-tired vehicle to be utilized for all bus modes and priority techniques that are applicable to the primary level of transit service. Motor buses may be classified into three broad categories, based upon their relative size or configuration: compact or mini-vehicles, standard vehicles, and high-capacity vehicles. Standard and high-capacity vehicles are suitable for use in primary transit service. Compact or mini-vehicles are small, low-passenger-capacity vehicles designed specifically for use in certain tertiary collection/distribution service, in low-density-load tertiary transit service, in special circulation service within activity centers, and in other special service applications such as nonfixed route service. The need to minimize operating costs per passenger generally precludes the consideration of low-capacity, compact buses for primary transit service. Two other types of motor bus vehicles also are not herein considered. The first is the intercity bus, which is designed specifically to serve long-distance trips with infrequent stops. The second is the school bus, the design and service life of which are generally considered to be unsuitable for primary transit service.

The standard urban motor bus is by far the most common vehicle used in primary transit service in the United States and Canada. The typical vehicle consists of a single-unit body with an overall length of 35 to 40 feet, a width of 8.0 to 8.5 feet, and a height of 9.6 to 10.1 feet. Currently, new designs significantly different from previous models are coming into production and use in North America. The standard urban motor bus is also the most common vehicle used in primary transit service outside the United States. Table 12 sets forth selected technical characteristics of standard motor bus vehicles, including the characteristics of two models available from Canadian manufacturers, as well as a single model available from a West German manufacturer. Figures 19 through 24 illustrate these vehicles. The characteristics of discontinued models have not been included in the table and figures, although they may still be in use on some existing systems.

A characteristic given in Table 12 critical to guideway design for motor bus operation is the vehicle's largest minimum turning radius. The turning radius of the outside front vehicle corner will always be larger than the various turning radii for the vehicle tires because of body overhand ahead of the front axle. Figure 25 shows the relationship of the three limiting turning radii for motor bus vehicles.

Articulated buses represent a potentially attractive high-capacity vehicle for use on high-density-load primary transit routes because of the reduction in operating costs per passenger attributable to the vehicle's larger passenger-carrying capacity. Popular in other foreign countries, especially countries in Europe, for many years, such coaches are just coming into use in the United States. Articulated buses are extra-length vehicles that "bend" in order to negotiate sharp turns. The typical vehicle consists of two units having an overall length of 55 to 60 feet, a width of 8.0 to 8.5 feet, and a height of about 10.0 to 10.5 feet. Most articulated motor buses have two axles supporting the front unit and a third axle supporting the rear unit. The articulation joint is located behind the second axle. The second axle propels the vehicle while the first and third axles perform the steering function. At least one design has two axles supporting the rear unit, with the first and second axles being steerable; the third axle propels the vehicle.

Specifications for selected articulated buses are presented in Table 13, with accompanying illustrations in Figures 26 and 27. In the United States, these buses are currently being operated in and around the Cities of Atlanta, Chicago, Los Angeles, Minneapolis-St. Paul, Oakland, Phoenix, Pittsburgh, San Diego, San Francisco, San Rafael, Seattle, and Washington, D. C.

Map 4

EXISTING ARTERIAL EXPRESS BUS SERVICE IN THE MILWAUKEE AREA

As shown on this map, existing arterial express bus service within the Milwaukee urbanized area was provided in 1979 over portions of three bus routes. The segments of the bus routes operated in express service include: Route 5—Oklahoma Avenue UBUS between N. 107th Street and W. Oklahoma Avenue and the North-South Freeway (IH 94) and W. Becher Street during hours that school is in session; Route 31—Sherman-Wisconsin between N. Sherman Boulevard and W. North Avenue and N. 12th Street and W. Wisconsin Avenue during weekday peak travel periods; and Route 66—Cudahy-South Milwaukee between N. Plankinton Avenue and W. Wells Street and S. Kinnickinnic Avenue and E. Pryor Avenue during weekday peak travel periods.

Source: SEWRPC.

Map 5

RECOMMENDED ARTERIAL EXPRESS BUS SERVICE IN THE MILWAUKEE AREA

As illustrated on this map, the adopted regional transportation system plan for the year 2000 recommends the provision of greatly expanded secondary, or arterial express, bus service on 14 individual transit routes operating over 156 miles of surface arterials. Reserved transit lanes would be provided over 10 miles of surface arterials on eight individual transit routes. Reserved transit lanes would, under the plan, be provided along segments of N. 27th Street, N. Farwell Avenue, N. Prospect Avenue, E. Kenwood Boulevard, E. and W. Wells Street, and W. Wisconsin Avenue.

Source: SEWRPC.

Table 12

PHYSICAL AND PERFORMANCE CHARACTERISTICS OF SELECTED TRANSIT MOTOR BUSES—STANDARD CONFIGURATION

Characteristic	General Motors RTS II[a]	Grumman Flxible 870[a]	General Motors of Canada "New Look" Bus[a]	Flyer Industries D900[a]	Neoplan N416	Eagle Model 05
Length (feet)	40.0	40.0	40.0	40.0	40.0	40.0
Width (inches)	96.0 or 102.0	96.0 or 102.0	101.8	101.9	96.0	96.0
Height (inches)	118.5	120.0	121.5	120.5	117.0	133.5
Net Weight (pounds)	27,600	Maximum 24,700[b]	Maximum 22,050[c]	22,900	25,000	26,540
Wheelbase (inches)	298.7	299.0	284.8	284.8	267.0	285.5
Minimum Turning Radius (feet)[d]	44.0[b]	44.0[b]	42.0	42.0	N/A	42.5
Manufacturer	GMC Truck and Coach Division	Grumman Flxible Corporation	Diesel Division General Motors of Canada, Ltd.	Flyer Industries Ltd.	Neoplan U.S.A.	Eagle International Incorporated
Approximate Year of Introduction	1977	1978	1959	1978	N/A	N/A
Front Step Height (inches)	13.1	14.0	13.5	13.5	13.0	N/A
Door Type/Number	Plug/2	Folding/2	Folding/2	Folding/2	Swinging/2	Swinging/1
Front Door Width (inches)	30.0	36.0	30.0	34.0	30.0	N/A
Rear Door Width (inches)	44.0	32.0	26.5	26.5	42.0	N/A
Design Capacity Seats/Standees	47/24	48/24	53/27	51/26	47/35	53/N.A.
Maximum Speed (mph)	55-60	70	55-60	54	55-60	70
Engine Type	6 or 8 cylinder	6 or 8 cylinder	6 or 8 cylinder	6 cylinder	6 cylinder	6 or 8 cylinder
Service Acceleration[f] (miles per hour per second)	2.5	2.5	2.5	2.5	2.5	2.5
Service Deceleration[f] (miles per hour per second)	2.5	2.5	2.5	2.5	2.5	2.5
Emergency Deceleration[f] (miles per hour per second)	6.0-12.0	6.0-12.0	6.0-12.0	6.0-12.0	6.0-12.0	6.0-12.0
Maximum Grade	N/A	N/A	N/A	N/A	N/A	N/A
Capital Cost per Vehicle	$138,000	$134,000	$128,000	N/A	$139,000	$120,000
Fuel Economy (mpg)	3.4[e]	N/A	N/A	N/A	N/A	N/A

NOTE: N/A indicates data not available.

[a] *This vehicle is available in one or more shorter lengths with a corresponding decrease in net weight, wheelbase, minimum turning radius, and passenger capacity.*

[b] *102.0-inch-wide vehicle.*

[c] *8-cylinder diesel.*

[d] *Turning radius of outside front body corner.*

[e] *Milwaukee County Transit System data which reflect combined local and express service.*

[f] *These rates of acceleration and deceleration for motor bus vehicles are typical, and actual rates will depend not only upon the engine and drive train design, but also upon the loaded vehicle weight, roadway conditions, and roadway gradient.*

Source: SEWRPC.

The other high-capacity vehicle configuration is the double-deck motor bus. Always remaining popular in Great Britain and other countries with historic British links since its inception, this type of vehicle has completely disappeared from the streets of United States cities—including Chicago, New York City, and Milwaukee, where such buses were once used.

Current interest in improving transit operating efficiency, however, has renewed interest in this vehicle configuration. Presently, a small number are being operated on an experimental basis in the Cities of Los Angeles and New York City. Specifications for the double-deck vehicle undergoing demonstration service in these cities are given in Table 14. The vehicle itself is shown in Figure 28.

A brief discussion of the status of the federal Urban Mass Transportation Administration (UMTA) Tranbus is pertinent, although it is not a currently available vehicle configuration. The UMTA initiated a program in the late 1960's to develop a new urban transit bus to serve as an eventual replacement for the buses then in service in the United States that had had no major design changes since

Figure 19

GENERAL MOTORS CORPORATION
MOTOR BUS VEHICLES

Perhaps the best known motor bus manufacturer in the United States is the General Motors Corporation Truck and Coach Division. The top view illustrates the GMC "old look" vehicle, of which 50 different models of various sizes and features were produced from 1940 through 1969. The middle view illustrates the GM "new look" bus, produced by GM in the United States from 1960 through 1977 in 29-foot, 35-foot, and 44-foot lengths. The most recent GMC motor bus is the advanced design bus (ADB), first produced in 1977 as an interim design pending application of the federal Transbus specifications. Because of the indefinite delay in final adoption of the Transbus requirements, this vehicle design can be expected to be available for many years. As of 1979, both the "new look" and advanced design vehicle were used in the Milwaukee area. Some "old look" vehicles were still in use, but only to a limited extent, by the Milwaukee County Transit System.

Photos courtesy of Milwaukee County Transit System.

Figure 20

GRUMMAN FLXIBLE CORPORATION
MOTOR BUS VEHICLES

The top view illustrates the Grumman Flxible "new look" style vehicle which was manufactured from 1961 until 1978. One hundred of these vehicles are in service on the Milwaukee County Transit System. The lower photo illustrates the Grumman Flxible version of the advanced design bus (ADB) which has been influenced in many respects by the Urban Mass Transportation Administration's Transbus program.

Photo (top) courtesy of Milwaukee County Transit System.
Photo (bottom) by Otto P. Dobnick.

1959. Improvements were sought in passenger comfort and quality of ride, maintenance costs, and accessibility for the elderly and handicapped.[6]

Following the development of salient design characteristics for the proposed Transbus vehicle, the UMTA developed the following set of "perfor-

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[6] *One particular study that encouraged such improvements, conducted by the National Academy of Engineering in 1968, concluded that improved service would be more likely to attract new riders than would improved vehicle designs.*

Figure 21

DIESEL DIVISION–GENERAL MOTORS OF CANADA "NEW LOOK" BUS

In response to the continued demand for the proven "new look" motor bus manufactured for 18 years in the United States by the General Motors Corporation Truck and Coach Division, the Diesel Division of General Motors of Canada, Ltd., is now manufacturing the same vehicle with some minor improvements. These vehicles have been purchased for use in several American cities, including Appleton, Boise, Denver, Hartford, and St. Louis.

Photo courtesy of Diesel Division–General Motors of Canada, Ltd.

Figure 22

FLYER INDUSTRIES MODEL D900

The Flyer D900 is manufactured in Winnipeg, Canada, and is available in either 35-foot or 40-foot lengths. In addition to being used in numerous Canadian cities, this model of bus vehicle has also been sold for use in the American cities of Seattle, Oakland, Syracuse, Anchorage, and San Mateo. The manufacturer has indicated that this vehicle model will be replaced during 1980 with the Model D901, an updated version of the D900 with some engineering and exterior styling modifications.

Photo by Otto P. Dobnick.

Figure 23

NEOPLAN U.S.A. CORPORATION MODEL N4616b VEHICLE

Neoplan is one of several foreign motor bus manufacturers which have entered the United States market through creation of a separate American company. The Model N4616b vehicle is an Americanized version of the Neoplan Model N416 city bus, manufactured in West Germany. This vehicle may be selected as the low bid by the Milwaukee and Atlanta systems.

Photo courtesy of U. S. Department of Transportation.

Figure 24

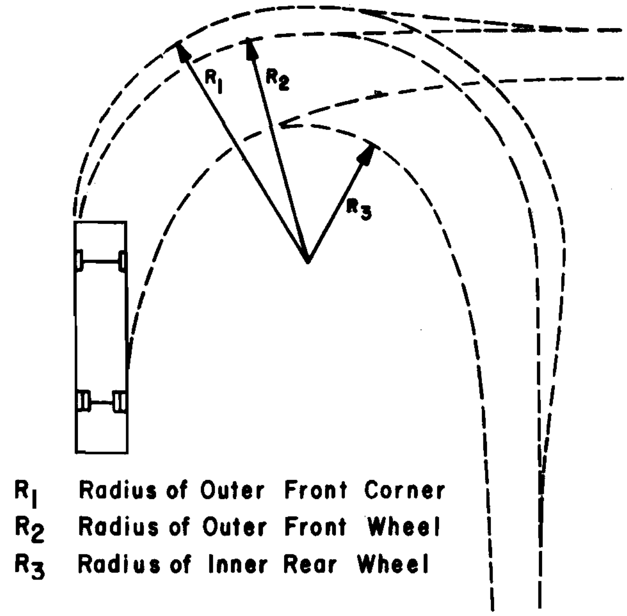
EAGLE INTERNATIONAL, INC., MODEL 05 VEHICLE

Shown above is one of the Eagle International Model 05 buses purchased by the Metropolitan Transit Authority of Harris County, Texas, for commuter service into downtown Houston. The 55 vehicles purchased for this service are basically intercity coaches with modified interiors for commuter service. The manufacturer has announced a suburban two-axle version of the new American Eagle Model 10 vehicle to be available during 1982. The vehicle is shown at the recently constructed Kuykendahl Park-and-Ride Center north of Houston.

Photo courtesy of Metropolitan Transit Authority of Harris County.

Figure 25

MOTOR BUS TURNING RADII



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Table 13

PHYSICAL AND PERFORMANCE CHARACTERISTICS OF SELECTED TRANSIT MOTOR BUSES–ARTICULATED CONFIGURATION

Characteristic	M.A.N. SG220US[a]	Ikarus 286 City Bus
Length (feet)	60.0	59.8
Width (inches)	102.0	102.0
Height (inches)	124.1	119.0
Net Weight (pounds)	37,200	36,377
Front Wheelbase (inches)	222.4	224.0
Rear Wheelbase (inches)	287.4	280.0
Minimum Turning Radius (feet)	43.3	40.0
Manufacturer	American M.A.N. Truck & Bus Corporation	Crown Coach Corporation
Approximate Year of Introduction	1978	N/A
Front Step Height (inches)	14.7	14.0
Door Type/Number	Swinging/ 2 or 3	Swinging/ 2 or 3
Front Door Width (inches)	49.2	48.0
Other Door Width (inches)	49.2	48.0
Design Capacity Seats/Standees	72/N.A.	67/40
Maximum Speed (mph)	N/A	N/A
Service Acceleration[c] (miles per hour per second)	1.5-2.0	1.5-2.0
Service Deceleration[c] (miles per hour per second)	2.5	2.5
Emergency Deceleration[c] (miles per hour per second)	6.0-12.0	6.0-12.0
Maximum Grade (percent)	N/A	N/A
Capital Cost per Vehicle	$225,000	$213,000
Fuel Economy (mpg)	N/A	2.9[b]

NOTE: N/A indicates data not available.

[a] *This vehicle is available in one or more shorter lengths with a corresponding decrease in net weight, wheelbases, minimum turning radius, and passenger capacity.*

[b] *Milwaukee County Transit System data which reflect combined local and express service.*

[c] *These rates of acceleration and deceleration for motor bus vehicles are typical, and actual rates will depend not only upon the engine and drive train design, but also upon the loaded vehicle weight, roadway conditions, and roadway gradient.*

Source: SEWRPC.

mance specifications" for all buses manufactured after September 1979:

- All new buses must have a 22-inch floor height, and the floor must have the capability to "kneel" to 18 inches for boarding.
- All new buses must be equipped with either a wheelchair ramp or lift.
- All new buses must have tandem rear axles to accommodate the low floor.

In addition, a maximum of 54 months without penalty was allowed for development and delivery, the designs and prototypes being subject to endurance, performance, and maintenance tests.

In January 1979, the Cities of Los Angeles, Miami, and Philadelphia formed a consortium and requested bids for 530 buses manufactured according to the Transbus Procurement Requirements developed by the UMTA. On May 2, 1979—the bidding deadline—both domestic and foreign manufacturers declined to offer bid proposals. The manufacturers claimed the tendering of bids was inhibited by the difficulty in building a low-floor bus, which required the development of brand new components that would have unknown reliability and development costs, by the inflationary aspects pertaining to the manufacture, operation, and maintenance of the proposed vehicle, and by the interpretation that some of the proposed vehicle requirements were in conflict with other federal policies. In addition, the potential bidders could not envision a design that would meet the requirements pertaining to overall and component weight, space limitations, performance criteria, and time allowed for contract completion. In addition, both companies manu-

Figure 26

M.A.N. TRUCK AND BUS CORPORATION MODEL SG 220 US ARTICULATED VEHICLE

The M.A.N. Truck & Bus Corporation articulated buses are available in either a 55-foot length (upper photo) or 60-foot length (lower photo). The M.A.N. articulated vehicles are currently being operated in the Atlanta, Chicago, Los Angeles, Minneapolis, St. Paul, Oakland, Phoenix, Pittsburgh, San Diego, San Francisco, San Rafael, Seattle, and Washington areas, and some of these cities have placed orders for additional vehicles.

Photo (top) courtesy of Chicago Transit Authority.
Photo (bottom) by Russell E. Schultz.

Figure 27

IKARUS MODEL 286 ARTICULATED VEHICLE

The Ikarus 286 articulated motor bus is a Hungarian design which has been Americanized by Crown Coach Corporation. The vehicle, demonstrated for one week during 1980 on the Milwaukee County Transit System, is available only in a 60-foot length. As of 1979, these vehicles were being manufactured for use in Portland, Oregon.

Photo courtesy of Crown Coach Corporation.

facturing buses in the United States maintained that recent vehicle designs met many of the Transbus requirements, including accessibility for the elderly and handicapped. Transbus proponents countered that the vehicle manufacturers could be guilty of collusion, and that the manufacturers were opposed to the new vehicle design because of the very recent introduction of advanced-design motor buses by both American builders.

In the absence of any bids, the Urban Mass Transportation Administration requested an independent technical review as to whether the bus manufacturers' decision was reasonable. The resulting review almost fully concurred with the potential bidders' decision, noting that even when financial and business considerations were discounted, the bus could not, on technical grounds, be provided within the specified time constraints.[7] A subsequent review of these findings by the National Research Council agreed that the principal conclusions were warranted by the evidence. In addition, this review specifically addressed alternative means of providing mobility for the elderly and handicapped.

In August 1979, the U. S. Department of Transportation announced a temporary delay in the effective date of the Transbus procurement requirements. In the interim, currently available buses may be purchased providing they meet established federal requirements, including a wheelchair lift. The

[7] *The technical review and assessment of the Transbus Procurement Requirements was performed by the Mitre Corporation of McLean, Virginia. This plus the subsequent review of the Mitre findings are documented in the National Research Council Transbus Study, published by the National Research Council, Washington, D. C.*

Table 14

PHYSICAL AND PERFORMANCE CHARACTERISTICS OF SELECTED TRANSIT MOTOR BUSES—DOUBLE-DECK CONFIGURATION

Characteristic	Neoplan N122/3	Leyland Metro
Length (feet)	39.4	36.5
Width (inches)	102.0	98.0
Height (inches)	174.0	174.0
Net Weight (pounds)	48,500	23,439
Wheelbase (inches)	270.0	N/A
Minimum Turning Radius (feet)	N/A	71.3
Manufacturer	Neoplan	British Leyland
Approximate Year of Introduction	N/A	1980
Front Step Height (inches)	N/A	N/A
Door Type/Number	Swinging/2	Swinging/ 1 or 2
Front Door Width (inches)	53.1	47.2
Rear Door Width (inches)	53.1	47.2
Design Capacity Seats/Standees	84/14	80/N.A.
Maximum Speed (mph)	50-60	43.5
Service Acceleration[a] (miles per hour per second)	1.5-2.0	1.5-2.0
Service Deceleration[a] (miles per hour per second)	2.5	2.5
Emergency Deceleration[a] (miles per hour per second)	6.0-12.0	6.0-12.0
Maximum Grade (percent)	N/A	22
Capital Cost per Vehicle	$261,000	N/A
Fuel Economy (mpg)	3.9	N/A

NOTE: N/A indicates data not available.

[a] *These rates of acceleration and deceleration for motor bus vehicles are typical, and actual rates will depend not only upon the engine and drive train design, but also upon the loaded vehicle weight, roadway conditions, and roadway gradient.*

Source: SEWRPC.

applicability of the Transbus specifications to contemporary and future motor bus design is uncertain at this time. It can be reasonably assumed, however, that current models offered by manufacturers will be utilized for primary transit services in at least the near-term future.

Propulsion of motor bus vehicles is accomplished predominantly by the use of either a six-cylinder or eight-cylinder diesel engine propelling the driving axle via a direct mechanical drive-train assembly. Diesel-powered vehicles predominate in the existing motor bus fleets and can be expected to do so over at least the next decade. The present diesel prime mover has a proven performance and

Figure 28

NEOPLAN U.S.A. CORPORATION SKYLINER MODEL N122/3

Following completion of a federally funded demonstration study in the Los Angeles area, the Southern California Rapid Transit District will acquire 20 double-deck buses of West German design. These vehicles represent a high-capacity alternative to articulated single-level motor coaches, and their operation in Los Angeles will mark the first regular use of such a bus design for urban transit service in the United States in about 30 years.

Photo courtesy of Southern California Rapid Transit District.

is efficient, durable, and relatively inexpensive to maintain. Transit operators and their maintenance staffs are familiar with its capabilities and design. Some articulated motor buses require the use of a special underfloor diesel engine.

The gasoline engine is no longer preferred for heavy motor vehicles, including transit buses, because of its inferior performance when compared with diesel prime movers. Liquid propane-fueled buses have been utilized in some cities until recently. These vehicles, however, have also been replaced by conventional diesel buses. Other engine types suitable for motor bus operation are in various experimental stages. These are noted and briefly discussed in the section in Chapter V of this report on alternative propulsion technologies. Electric propulsion and semi-electric propulsion have attracted interest because they are less dependent upon petroleum-based fuels. Electric trolley buses that draw power from an overhead wire system are presented as a specific mode in Chapter IV of this report. Semi-electric bus systems, as well as battery-powered vehicles, are discussed in Chapter V, along with other experimental technology relevant to primary transit systems.

Based upon the reported experience of transit operators in the United States, as shown in Table 15, buses provide on a systemwide average basis from 4.0 to 5.3 vehicle miles per gallon of diesel fuel. This variation in fuel use is a result not only of the type of bus, its engine and drive-train components, its weight, and its optional equipment, but also of the characteristics of its route, including average speed, frequency of stops, degree of traffic congestion, terrain, and the weight of passenger loading. It has been estimated that the General Motors "new look" vehicles used by the Milwaukee County Transit System for Freeway Flyer (express) service can attain propulsion energy efficiencies 25 percent greater than those attained by the same vehicles in local service, approaching 5.5 miles per gallon (mpg) of diesel fuel used in propulsion, as compared with an overall propulsion efficiency of 4.4 mpg for these same vehicles used in local service in 1979. Also, new buses such as the General Motors RTS buses, recently acquired by the Milwaukee County Transit System, tend to be less fuel efficient in propulsion than the older vehicles which comprise the majority of the transit fleet. The General Motors RTS bus had an overall average fuel propulsion efficiency in 1979 of only 3.4 miles per gallon of diesel fuel and as low as 2.0 mpg on some routes. This reduced propulsion fuel efficiency is due in part to the added weight of the wheelchair lift and air-conditioning equipment, and also to the energy required to operate the air-conditioning equipment on these newer buses.

The average propulsion energy efficiency of buses operated by various transit systems is given in Table 15 in both miles per gallon of diesel fuel and miles per British Thermal Units (BTU's). A BTU is the energy needed to raise the temperature of one pound of water one degree Fahrenheit. By using this measure, it is possible to compare the energy requirements of vehicles using gasoline, diesel fuel, or any other type of fuel or energy, including liquid propane and electric power.

The number of seat miles provided per gallon of fuel consumed is another important measure of the energy efficiency of transit vehicles. Large buses capable of carrying more passengers may consume more fuel per mile than do smaller buses; however, at high load factors, fuel consumption per seat mile may actually be less for large vehicles than for smaller vehicles. Therefore, a transit system may be able to operate with greater propulsion fuel efficiency by using motor buses which provide more seat miles—and therefore potentially more passenger miles—per unit of energy used. An example of such an increase in fuel efficiency is that provided by a fully loaded Ikarus articulated motor bus, which provides 42 percent more seats—67 seats compared with 47 seats—than does a typical General Motors RTS "Advanced Design" bus while consuming only about 14 percent more fuel.

Table 15

VEHICLE PROPULSION ENERGY EFFICIENCY FOR SELECTED URBAN BUS TRANSIT SYSTEMS: 1975-1979

Location of Transit System	Propulsion Energy Efficiency: Miles per Gallon[a]	Propulsion Energy Efficiency: Vehicle Miles per Million BTU's[b]
Average Urban Bus (1977)[c]	3.9	28.7
New York City (1975)	3.9	28.7
Milwaukee (1979)	4.0	29.4
Atlanta (1976)	4.4	32.4
Cleveland (1976)	4.5	33.1
Northern New Jersey (1975)	5.2	38.3

[a] *Miles per gallon of diesel fuel or equivalent.*

[b] *One gallon of diesel fuel is equivalent to 136,000 BTU's.*

[c] *An average figure for buses providing all types of service in 928 urban areas in the United States.*

Source: Congressional Budget Office, Milwaukee County Transit System, and SEWRPC.

For planning purposes, passenger miles per gallon of fuel consumed is a more important measure than is vehicle miles or seat miles per gallon. At a load factor of 1.0—that is, with all seats occupied—fuel consumption per seat mile and per passenger mile are equal. Transit systems in the United States, however, presently operate at load factors well below 1.0, as shown in Table 16. These low load factors are the result of operation during periods of limited, as well as peak, passenger demand in order to provide transportation services capable of meeting the needs of passengers for a variety of trip purposes throughout the day. During the peak morning and evening travel periods, when the trips

Table 16

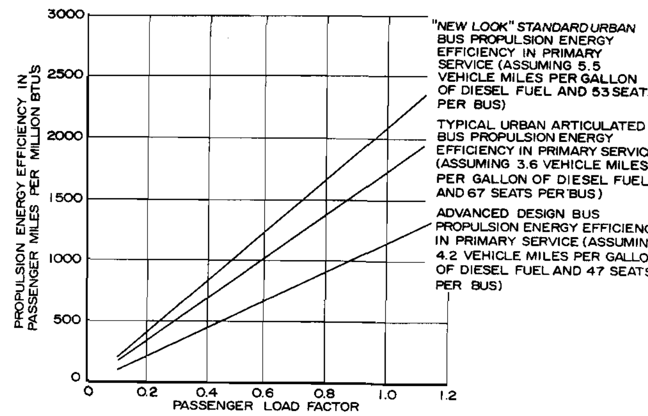
VEHICLE OCCUPANCY AND PASSENGER LOAD FACTORS FOR SELECTED URBAN BUS TRANSIT SYSTEMS: 1972-1978

Location of Transit System	Passenger Miles per Vehicle Mile	Load Factor (passenger miles per seat mile)
Albuquerque (1976)	4.9	0.10
Southern Connecticut (1972)	9.8	0.20
Chicago (1976)	10.9	0.22
San Diego (1976)	11.7	0.23
Milwaukee (1979).	11.3	0.23
New York City (1972)	13.8	0.28
Baltimore (1976)	19.1	0.28
National Urban Average (1978) . . .	12.7	- -

Source: Congressional Budget Office, American Public Transit Association, Milwaukee County Transit System, and SEWRPC.

Figure 29

PRIMARY BUS TRANSIT PROPULSION ENERGY EFFICIENCY FUNCTION OF PASSENGER LOAD FACTORS



Source: SEWRPC.

carried are being made primarily to and from work and school, it is not uncommon for passenger load factors to exceed 1.0 at the peak load point of transit routes in the peak direction. However, since demand drops off past the peak load points, as well as during other periods of the day, very high load factors are usually achieved only during the morning and afternoon peak travel periods and only over limited segments of the total transit system. Therefore, measures of transit vehicle fuel efficiency need to include passenger miles per unit of energy consumed based upon realistic load factors. Such load factors are a function of passenger demand, which is, in turn, a function of, among other factors, specific route configurations, level of service, and adjacent land use type and intensity. Therefore, unless specific route configurations and passenger demand are known and analyzed, comparisons of energy consumption expressed as passenger miles per gallon can only be reported as a range, based upon an assumed range of load factors. In order to illustrate the importance of passenger load factors in fuel efficiency, the relationship between load factors and bus passenger miles per unit of energy consumed is shown in Figure 29. For comparative purposes the present propulsion energy efficiency of the Milwaukee County Transit System Freeway Flyer service is also shown in Figure 29. The service's current overall passenger load factor of 0.39 and estimated fuel consumption of 24,700 BTU's per vehicle mile correspond to an energy efficiency of approximately 840 passenger miles per one million BTU's.[8] However, if all buses operating in Freeway Flyer service had a load factor of 1.0, the energy efficiency would be increased to about 2,100 passenger miles per one million BTU's, equal to the propulsion fuel efficiency per seat mile.

The vehicle speed and acceleration of conventional motor buses are controlled directly by the vehicle operator. A foot pedal is manipulated which governs the amount of fuel mixture that is allowed

[8] *The General Motors "new look" vehicles used by the Milwaukee County Transit System for the Freeway Flyer service are operated in both primary and tertiary service, but the fuel consumption rate is not available for primary service. However, the overall fuel consumption rate for these vehicles is 30,900 BTU's per vehicle mile (4.4 mpg), and transit company officials estimate that because of the reduced number of stops and higher average speeds, these vehicles consume approximately 25 percent less fuel when used in primary service, or 24,700 BTU's per vehicle mile (5.5 mpg).*

into the engine's combustion chambers. A transmission or torque converter consisting of a series of gears of varying size and with different ratios is used to make maximum power available through a series of speed ranges. Automatic transmissions utilizing hydraulic gear selection are typically used on vehicles operating within the United States. On foreign models, an automatic transmission is optional. The typical transmission is divided into either three or four forward speeds and one reverse speed.

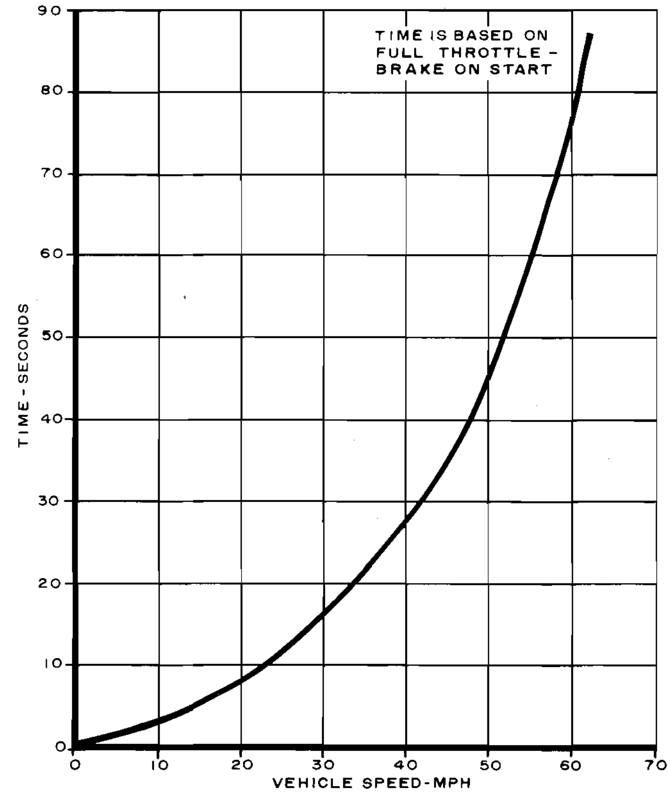
The rate of acceleration for motor bus vehicles is dependent not only upon the engine and drive-train specifications, but also upon the loaded vehicle weight, roadway conditions, and roadway gradients. Typical rates of acceleration are approximately 2.0 miles per hour per second for older, conventional, standard configuration vehicles; 2.5 miles per hour per second for modern standard vehicle designs; and 1.5 to 2.0 miles per hour per second for articulated vehicles (see Figure 30). Maximum vehicle speeds for American urban bus designs vary between 50 and 70 miles per hour, depending upon the engine and drive-train used.

Vehicle deceleration and service braking are accomplished by dual brake shoes with attached linings for each wheel assembly. The brake shoes are activated by an air system which requires an on-board air compressor. Emergency and parking brakes are integrated with this vehicle subsystem. Rates of deceleration are generally 2.5 miles per hour per second for service applications and a maximum of 12.0 miles per hour per second for emergency applications, although such rates should not exceed 5.0 or 6.0 miles per hour per second when standing passengers are being carried.

Passenger access depends upon the vehicle configuration as well as upon the method of fare collection utilized. Standard single-unit configuration vehicles generally have two doors on the same side, one located at the front and the second located midway along the length of the vehicle. On double-deck designs, the doors are usually located at the front and midway along the side, although on many older British designs the second doorway was located at the rear end of the vehicle to accommodate the stairway placement and the on-board conductor who collected the fares. Articulated buses, of which there are several designs in European service, typically have three doors per side, two in the front unit and one in the rear unit. An optional fourth door behind the rear axle is available on some European models. The three door

Figure 30

CONVENTIONAL MOTOR BUS VEHICLE PERFORMANCE



Source: Barton-Aschman Associates General Criteria for Transitway Design, Milwaukee County Transitway.

openings per vehicle facilitate rapid loading and unloading when a self-service fare collection system is utilized. Self-service fare collection has not yet been attempted within the United States. Because of this, the articulated buses currently being used in selected American cities have only two doors—one on each vehicle unit—so that boarding passenger flows can be directed past the operator and fare collection apparatus.

In 1976, the UMTA mandated a policy that all new buses bought with federal funding after February 15, 1977 must have front steps that are no greater than eight inches in height. Also, the effective floor height must be 24 inches or less after use of a "kneeling" feature which permits the right front corner of the vehicle to be lowered to new curb height. Designed especially to aid in the boarding of children, the elderly, and the handicapped, this operation is accomplished by exhausting the right-front suspension.

On May 31, 1979, the U. S. Department of Transportation issued a rule to implement Section 504 of the Rehabilitation Act of 1973, effective July 2, 1979. The rule requires recipients of financial assistance from the Department to make their federally assisted programs and activities accessible to handicapped persons. Specifically, this rule requires that a minimum of 50 percent of all motor buses operating in federally assisted fixed route systems be accessible to handicapped persons during peak travel periods. In addition, accessible vehicles must be utilized before nonaccessible vehicles during nonpeak periods. Such accessibility is usually provided by equipping the buses with wheelchair lifts. The wheelchair lifts consist of a stairway assembly, located in either the front or rear of the stairwell, that folds out into a platform large enough to accommodate a wheelchair. The platform can then be raised to the vehicle floor level, with appropriate safeguards for the wheelchair passenger (see Figure 31). In addition, certain areas of the bus interior are designated for the wheelchair passenger, these areas being equipped with folding seats and a wheelchair securement device.

Outside-hung plug or folding/swinging passenger doors are generally used on motor bus vehicles. Plug doors open outside and parallel to the body. Sensing edges are usually used to prevent the doors from closing on obstructions. Some European designs are equipped with push buttons to be activated by the passengers for opening certain doors.

Almost all motor buses have a two-plus-two across seating arrangement. Some designs incorporate some one-plus-one across seating or some longitudinal seating in order to gain additional space for standees, and thus a larger maximum vehicle capacity. Such variations are usually more common on foreign vehicles than on American vehicles. Individual seats are permanently installed so that all across seating faces forward.

Other important considerations in the physical design of motor bus vehicles are the suspension equipment and interior climate control equipment. Full air suspension is provided on most currently available models, with leveling valves for maintaining the proper coach height. Independent front suspension is integrated with the "kneeling" feature.

Heating equipment is universal. Air conditioning, although widely used in the United States, is considered optional on most foreign vehicle designs, which rely more on open window and forced air ventilation.

Guideway Technology

Primary transit modes that incorporate motor bus technology employ the basic guidance principle of rubber-tired vehicles operating over rigid-surfaced roadway pavements. The motor bus has what is referred to as "two degrees of freedom"—that is, the vehicle is able to freely move not only forward and backward along a guideway but also laterally at the operator's discretion.[9] Because of this inherent directional flexibility, bus transit modes generally require greater guideway cross-sections than do rail transit guideways, as well as larger horizontal clearances.

The guideway characteristics for motor bus operation in mixed traffic over freeways are not unique to the mode since existing facilities are utilized with little or no modification. The guideway characteristics for exclusive busways are, in contrast, unique to the mode. Reserved freeway bus lane systems and arterial express bus systems possess intermediate characteristics that vary with the extent of lane reservation and the method in which such reservation is accomplished.

The various bus modes and public highway systems designed for use by mixed automobile and truck traffic have one component in common: the roadway surface itself. In fact, express bus operation, whether over freeways in mixed traffic, over reserved freeway lanes, or over arterial streets, usually utilizes roadway facilities that are already in place, the design and construction of which generally conform to the widely accepted engineering standards prescribed by the American Association of State Highway and Transportation Officials (AASHTO).[10]

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[9] *Fixed rail transit systems are confined to the trackage and thus have one "degree of freedom" while aircraft may move in a forward, lateral, or vertical direction, and thus are considered to have three "degrees of freedom."*

[10] *American Association of State Highway and Transportation Officials, A Policy on Geometric Design of Rural Highways, 1965; and A Policy on Design of Urban Highways and Arterial Streets, 1973.*

Figure 31

TYPICAL MOTOR BUS WHEELCHAIR LIFT

In order to make fixed route public transit services accessible to physically handicapped persons, new motor buses acquired with federal funding assistance since 1979 have been equipped with wheelchair lifts. Available from a number of manufacturers, the lifts basically incorporate a stairway mechanism that unfolds and raises or lowers a wheelchair passenger between the curb and the bus floor, as shown in this series of photos.

Photos courtesy of Transportation Design and Technology, Inc.

Engineering standards for surface segments of primary transit motor bus systems that do require new guideway construction are identical to those for normal heavy-duty highways designed for high-speed mixed traffic. Typical roadways that are designed for such demands consist of pavement, usually placed on a base course, and sometimes in turn on a subbase course. The base and subbase course are placed, in turn, on the subgrade or basement soil. The base and subbase courses are usually layers of granular material that serve to distribute and diminish the loading pressures imposed on the roadway structure, to facilitate drainage, and to provide a smooth and uniform alignment on the land surface for placement of the pavement. The pavement often consists of a wearing surface underlaid by one or more pavement layers which serve to support the wearing surface and distribute the loadings to the base course. The pavement may be either of Portland Cement concrete or of asphaltic concrete, the former being classified as a rigid pavement and the latter as a flexible pavement.

For subway or tunnel applications, the wearing surface and base courses are laid directly on the floor of the underground structure. For elevated roadway segments, the wearing surface may be placed directly on top of prestressed concrete box girders or other structural shapes which are cast in place. As an alternative method, the pavement can be placed atop structural steel girders which are in turn supported by other structural steel or reinforced concrete columns. The particular design of either subsurface or elevated guideway structures depends upon the site-specific requirements.

It is not within the scope of this report to describe the geometric or structural design of existing streets and highways that might be used for primary transit service, it being assumed that such facilities will generally meet both the geometric and structural standards required to permit the operation of motor buses along with automobiles and motor trucks. The general geometric and structural standards for the specialized guideway components required in addition to existing street and highway facilities for the operation of each of the four motor bus transit modes are described below:

Mixed Traffic Operation on Freeways: Little or no guideway-related additions or modifications to the existing freeway facilities are required to operate motor buses in mixed traffic over existing freeways. However, bypass lanes for transit vehicles may need to be constructed at metered freeway entrance ramps, or entrance ramps may need to be constructed for the exclusive use of buses.

Bypass lanes for buses at metered freeway entrance ramps can assume one of two basic configurations. The first configuration involves the widening of the existing entrance ramp to accommodate an additional lane. Such an added lane can be provided wherever the ramp and shoulder width together are equivalent to two traffic lanes. Standard 12-foot-wide traffic lanes are desirable. The priority lane should be marked with preferential lane markings and appropriate signing.

The second configuration involves the construction of an additional ramp parallel to the existing ramp for the use of motor buses only. Such a ramp would have its own entrance from the arterial street system, merging with the existing ramp prior to entering the freeway lanes but after passing the traffic metering control signals located along the mixed traffic ramp. Proper signing at the ramp entrance is required. Bus-only lanes should be a minimum of 12 feet wide and should have appropriate shoulders.

Both ramp bypass configurations should be designed so that priority traffic and mixed traffic are merged before entrance to the freeway lanes. This permits a single-lane entrance to the freeway to be maintained. The basic bypass ramp configurations are shown in Figures 32 through 34.

Priority freeway access for buses can also be provided by constructing new exclusive entrance ramps, or by converting existing entrance ramps for mixed traffic to ramps for exclusive bus use. The conversion of mixed traffic ramps to exclusive bus ramps would involve minimal costs, these being for appropriate signing and pavement markings. The closing of specific ramps to automobile traffic, however, may have a significant impact on established traffic patterns. The construction of new ramp facilities would minimize disruption to existing traffic patterns and facilitate bus vehicle movement to special generators, but would entail substantial capital costs. The design of any new entrance ramps for the exclusive use of buses should comply with accepted freeway ramp design standards.

Reserved Freeway Bus Lane Systems: Reserved freeway lanes for motor bus operation also require a minimum amount of physical construction. As of 1980, reserved lane systems had been created either by reserving one or more existing mixed traffic lanes, or by constructing new lanes for the sole purpose of accommodating transit vehicles during peak periods.

Normal flow reserved lanes are separated from other lanes either by temporarily placing traffic cones, barricades, or flexible traffic posts between the reserved and mixed traffic lane, or by delineating the lanes with pavement markings and striping. Appropriate signing at frequent intervals is also required. While the daily installation and removal of cones, barricades, posts, and signs may represent a significant operating cost, these devices permit entrance to the lane at one point only and are thus self-enforcing. High rates of violation are found on facilities with normal flow lanes separated from other traffic solely by lane markings.

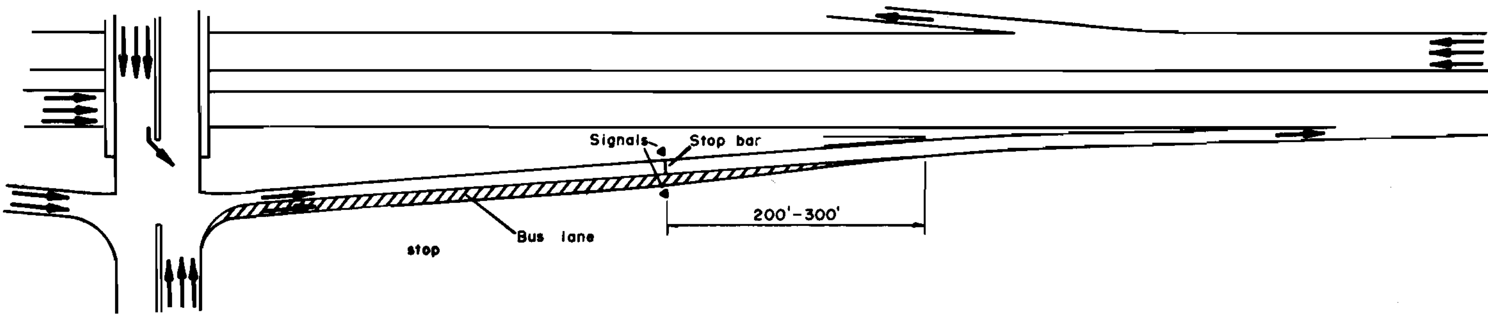
Contraflow reserved lanes are separated from other lanes in the same manner, using traffic cones, traffic posts, or barricades. Because contraflow lanes operate against the normal traffic flow without any substantial median or median barriers, pavement markings and striping alone are not used. When three freeway lanes are available in the underutilized direction, the posts or cones are normally placed on or just inside the dashed lane line, thus reserving one lane. If the directional traffic split is great enough and four lanes are available in the underutilized direction, the lane dividers may be placed in the middle of the second inside lane, as shown in Figure 35. This type of placement allows for an additional safety zone between opposing traffic flows.

One specialized modification to the existing freeway facility is normally required for the operation of contraflow reserved lanes. At the contraflow lane endpoints, special transition lanes are necessary so that motor buses are able to cross between the peak flow and underutilized directions. As shown in Figures 36 and 37, the transition lane must be installed in the median area, and thus any concrete barrier in that median area must be removed. Transition lanes should be located on tangent highway segments so that approach visibility is not restricted, and should be located far enough downstream from where buses enter the freeway to provide adequate distance for weaving from right-hand to left-hand lanes during peak traffic periods. Where the inside lane in the underutilized direction terminates, a transition area is necessary to direct traffic away from the oncoming contraflow vehicles. Such an area is usually designated by a line of flexible posts tapered to the median strip.

Busway Systems: Primary bus transit service that operates in freeway mixed traffic or over reserved freeway lanes utilizes existing guideway facilities,

Figure 32

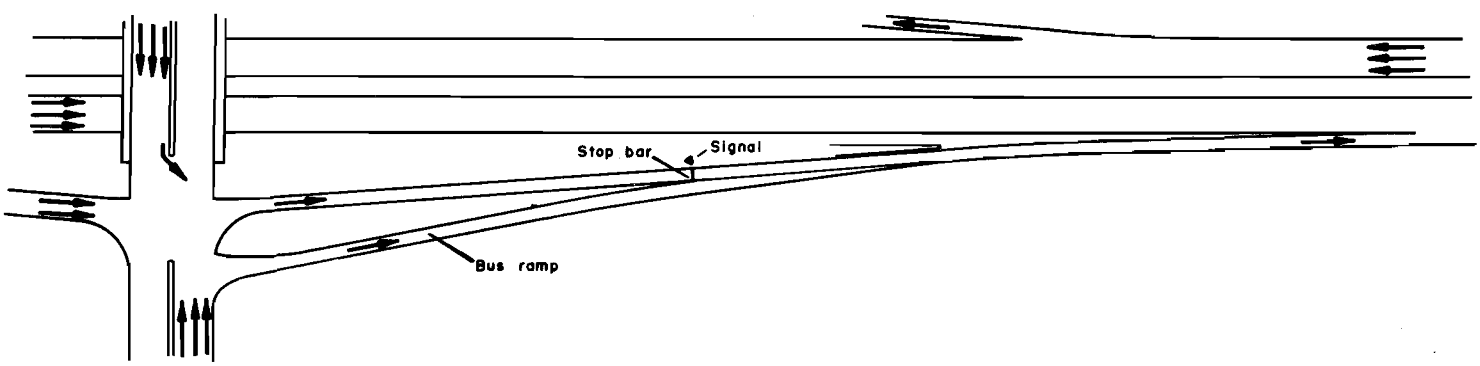
BYPASS LANE OF FREEWAY ENTRANCE RAMP CREATED BY WIDENING OF EXISTING RAMP



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Figure 33

BYPASS LANE OF FREEWAY ENTRANCE RAMP CREATED BY ADDITION OF PARALLEL RAMP



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

and thus it is not necessary to provide specific cross-sectional and clearance dimensional data in this report. However, the implementation of busway systems in the Milwaukee urbanized area would require the construction of completely new guideway facilities. General design data for such a busway as required for systems level analysis are therefore provided in this section.

Exclusive busways can be classified into one of two types, based upon the overall level of service. Class A busways provide for high-speed, high-quality, rapid transit service analogous to service provided by the heavy rail rapid transit mode. Being full grade-separated, Class A busways are generally applicable in large urbanized areas where express buses must operate nonstop over relatively long distances.

Class B busways provide for a somewhat lower quality of service analogous to that provided by the light rail transit mode. Class B busways serve shorter distance trips and operate at lower overall speeds than do Class A busways. Station frequency is greater, and there may be at-grade crossings with arterial streets. Class B busways are also applicable in large planned-unit developments, as evidenced by the use of such a busway in the new community of Runcorn, England. Figure 38 illustrates the distinction between Class A and Class B busways.

Both classes of busways may be further classified according to the direction of vehicle flow and the placement of shoulders for disabled vehicles. Normal flow busways employ standard right-hand operation, with the breakdown lanes and stations located on the outside portion of the roadway. The

Figure 34

BUS BYPASS LANE AT METERED FREEWAY ENTRANCE RAMP: N. THIRTEENTH STREET AND W. CLYBOURN STREET IN MILWAUKEE, WISCONSIN

As of 1979, there were two bypass lanes for motor buses in operation at metered freeway entrance ramps in the Milwaukee area. In addition to the bus bypass lane at N. Thirteenth Street and W. Clybourn Street, shown in this view, another such lane is located on the northbound entrance ramp of IH 43 at W. North Avenue.

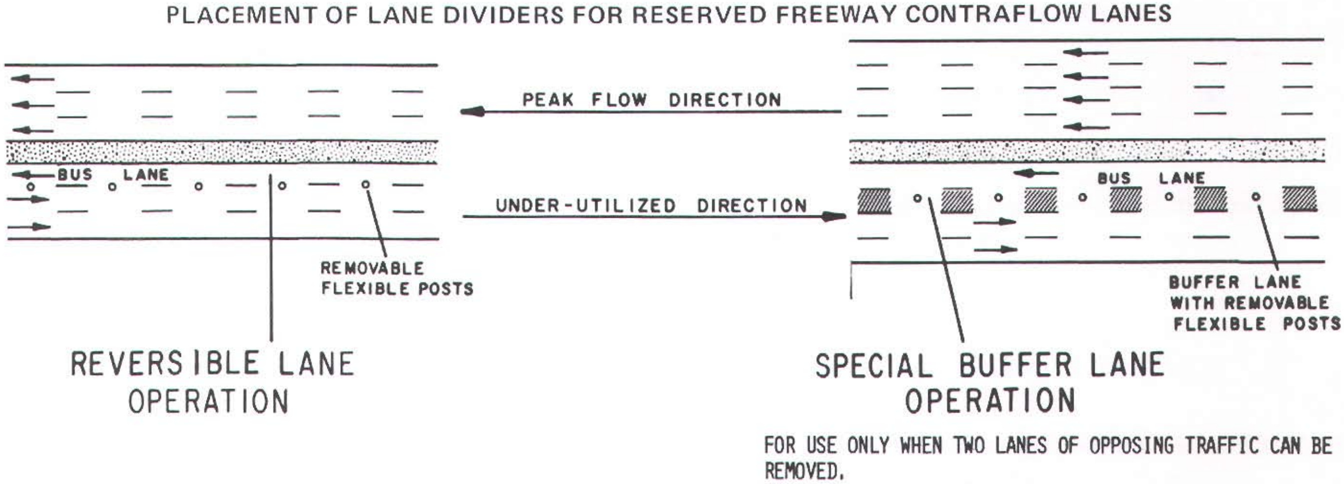
Photo courtesy of Wisconsin Department of Transportation, District 2.

stations of special flow busways are also located on the outside portion of the roadway, but a breakdown lane is located in the median area. Contraflow busways employ left-hand operation, permitting both the breakdown lane and stations to be located in the median area. This design may facilitate certain capital cost savings because of the reduced total cross-sectional area required. It should be noted that station placement determines the direction of traffic flow for opposing busway lanes, since most North American vehicles have passenger doors on the right-hand side only. These three types of busway design are illustrated in Figure 39.

The most restrictive elements that must be considered in the design of any new exclusive busway are the amount of vertical and horizontal space required for facility construction and the minimum clearances required for safe and efficient vehicle operation. Suggested busway design specifications are set forth in Tables 17 through 20. This design information, published by the Transportation Research Board, reflects the highway design standards of the American Association of State Highway and Transportation Officials modified

Figure 35

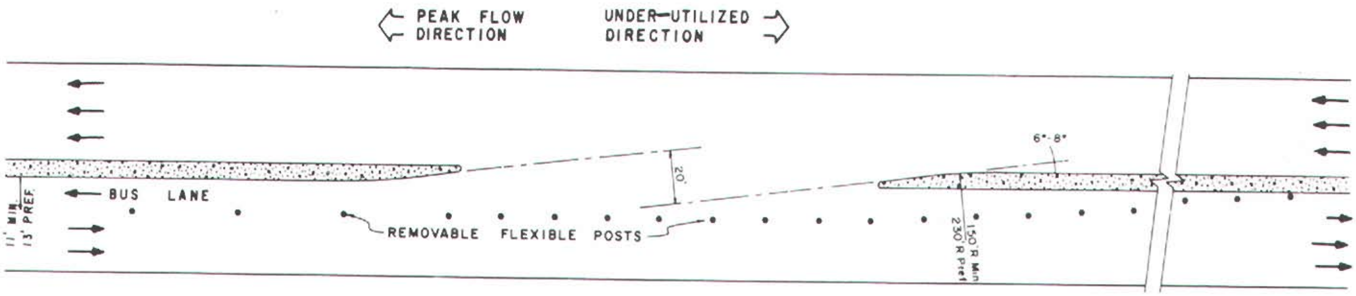
PLACEMENT OF LANE DIVIDERS FOR RESERVED FREEWAY CONTRAFLOW LANES



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Figure 36

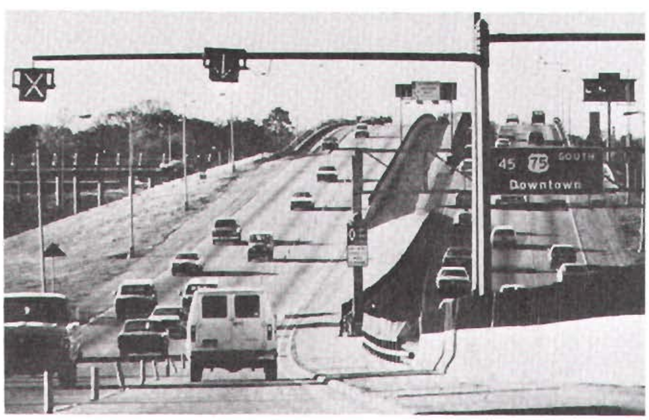
DETAILS OF TYPICAL FREEWAY CONTRAFLOW TRANSITION LANE



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Figure 37

TRANSITION LANE ON HOUSTON'S NORTH FREEWAY RESERVED CONTRAFLOW LANE



The implementation of a reserved contraflow freeway lane requires some specialized modifications to existing freeway facilities. At entrance and exit points to the contraflow lane, special transition lanes are necessary so that vehicles are able to cross between the peak-flow and underutilized traffic directions. As shown in this view, such a transition lane requires specialized signing, directional lights, and other traffic control measures, as well as the reconstruction of any concrete median barriers.

Photo courtesy of Metropolitan Transit Authority of Harris County.

as appropriate for express motor bus operations.[11] The application of these specifications is illustrated in the cross-sectional views in Figures 40 through 44. It is important to recognize that this information is for general systems planning purposes only. Actual guideway specifications for a particular system proposed for implementation within the Milwaukee urbanized area would be dependent upon site-specific requirements.

As already noted, the construction of an eight-mile-long busway was recommended for the Milwaukee urbanized area in previous regional and local transportation system and facility plans. Although this facility was not constructed, preliminary engineering was completed. Selected specifications used in the preliminary engineering of this busway are set forth in Table 21. Proposed cross-sections for this facility, known as the "East-West Transitway," are illustrated in Figure 45. The proposed facility was a Class A busway with normal flow.

The exclusive busway design guidelines set forth herein are based on accepted highway design standards. Because busways are highly specialized facilities having no need to accommodate mixed automobile and truck traffic, less stringent geometric and structural design standards may be applicable, thus reducing the costs of such facilities. For example, because all of the vehicles will be operated by professional drivers, a single 12-foot-wide reversible lane on a very narrow right-of-way may be a valid design possibility for certain situations. The busway proposal for Milwaukee County's East-West Freeway corridor as advanced in the initial regional transportation system plan called for a single 24-foot bituminous roadway constructed on a former electric interurban railway right-of-way.

Entrance to or egress from exclusive busways is normally accomplished through transition lanes to and from freeways and possibly certain other limited access highways, and through surface inter-

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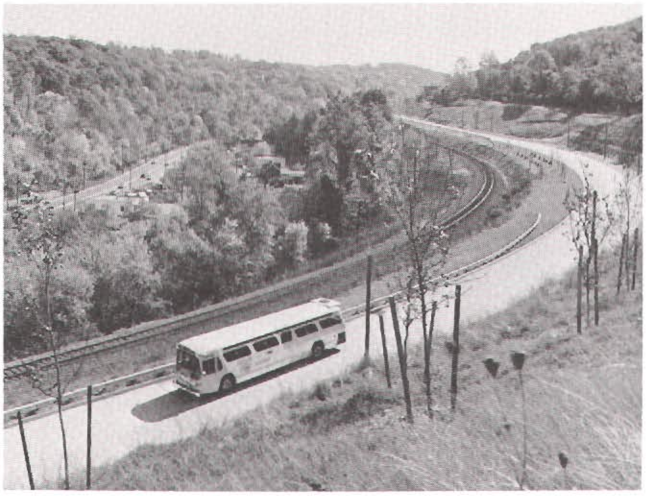
[11] *Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 55.*

Figure 38

DISTINCTION BETWEEN CLASS A BUSWAY AND CLASS B BUSWAY

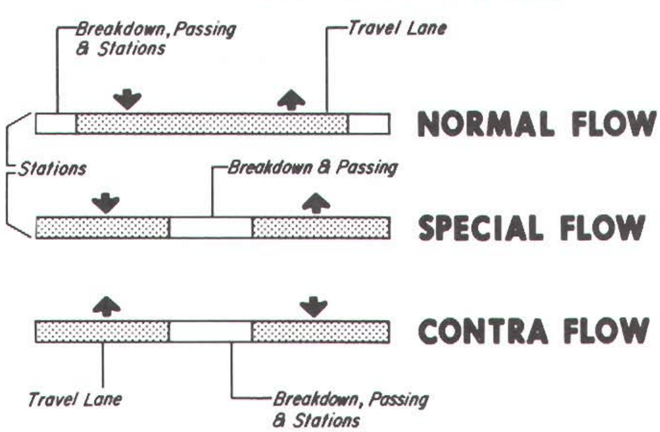


These two views illustrate two extremes of busway design. The left view shows a portion of Pittsburgh's South Busway, a Class A busway, which provides a high-speed, high-level service. The right view typifies an at-grade Class B busway. The facility is a quarter-mile-long private roadway located on a hospital grounds for the exclusive use of Edmonton Transit System vehicles.

Photo (left) courtesy of Port Authority of Allegheny County.
Photo (right) by Russell E. Schultz.

Figure 39

TYPES OF BUSWAYS CLASSIFIED ACCORDING TO DIRECTION OF VEHICLE FLOW AND PLACEMENT OF STATIONS



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

sections for connection to surface arterial street systems. Transition lanes are short roadway segments that are situated between the mixed traffic and exclusive transit lanes, normally in a median area. Such channelized lanes should have a minimum length of 400 feet to allow for merging. Where busways split into branches or approach freeway-to-freeway interchanges, grade separations between mixed traffic lanes and busway lanes may be necessary. At locations where either busway ramps or the busway itself connects with arterial streets, some form of at-grade intersection will be required. Because motor bus vehicles require a relatively large minimum turning radius, some sections of at-grade intersections may need to be widened, and such intersections may require larger radius corners than are normally required, as shown in Figure 46. These special requirements may not be necessary at surface intersections where Class B busways cross arterial streets, and where there is no need for buses to turn.

Ridership forecasts may sometimes indicate the potential for the future conversion of a busway into a rail transit guideway. In such cases, the right-of-way cross-section should be wide enough to accommodate future rail facilities, as well as temporary guideways during the conversion period if service is to be maintained. In addition, gradients, curvatures, structures, and all other features of the busway should be designed such that minimal changes are required in the right-of-way for conversion to the rail transit mode.

Special consideration is required for exclusive busway segments that are to be located in tunnels or subways. Because motor buses may be expected to continue to be primarily powered by diesel engines for the foreseeable future, and because

Table 17

SUGGESTED DESIGN SPECIFICATIONS FOR CLASS A AND CLASS B EXCLUSIVE BUSWAYS

Item	Class A Busway	Class B Busway
Design Speed (mph)		
Desirable	70	50
Minimum	50	30
Lane Width (feet)		
With Paved Shoulders	12[a]	11-12[a]
Without Paved Shoulders	13[a]	12[a]
Paved Shoulder Width[b] (feet)	8-10	6-8
Total Paved Width (feet)		
Normal Flow	26-44	24-40
Special Flow	30-36	
Contraflow	30-36	
Minimum Viaduct Width[c] (feet)	28	28
Minimum Tunnel Width[d] (feet)	31	31
Minimum Vertical Clearance (feet)		
Desirable	14.5-18[e]	14.5
Absolute Minimum		12.5
Minimum Lateral Distance to Fixed Obstructions[f] (feet)		
Left	3.5	2
Right	6	3
Minimum Radius of Horizontal Curves (feet)		
70 mph	1,600	1,600
60 mph	1,150	1,150
50 mph	750	750
40 mph	450	450
30 mph	250	250
Absolute Minimum Radius[g] (feet)		
Convertible to Conventional Rail	250	250
Convertible to Light Rail	100	100
Nonconvertible	30	30
Maximum Gradients (percent)		
Desirable		
Convertible to Rail	3-4	3-4
Other	5	6
Ramps, Up	6	7
Ramps, Down	7	8
Absolute		
Main Line	8	8
Ramps	10	10
Vertical Curve K-Values[h]		
70 mph, Crest	255	255
Sag	145	145
60 mph, Crest	160	160
Sag	105	105
50 mph, Crest	85	85
Sag	75	75
40 mph, Crest	55	55
Sag	55	55
30 mph, Crest	28	28
Sag	35	35
Ramps		
Design Speed (mph)	30-35	15-25
Lane Width (feet)		
With Paved Shoulders	12[i]	12[i]
Without Paved Shoulders	14[i]	13[i]
Paved Shoulder Width (feet)	8	8
Total Paved Width (feet)	14-22	13-20

Table 17 - footnotes

[a] Increase lane width one foot when nonmountable-type curbs are used adjacent to travel lane.

[b] Applies only to normal flow busways.

[c] Curb to curb; excludes pedestrian walks and width required by curbs.

[d] Inside envelope.

[e] Varies according to requirements for possible future conversion to rail transit.

[f] Distance from edge of traveled lane to vertical face of a noncontinuous obstruction, such as a bridge pier or abutment.

[g] Inner lane edge.

[h] Length of vertical curve = K x algebraic difference in grades. The K-values given conform to the current policy of the American Association of State Highway and Transportation Officials.

[i] Refer to Table 17 for minimum ramp width on curves. Increase lane width one foot when nonmountable-type curbs are used adjacent to travel lane.

Source: Transportation Research Board.

Table 18

PAVEMENT WIDENING RECOMMENDED FOR CURVES OF TWO-WAY LANE EXCLUSIVE BUSWAYS

Type of Busway	Normal Roadway Width (feet)	Design Speed (mph)	Feet of Pavement Widening for Curve with Radius of:[a] 500	750	1,000	2,000	3,000	4,000
Class A	24	30	1.5	1.0	0.5	0.0	0.0	0.0
		40	2.0	1.0	1.0	0.0	0.0	0.0
		50		1.5	1.0	0.5	0.0	0.0
		60			1.5	0.5	0.0	0.0
		70				1.0	0.5	0.0
Class B	22	30	2.5	2.0	1.5	1.0	0.5	0.5
		40	3.0	2.0	2.0	1.0	1.0	0.5

[a] Values less than 0.5 may be disregarded.

Source: Transportation Research Board.

these engines emit air pollutants which can be hazardous in sufficient concentrations, such guideway segments must be adequately ventilated. The construction costs for the underground portion of subways and tunnels may thus be expected to be at least 20 to 30 percent higher with diesel bus operation than with electric operation because of the supply and exhaust equipment necessary to control air quality in tunnels longer than 1,500 feet. Proposed underground stations would also require special design considerations in order to minimize air pollution in passenger waiting areas.

Table 19

RAMP PAVEMENT WIDTHS RECOMMENDED FOR USE BY MOTOR BUS VEHICLES

Conditions	Feet of Pavement Width for Inner-Pavement-Edge Radius of:								
	50	75	100	150	200	300	500	1,000	Tangent
One-Lane, One-Way, No Passing.	22	19	17	16	16	15	15	14	12
One-Lane, One-Way, with Provision for Passing Stalled Vehicle	39	31	28	25	24	23	22	22	20
Two-Lane, One-Way or Two-Way	45	37	34	31	30	29	28	27	24

Source: Transportation Research Board.

Table 20

HORIZONTAL CLEARANCES RECOMMENDED FOR EXCLUSIVE BUSWAYS AT SPECIAL OBSTRUCTIONS

Type of Busway	Obstacle	Minimum Distance from Edge of Lane (feet)	
		Left Edge	Right Edge
Class A[a]	Bridge Pier	4.5	6.0
	Parapet[c]	3.0	3.0
	Tunnel Wall[c].	3.5	3.5
	Retaining Wall[c] . . .	3.5	3.5
Class B[b]	Bridge Pier		4.0
	Parapet[c]		3.0
	Tunnel Wall[c].		3.5
	Retaining Wall[c] . . .		3.5

[a] *Based on 12-foot lanes.*

[b] *Based on 11-foot lanes.*

[c] *Clearance width includes safety or barrier-type curb.*

Source: Transportation Research Board.

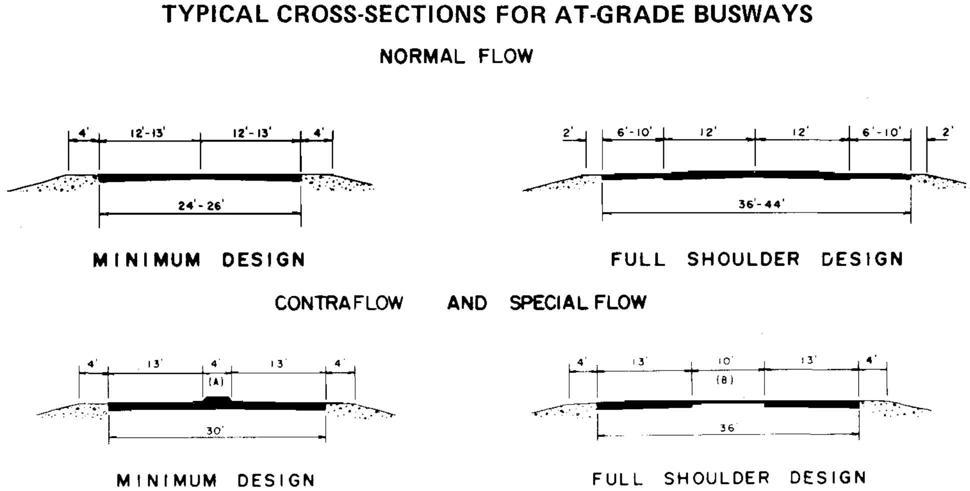
Because of the ventilation requirements inherent in the operation of diesel engines within enclosed areas such as subways, underground alignments for busways are not considered desirable.

Arterial Express Bus Systems: Express bus operation over arterial streets requires some means of providing priority for the buses. Such means may take the form of reserved lanes or priority at traffic signals. Bus priority at signalized intersections is a traffic control measure that can be implemented with or without reserved lanes, and is therefore discussed in the section of this chapter entitled "Support Requirements."

Reserved lanes for bus operation on arterial streets can be located over curb lanes in either a normal flow or contraflow fashion, or over center lanes. Such lanes are typically provided in intensely developed areas, where the facility can be used by large concentrations of motor buses. Thus, street widening to accommodate reserved transit lanes is usually not an available option, and existing mixed traffic lanes must be dedicated for this purpose.

Figure 40

TYPICAL CROSS-SECTIONS FOR AT-GRADE BUSWAYS



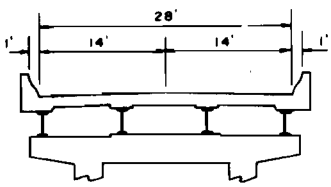
NOTES: LANE WIDTHS MAY BE INCREASED ON CURVES
(A) RAISED MOUNTABLE MEDIAN FOR CONTRA FLOW; FLUSH MEDIAN FOR SPECIAL FLOW
(B) FLUSH MEDIAN
(C) 4' MIN. IF ADJACENT TO FREEWAY LANES

Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

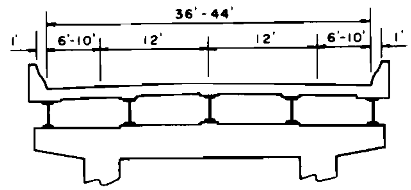
Figure 41

TYPICAL CROSS-SECTIONS FOR ELEVATED BUSWAYS

NORMAL FLOW

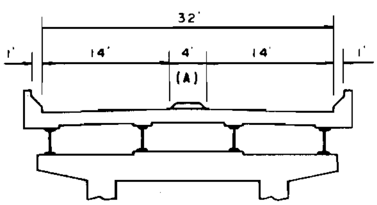


MINIMUM DESIGN

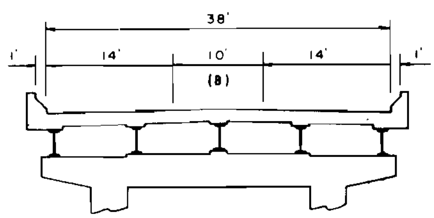


FULL SHOULDER DESIGN

CONTRAFLOW AND SPECIAL FLOW



MINIMUM DESIGN



FULL SHOULDER DESIGN

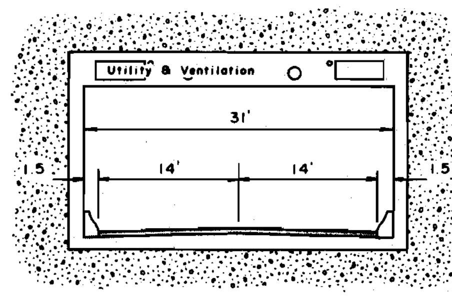
NOTE: LANE WIDTH MAY BE INCREASED ON CURVES
(A) RAISED MEDIAN, MOUNTABLE
(B) FLUSH MEDIAN

Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

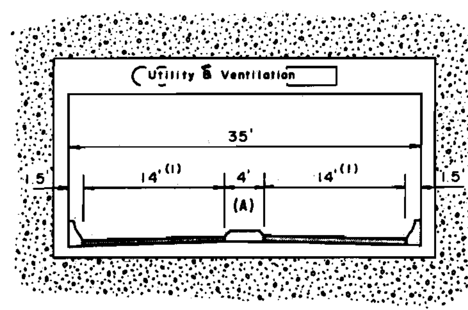
Figure 43

TYPICAL CROSS-SECTIONS FOR UNDERGROUND BUSWAYS

NORMAL FLOW



CONTRAFLOW AND SPECIAL FLOW



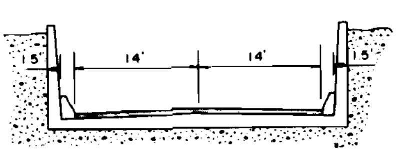
NOTE: LANE WIDTH MAY BE INCREASED ON CURVES.
(A) MOUNTABLE RAISED MEDIAN

Source. Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

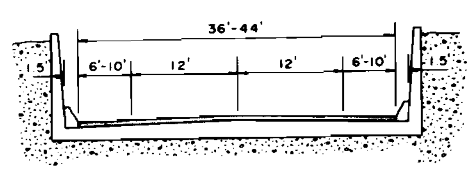
Figure 42

TYPICAL CROSS-SECTIONS FOR DEPRESSED BUSWAYS

NORMAL FLOW

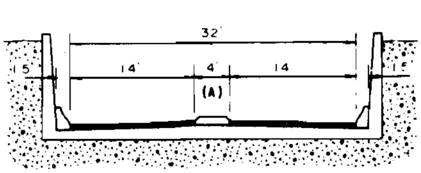


MINIMUM DESIGN

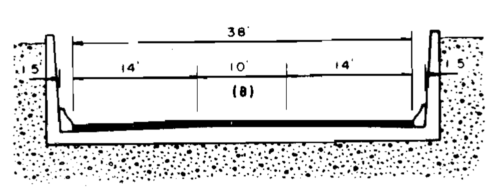


FULL SHOULDER DESIGN

CONTRAFLOW AND SPECIAL FLOW



MINIMUM DESIGN



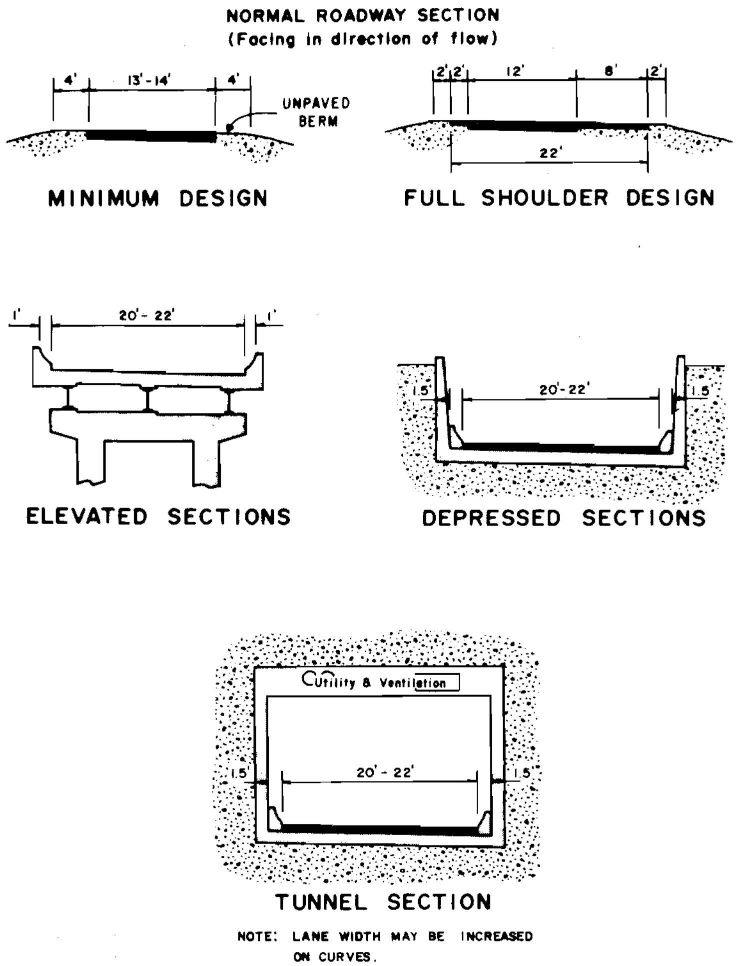
FULL SHOULDER DESIGN

NOTE: LANE WIDTH MAY BE INCREASED ON CURVES.
(A) MOUNTABLE RAISED MEDIAN
(B) FLUSH MEDIAN

Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Figure 44

TYPICAL CROSS-SECTIONS FOR
BUSWAY ENTRANCE AND EXIT RAMPS



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

However, if these lanes are implemented in conjunction with one-way street projects or with curb parking prohibitions, they will not necessarily result in a reduction in street capacity. If implemented otherwise, the impacts of the removal of one or more mixed traffic lanes upon existing traffic patterns would need to be determined.

A variety of traffic engineering practices may be employed to separate the reserved lanes on arterial streets from the remaining lanes. If the reserved lanes are to be in service only during peak periods, lane separation can be effected by either lane

Table 21

DESIGN SPECIFICATIONS FOR PROPOSED
EAST-WEST TRANSITWAY: MILWAUKEE, WISCONSIN

Item	Specification
Design Speed (mph)	
Transitway	70
Ramps	30 (minimum)
Lane Width (feet)	
Transitway	13 (minimum)
Ramp	
One-Lane, One-Way	15-18[a]
One-Lane, One-Way with Passing Provision	21-29[a]
Two-Lane Operation	26-35[a]
Grade (percent)	
Transitway	5 (maximum)
Ramp	6 (maximum)
Vertical Clearance	
Transitway under Highway or Railroad, or over Freeway	15'-0" (minimum)
Transitway over Freeway	16'-6" (minimum)
Transitway over Railroad	23'-0" (minimum)
Horizontal Clearance	
Left Edge of Pavement to Vertical Obstruction	30'-0" (desirable) 3'-6" (minimum)
Right Edge of Pavement to Vertical Obstruction	30'-0" (desirable) 8'-0" (minimum)
Median	4'-0"
Sight Distance (feet)[b]	
70 mph	600
60 mph	475
50 mph	350
45 mph	315
35 mph	240
Horizontal curves	
Transitway	
Desirable Maximum	2^{o}-00'
Maximum	3^{o}-00'
Ramps	
Maximum	18^{o}-00'
Shoulders	
Desired	10'-0"
Minimum	8'-0"
Cross-Slope	1/2" per foot
Side Slope	
Fill	4:1[c]
Cut	3:1[c]

[a] *Depends on radius of inner edge of pavement.*

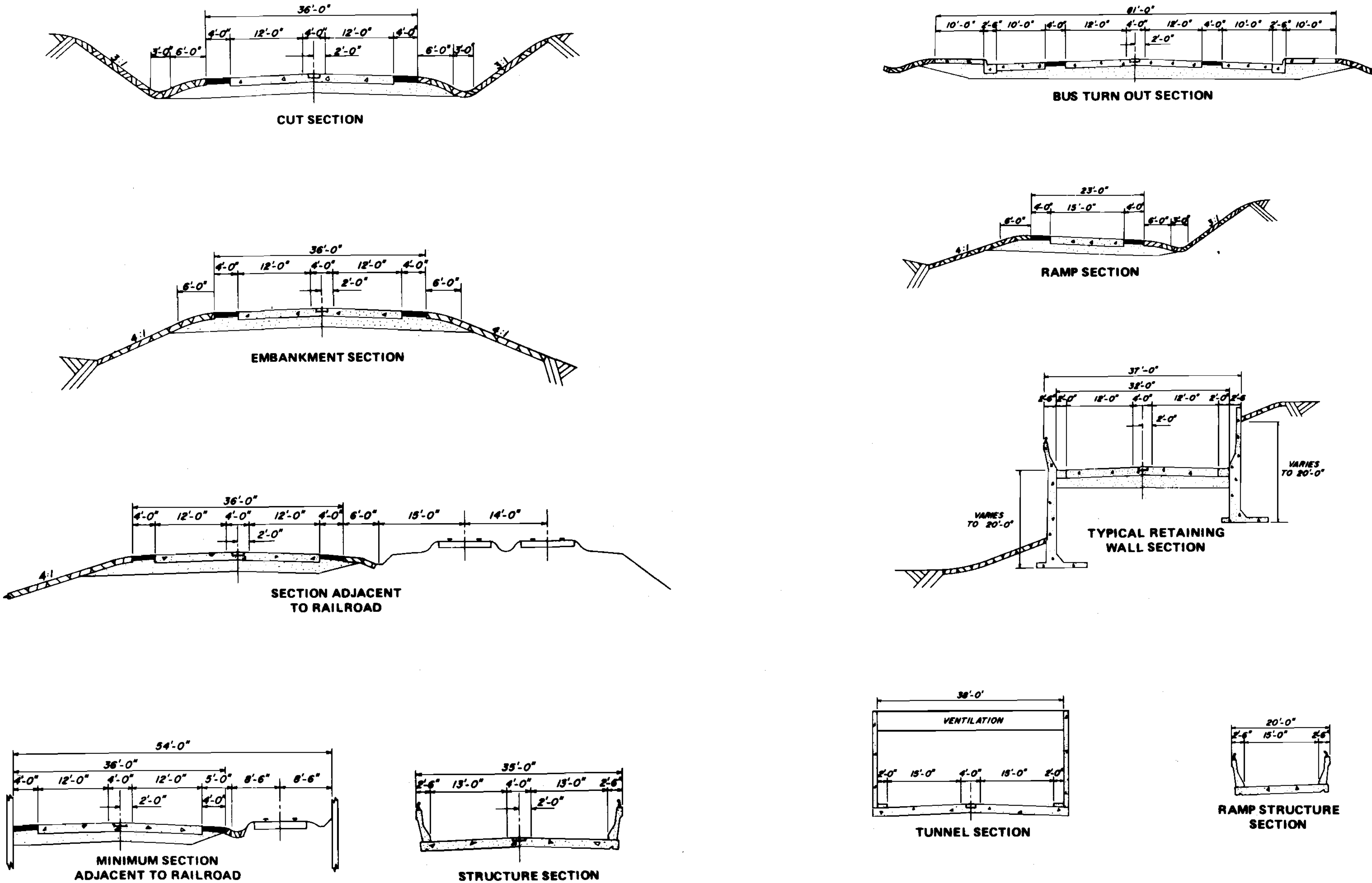
[b] *Minimum safe stopping sight distance for design speed.*

[c] *Outside the 6:1 side slopes.*

Source: Barton-Aschman Associates, General Criteria for Transitway Design, Milwaukee County Transitway.

Figure 45

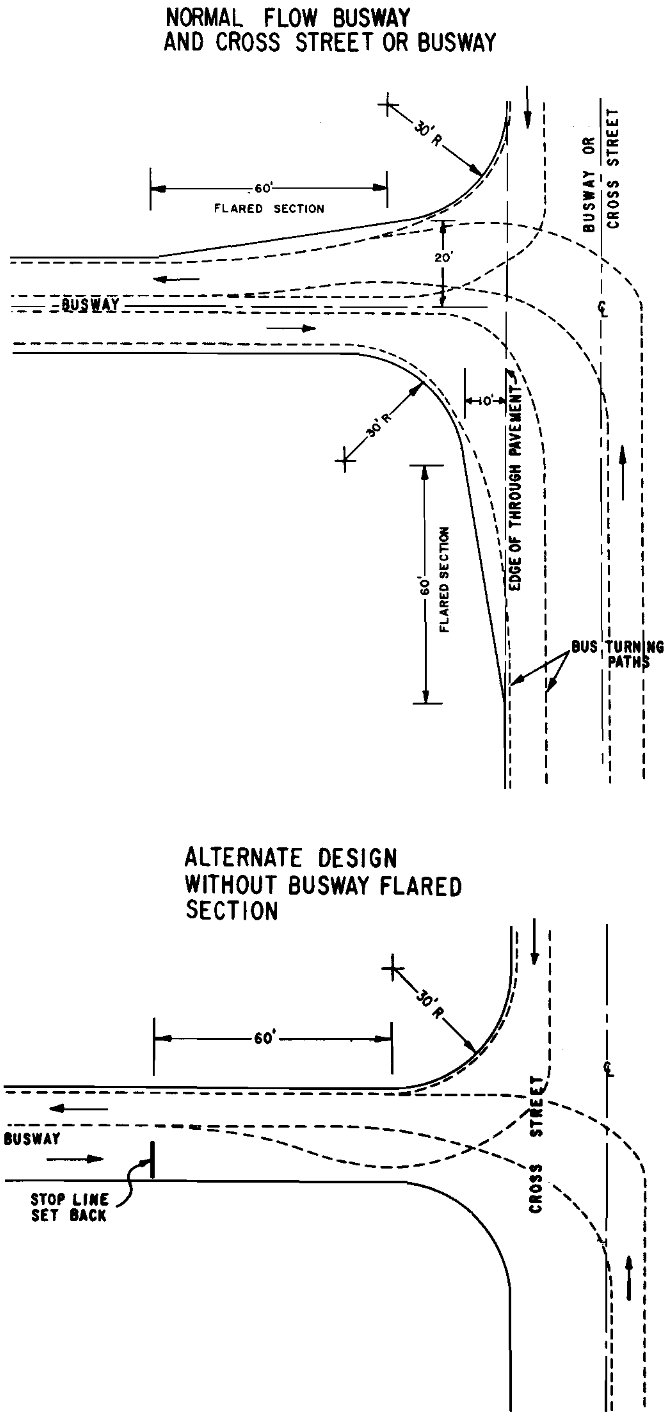
RECOMMENDED CROSS-SECTIONS FOR PROPOSED EAST-WEST TRANSITWAY: MILWAUKEE, WISCONSIN



Source: Milwaukee County Expressway and Tranportation Commission, Milwaukee Area Transit Plan.

Figure 46

DETAILS OF TYPICAL AT-GRADE INTERSECTIONS FOR BUSWAY RAMPS



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

markings and striping, or by daily installation and removal of traffic cones, barricades, or traffic posts. Reserved lanes that are permanently in service 24 hours a day should be separated by traffic islands, channelization curbs, mountable curbs, or permanent traffic posts. Contraflow lanes can be separated from other lanes using only lane markings and striping since, because of the high visibility of the opposing traffic flow, use of these lanes is relatively self-enforcing. Appropriate signing is required for all facilities.

Usually, the width of reserved lanes will be determined by the existing pavement width. Normal flow curb lanes should be at least 10 feet wide. Lanes may have to be widened around curves to accommodate bus turning movements. Contraflow curb lanes should be at least 12 feet wide, although 10-foot lanes may be utilized where separation is effected with pavement striping. General configurations for arterial normal flow and contraflow reserved lanes are shown in Figures 47 and 48, respectively.

Reserved center lanes are generally applicable only in areas with wide arterial street pavements and rights-of-way. Sufficient median area must be provided for passenger safety islands. Center lanes should be at least 10 feet wide for one-way operation (see Figure 49), and 20 to 22 feet wide for two-way operation. When two-directional reserved lanes are located on arterial streets, a Class B surface busway, is, in effect, created, as shown in Figure 50.

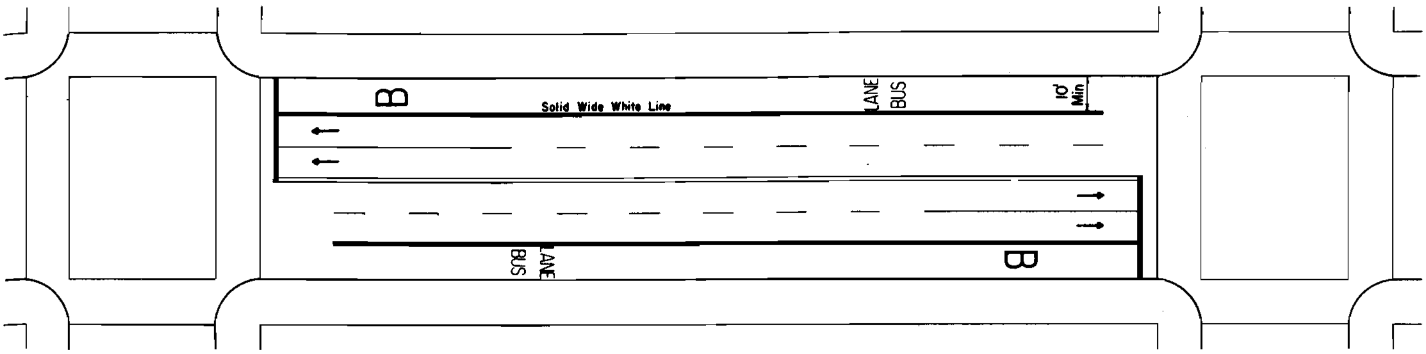
Entrance to and egress from reserved lanes on arterial streets can be provided in one of two ways. The simplest way is to begin the reserved lane at an intersection such that, when the buses and other mixed traffic cross the intersection, they weave into the appropriate lanes. A somewhat more intensive lane transition technique involves the use of lane channelization and extensive pavement markings, striping, and signing to initiate and terminate reserved lanes away from intersection conflict points. An example of this type of treatment is shown in Figure 51.

Station Characteristics

There are three general categories of motor bus stations: minor stations, major stations, and cen-

Figure 47

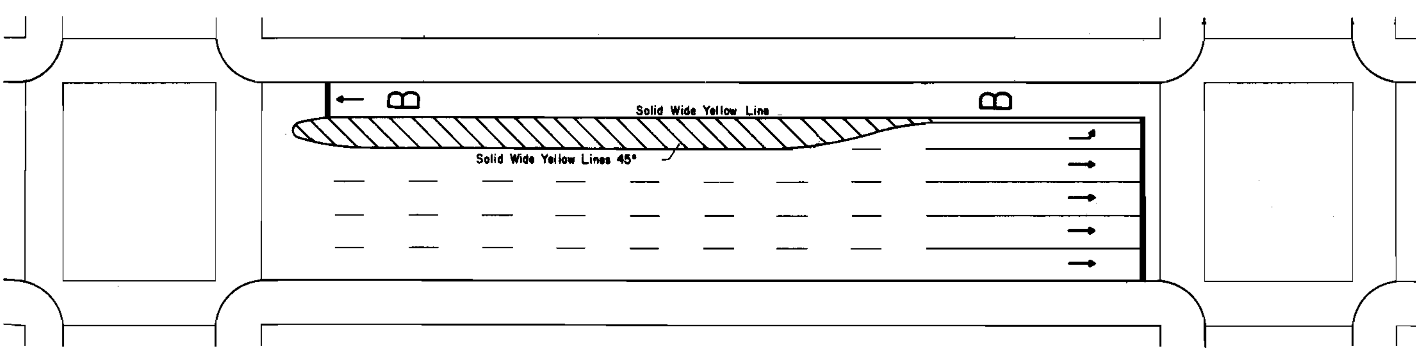
TYPICAL CONFIGURATION FOR RESERVED NORMAL FLOW CURB LANES ON ARTERIAL STREETS



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Figure 48

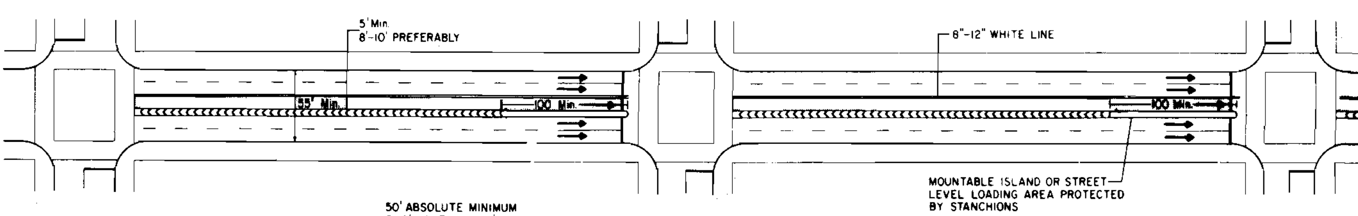
TYPICAL CONFIGURATION FOR RESERVED CONTRAFLOW CURB LANES ON ARTERIAL STREETS



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Figure 49

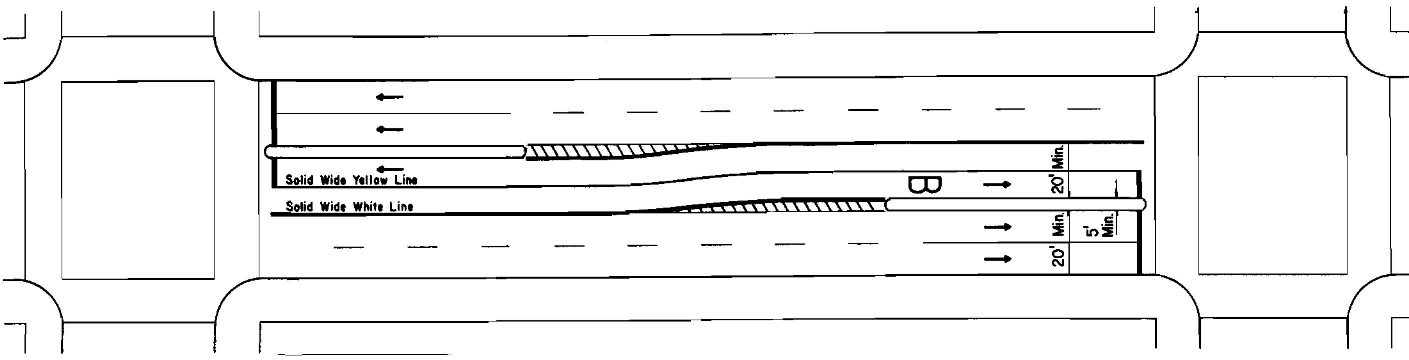
TYPICAL CONFIGURATION FOR ONE-DIRECTIONAL RESERVED MEDIAN LANES ON ARTERIAL STREETS



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Figure 50

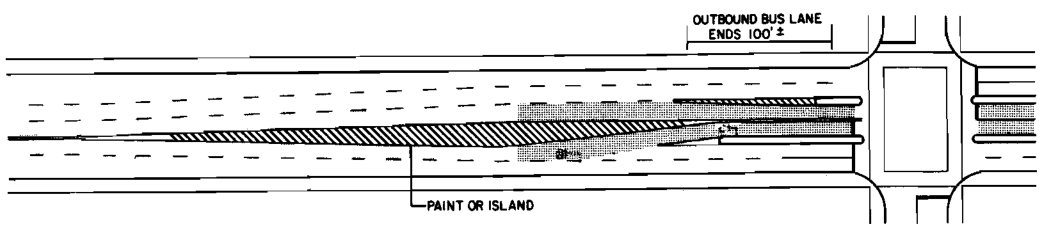
TYPICAL CONFIGURATION FOR TWO-DIRECTIONAL RESERVED MEDIAN LANES ON ARTERIAL STREETS



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Figure 51

TYPICAL CONFIGURATION FOR TRANSITION TO RESERVED MEDIAN LANES ON ARTERIAL STREETS



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

tral business district or other major activity center passenger collection and distribution. The third category relates more to a route configuration than to a specific facility type.

Minor station facilities are the most applicable for primary bus transit services. The simplest type of minor station facility is a curb-side stop marked solely by proper signing, as are many local bus stops. Other amenities may be added as desired, such as additional signing, information standards, benches, landscaping, and a shelter (see Figure 52). This type of station is applicable for any of the primary transit bus modes, including busway systems (see Figure 53). Where such a station is on an arterial street, the motor buses may stop adjacent to the existing curb or at the edge of the road (either on the near-side or far-side of an intersection, or mid-block), in a special bus turnout bay, or in an off-street layover area.[12]

Turnout bays, as illustrated in Figure 54, are an option that may be difficult to implement in developed areas where streets cannot be widened. Turnout bays are most applicable to arterial streets that have high automobile traffic volumes, high speeds, and relatively long bus dwell times. If waiting shelters are provided at such stops, they

[12] *Stations can also be located on safety islands, but such location is not preferred because of the inherent safety hazards. The island creates an obstruction to moving traffic, and forces pedestrians to cross active traffic lanes to gain access to the waiting area. Reserved median bus lanes on arterial streets generally require safety island stations.*

Figure 52

TYPICAL MINOR BUS STOP FACILITY

The simplest type of motor bus transit station is the curbside stop marked solely by signing, as are many local bus stops. Other passenger amenities may be added as desired, such as benches, landscaping, and shelters as in the top view of a Milwaukee County Transit System bus stop near Washington Park. Similar station facilities may be provided at outlying terminals, as illustrated by the bottom view of a park-ride facility in the Milwaukee area.

Photo (top) by Otto P. Dobnick.
Photo (bottom) courtesy of Milwaukee County Department of Public Works.

Figure 53

TYPICAL BUS STATION ON PITTSBURGH'S SOUTH BUSWAY

Stations for busway systems, not unlike those for light rail transit systems, can range from being very spartan to being very elaborate. As shown in this view of a station on the South Busway in Pittsburgh, a busway station may consist simply of a widened pavement together with a simple waiting platform and proper pedestrian access.

Photo courtesy of Port Authority of Allegheny County.

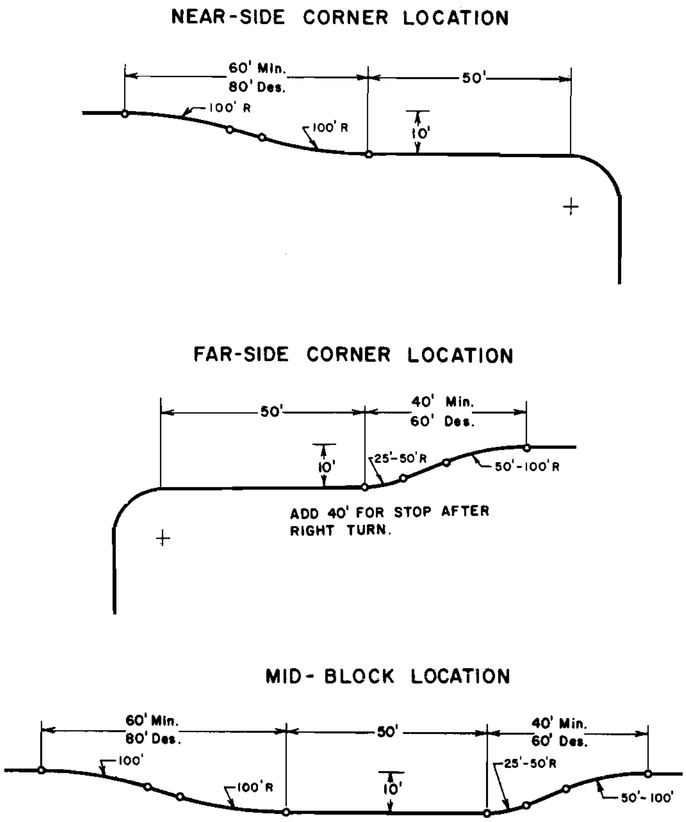
should be located at the inbound waiting area, but not necessarily at the outbound area since passengers do not normally wait at the stop after leaving the vehicle.

Turnout bays are necessary at stations on exclusive busways to permit moving vehicles to pass those that are standing. The lengths of such bays are dependent upon the maximum number of vehicles expected at the station at any one time. Figure 55 shows a typical normal flow busway station, and Figure 56 shows a station layout for a contraflow facility. The latter requires less cross-sectional area.

Major station facilities are applied primarily at transit centers and along exclusive busways. Transit centers are stations located and designed to facilitate the transfer of passengers between various primary transit routes and secondary and tertiary bus routes. Generally located at major trip generators, transit centers may be located within an urbanized area to form what is known as a "timed transfer" network. A "timed transfer" network is an arrangement of route schedules that allows passengers to transfer between routes at the transit centers with a minimum of layover time. Transit center design is based upon the frequency of service, variety of modes, and number of routes to be served, making areal requirements highly dependent upon the specifics of the individual system. A typical time-transfer station is shown in Figure 57 and basic motor bus transit center layouts are shown in Figure 58.

Figure 54

MINIMUM DIMENSIONAL REQUIREMENTS FOR BUS TURNOUTS ON ARTERIAL STREETS

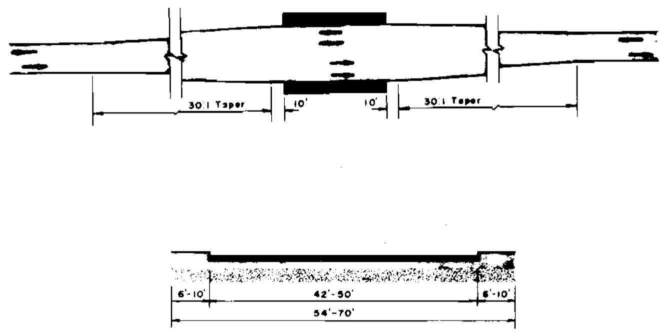


NOTE: DESIGNS ARE BASED ON STANDARD 40 FOOT BUS; ADD 45 FEET FOR EACH ADDITIONAL BERTH.

Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Figure 55

BASIC STATION LAYOUT FOR NORMAL FLOW BUSWAY STATIONS



NOTE: THIS LAYOUT IS APPLICABLE FOR SPECIAL FLOW BUSWAY STATIONS.

Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Some of the station facilities that have been proposed along exclusive busways resemble those constructed for heavy rail rapid transit systems, and, in practice, both major and minor stations have been used along busways within the United States (see Figures 53 and 59). The larger facilities, while resembling heavy rail stations, are not as complex, since boarding is done at curb level and the fare is collected on board the vehicle.

Design criteria for busway stations are dependent upon the pedestrian and vehicular volumes anticipated. A station length of 80 to 100 feet allows for two bus berths. A width for center-island stations of approximately 60 feet permits ample room for stopped vehicles to be passed. Single parallel platforms along each side of an exclusive busway should be at least six feet wide and preferably 10 feet wide. Island platforms that separate each direction of travel should be at least 11 feet wide, increasing to 23 feet if pedestrian access is provided in the center of the platform. Linear station designs will generally be more appropriate than will sawtooth, transverse, or diagonal configurations because they are more adaptable to linear rights-of-way.

If park-and-ride lots are to be utilized by an exclusive busway facility to attract substantial ridership, the layout of the parking lots will be a major determinant of station area requirements and total cost. For self-parking, single level parking lots with intermeshed multiple parking lanes, the gross area per parking space required typically varies between 246 and 255 square feet, depending upon the parking angle. For self-parking, multiple-level parking garages, the gross area typically varies between 350 and 400 square feet per parking space.[13] Large parking lot capacities will necessitate large land parcels if single-level structures are used, and a large capital investment if multiple-level structures are used.

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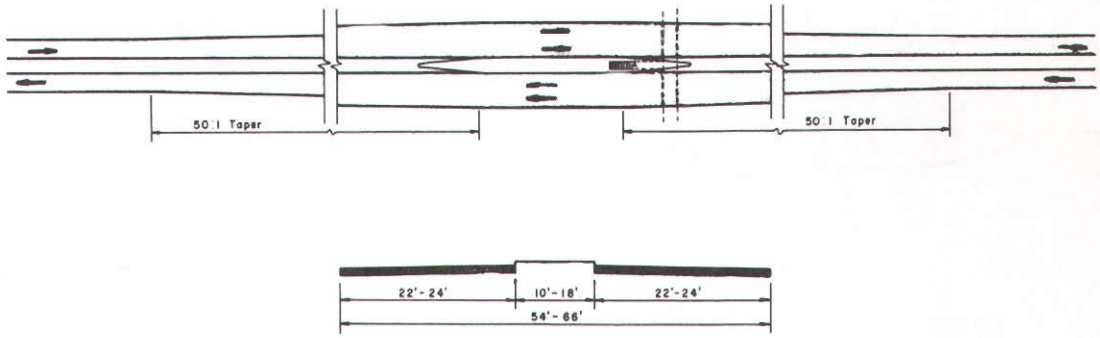
[13] *The amount of bicycle parking space required may be determined as follows: about 5 to 12 bicycle parking spaces per automobile parking space should be provided.*

Figure 56

BASIC STATION LAYOUT FOR CONTRAFLOW BUSWAY STATIONS



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Figure 57

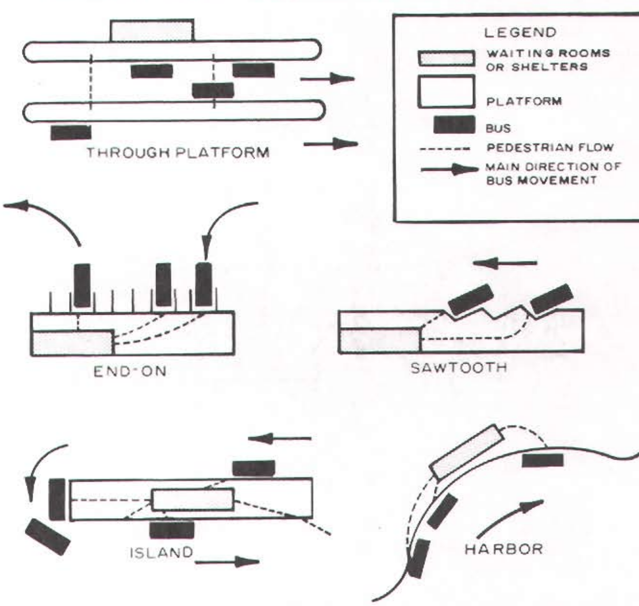
TYPICAL TIMED-TRANSFER STATION

The Edmonton Transit System, one of the first transit operators in North America to make wide use of the "timed-transfer" concept, has designed its transit route network to focus on several transit centers which expedite the transfer of passengers between and among the various motor bus, electric trolley bus, and light rail transit routes. This particular station, located at Westwood, involves an island platform with sawtooth bays for the various bus vehicles which exchange passengers here.

Photo by Russell E. Schultz.

Figure 58

BASIC TRANSIT CENTER STATION LAYOUTS

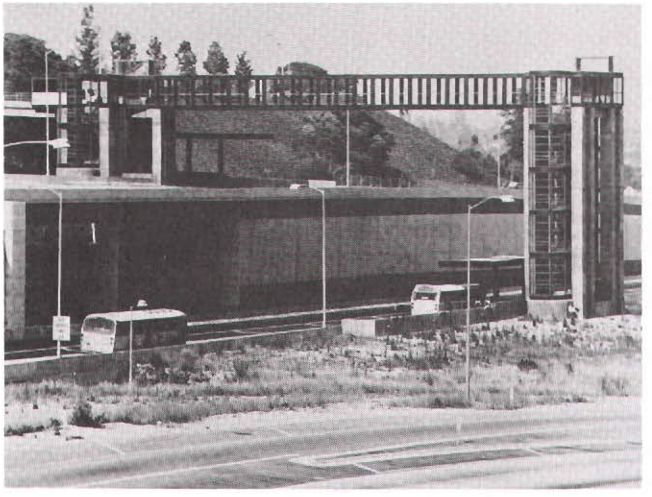


Source: Peter R. White, Planning for Public Transport, London: Hutchinson and Company, 1976.

Passenger distribution in a central business district may be facilitated by operating buses over surface streets or directly into terminal buildings. Downtown off-street terminals for primary motor bus service require a large capital investment in land and structure. Thus, such facilities are appropriate only where large, concentrated volumes of express buses can be accommodated; where on-street routing is slow and unreliable and cannot be improved through bus priority measures; where downtown curb loading capacity is limited; and where major concentrations of trip destinations are within walking distance of the terminal, or accessible by downtown circulation systems. This type of terminal, therefore, is usually practical only in the largest cities. Indeed, examples in the United States exist only in Chicago, New York City, Philadelphia, and San Francisco.

Figure 59

COLLEGE STATION—SAN BERNARDINO FREEWAY EXPRESS BUSWAY



The College station is one of three major station facilities located on the 11-mile-long high-speed busway between downtown Los Angeles and the San Gabriel Valley. Located near the California State University campus, this station has a unique design that results from the necessity for three levels: one for entrance from the University campus, a second level for access to the westbound busway lane, and the third level—60 feet below the surface—for access to the eastbound busway lane.

Photo courtesy of Southern California Rapid Transit District.

More commonly, passenger collection and distribution is accomplished in central business districts and other major activity centers by routing primary service motor buses throughout the district or center. The buses are operated either over surface streets in mixed traffic, possibly with some sort of priority over other traffic, or over reserved lanes. What have also become popular within the United States, as well as in some foreign countries, are bus streets, or transit malls. Although largely motivated in the United States by environmental and downtown redevelopment considerations, transit malls separate motor bus traffic from mixed vehicular traffic. This increases overall speeds and service reliability, and enhances the identity of the transit system. Transit malls may be particularly warranted where large volumes of buses must operate over relatively narrow streets.

Transit malls may be created by simply designating an entire street for transit use only. In many cases, however, the street is narrowed to two lanes—with or without turnout bays—so that sidewalks can be widened along a major retail shopping street. This action, along with the addition of kiosks, sheltered waiting areas, and landscaping, helps to create a pedestrian mall effect. Such transit malls should provide for at least a 22-foot-wide roadway. It is important to ensure that the creation of transit malls does not excessively impact existing traffic patterns, nor restrict access to adjacent property by emergency and maintenance vehicles. To take full advantage of a transit mall, exclusive busways, reserved freeway lanes, and reserved arterial lanes should connect directly with the transit mall near or in the central business district fringe area.

Station frequency varies widely for the primary motor bus modes discussed herein. Express bus services that operate in mixed traffic on freeways typically are nonstop while on the freeway, but utilize some or all local stops upon reaching the central business district or other distribution area. Collection at the outer end of the route also utilizes local stops unless the service originates and terminates at a park-and-ride station. For safety reasons, bus stops are not practical along freeways unless the station area is physically separated from the main traffic flow (see Figure 60).

Primary transit service operating over reserved lanes on freeways also does not stop over the line-haul portion of the trip. Vehicles pick up passengers either at local outlying stops or at an outlying centralized station, operate nonstop over the freeway, and discharge passengers at local stops in the central business district or other activity center served. Again, the nature of reserved lane operation prohibits vehicles from stopping to load and unload passengers.

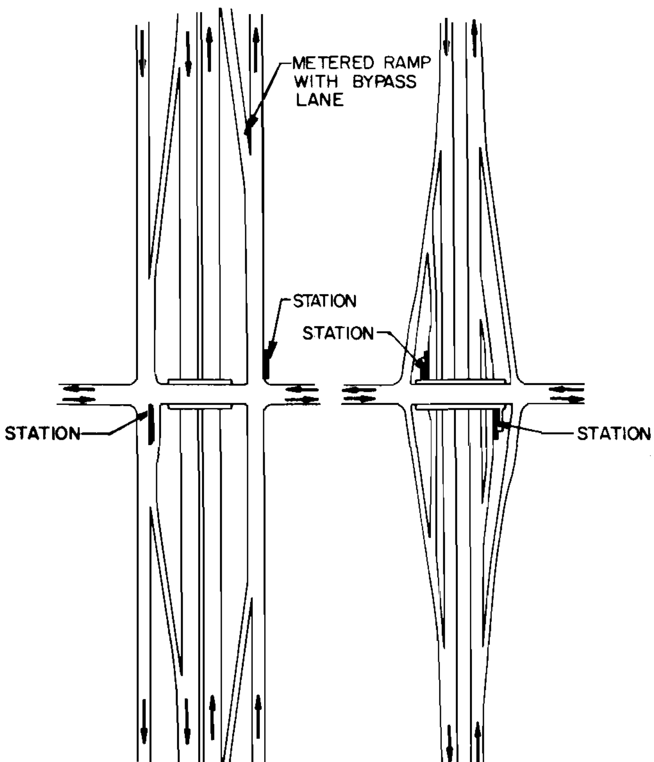
The station spacings for exclusive busways tend to be similar to those for heavy rail rapid transit. Existing busway facilities have station spacings ranging up to 3.7 miles, with 0.5 mile being typical. Proposed facilities have station spacings ranging up to 3.1 miles, with 2.0 miles being typical.

Arterial express bus systems usually stop only at intersections with other transit routes, and may operate nonstop over prolonged distances during peak travel periods. Stops, when made, are usually at regular local curb-side bus stops, and at intervals ranging from 0.2 to 0.5 mile.

All motor bus modes applicable to primary transit service employ low-level or curb-level loading. High-level motor bus boarding is, at the present time, considered to be impractical.

Figure 60

STATION LOCATION CONCEPTS FOR PRIMARY SERVICE BUS ROUTES OPERATING IN MIXED TRAFFIC ON FREEWAYS



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Support Requirements

The following support requirements pertain to all four motor bus modes discussed herein: vehicle storage and maintenance, guideway and structure maintenance, traffic control, and fare collection. The extent to which each of these ancillary elements is applied to any new system, or system modification, depends upon the site and operational specifics of the system. The information on support requirements presented herein is considered sufficient for systems level planning.

Vehicle Storage and Maintenance: Vehicle storage for motor bus transit modes consists of garages and paved lots large enough to hold all vehicles not in service during the system's least active operating period. On larger systems, such as the Milwaukee County Transit System, more than one garage location is generally required. For example, the Milwaukee system presently has three garage locations. If one or more motor bus modes were to be utilized for primary transit service in Milwaukee County, the existing locations could probably be enlarged for additional vehicle storage. Because motor buses are powered by diesel engines, indoor storage is recommended in winter. Bus garages should include the appropriate facilities and equipment for daily servicing, including fueling, fare removal, washing, interior cleaning, and daily light inspection, and should have locker and washroom facilities for bus drivers.

Minor maintenance and other "running repairs" should also be provided at the garage facilities. Heavy maintenance and repairs, including major unit overhauls, are usually provided at a central shop facility. Appropriate components for a shop facility may include diagnostic equipment; underfloor pits; apparatus for either jacking or lifting the vehicle bodies; individual shop areas for repairing engines and wheel, brake, and electrical equipment, and interiors; and a paint booth. Should implementation of primary transit services require an increase in fleet size, the shop facilities may need to be significantly expanded.

Guideway and Structure Maintenance: The roadways, structures, and traffic control apparatus utilized by motor bus modes require the same maintenance as do ordinary freeways and arterial streets. Major guideway maintenance tasks include wearing surface repairs, bridge repairs, and repair or replacement of signs and other traffic control devices. Since buses operating in primary transit service over freeways in mixed traffic, over reserved lanes on freeways, and over reserved lanes on arterial streets utilize roadways already constructed and maintained by municipal, county, or state authorities for all motor vehicle traffic, guideway maintenance is not the responsibility of the transit operator.

The maintenance of exclusive busways and of reserved lanes on arterial streets that are similar to Class B busways, however, may be the responsibility of the transit operator. However, because of the limited maintenance normally required on an annual basis, the transit operator should not have to invest in highway and street maintenance and repair equipment and vehicles. Unless the total mileage of the busway system is unusually large, it would be more cost-effective to have such services performed by an outside contractor or by municipal or county street and highway departments.

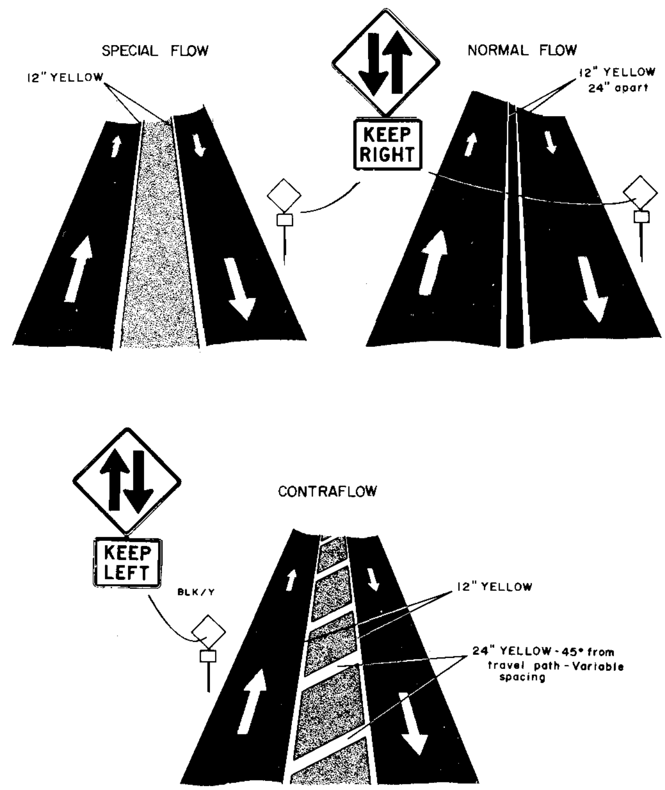
Station facility, garage, shop, and grounds upkeep may or may not be the responsibility of the transit operator. This will depend upon the cost-effectiveness of the arrangements involved and upon the extent to which such areas are shared with other public or private uses.

Traffic Control: As used herein, the term traffic control refers to the use of signing, pavement markings, channelization, and traffic signal priority measures to improve motor bus movement through existing traffic patterns. Because buses are not steered by the guideway, as are rail cars, traffic control only passively—and not actively—affects vehicle speed, spacing, and conflict resolution at crossings.[14]

Appropriate signing and pavement markings are critical to the proper delineation of reserved and exclusive ramps and transit lanes. The number and placement of signs, and the amount and placement of lane striping and cross-hatching, are very site-specific. Typical applications for busway travel lanes and ramps are shown in Figures 61 and 62. An example of signing for a reserved freeway contraflow transition lane is provided in Figure 63.

Figure 61

TYPICAL PAVEMENT MARKINGS AND SIGNING FOR TANGENT BUSWAY SEGMENT



Source: Highway Research Board, Bus Use on Highways: State of the Art, NCHRP Report 143.

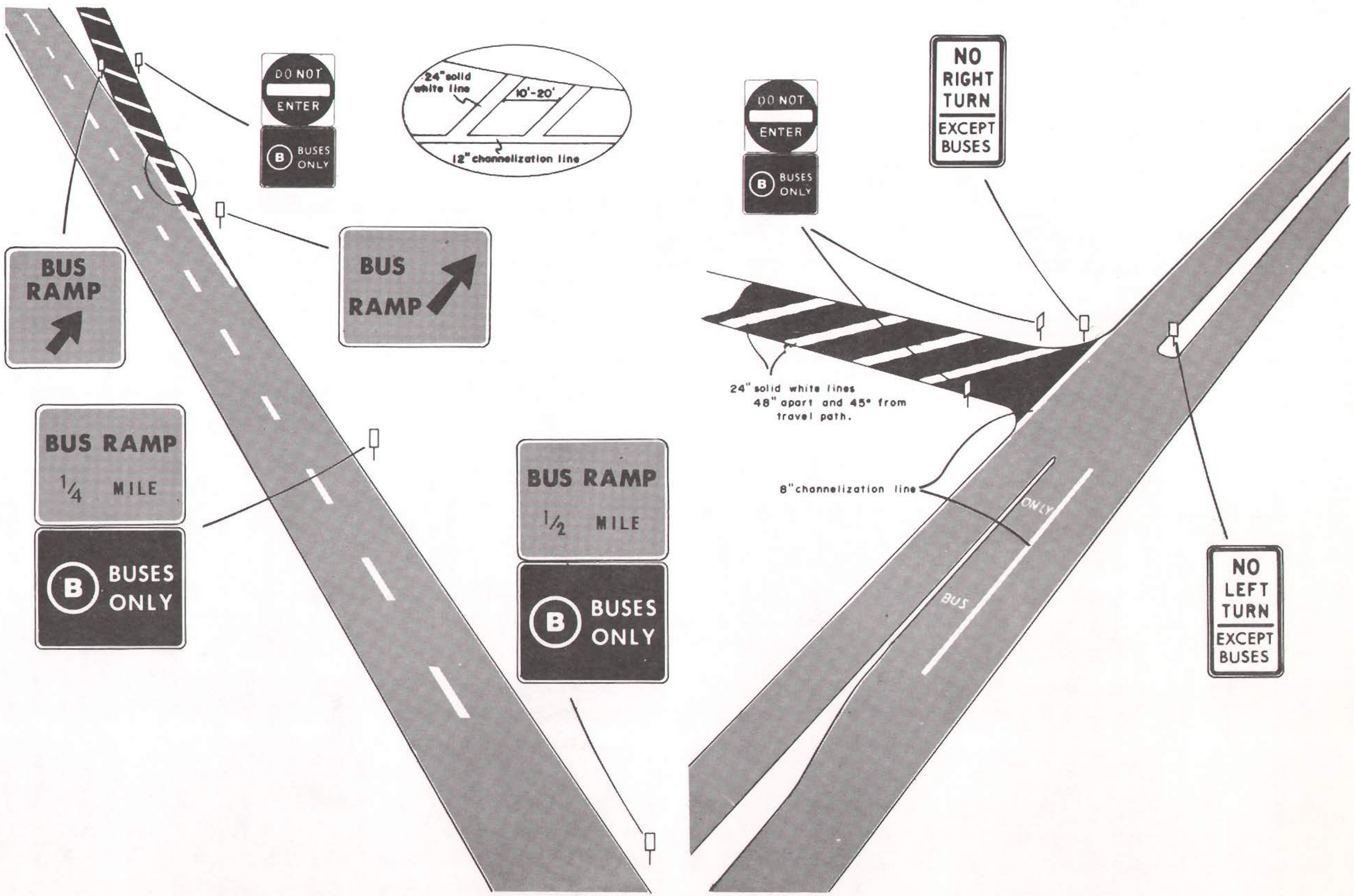
[14] *Under the proposed Milwaukee Area Transit Plan, which includes preliminary engineering information for the East-West Transitway, it was suggested that consideration be given to the use of a guidance control for steering the vehicles while on the exclusive guideway. A coil mounted on the underside of the vehicle would interpret the absolute displacement and rate of change of displacement of the vehicle detector from a wire embedded in the roadway surface. The resulting electrical impulses would be translated into an electrical error signal which would correct the displacement and steer the vehicle back to its proper path. Some vehicular guidance control systems of this nature permit between 1/16 inch and two inches of maximum deviation, and have been shown to be effective in negotiating tight turning radii. This system has been subjected to testing and can therefore be termed "operational." However, no such devices exist in regular service and should, therefore, be regarded as unproven.*

Reserved lanes on surface arterial streets also must be provided with appropriate signing and marking. Such additional signing and marking includes "bus only" information and the hours such restrictions are in effect, peak-period turning restrictions, and signs warning drivers to stay clear of obstructions such as mountable curbs and safety islands. Standards recommended in the latest revision of the Manual on Uniform Traffic Control Devices, published by the U. S. Department of Transportation, generally should be adhered to.

Illuminated reserved lane signs and special reserved lane controls are options applicable to freeway

Figure 62

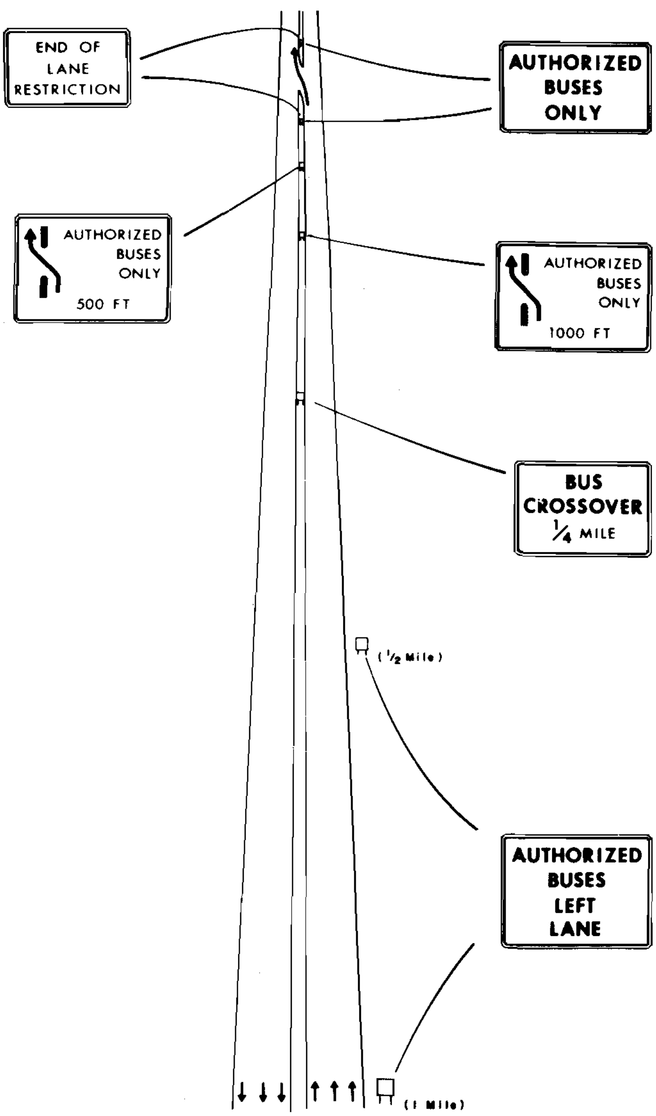
TYPICAL PAVEMENT MARKINGS AND SIGNING FOR BUSWAY RAMPS



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

Figure 63

TYPICAL SIGNING FOR CONTRAFLOW TRANSITION LANES



Source: Highway Research Board, Bus Use on Highways: Planning and Design Guidelines, NCHRP Report 155.

priority modes. Such controls may take the form of lighted signs, changeable message displays, or arrows and cross bars that denote whether a particular lane is open or closed to mixed traffic. Cost considerations may limit or preclude the use of such apparatus for governing reserved arterial street lanes.

The separation of mixed flow and reserved lanes requires special attention. Reserved normal flow lanes may be difficult to enforce if only painted lines are used to separate lanes. Painted lines, however, have low installation and maintenance costs, do not affect water drainage and snow removal, can be easily modified, and allow bus access around stalled vehicles. Because automobiles and trucks can still drive across the lines at random, however, enforcement may be difficult, creating a high incidence of illegal use. Traffic islands, mountable curbs, and channelization curbs offer a more positive delineation of reserved lanes, particularly if the reservation is in effect 24 hours per day. The lanes can then be entered only at intersections or other special locations.

Most reserved lanes, however, are activated only during certain time periods of each weekday, making the use of permanent lane dividers impractical. In such cases, physical lane separation is facilitated by daily installation and removal of traffic cones, posts, or barricades between lanes, together with the use of signs that light up or unfold. The preferred lane separation marker appears to be a flexible plastic traffic post that is inserted into a predrilled hole in the roadway surface. Traffic posts should be a minimum of 18 inches in height, be painted in the color of the pavement markings they represent, and have two reflectorized bands near their tops. Suggested spacing is 20 feet in transition areas and 40 feet elsewhere. Recent experience indicates that up to half of the traffic cones or posts may require replacement annually.

Traffic signal priority measures for motor buses may be provided along Class B busways or along arterial streets where buses operate either in reserved lanes or in mixed traffic. Bus priority at traffic signals is based upon either passive or active operational concepts.

Passive signal priority involves the retiming of signals and reordering of signal phases to activate a special phase for bus movements. Special phases can be used to control reserved bus lanes, turning movements at intersections, and entrance to or exit from busways and off-street stations and terminals. This concept is a direct extension of the special light rail transit signal phases that are widely used on European systems. Another passive measure involves setting the signal progression for a series of consecutive intersections such that, when operating at an average speed, buses can run through all the intersections without stopping. This, however, may only be practical where buses operate nonstop over significant lengths of the route.

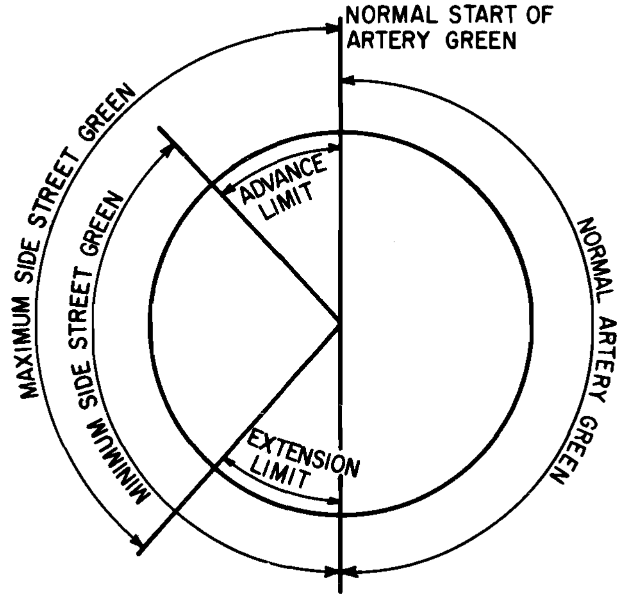
Active signal priority involves the detection of approaching vehicles in order to activate a special phase or to modify the existing green phase. Vehicle detection is accomplished by one of two devices. One device is a strobe light that is mounted on the roof of the bus. An optical signal is transmitted to a sensor near the controller cabinet.[15] The other device is a transponder placed on the underside of the bus that emits a radio signal. A loop detector embedded in the roadway picks up the signal and transmits it to the controlled cabinet or to a central control center.

These active traffic signal priority measures can either activate a special phase for buses only, extend or advance the available green time, or "register" the presence of the bus to a computerized traffic control system which can be programmed to open a "green window" through a continuous series of signalized intersections. The necessary extension or advance of the green time is illustrated in Figure 64.

The advantages of traffic signal priority are obvious in that average vehicle speeds are increased, raising the level of service that can be offered. It is apparent that peak-hour bus frequency must be substantial for the installation of the appropriate electronic components to be cost-effective.

Figure 64

TRAFFIC SIGNAL CYCLE WITH MOTOR BUS PREEMPTION CAPABILITY



NOTE: (A) THE MINIMUM SIDE-STREET GREEN IS REQUIRED EACH CYCLE
(B) IF THE ARTERY GREEN IS ADVANCED, IT SHOULD NOT BE EXTENDED IN THE SAME CYCLE, BUT
(C) IF THE ARTERY GREEN IS EXTENDED, IT SHOULD NOT BE ADVANCED IN THE NEXT CYCLE.
(D) YELLOW INTERVALS ARE NOT SHOWN.

Source: Highway Research Board, Bus Use on Highways: State of the Art, NCHRP Report 143

Traffic signal priority systems have two disadvantages, one being the manner in which traffic on cross streets is restrained by the reduced green time, and the other being the fact that automobile drivers may follow buses too closely in order to benefit from the green light extension. These autos may consequently tend to run through amber and red lights and thereby risk collisions.

Preemption measures are not as effective for local buses or for buses in mixed traffic because of the frequent stops made, and because of the fact that such measures have negative effects on traffic. Such measures are best applied for express buses utilizing a reserved lane. When such measures are applied, it is desirable to locate stops on the far side of intersections so that buses will not have to stop after the preemption sensor has been activated. The traffic signal preemption apparatus allows for a minimum green phase during every signal cycle for cross traffic so that a light cannot be continuously red or green in any one direction for an undue length of time.

Fare Collection Procedures: Motor bus transit modes utilize one of two basic types of fare collection: pay-as-you enter procedures and self-service procedures.

Public transit operations in the United States and Canada utilize the pay-as-you-enter fare collection system on all motor buses. Passengers deposit either coins, tickets, or tokens into a farebox upon entering the vehicle, or present a weekly or monthly pass to the driver for inspection. Exact fare is almost universally required to promote driver safety. Most European systems have converted from two-man to one-man motor bus opera-

[15] *This system has also been utilized in some cities to provide preemption for emergency vehicles.*

tion, eliminating the need for a conductor. Also, most major European systems have converted or propose to convert to self-service fare collection procedures.

Self-service ticketing, also known as "barrierless" and "honor system" ticketing, is a popular, if not the predominant, fare collection system utilized on major transit systems throughout Western Europe. The most common system utilizes two types of devices: a ticket vending machine and a ticket canceling machine. Ticket vending machines are either freestanding or wall-mounted at stations, or are located on board the vehicle (see Figure 65). Ticket validation equipment is also located at stations or on board the vehicle. Sometimes these two machines are combined into one unit. Passengers must purchase tickets and validate them at the time of use.

Compliance with this system is maintained by a staff of checkers who typically sample about 5 percent of the daily vehicles operated, and who are legally empowered to fine offenders on the spot. Reported levels of noncompliance range between 0.1 and 3.0 percent, with 1.0 percent being typical. According to a recent study, this range compares well with estimates of the extent to which conventional fare collection systems are defrauded. A recognized key to the success of self-service fare collection systems is the capability to impose immediate financial penalties, thereby avoiding costly and time-consuming court procedures.

Self-service ticketing is readily accepted by the public in Western Europe. A somewhat higher quality of transit service is attributed to adoption of this type of fare collection since overall operating speeds are increased. These greater operating speeds result from the fact that dwell time at stops is reduced since all doors of a vehicle may be used by passengers for boarding and disembarking simultaneously.

The extent to which such a system would succeed or fail when applied to transit services in the United States is speculative at this time, since such procedures are not presently used anywhere in the nation. The Urban Mass Transportation Administration is considering funding demonstration projects in selected cities to gain experience with self-service fare collection in the United States.

PERFORMANCE CHARACTERISTICS

System performance for all four modes of primary service motor bus operation may be defined in terms of three critical characteristics: speed, headway, and capacity. These factors are important determinants of the level of public acceptance and patronage of a new primary transit system.

Figure 65

TYPICAL OUTDOOR TICKET VENDING MACHINE

Many European transit systems utilize a self-service fare system for motor bus routes as well as light rail transit and subway routes. Under such a system, passengers purchase their tickets from a vending machine and validate them either at the same machine or on board the vehicle. Proponents of this fare collection system cite the advantages of reduced operating costs and faster average speeds since station dwell times can be reduced.

Photo courtesy of Shepard Transitron, Inc.

Speed Characteristics

Transit speeds may be expressed in three different ways: as absolute vehicle speeds, as typical operating speeds, or as average speeds over an entire route. Absolute or maximum vehicle speeds are determined by the capabilities of individual vehicle design. Motor buses designed for urban transit operations generally have maximum attainable speeds of 50 to 55 miles per hour (mph). Such buses typically have a maximum rate of acceleration of 2.5 miles per hour per second. Vehicles equipped with an optional eight-cylinder diesel engine, instead of a six-cylinder diesel engine, have maximum speeds of 70 mph. The larger engine also provides a higher rate of acceleration, up to 3.3 miles per hour per second. Maximum speeds for articulated buses generally range from 50 to 60 mph, with a maximum rate of acceleration of 1.5 to 2.0 miles per hour per second. Double-deck buses designed exclusively for city service are able to reach a maximum speed of approximately 40 to 45 mph.

Operating speeds for motor buses in primary level transit service are primarily dependent upon posted speed limits. These limits govern not only bus traffic, but also all other traffic on roadways that are shared by all types of vehicles. Posted speed limits on freeways and arterial streets will generally restrict the operating speed to below the maximum speed that the bus is capable of attaining.

The usual operating speed for buses operating on freeways in mixed traffic in the Milwaukee area is 55 mph. Due to geometrics or operational determinants, certain freeway segments are limited to a maximum speed of 50 mph. Freeway-to-freeway ramps may have maximum operating speeds of as low as 35 mph.

Bus speeds, when operated over reserved lanes on freeways, are dependent upon the direction of reserved lane flow. Normal flow lanes may be operated up to 55 mph or at the prevailing posted speed limits for the adjacent mixed traffic lanes. Maximum operating speeds of 35 to 40 mph are normally prescribed for contraflow lanes. If higher speeds are desired, reserved lane widths should be increased accordingly. Eleven-foot-wide lanes should permit a maximum speed of 35 mph; 12- to 13-foot-wide lanes, 50 mph; and 17-foot-wide lanes, 70 mph. Transition lanes and exit ramps require further special speed restrictions.

Because of the large capital investment required to provide exclusive busway operation, busway facilities are generally designed for the highest vehicle speeds possible. Class A busways are grade-separated and are typically designed for operating speeds of 50 to 70 mph. Class B busways can incorporate grade crossings as well as sharper horizontal curves, and therefore are normally designed for operating speeds of 30 to 50 mph. Such busways may incorporate various guideway segments having lower design speeds, but changes in speed between sections should be minimal and gradual. Milwaukee County's East-West Transitway was designed for a mainline speed of 70 miles per hour and a minimum ramp speed of 30 mph.

Typical operating speeds for express buses operating in mixed traffic on arterial streets should correspond to the prevailing speeds of the other traffic. In low- and medium-density areas, and along major arterial streets divided by median strips, such speeds would range from 30 to 45 mph. In densely developed areas near the fringe of the central business district and on narrower arterial streets in older portions of the city, posted speed limits can be expected to range from 25 to 30 mph. Where reserved lanes—either normal flow, contraflow, or median—are able to facilitate bus vehicle movement for substantial distances without interference from cross traffic or the need for frequent stops, an operating speed limit of 5 to 10 mph in excess of that posted for adjacent mixed traffic may be used. In downtown areas, buses should operate at maximum speeds of 20 or 25 mph because of the pedestrian movement.

Average speeds for primary level motor bus transit systems are dependent upon the performance characteristics of the individual vehicle, such as acceleration and deceleration rates and maximum operating speeds, as well as upon station or stop frequency, dwell time at stops, waiting time at traffic signals, and the extent of priority afforded over automobile and truck traffic, especially during peak periods. Table 22 indicates the average speeds at which express buses may be expected to operate over various types of guideway segments. These are overall values based upon a normal frequency of stops and normal dwell times. It is apparent from this table that average speeds increase as buses are increasingly isolated from interference by cross traffic and adjacent mixed traffic.

The frequency of stops to permit passengers to board and alight has a greater impact on the average speed than does the maximum speed attainable by the vehicle. Figure 66 shows the relationship between station or stop spacing and average speeds for busways and arterials. For vehicles operating in mixed traffic in downtown areas, where bus stops are likely to be closely spaced, the speeds may be expected to average between 5 and 10 mph. Outside the central business district, stops or stations are likely to be located farther apart, permitting the average speed on arterial streets to range from 10 to 20 mph. Exclusive busways permit average speeds of 20 to 50 mph. It must be recognized that traffic congestion may reduce the average speed of motor buses operating in mixed traffic to below the normal value given in the arterial street curve. Conversely, the application of either reserved arterial street lanes or reserved freeway lanes will create the potential for average speeds between those indicated on the two curves shown in Figure 66. The actual average speeds of buses providing primary transit service in selected urban areas of the United States are given in Table 23. The differences between the average speed while on the freeway and the average speed while transversing the entire primary transit route should be noted.

Table 22

AVERAGE MOTOR BUS SPEEDS IN LARGE URBANIZED AREAS

Type of Service	Speed (mph) Peak Period	Nonpeak Period
Local Bus on Collector Street	5	7
Local Bus in Reserved Lane on Collector Street[a]	8	10[c]
Local Bus on Arterial Street.	10-11	13-15
Local Bus in Reserved Lane on Arterial Street[b].	15	17[e]
Express Bus on Freeway	30	45
Express Bus in Reserved Lane on Freeway[d]	45	45[c]
Express Bus on Exclusive Busway[e] . . .	20-50	20-50

[a] *Data reflect speeds of buses in normal flow lanes, contraflow lanes, and median lanes, and on bus streets in downtown areas.*

[b] *Data reflect speeds of buses in normal flow lanes, contraflow lanes, and median lanes outside downtown areas.*

[c] *Value is estimated since facility is not usually operated during nonpeak periods.*

[d] *Assumes no stops while on freeway portion of route.*

[e] *Average speed depends upon frequency of stops and geometrics of facility.*

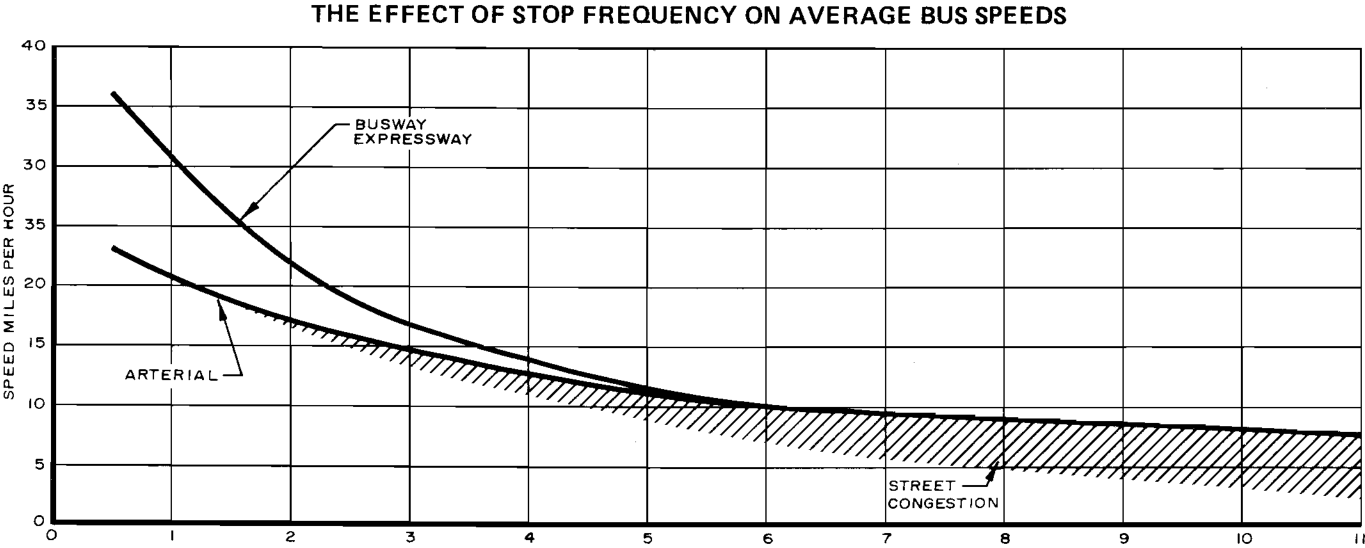
Source: U. S. Department of Transportation and SEWRPC.

The average speed of buses operating on freeways can be increased through the implementation of ramp metering in combination with bus bypass lanes at freeway entrance ramps. For example, peak-hour speeds on the Harbor Freeway in Los Angeles averaged 15 to 20 mph prior to ramp metering. After ramp metering, the average speed increased to approximately 40 mph. Similarly, ramp metering caused the average speed on the North Central Freeway in Dallas to increase from 14 mph to 30 mph. It should be pointed out that such a freeway traffic management system could negatively affect traffic operating conditions on surrounding surface streets because of the diversion of traffic to such streets.

The average speeds of motor buses operating over reserved lanes on freeways will be similar to typical off-peak-period freeway operating speeds. For normal flow lanes, observed speeds were reported to approximate 50 mph on the Southeast Expressway in Boston, the Santa Monica Freeway in Los Angeles, and IH 95 in Miami. Actual speeds for existing contraflow freeway lanes were reported as 45 mph on the Southeast Expressway in Boston and on IH 495 in Northern New Jersey on the approach to the Lincoln Tunnel. Average speeds of between 30 and 40 mph have been observed on the Long Island Expressway contraflow lane in New York City.

Figure 66

THE EFFECT OF STOP FREQUENCY ON AVERAGE BUS SPEEDS



Source: U. S. Department of Transportation and SEWRPC.

Table 23

FREEWAY AND ROUTE SPEEDS FOR BUSES OPERATING ON FREEWAYS IN MIXED TRAFFIC IN SELECTED UNITED STATES CITIES

City	Bus Route[a]	Bus Speeds During Rush Hour (mph) On Freeway	Bus Speeds During Rush Hour (mph) Terminal to Terminal
Baltimore (1971)	Jones Falls Expressway		
	Towson-Metro Flyer	35.0	26.0
Chicago (1972)	South Lake Shore Drive		
	2A-Hyde Park Express	36.0	23.0
	5A-Jeffery Express	36.0	13.0
Cleveland (1972)	Memorial Shoreway East (IH 90)		
	39-Lake Shore	30.0	26.0
	49-Wickliffe	33.0	26.0
	Memorial Shoreway West		
	31-Avon Lake	30.0	21.0
Dallas (1972)	Dallas North Tollway		
	72	30.5	21.5
	North Central Expressway		
	21	21.3	13.2
	32	20.9	16.3
	36	22.5	18.4
	67	20.9	15.7
	73	22.8	20.5
	Thornton Freeway East		
	60	22.1	14.3
	64	26.4	19.6
	Thornton Freeway South		
	55	23.5	15.7
	61	25.7	21.0
Detroit (1972)	Chrysler Freeway		
	John R-Oakland Express	35.0	23.6
	Second Avenue Express	35.0	18.5
	John Lodge Freeway		
	Fenkell Express	35.0	18.1
	Hamilton Express	35.0	19.1
	Imperial Express	35.0	18.7
	Plymouth Express	35.0	12.3
Houston (1972)	IH 10 West		
	48-Spring Branch	33.0	19.5
	IH 45 North		
	44-Studewood	27.8	18.3
	50-Heights	30.0	16.8
	Memorial Drive		
	16-Memorial Drive	35.2	19.0
	16M-West Memorial Drive	34.0	23.4
	17-Tanglewood	37.2	19.7
	USH 59		
	65-Bissonet	29.2	13.7
	88-Beachnut	36.8	16.3

Table 23 (continued)

City	Bus Route[a]	Bus Speeds During Rush Hour (mph) On Freeway	Terminal to Terminal
Los Angeles (1971-1972)	Harbor Freeway		
	5-Hawthorne - Union Station	29.0	15.0
	7-Eagle Rock - South Broadway	15.4	12.7
	37-Harbor Freeway Flyer	27.1	21.2
	Hollywood Freeway		
	35-West Valley Freeway Flyer	29.6	21.0
	44-Beverly Boulevard - W. Adams Boulevard	16.5	12.6
	91-Hollywood Boulevard	24.5	14.0
	93-Los Angeles - Pacoima	27.2	18.8
	Pasadena-Golden State Freeway		
	56-Los Angeles - Sunland	16.4	16.1
	86-Los Angeles - Canoga Park	33.8	22.0
	Riverside Freeway		
	59-Los Angeles - Riverside	48.0	26.1
	Santa Ana Freeway - Long Beach Freeway		
	34-Los Angeles - Bellflower	27.5	18.0
	36-Long Beach Freeway Flyer	28.4	23.5
Milwaukee (1970)	East-West Freeway - Zoo Freeway		
	41-Mayfair	N/A	20.7
	44-Treasure Island South	N/A	17.1
	45-Treasure Island North	N/A	22.4
	North-South Freeway - Airport Freeway		
	43-Country Fair	N/A	24.7
	46-Spring Mall	N/A	25.3
	North-South (USH 141) Freeway		
	42-Bayshore	N/A	19.8
Minneapolis-St. Paul (1971)	IH 35W		
	5-Portland Red Ball	43.0	18.0
	6-Southdale Red Ball Express	36.6	22.7
	18-Nicollet	31.2	20.6
	50-Minneapolis Airport	38.5	23.3
	IH 94		
	1-Har-Mar	43.0	18.0
	IH 494		
	St. Paul Airport	47.0	22.8
Philadelphia (1971)	Schuylkill Expressway		
	A	35-40	24.0
	38	35-40	17.0
	44	35-40	23.0
	45	35-40	29.0
	E	35-40	17.0
	G	35-40	18.0
	IH 95		
	Route 20 Express	35-40	23.0

Table 23 (continued)

City	Bus Route[a]	Bus Speeds During Rush Hour (mph)	
		On Freeway	Terminal to Terminal
St. Louis (1972)	Daniel Boone		
	55X-Kirkwood Express	26.1	16.0
	152X-Clayton Road Express	23.3	16.4
	608X-Big Bend Express	26.1	17.7
	Mark Twain		
	16R-Ramona Rapid	31.7	19.6
	40R-Bissell Hills Rapid	29.1	15.5
	41R-Northside Rapid	29.5	15.8
	174R-Florissant Rapid	30.4	19.8
	530X-Pontoon Express	20.9	15.9
	635X-Riverview Gardens Rapid	29.1	16.1
San Francisco-Oakland (1970)	A. C. Transit-Bay Bridge		
	A	36.0	27.0
	B	36.0	28.0
	C	35.0	28.0
	E	36.0	25.0
	F	33.0	21.0
	H	33.0	25.0
	L	37.0	26.0
	R	33.0	24.0
	S	36.0	32.0
	W	35.0	28.0

NOTE: N/A indicates data not available.

[a] *The primary transit bus routes shown in this table represent only a select portion of all such routes in service during 1971 and 1972. These routes are shown because of the availability of the desired data.*

Source: Highway Research Board, Bus Use on Highways—State of the Art, NCHRP Report 143.

Because of the exclusive nature of busway facilities, average bus speeds on such facilities are the highest of all primary transit modes. Actual speeds on existing busways, however, appear to be affected not only by the design and alignment of the guideway and by the stop spacing, but also by the vehicle headway on the facility. Average speeds on busways in the United States are indicated in Table 24.

Average speeds for bus operation over reserved lanes on arterial streets vary considerably according to whether the priority treatment is applied to an outlying arterial or to a street in a central business district. For example, the average speed of buses operating over normal flow reserved lanes is 5.0 mph on Paca Street in the central business district of Baltimore, 6.0 mph on Market Street in Newark, 7.3 mph on O'Farrel and Geary Streets in San Francisco, and 10.7 mph on Georgia Street in Vancouver. The Washington Street median lane in Chicago operated at 6.3 mph. Selected examples of normal flow lanes located outside downtown areas illustrate the increased average speeds that are attainable in outlying areas. For example, buses using the reserved lanes on First and Second Avenues in New York City average 17.5 mph and 13.9 mph, respectively. In Toronto, buses using reserved normal flow lanes on two separate segments of Eglinton Avenue average 14.3 mph and 18.2 mph.

Headway Characteristics

Bus transit headways may be given in terms of theoretical limits and actual experience. Actual headways realized on existing systems seldom approach the theoretical limits except under exceptionally high travel demand conditions. Vehicle spacing is not controlled by a centralized, automatic, or automated traffic control system as it

Table 24

OBSERVED AVERAGE SPEEDS ON EXCLUSIVE BUSWAYS

Urbanized Area	Busway Facility	Number of Stops	Average Speed (mph)
Los Angeles	San Bernardino Freeway Express Busway	2	47.1
Pittsburgh	South Busway	None	30.0
		Limited	28.9
		All	20.0
	East Busway[a]	None	40.8
		Limited	32.6
		All	20.1
Washington	Shirley Busway	None	35.0 to 40.0

[a] *Scheduled for completion in 1982.*

Source: SEWRPC.

Table 25

MINIMUM THEORETICAL HEADWAYS FOR MOTOR BUS TRANSIT UNDER SPECIFIC CONDITIONS

Traffic Condition	Frequency of Buses per Hour	Headway in Seconds
Uninterrupted Test Track Flow[a]	1,450	2.5
Freeway Level of Service D[b,e]	940	3.8
Freeway Level of Service C[b,e]	690	5.2
Arterial Bus Lanes[c]	120	30.0
CBD Normal Flow Reserved Auto Lanes[d]	160-120	23.0-30.0
CBD Bus Streets, Contraflow Reserved Lanes, and Median Lanes[d]	100	36.0

[a] *Observed data at General Motors proving grounds under ideal conditions, with no fluctuations in traffic flow and perfect guideway geometrics.*

[b] *No on-line bus stops.*

[c] *Includes 20-second on-line bus stops with 10-second station clearance and perfect roadway geometrics.*

[d] *Observed data.*

[e] *Applicable for all freeway priority treatments.*

Source: U. S. Department of Transportation.

is under rail transit modes. Rather, vehicle spacing is under the direct control of the driver of each vehicle, making headways dependent upon visual-manual control. For safety reasons, higher speeds require increased distances between vehicles.

Theoretical maximum frequencies of transit buses per unit time are identical for all modes or priority measures. Table 25 sets forth such values for selected traffic conditions. It should be recognized that the shortest headways listed occur only with the highest traffic densities, and then only for short periods of time. In order to achieve very high frequencies, bus systems generally must have several major routes utilizing the same guideway or roadway segment.

Actual observed headways provide a more realistic perception of the scheduling that has been designed for contemporary bus transit systems, as well as of the utilization of various priority treatments. Depending on local demand, primary bus service that utilizes any of the aforementioned priority measures may have a scheduled peak-period headway ranging from five minutes to one hour. The same routes may continue to operate during off-peak periods with greater headways or may not operate at all. Service on Saturdays, Sundays, and holidays is generally at no greater frequency than is midday service.

The priority facilities discussed within this chapter are generally implemented within corridors of high travel demand entering central business districts. The facilities are characteristically used by more than one primary bus route and, where reserved arterial street lanes constitute part of the primary route, by secondary and tertiary routes also. Observed headways, therefore, are for a combination of vehicles operating over a number of routes. Actual peak-hour bus flows for individual bus priority projects in the United States are given in Tables 1 through 10 of this chapter.

Capacity Characteristics

The maximum passenger-carrying capacity of any motor bus transit system is dependent upon vehicle capacity, vehicle configuration, and headway. In addition, certain other design, policy, and institutional considerations that reflect local conditions have a bearing on capacity. Busways can achieve the highest capacities, the capacity being constrained only by the operating speed and the guideway design. The capacity of reserved arterial street lanes depends upon the constraints imposed by at-grade operation and cross traffic conflicts. Motor buses that are able to secure priority over other traffic at freeway entrance ramps may still be subject to traffic congestion if operating in mixed traffic.

Data on the actual capacity of the four bus transit modes vary significantly. Express bus modes that predominantly utilize arterial street rights-of-way can generally meet peak demands of from 2,000 to 8,000 passengers per hour. Express bus modes that predominantly utilize freeway or exclusive rights-of-way are able to meet peak demands ranging from 4,000 to 12,000 passengers per hour.

Table 26 illustrates the range of passenger-per-hour capacities attainable under various vehicle and operational configurations, based upon recent vehicle designs. Extreme values in the matrix would not be reached except under unusual circumstances. It should be noted that unit capacity is limited to that of one vehicle, since it is not currently practical to couple motor buses into trains.

These capacity considerations are applicable only in a line-haul context. Unlike rail transit facilities, most motor bus primary transit services are operated nonstop over lengthy portions of the route. Should station stops be required of most vehicles along a designated priority facility, station or bus stop design becomes critical. Because headways may be very small on bus transit facilities with large peak demands, the necessary dwell time per vehicle at a stop may be greater than the headway, causing bus queues to form outside the stop area if there is an insufficient number of berths.

Table 26

THEORETICAL PASSENGER CAPACITIES PER HOUR FOR MOTOR BUS TRANSIT

Headway	Passenger-per-Hour Capacity		
	Standard Single-Unit[a]	Articulated[b]	Double Deck[c]
5 Seconds	34,560	51,840	60,480
10 Seconds	17,280	25,920	30,240
15 Seconds	11,520	17,280	20,160
20 Seconds	8,640	12,960	15,120
30 Seconds	5,760	8,640	10,080
1 Minute	2,880	4,320	5,040
2 Minutes	1,440	2,160	2,520
3 Minutes	960	1,440	1,680
4 Minutes	720	1,080	1,260
5 Minutes	576	864	1,008
10 Minutes	288	432	504
12 Minutes	240	360	420
15 Minutes	192	288	336
20 Minutes	144	216	252
30 Minutes	96	144	168
60 Minutes	48	72	84

NOTE: All calculations are based upon full seated capacities. Passenger loads that include standees may be calculated by multiplying the theoretical capacity by the desired load factor.

[a] *Assumes use of conventional vehicle with seated capacity of 48 passengers.*

[b] *Assumes use of articulated vehicle with seated capacity of 72 passengers.*

[c] *Assumes use of double-deck vehicle with seated capacity of 84 passengers.*

Source: SEWRPC.

In such instances, the bus stop or station capacity at the maximum load point may become the key variable to be increased, as opposed to the line-haul capacity. The number of bus berths required at the maximum load point varies directly with the total number of passengers to be served at that point, the loading and unloading times required per passenger, and the clearance times between buses. Thus, alternatives to increasing the number of bus berths at the maximum load point include: increasing the number of stations around the maximum load point; reducing the loading and unloading times per passenger; and using larger-capacity vehicles. Loading/unloading times can be reduced by equipping vehicles with more than one door, collecting fares off the vehicle, and utilizing wider-vehicle doors. Off-vehicle fare collection would require either that a self-service fare collection system be instituted, or that fares be collected on station platforms by agent or turnstile. Larger-capacity vehicles may serve to reduce the time lost queuing at stations or stops. This consideration is important to systems level planning efforts because of the additional space that may be required for multiple-berth stations or stops if maximum system capacity is to be realized.

ECONOMIC CHARACTERISTICS

Within the context of this report, the term "economic characteristics" pertains primarily to the capital and operating costs of each transit mode or priority treatment. This section presents cost data relevant to system planning for all four motor bus modes. The cost data presented represent generalized, nonsite-specific information developed from data collected on actual systems operated in selected urban areas of the United States, and from generalized costs furnished by consultants to the U. S. Department of Transportation. The cost data are intended to be utilized at the systems planning level to comparatively evaluate primary transit system plans.

Capital Costs

Capital costs are those investments required to acquire and construct the physical facilities—both fixed facilities and vehicles—necessary for the operation and maintenance of a motor bus transit system. Capital costs thus include the costs of acquiring right-of-way and vehicles; the costs of constructing or modifying specific guideway segments, stations and boarding facilities, signals and communication equipment, and maintenance and storage facilities; agency costs; and contingencies.

Right-of-way: Right-of-way acquisition costs include all costs entailed in obtaining easements over, or fee simple title to, all real property required for the construction and operation of the motor bus transit system. Primary transit systems that utilize mixed traffic freeway operation, reserved lanes on freeways, and arterial street priority measures usually have no significant right-of-way requirements since existing freeway and arterial street rights-of-way serve as the guideway. Exclusive busway development, however, may require the acquisition of a new right-of-way. Although right-of-way acquisition costs are difficult to estimate in the absence of a specific system design and definitive knowledge of local real estate values, some measure of those costs is provided in Table 27. The cost of land for major stations and parking facilities must be estimated separately on a per-acre or per-parking-space basis. When the proposed alignment for an exclusive busway requires that existing structures, utilities, or other transportation facilities be relocated, such relocation can become a significant element in the total right-of-way cost.

Vehicles: The cost of vehicles is a function of the basic vehicle configuration chosen plus the options selected by the transit operator. Included within this item are the costs of vehicle delivery and any special equipment such as wheelchair lifts. Over the past several years, bus costs have escalated at about the same rate as have the costs of other capital items, unlike rail transit vehicle costs, which have increased at a more rapid rate. The procurement of motor buses involves the use of proven, "off-the-shelf" technology that should require a minimum of presystem start-up testing. This situation may change somewhat should a final decision be reached by the U. S. Department of Transportation concerning the Transbus requirements. Recent cost data are presented along with other vehicle data under the section above entitled "Vehicle Technology" (see Tables 12, 13, and 14).

Guideway Construction: The guideway generally accounts for the major portion of the total cost of exclusive busway construction. Because the other bus transit modes make extensive use of existing streets, highways, and freeways, the guideway cost element for such modes may be small in comparison to the new vehicle acquisition cost. Busway costs are difficult to generalize since they are greatly affected by horizontal and vertical alignment. Therefore, only approximate costs per mile can be provided in the absence of a preliminary engineering plan. Capital costs for the initiation of reserved lane treatments either on freeways or arterial streets will normally be minimal and depend primarily upon the length of the facility.

Guideway costs that are cited within Table 28 for exclusive busways include the costs of all structures necessary to support the roadway. The major cost elements for busways are earthwork and grading, the subbase, pavement, drainage, fencing, landscaping, and traffic control requirements such as signing and pavement markings. Items included in the unit costs of aerial structures include foundations, footings, columns, the superstructure, drains, pavement, utility adjustments, street restoration, and landscaping.

Guideway costs that are cited within Tables 29, 30, and 31 for mixed traffic and reserved lane operation on either freeways or arterial streets include the costs of a variety of elements, some or all of which may be required to modify existing freeway facilities for use by primary transit service. Such elements include, but are not limited to, freeway transition lanes, the traffic control apparatus necessary for implementation of reserved lanes on freeways and arterial streets, and lane widenings or ramp bypasses if a freeway operation control system is initiated.

Table 27

LAND COSTS PER MILE FOR EXCLUSIVE BUSWAY RIGHTS-OF-WAY

Location[a]	Land Costs per Population of SMSA[b,c] (in millions of dollars)					
	Less than 50,000	50,000-100,000	100,000-250,000	250,000-500,000	500,000-1 Million	More than 1 Million
Central Business District . . .	1.47	1.47	1.75	2.20	2.94	3.24
Central Business District Fringe Area	1.47	1.47	1.58	1.75	2.20	2.92
Residential Area.	1.30	1.30	1.47	1.47	1.88	2.60

[a] *Based on land required for two 12-foot-wide bus lanes with 8-foot shoulders on each side, including a 1-foot median. Total cross-sectional areas would be 41 feet. Smaller cross-sections would cost proportionately less.*

[b] *Data are estimated from typical urban freeway land costs and adjusted to reflect busway land costs in 1979 dollars.*

[c] *SMSA = Standard Metropolitan Statistical Area.*

Source: U. S. Department of Transportation.

Stations: Costing procedures for station facilities depend on the requirements of a specifically designed system. Most primary bus transit applications will require only minor stations, many of which will be nothing more than normal bus stops with shelters. Major stations may be required on exclusive busways and at off-street locations of major transfer points. A primary determinant of the cost of any major station is its physical size, which must be related to projected passenger volumes, number of bus berths, and the fare collection system utilized. Other factors requiring consideration include the location and design of loading platforms, architectural treatment, security requirements, and intermodal facilities. The cost of park-ride facilities is generally estimated separately from the cost of the station proper. Construction costs for busways as given in Tables 29 and 32 are for such busways with less intensive station development.

Signals and Communication: Motor bus transit modes do not require sophisticated signalization and communication equipment, since traffic control is governed principally by wayside signs and pavement markings. Traffic signals at arterial street intersections and freeway entrance and exit ramps may be required if not already in place. A freeway operational control system will require several items, including a central control center, traffic detectors, ramp control signals, and the appropriate hookups to tie the system together. Communications equipment for bus systems is generally limited to two-way radios in all buses, supervisory and maintenance vehicles, and a centralized message dispatch center.

Maintenance and Storage: A new primary transit system based upon the operation of express buses will most likely be integrated with the existing motor bus services. Bus garages, maintenance and servicing facilities, and repair shops may therefore already be in place. Expansions of all of these facilities, however, may be necessary, depending upon how much the size of the vehicle fleet increases because of the initiation of new service. The extent of such expansion will depend upon what functions are carried out by in-house forces and the amount of unused property that is owned by the transit operator. It is possible that additional garage or repair facility sites may have to be sought in order to obtain sufficient space. Actual costs for these facility expansions are difficult to estimate in the absence of at least a conceptual layout.

Agency Costs: Agency costs are the unallocated allowances for engineering and administration during project implementation. Specific tasks covered under this item include engineering and architectural design, construction management, cost estimation and control, construction supervision, inspection and testing, and system start-up. Fifteen percent of total capital costs is typically allotted to cover these needs. This cost does not apply to vehicle acquisition.

Contingencies: Contingencies are an unallocated allowance that is intended to cover unforeseen and

Table 28

UNIT CONSTRUCTION COSTS FOR BUSWAY FIXED GUIDEWAYS

Unit	Construction Costs (in 1979 dollars—agency and contingency costs not includes)								
	Medium Density			High Density				Central Business District	
	At-Grade	Elevated on Fill or Structure	Retained Cut	At-Grade	Elevated on Fill	Aerial Structure	Retained Cut	At-Grade on Median or in Transit Mall	Aerial Structure
Grading (per mile)	$453,000[a] $362,000[b]	$ 393,000	$ 1,812,000	$453,000[f] $181,000[g]	$ 393,000	$ 906,000	$ 1,812,000	$181,000	$ 906,000
Drainage	$ 18,000 per stream crossing	$ 30,000 per stream crossing	$ 120 per linear foot	$169,000 per mile	$ 30,000 per stream crossing	- -	$ 120 per linear foot	$310,000 per mile	- -
Utilities (per crossing)	$ 24,000[a] $ 6,000[b] each highway	$ 24,000 each highway	$ 72,000 each highway	$ 24,000 each railroad and highway	$ 24,000 each railroad and highway	$ 24,000 each railroad and highway[c]	$ 72,000 each railroad and highway	$ 18,000 each highway	$ 24,000 each railroad and highway[c]
Structures—Primary (per mile)	- -	$12,756,000	$15,946,000	- -	$12,756,000	$15,100,000	$15,946,000	- -	$15,100,000
Structures—Other (each railroad, highway, and river crossing if required)	$362,000	$ 362,000	$ 362,000	$362,000	$ 362,000	- -	$ 362,000	- -	- -
Traffic Handling (each railroad and highway crossing)	$ 36,000[a] $ 6,000[b]	$ 48,000	$ 48,000	$ 36,000[a] $ 18,000[b]	$ 60,000	$ 60,000[d]	$ 60,000	$ 48,000	$ 60,000[d]
Demolition (per building)	$ 9,000	$ 9,000	$ 9,000	$ 12,000	$ 12,000	$ 12,000	$ 12,000	- -	$ 12,000
Fencing (per mile)	$133,000	$ 133,000	$ 133,000	$133,000	$ 133,000	- -	$ 133,000	- -	- -
Roadway (per two-lane mile)	$196,000	$ 196,000	$ 196,000	$234,000	$ 234,000	$ 234,000	$ 234,000	$461,000	$ 234,000
Access Ramp (one-way single lane for Class A busway alignments)	$217,000	$ 544,000	$ 566,000	$217,000	$ 544,000	$ 544,000	$ 566,000	- -	$ 566,000
Signalization (per arterial street intersection for Class A busway alignments)	$ 15,000	- -	- -	$ 15,000	- -	- -	- -	$ 15,000	- -
Incidentals (per mile)	$128,000	$ 128,000	$ 128,000	$257,000	$ 257,000	$ 257,000	$ 257,000	$257,000	$ 257,000

[a] *Applicable for Class A busway alignments.*

[b] *Applicable for Class B busway alignments.*

[c] *If not located on street right-of-way; otherwise use $604,000 per mile.*

[d] *If not located on street right-of-way; otherwise use $966,000 per mile.*

[e] *If building is more than three stories in height, then number of buildings equals the number of stories minus two.*

[f] *On exclusive right-of-way.*

[g] *In median area of arterial street.*

Source: U. S. Department of Transportation and SEWRPC.

Table 29

TYPICAL IMPLEMENTATION COSTS FOR RESERVED FREEWAY LANE OPERATION

Item	Range of Costs per Mile[a]	Typical Cost per Mile[a]
Reserved Lane on Freeway		
Basic Lane Separation and Signing (theoretical minimum application)	$12,000-$35,000	$ 22,000
Contraflow Freeway Lane		
Based on Actual Projects	$8,700-$109,000	$ 54,000
Normal Flow Freeway Lane		
Additional At-Grade Lane	$500,000-$1,100,000	$1,100,000
Additional Lane in Cut	- -	2,700,000
Additional Lane on Fill	- -	3,050,000
Miscellaneous		
Concrete Lane Barrier	- -	$ 196,000
Agency Costs	- -	15 Percent
Contingency Costs	25-35 Percent	30 Percent

[a] *Costs are based on 1970 data adjusted to reflect 1979 prices. Extreme values may represent the inclusion of sophisticated traffic signals and other project items such as park-ride lots or exclusive bus ramps.*

Source: U. S. Department of Transportation and SEWRPC.

detailed design or construction. Values for this item, which applies to all capital cost items except vehicle acquisition, range between 20 and 35 percent, and depend upon the depth of the preliminary engineering studies.

Summary of Capital Costs: Overall capital construction costs for the various bus transit modes and priority treatments vary considerably. Unit construction costs for the components of a freeway operational control system are presented in Table 30. This system is applicable to the "operation in mixed freeway traffic" mode. The costs of capital items for reserved freeway bus systems are shown in Table 29. Busway system unit construction costs are given in Tables 28 and 32, according to several vertical guideway alignment configurations. Finally, the capital costs pertinent to the arterial express bus mode are set forth in Table 31. Capital costs for motor bus vehicles are set forth in Tables 12 through 14 of this chapter.

Table 30

TYPICAL IMPLEMENTATION COSTS FOR OPERATION OF MOTOR BUSES ON FREEWAYS IN MIXED TRAFFIC

Item	Range of Costs[a]	Typical Cost[a]
Freeway Operational Control System[b]		
Control Center Building	System Specific	$0.5 million
Surveillance and Control System	$1.1-5.4 million	3.3 million
Per Interchange	--	135,000
Ramp Bypass Lanes	Site Specific	50,000 each
Exclusive Ramp Construction	Site Specific	0.22 million
Stations		
Curbside Stops with Shelter	$ 3,300-8,700 each	$ 4,300 each
Outlying Terminals	5,400-22,000 each	16,300 each
At-Grade Terminal/Transfer Points	22,000-109,000 each	54,000 each
Station Parking		
At-Grade	--	2,200 per space
In Structures	--	4,300 per space
Maintenance and Storage	Varies with System Requirements	$ 25,000 per vehicle
Agency Costs	--	15 Percent
Contingency Costs	25-35 Percent	30 Percent

[a] *Costs are based on 1972 through 1978 data adjusted to reflect 1979 prices.*

[b] *Actual costs for a specific project may vary according to the sophistication of the surveillance and control system, the number of ramps to be controlled, and the extent of other traffic control devices utilized, such as changeable message signs or lane control signs.*

Source: U. S. Department of Transportation and SEWRPC.

Two basic conclusions can be drawn regarding primary bus transit modes. First, the initial investment in exclusive busway systems may be expected to be considerably greater than that for reserved freeway lanes and reserved arterial street lanes because of the need for new guideway segments and the possible need for right-of-way acquisition. Both of these items are not required for reserved lane implementation. Other capital cost items for primary bus service, such as exclusive entrance ramps, ramp metering, transition lanes for reserved contraflow lanes, and downtown street modification for bus use only, may be significant to the total project cost, but nevertheless represent relatively small costs when compared with the costs of exclusive busway facilities.

Second, there are large differences in the capital costs of the different vertical busway alignments. Aerial segments cost 2 to 4 times that of surface segments, and underground segments cost 5 to 20 times that of elevated segments. The costs of fixed guideway construction on the surface are highly variable, depending upon the extent of grade separations and the choice of right-of-way. These differences are illustrated in Figure 67.

Operating Costs

Operating costs for primary transit motor bus systems consist of the daily costs of operating a bus fleet, regardless of the type of guideway utilized, and the costs associated with the routine operation of the various bus priority facilities, such as exclusive busways and reserved lanes. Normally expressed in units of dollars or cents per variable unit, the daily costs would be similar for any major urban bus system. These costs can be broken down into five categories: transportation expenses, which include the cost of drivers and supervisory personnel and fuel and station expenses; maintenance and garage expenses, which primarily include storage costs and the costs of vehicle repairs, along with the attendant labor costs; administrative costs and general expenses, which include insurance and safety and management costs; operating taxes and the costs of licenses; and miscellaneous expenses, which include items such as depreciation and amortization.

Typical operating costs for motor bus systems are provided in Table 33, aggregated on a vehicle-mile basis. For a service area of 750,000 to 2.50 million people—representative of the Milwaukee urbanized

Table 31

TYPICAL IMPLEMENTATION COSTS FOR ARTERIAL EXPRESS BUS SYSTEMS

Item	Range of Costs[a]	Typical Cost[a]
Reserved Normal Flow Curb Lane	\$4,000 - \$110,000 per mile[b]	\$ - -
On Major Arterial Street	- -	4,300 per mile
In Central Business District	- -	8,700 per mile
Reserved Contraflow Curb Lane	\$5,000 - \$140,000 per mile[b]	\$ - -
On Major Arterial Street	- -	6,500 per mile
In Central Business District	- -	12,000 per mile
Reserved Median Lane	\$20,000 - \$210,000 per mile[b,c]	\$ - -
On Major Arterial Street	- -	23,000 per mile
In Central Business District	- -	46,000 per mile
Exclusive Bus Street Mall		
In Central Business District	\$700,000 - \$2,700,000 per mile[d]	\$760,000 per mile
Traffic Signal Preemption Equipment		
Vehicle Signal Transmitters	\$200 - \$900 each	\$ 435 each
Fixed Intersection Apparatus	\$1,000 - \$3,300 per intersection	\$ 2,700 per intersection

[a] *Costs are based on 1968 through 1978 data adjusted to reflect 1979 prices.*

[b] *Extreme values may represent the use of sophisticated lane control apparatus and/or the use of either temporary or permanent physical barriers.*

[c] *Extreme values may represent reversible use of lane, including appropriate lane control apparatus.*

[d] *Extreme values may represent the use of various pedestrian amenities. Total cost will reflect the reconstruction of existing street.*

Source: U. S. Department of Transportation and SEWRPC.

Table 32

UNIT CONSTRUCTION COSTS FOR BUSWAY STATIONS

Unit	Construction Costs (in 1979 dollars—agency and contingency costs not included)								
	Medium Density			High Density			Central Business District		
	At-Grade	Elevated on Fill or Structure	Retained Cut	At-Grade on Private Right-of-Way or Median	Elevated on Fill	Aerial Structure	Retained Cut	At-Grade on Median or in Transit Mall	Aerial Structure
Awning per Two Articulated Bus Vehicles	\$ 97,000[a]	\$ 97,000[a]	\$ 97,000[a]	\$ 97,000[a]	\$ 97,000[a]	\$ 97,000[a]	\$ 97,000[a]	- -	\$ 97,000[a]
Parking per 75 Autos	139,000[a]	139,000[a]	139,000[a]	139,000[a]	139,000[a]	139,000[a]	139,000[a]	- -	- -
Access per 75 Autos	174,000[d]	242,000[b]	242,000[b]	174,000[d]	242,000[c]	242,000[c]	242,000[c]	- -	906,000 plus 293,000 per each additional 1,800 people
Platform per Two Articulated Bus Vehicles	18,000	155,000	181,000	18,000	155,000	155,000	181,000	18,000	193,000
Shelters per 360 People	6,000	12,000	12,000	6,000	12,000	12,000	12,000	6,000	- -
Station Facility	- -	- -	- -	- -	- -	- -	- -	- -	435,000 plus 284,000 per each additional 1,800 people

[a] *Optional if included in station layout design.*

[b] *If no parking is included, use \$30,000 plus \$30,000 per 360 people.*

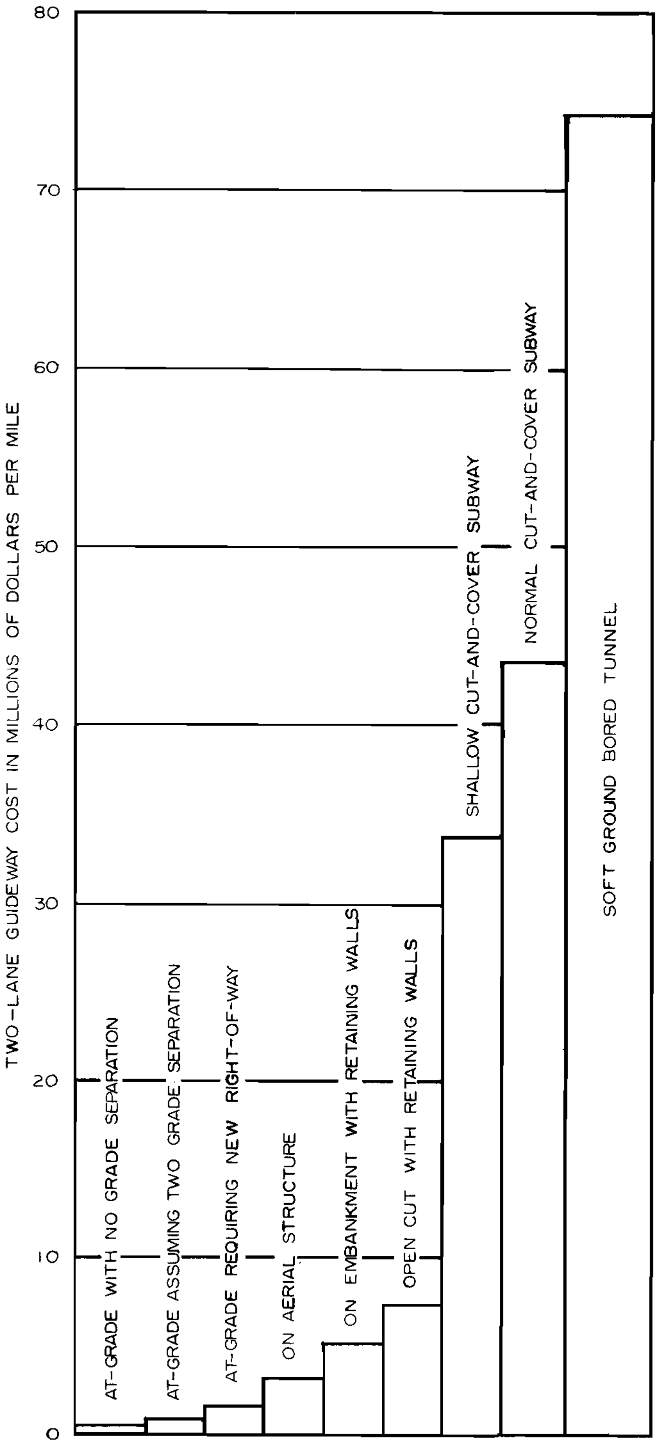
[c] *If no parking is included, use \$36,000 plus \$36,000 per 100 people.*

[d] *Do not include if there is no parking included.*

Source: U. S. Department of Transportation and SEWRPC.

Figure 67

EFFECT OF VERTICAL CONFIGURATION AND RIGHT-OF-WAY ON TOTAL CAPITAL COSTS FOR EXCLUSIVE BUSWAY FACILITIES



Source: U. S. Department of Transportation and SEWRPC.

Table 33

TYPICAL OPERATING COSTS FOR MOTOR BUS TRANSIT SYSTEMS

Population of Service Area	Range of Costs per Bus Mile	Typical Cost per Bus Mile
More than 2,500,000. . .	$1.39-$4.61	$2.58
750,000 - 2,500,000 . . .	$1.42-$2.61	$1.84
100,000 - 749,999	$0.78-$1.92	$1.37
Less than 100,000	$0.69-$1.23	$1.08

NOTE: Costs are based on 1975 data adjusted to reflect 1978 prices.

Source: U. S. Department of Transportation.

area—annual per-mile vehicle costs may be expected to range from $1.42 to $2.61. In fact, in 1979, the systemwide operating expense per vehicle mile on the Milwaukee County Transit System was $2.05. For the two remaining urban transit systems serving the Southeastern Wisconsin Region, the systemwide operating expenses per vehicle mile in 1979 were $1.37 for Racine and $1.36 for Kenosha.

It should be be recognized that major transit operators allocate expense accounts for bus operations on the basis of four variables: vehicle hours, vehicle miles, peak vehicle needs, and system revenue. Vehicle hours are used to allocate wage expenses for drivers and supervisory personnel, since such wages are paid on an hourly basis. This expense represents by far the largest single cost for most transit operators. Expenses for such items as fuel, tires, vehicle parts, and vehicle taxes are a function of vehicle use, and therefore are logically allocated on the basis of vehicle miles. The cost of many items—such as the cost of operation and maintenance facilities, including the cost of service equipment and of maintaining these facilities—is related to the maximum fleet size, and thus is allocated on the basis of peak vehicle needs. Finally, system revenue is used as a parameter of many general or systemwide costs. This category might include the costs of injuries and damages and marketing and promotion, as well as station expenses and taxes.

Table 34

TYPICAL ANNUAL OPERATING COSTS FOR MOTOR BUS PRIORITY FACILITIES

Priority Treatment	Range of Costs[a]	Typical Cost[a]
Exclusive Busway		
Guideway	$10,000 - $15,000	$ 12,500 per lane mile
Major Stations	4,000 - 15,000	10,000 each
Minor Stations/Shelters	200 - 1,000 each	900 each
Reserved Freeway Lanes	$6,500 - $130,000 per lane mile[b,c]	$ 35,000 per lane mile
Reserved Arterial Street Lanes	$2,200 - $196,000 per lane mile[b,d]	$ 4,300 per lane mile
Freeway Operational Control System		
Control Center	- -	$ 70,000
System Operation and Maintenance	- -	650,000
Ramp Meter Operation and Maintenance	- -	1,000 per ramp
Traffic Signal Preemption		
Operation and Maintenance	- -	$ 1,300 per intersection
Station Parking		
Operation and Maintenance[e]	- -	$ 20 per space

[a] *Costs are based on 1974 through 1978 data adjusted to reflect 1979 prices.*

[b] *Extreme values may represent use of sophisticated lane control equipment.*

[c] *Does not include costs of enforcement.*

[d] *Extreme values may represent use of sophisticated lane control equipment and traffic signal preemption.*

[e] *Self-service lots.*

Source: U. S. Department of Transportation and SEWRPC.

The costs associated with the routine operation of bus priority facilities include the costs of maintaining and repairing fixed facilities, and, where a facility is in operation for only a portion of the day, the expenses incurred to open and close reserved lanes. Table 34 sets forth annual operating costs for such priority treatments, based upon the actual experience of existing selected operations.

Amortization Periods

Amortization periods for major components of a bus transit system should be properly related to the expected service life. Amortization periods typically utilized for primary transit systems planning are set forth in Table 35.

Energy Intensity of Bus Transit

Energy requirements for transportation systems are frequently reported in terms of vehicle propulsion energy efficiency—that is, the number of vehicle miles per unit of energy. However, vehicle energy efficiency is only one aspect of transit system total energy consumption. In addition to the energy required to propel vehicles, transit energy requirements that should be analyzed include the energy needed to maintain vehicles, to operate stations, and to maintain other system facilities, and the energy expended in the construction of the system and manufacture of the vehicles. This more comprehensive consideration of energy requirements provides a basis for comparison of transit systems

Table 35

TYPICAL AMORTIZATION PERIODS FOR MOTOR BUS TRANSIT COMPONENTS

System Component	Amortization Period in Years
Motor Bus Vehicles	12
Rights-of-Way	100
Surface Roadways	20-30
Structures	50
Stations, Including Parking	30
Control and Communication Equipment	30
Maintenance and Storage Facilities	30-40
Contingency and Agency Costs	30

Source: SEWRPC.

which may differ in vehicle, guideway, and system types, in system configuration, and in energy source, as well as in vehicle fuel consumption.

The separation of energy requirements into operation and construction energy permits consideration of potential future, as well as current, availability and cost of energy sources. Systems that require relatively small amounts of construction energy but relatively large amounts of operating energy may be less desirable in the future than systems that require less operating energy, or which use energy sources other than petroleum, but require more energy for construction. Data on construction energy intensity are not as readily available as are data concerning vehicle propulsion energy consumption.

For the purposes of this analysis, system operating energy is defined as the propulsion energy for the transit vehicles and the energy required to operate stations and maintain vehicles and system facilities. System construction energy is defined as the energy required for guideway construction and vehicle manufacture. Together, these elements constitute the total energy requirements, or energy intensity, of a bus transit system.

Vehicle propulsion energy requirements constitute the majority of energy consumed and account for most of the variation in the overall energy utilization of bus transit systems. The propulsion energy requirements of bus transit systems, based on the experience of transit operators in the United States, were discussed in an earlier section of this chapter. With respect to the second element of system operating energy—the energy used to maintain vehicles and to maintain and operate stations—relatively few data are available, since data on maintenance and station energy requirements are rarely segregated from overall energy consumption data by transit operators. Moreover, there has been relatively little research to identify these requirements. Bus maintenance energy, which principally includes the energy required for lubrication and for other service, parts, and repair, is estimated to range between 800 and 1,000 BTU's per vehicle mile. No specific data are available on station operation and maintenance requirements, although these requirements have been estimated to range between 10 and 20 percent of propulsion energy requirements.

With respect to the energy requirements for system construction, no specific energy consumption estimates for the construction of an exclusive busway and its attendant station facilities are available. In order to estimate the energy required to construct a dual-lane guideway for bus transit, it was assumed that the amount of energy required to construct an at-grade dual-lane guideway would approximate the amount of energy required to construct two lanes of freeway facility. Recent studies have reported that such a facility requires between 18.4 to 52.5 billion BTU's, or an average of 34 billion BTU's, per mile of two-lane roadway. The construction of an elevated segment of a busway has been estimated to require 153.2 billion BTU's per mile of dual guideway. Estimates of the energy that can be expected to be expended in the construction of station facilities for busways are not available. The energy required to manufacture a standard urban bus is reported to approximate 1,020 million BTU's per vehicle.

SUMMARY

Within the context of this chapter, motor bus technology is examined only to the extent of application for primary transit service. Existing arterial streets and freeways are utilized to a large extent in the implementation of such primary motor bus service since, unlike rail transit modes, an individual guideway separating the vehicles from other traffic is not required. Four specific modes of bus operation may be utilized to provide high-speed primary transit service: operation in mixed traffic on freeways, operation over reserved lanes on freeways, operation on busways, and preferential operation on arterial streets and highways. Unlike the various rail transit modes discussed in Chapter III of this report, these modes of operation need not comprise self-contained systems since any primary transit service that utilizes motor buses can operate over a local arterial street network for collection, distribution, and terminal access.

Bus operation in mixed traffic on freeways can be defined as the operation of conventional, rubber-tired transit buses over freeway lanes that are open to all motor vehicle traffic. The collection and distribution portions of the trip utilize surface arterial streets and highways. The transit vehicles may be provided with preferential access to the freeway network at entrance ramps, or may be provided such access over exclusive freeway entrance ramps. The freeway itself may be operationally controlled or access uncontrolled. Such a freeway operational control system will constrain access to the freeway network during peak traffic hours, ensuring high rates of traffic flow at reasonable operating speeds. A typical system will consist of interconnecting demand-responsive ramp meters, priority access lanes for high-occupancy vehicles, including motor buses, at freeway entrance ramps, and improved driver information and incident management procedures.

Of all the bus transit modes, operation in mixed traffic on freeways is the most widely used, becoming popular during the 1950's and 1960's with the expansion of major expressway, parkway, and freeway systems. Application of this mode is almost entirely limited to peak-period service between outlying residential areas or stations and a central business district. Because this type of service requires no major fixed facility construction, the implementation period can be relatively short. Thus, many major cities find this mode attractive. Nevertheless, systems that provide preferential access to buses at freeway entrance locations are operated only in a small number of metropolitan areas within the United States. Similarly, the application of metered freeway entrance ramps and the use of exclusive freeway ramps for transit vehicles is currently limited to a small number of cities.

Reserved freeway bus lane systems can be defined as the operation of conventional motor transit buses over normal flow or contraflow reserved lanes within the freeway rights-of-way. This type of guideway is utilized for the line-haul portion of the trip, while passenger collection and distribution service is provided over service streets and highways. While on these facilities, vehicle operation is generally nonstop. Reserved freeway bus lanes are a relatively recent phenomenon, being implemented during the 1970's. Therefore, such systems exist in only a few of the largest United States metropolitan areas. Since existing facilities are utilized with little or no physical modification, initial capital costs and implementation time can be kept to a minimum.

Designation of the normal flow reserved freeway lane is usually accomplished by appropriate pavement markings or more intensive traffic engineering measures such as traffic cones, traffic posts, or barriers positioned to separate one of the existing traffic lanes from the remaining mixed-traffic lanes. These lanes are typically installed on the inside of the roadway, adjacent to the median area, so that conflicts with traffic movements to and from ramps are prevented.

Contraflow reserved freeway lanes are applicable where a large directional imbalance exists between opposing traffic movements during peak periods. Because of the safety factor involved with opposing flows of traffic within the same roadway, more positive means of lane separation than just signs and pavement markings must be employed, such as traffic cones or posts and barricades.

Busways are special-purpose roadways designed for the exclusive or predominant use of motor buses in order to improve vehicle movement and passenger travel times. The facility may be constructed at, above, or below grade and may be located on separate rights-of-way or within freeway corridors. This method of separating motor bus traffic from other traffic is the most positive, making this mode able to provide the highest quality primary transit service of all of the motor bus modes. The implementation of exclusive busways involves major facility construction, and thus the implementation time may be long in comparison to that of the other bus transit modes. In addition, capital costs are high relative to those of the other bus modes, and may approach those of light and heavy rail transit facilities. Motor bus vehicles may, however, leave the exclusive busway facility and provide their own feeder and distribution service. Exclusive busways existing in the United States generally provide high-quality, peak-period service into central business district areas. Busways may be constructed either with or without intermediate station facilities and access locations.

Although there are currently no exclusive busways in the Milwaukee urbanized area, the implementation of this type of facility was recommended in the initial regional transportation system plan, adopted in 1966. Following completion of a preliminary engineering study for this facility, the Milwaukee County Board of Supervisors refused to proceed with construction of the proposed busway, acting in 1973 to adopt the Milwaukee Area Transit Plan without inclusion of the busway proposal.

Arterial express bus operation is simply the operation of conventional, rubber-tired transit buses over arterial streets with provision for some form of preferential treatment over other motor traffic. By strict definition, arterial express bus systems are a secondary service, a discussion of which is outside the scope of this report. However, it must be recognized that there is a "gray area" between primary and secondary service because of the ability of some modes to be operated under a wide variety of conditions. Therefore, this mode is included insofar as it can be applied to fulfill high-quality, line-haul public transportation needs.

Priority for transit vehicles operating in the arterial express bus mode can be provided through the use of reserved lanes on existing streets or preferential treatment at selected traffic signals.

Reserved lanes on arterial streets can be operated either normal flow or contraflow, and can be located along one of the curbs or in the median area. An extension of the arterial reserved lane concept is the transit mall, or bus street. Bus streets are typically implemented only in major business and shopping areas, and include many pedestrian amenities, usually in concert with districtwide redevelopment.

Preferential treatment for motor buses is granted at selected intersection locations to reduce overall vehicle travel time. Preferential treatment can be achieved through the provision of special traffic phases for transit movements, the phasing of green cycles to facilitate bus movements through a series of signaled intersections, and the modification of the green phase time, determined by the presence or absence of a vehicle on the approach lane.

Because extensive use is made of existing fixed facilities, only minor capital outlays are required for the initiation of an arterial express project. Like reserved lane freeway operation, reserved lane on arterial street operation is typically in service only during weekday peak periods.

The nature of motor bus transit enables the same rubber-tired vehicle to be utilized for all bus modes and priority techniques that are applicable to the primary level of transit service. Motor buses may be classified into three broad categories, based upon relative size or configuration: compact or mini-vehicles, standard vehicles, and high-capacity vehicles. The standard urban motor bus is by far the most common vehicle used in primary transit service in the United States. The typical vehicle consists of a single unit body with an overall length of 35 to 40 feet, a width of 8.0 to 8.5 feet, and a height of 9.6 to 10.1 feet. Articulated buses represent a potentially attractive high-capacity vehicle for use on high-density-load primary transit routes. Articulated buses are extra-length vehicles that "bend" in order to negotiate sharp curves. The typical vehicle consists of two units having an overall length of 55 to 60 feet, a width of 8.0 to 8.5 feet, and a height of 10.0 to 10.5 feet. Another basic vehicle configuration is the double-deck motor bus, popular in Great Britain and other countries with historic British links. This type of vehicle is presently being used on an experimental basis in some United States cities.

The Urban Mass Transportation Administration's Transbus project was an attempt to develop a new urban transit bus to serve as an eventual replacement for the buses in service within the United States in the late 1960's. Pertinent design characteristics included a 22-inch floor height and a floor having the capability to "kneel" to 18 inches for boarding passengers, a wheelchair ramp or a lift, and tandem rear axles to accommodate the low floor. Because of a failure of a consortium of United States cities to procure bids for a large quantity of buses meeting these specifications, the United States Department of Transportation in 1979 announced a temporary delay in the effective date of some of these requirements. In the interim, currently available buses may be purchased by transit operators provided they meet established federal requirements, including the provision of a wheelchair lift.

Because of its proven performance and durability, the diesel engine will probably continue to be the basic prime mover for motor bus vehicles for at least the next decade. Older, conventional diesel engine-powered buses have a rate of acceleration of approximately 2.0 miles per hour per second, and modern standard vehicle designs, of 2.5 miles per hour per second. Acceleration rates for articulated vehicles range from 1.5 to 2.0 miles per hour per second. Maximum vehicle speeds for American bus designs vary from 50 to 70 miles per hour, depending upon the engine and drive-train used. Rates of deceleration generally approximate 2.5

miles per hour per second for service application, and approach approximately 12.0 miles per hour per second in emergency situations.

Passengers board motor bus vehicles at curb level through two to four doors on one side of the vehicle. Federal regulations require that front steps be no greater than 8 inches in height, and that an effective floor height be 24 inches or less after use of a "kneeling" feature which permits the right front corner of the vehicle to be lowered to curb height. In addition, the vehicles purchased with federal financial assistance are to be accessible to handicapped persons. Such accessibility is usually provided by equipping buses with wheelchair lifts. Interior vehicle design depends on the space required for standee passengers; however, a two-plus-two across seating arrangement is typical.

Primary transit modes that incorporate motor bus technology employ the basic guidance principle of rubber-tired vehicles operating over rigid-surfaced roadway pavements. Express bus operation, whether over freeways in mixed traffic, over reserved freeway lanes systems, or over arterial streets, utilizes roadway facilities that are already in place, the design and construction of which generally conform to accepted highway engineering standards and practices. The operation of motor buses in mixed traffic over existing freeways usually requires little or no guideway-related additions or modifications to the existing freeway facilities. However, bypass lanes for transit vehicles may need to be constructed at metered freeway entrance ramps, or entrance ramps may need to be constructed for the exclusive use of buses. Exclusive bus lanes should be a minimum of 12 feet wide with appropriate shoulders, and the design of any new entrance ramps should comply with accepted freeway ramp design standards.

Reserved freeway lanes for motor bus operation also require a minimum amount of physical construction. Normal flow reserved lanes are separated from other lanes by temporarily placing traffic cones, barricades, or flexible traffic posts between the reserved and mixed traffic lanes, or by delineating the lanes with pavement markings and striping. Contraflow reserved lanes are separated from the mixed traffic lanes in the same manner, but posts or cones, rather than markings and stripping, are used since contraflow lanes operate against the direction of traffic. If the directional traffic split is great enough and four lanes are available in the underutilized direction, the lane dividers may be placed in the middle of the second inside lane instead of on the lane's dividing line, allowing an additional safety margin between opposing traffic flows. While the daily installation and removal of cones, barricades, posts, and signs may represent a significant operating cost, these devices permit entrance through the lane at only one point, and are thus self-enforcing. Contraflow lane operations also require a specialized transitional lane, which allows priority traffic to cross across the median area into the reserved lane.

Exclusive busways may be classified into one of two types, based upon the anticipated overall level of service desired. Class A busways provide for high-speed, high-quality rapid transit service analogous to that provided by the heavy rail rapid transit mode. Being fully grade-separated, Class A busways are generally applicable in large urbanized areas, where express buses must operate nonstop over relatively long distances. Class B busways provide for a somewhat lower quality of service, analogous to that provided by the light rail transit mode. Class B busways serve shorter distance trips and operate at lower overall speeds than do available Class A busways. However, station frequency is greater, and there may be at-grade crossings with arterial streets.

Actual guideway dimensions are dependent upon detailed, site-specific designs after a final selection has been made with respect to mode and alignment. Suggested design specifications for exclusive busways are a minimum lane width of 12 feet for Class A busways, and of 11 to 12 feet for Class B busways. Paved shoulder widths should be 8 to 10 feet for Class A busways, and 6 to 8 feet for Class B busways. The total paved width should be a minimum of 28 feet on aerial segments and 31 feet in tunnel segments. Desirable minimum vertical clearances are 14.5 feet for both types of busways. The minimum lateral distance to fixed obstructions is 3.5 feet on the left and 6 feet on the right for Class A busways, and 2 feet on the left and 3 feet on the right for Class B busways. Absolute minimum gradients are 8 percent for mainline segments and 10 percent for ramp segments. These suggested specifications reflect desirable design speeds of 70 miles per hour for Class A busways and 50 miles per hour for Class B busways.

Exclusive busways also require appropriate transition lanes for connection to freeways and appropriate intersections for connection to surface arterial streets. Ridership forecasts may sometimes indicate the potential for future conversion of a busway into a rail transit guideway. In such cases, the right-of-way cross-section should be designed so that minimal changes are required for conversion to the rail transit mode. Special consideration is required for exclusive busway segments that have to be located in tunnels or subways. The construction costs of such facilities will be higher than those of other segments because of the need to provide adequate ventilation for the emissions from the motor buses. Passenger waiting areas may also require special design consideration to minimize air contamination.

Arterial express bus systems utilize existing guideway facilities, but with some sort of preferential treatment over other traffic. This preferential treatment may be in the form of reserved lanes, which can be implemented in a variety of ways, depending upon the existing pavement width. Normal flow curb lanes should be at least 10 feet while contraflow curb lanes should be at least 12 feet wide. Reserved lanes in the center of the street should be at least 10 feet wide for one-way operation, and 20 to 22 feet wide for two-way operation. When two directional reserved lanes are located on an arterial street, a Class B surface busway is, in effect, created. Narrower lane widths may be necessary, but should be avoided if at all possible.

Appropriate transition lanes to and from the reserved transit lanes are also necessary. Lane transition techniques involve the use of proper lane channelization, extensive pavement markings, striping, and appropriate signing.

Stations for motor bus transit vary in complexity in accordance with the desired level of investment. There are three general categories of motor bus stations: minor stations, major stations, and central business district passenger collection and distribution, which refers more to a route configuration than to a specific facility type. Minor stations are quite similar to typical urban bus stops, consisting only of a location marked with appropriate signing, plus a shelter. Such stations, or stops, have application for all motor bus transit modes, including busway facilities, and may require turnout bays so that stopped vehicles can be easily passed by other vehicles.

Major station facilities are applied primarily at transit centers and along exclusive busways. Transit centers are located and designed to facilitate the transfer of passengers between different routes or different modes, or between different levels of service provided by the same mode. Additional land may be necessary at busway stations to provide for park-and-ride lots.

Passenger distribution in a central business district may be facilitated by operating buses over surface streets or directly into terminal buildings. Terminal buildings are practical only in some of the larger cities with intensive transportation demands. More commonly a street is dedicated for the exclusive use of transit vehicles. This is sometimes facilitated by the development of a pedestrian mall, with appropriate pedestrian amenities. Such malls should provide for at least a 22-foot-wide roadway and, under optimal circumstances, should connect directly with reserved freeway lanes, exclusive busways, or reserved arterial street lanes.

Station frequency varies widely for the primary motor bus modes discussed herein. Primary transit service operating over reserved lanes on freeways, or in mixed traffic on freeways, typically operates nonstop, while utilizing local bus stops in outlying and downtown areas. Existing busway facilities have stations spacing ranging up to 4 miles, although 0.5 mile represents a more typical value. Stop spacing for arterial express bus systems may be somewhat analogous to that for the light rail transit mode, ranging from 0.2 to 0.5 mile. On the other hand arterial express bus systems may operate nonstop between the origin and destination areas.

The following support requirements pertain to all four motor bus modes discussed herein: vehicle storage and maintenance, guideway and structure maintenance, traffic control, and fare collection. Vehicle storage for bus transit modes consists of garages and paved lots large enough to hold all vehicles not in service during the system's least active operating period. Bus garages should include appropriate facilities and equipment for daily servicing, including fueling, fare removal, washing, interior cleaning, and daily light inspection, and should have lockers and washrooms and driver facilities. On larger systems, such as the Milwaukee County Transit System, more than one garage location is required. Heavy maintenance and repairs, including major unit overhauls, are usually provided at a central shop facility. Should primary transit services requiring an increase in fleet size be implemented, the shop facilities may need to be significantly expanded.

The second support requirement includes the maintenance of the roadways, structures, and traffic controlling apparatus used by the bus mode. These activities are usually minor in scope unless an extensive exclusive busway system is developed. For the small amount of guideway and grounds maintenance that may be required, agreements may be able to be reached between the municipal, county, or state authorities, or an outside contractor may be hired to perform these services.

Traffic control refers to the use of signing, pavement markings, channelization, and traffic signal priority schemes, all of which are utilized to improve motor bus movement through existing traffic patterns. Appropriate signing, pavement marking, and other traffic control devices are very important not only on the guideways themselves, but in such areas as transitional lanes and other joint use areas. These items should follow standards recommended in the latest revision of the Manual on Uniform Traffic Control Devices, published by the U. S. Department of Transportation. The physical separation of reserved lanes from other lanes is generally facilitated by the daily installation and removal of traffic cones, posts, or barricades between the lanes, together with the use of signs that light up or unfold. The preferred lane separation marker appears to be a flexible traffic post that is inserted into a predrilled hole in the roadway surface. Suggested spacing of these posts is 20 feet in transition areas and 40 feet elsewhere.

Traffic signal priority measures for motor buses may be provided along Class B busways or along arterial streets where buses operate either in reserved lanes or in mixed traffic. Passive signal priority involves the retiming of signals for vehicle progression through a series of consecutive intersections, or the institution of special signal phases for bus movements. Active signal priority involves the detection of approaching vehicles by electronic means in order to activate a special phase or to extend or advance the available green time at the intersection.

Motor bus transit modes utilize one of two basic types of fare collection: pay-as-you-enter procedures and self-service procedures. Public transit operations in the United States and Canada utilize the pay-as-you-enter fare collection system on all motor buses. The use of self-service ticketing, popular throughout Western Europe, may serve to reduce average travel time and operating expenses for systems within the United States, although this is speculative without actual experience.

System performance for all four modes of primary service motor bus operation may be defined in terms of three critical characteristics: speed, headway, and capacity. These factors are important determinants of the level of public acceptance and patronage of a new primary transit system. Motor buses designed for urban transit operations generally have maximum attainable vehicle speeds of 50 to 55 miles per hour (mph). Vehicles equipped with an optional eight-cylinder diesel engine, instead of the six-cylinder diesel engine, have maximum speeds of about 70 mph.

Operating speeds for motor buses in primary level transit service are dependent upon posted speed limits. Generally, such operating speeds are limited to 55 mph in free-flow traffic on freeways, to 55 mph on normal flow freeway lanes, and to 35 to 40 mph on contraflow freeway lanes. Design speeds for exclusive busways generally range from 50 to 70 mph. Typical operating speeds for arterial street operations range from 30 to 45 mph, but are only 25 to 30 mph in downtown areas. Bus streets in downtown areas should have a maximum speed limit of about 20 to 25 mph because of the pedestrian movement.

Average speeds for motor bus transit systems are dependent upon the performance characteristics of the vehicle, station or stop frequency, dwell time at stops, waiting time at traffic signals, and the extent of priority afforded over mixed traffic during peak periods. Average speeds generally range from 5 to 10 mph in central business district (CBD) areas, 10 to 20 mph on arterial streets outside the CBD, 40 to 50 mph in reserved lanes on freeways and on exclusive busways, and approximately 20 to 40 mph in mixed traffic on freeways. The average speeds of buses operating in mixed traffic on freeways can be increased through the implementation of entrance ramp metering systems. Such increases, however, may be accompanied by an increase in traffic, and a reduction in operating speeds, on paralleling arterial surface streets, as a result of the division of traffic from the freeways.

Vehicle headways are dependent upon the desired level of service and the manner in which schedules are designed by the local transit operator. Minimum theoretical headways as short as 2.5 seconds between vehicles have been reported under test track conditions, although headways of between 10 and 30 seconds are more representative of actual high-demand conditions. Such traffic densities usually occur only during weekday peak periods.

The maximum passenger-carrying capacity of any motor bus transit system is dependent upon vehicle capacity, vehicle configuration, and headway. Express bus modes that predominantly utilize arterial street rights-of-way can generally meet peak demands of from 2,000 to 8,000 passengers. Express bus modes that predominantly utilize freeway or exclusive rights-of-way are able to meet demands ranging from 4,000 to 12,000 passengers per hour. These capacity considerations are applicable only in a line-haul context. Should station stops be required of most vehicles along a designated priority facility, station or bus stop design may become the most critical factor, since bus queues may form outside station areas if there is an insufficient number of bus berths available.

Capital costs are those investments required to acquire and construct the physical facilities necessary for the operation and maintenance of a bus transit system. Capital costs thus include the costs of acquiring right-of-way and vehicles; the costs of constructing or modifying specific guideway segments, stations and boarding facilities, signals and communication equipment, and maintenance and storage facilities; agency costs; and contingencies.

Two-lane exclusive busway facilities typically range in cost from $1.4 million per mile for an at-grade facility with no grade separation to about $22 million per mile for an alignment in a retained cut through a high-density urbanized area. Surface guideways elevated on an embankment or structure will typically cost from $4.0 million to $11.0 million per mile. Station costs for exclusive busway facilities range from $0.02 million to $4.2 million per facility, depending upon the location and design.

Typical implementation costs for reserved lane operation on freeways and on arterial streets vary considerably, the major factors being the project length and the extent to which sophisticated lane control equipment is used. Reserved freeway lanes will cost between $12,000 and $35,000 per mile for the basic lane separation and attendant signing. Based on actual project experience within the United States, contraflow freeway lanes range in cost from $9,000 to $109,000 per mile in 1978 dollars, with $54,000 being typical. The implementation of a normal flow lane within an existing freeway may require the construction of an additional lane, costing between $0.5 million and $1.1 million per mile for at-grade applications.

Arterial street reserved lane implementation costs will also depend upon project location—that is, on whether the facility is within or outside the central business district. A normal flow reserved curb lane may be expected to cost between $4,000 and $110,000 per mile, and a contraflow reserved curb lane, between $5,000 and $140,000 per mile. A reserved median lane may cost from $20,000 to $210,000 per mile, the higher costs representing reversible lane treatments. Finally, exclusive bus malls or bus streets will cost between $0.7 million and $2.7 million per mile, the cost being contingent upon the extent of modification to the existing street.

The implementation of motor bus primary transit services also requires the consideration of appropriate support items, such as maintenance and storage facilities, stations or shelters, and ramp or traffic signal priority treatments. Initial costs can be minimized because of the wide utilization of existing rights-of-way, guideways, and storage/shop facilities for motor bus service. However, the initial cost of exclusive busway systems can be expected to be much higher than that of the other systems discussed, since a significant amount of new facility construction will be required. In addition, initial investment requirements for exclusive busways increase substantially when the guideway is located on other than at-grade alignments.

Operating costs for motor bus primary transit service consist of the daily costs of normal bus fleet operations and the costs associated with the routine operation of the various bus priority facilities, such as exclusive busways and reserved lanes. Daily costs include transportation expenses, maintenance and garage expenses, administrative costs and general expenses, operating taxes and licenses, and miscellaneous costs. Typical daily operating expenses range from $0.69 per vehicle mile per year to $4.61 per vehicle mile per year. For a service area of 750,000 to 2.50 million people—which would be representative of the Milwaukee urbanized area—annual per mile vehicle costs may be expected to range between $1.42 and $2.61.

The costs associated with the annual routine operation of bus facilities will range from $3,300 per lane mile for exclusive busway maintenance to over $130,000 per lane mile for reserved arterial and freeway lanes with sophisticated lane control signals. Typical values are $4,300 per lane mile per year for arterial street reserved lane operation and $35,000 per lane mile per year for reserved freeway lane operation.

The energy requirements of motor bus technology include not only the energy needed to propel vehicles, but also the energy needed to operate stations and maintain vehicles and system facilities, and the energy needed to construct the system and manufacture the vehicles.

Vehicle propulsion energy requirements constitute the majority of energy consumed and account for most of the variation in the overall energy utilization of motor bus transit systems. The propulsion energy requirements of bus transit systems, based on the experience of transit operators in the United States, were estimated to range from 25,700 to 34,000 BTU's per vehicle mile. In the Milwaukee area, it has been estimated that the General Motors "new look" vehicles in local service can attain propulsion energy efficiencies approaching 30,900 BTU's per vehicle mile. Newer advanced-design buses, such as the GM RTS buses, are less fuel efficient in propulsion than are older vehicles, which comprise the majority of the transit fleet, requiring about 40,000 BTU's per vehicle mile. Articulated buses recently tested in the Milwaukee area represent a potentially attractive high-capacity vehicle, permitting operation with 42 percent more seats than the advanced design bus while consuming only 14 percent more fuel. It has been estimated that vehicles used by the Milwaukee County Transit System can attain 25 percent greater propulsion energy efficiencies in Freeway Flyer service than in local service.

Energy used to maintain vehicles and stations typically constitutes from 10 to 20 percent of the propulsion energy per vehicle mile. Motor bus maintenance energy needs range between 900 and about 1,300 BTU's per vehicle mile. Station energy needs vary from nothing for stations consisting of only small paved areas marked with appropriate signing to 4,000 BTU's per vehicle mile for larger station facilities. The energy used to construct busways is estimated at 34 billion BTU's per dual-guideway mile for at-grade sections and 153 billion BTU's per guideway mile for elevated sections. Finally, the energy required to manufacture a standard urban bus is estimated to approximate 1,020 million BTU's per vehicle.

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Chapter III

RAIL TRANSIT TECHNOLOGY

INTRODUCTION

Rail transit technology is represented by a series of individual and distinct fixed guideway modes, each of which is defined by different technical, economic, and performance characteristics. On this basis, rail transit may be classified into four specific modes: street railway, light rail transit, heavy rail rapid transit, and commuter rail. These modes, arranged in the preceding order, relate to an increasing level of service, increasing capacity, and increasing capital cost (see Figure 68). Accordingly, each mode will function best when fulfilling a specific level of travel demand.

Figure 68

RELATIONSHIP OF RAIL TRANSIT MODES TO EACH OTHER

Street Railway / Light Rail Transit		Heavy Rail Rapid Transit / Commuter Rail
Extensive ←	Network Coverage	→ Minimal
Low ←	Theoretical Capacity	→ High
High ←	Operating Cost Per Passenger	→ Low
Low ←	Station Dwell Times	→ High
Short ←	Average Trip Lengths	→ Long
Frequent ←	Station Spacing	→ Infrequent
Low ←	Passenger Comfort	→ High
Greatest ←	Frequency	→ Least
Low ←	Average Speed	→ High

Source: SEWRPC.

Three of these rail transit modes—light rail transit, heavy rail rapid transit, and commuter rail—are further described in this chapter, and the pertinent characteristics of these modes necessary for planning at a systems level are presented. The fourth mode—the street railway—is briefly described for comparative purposes only.

The street railway is at the low end of the spectrum of rail transit modes. Although this mode is no longer considered to be suitable for primary transit service application, being largely obsolete, mention of this mode is made herein to illustrate the complete range of rail transit modes, as well as the differences and similarities between this mode and the light rail transit mode.

The street railway mode serves the same function as does the motor bus in typical urban transit service, that being collection and distribution and some express service, and generally serves short- to medium-length trips within an urbanized area that is served by a full complement of modes. Stops are very frequent—about every two city blocks—and are usually located at street corners. Normal operating speeds are low, between 10 and 25 miles per hour (mph) when operating under capacity and between 5 and 13 mph when operating at capacity. Service is typically provided by single four-axle electric vehicles, sometimes pulling unpowered trailers, operating in mixed traffic on city streets. Loading is at street level with on-board fare payment. Capacity will range between 4,000 and 15,000 persons per hour. Operation in mixed traffic severely hinders the speed and reliability of street railways, a major factor that has contributed to the mode's diminishing role in urban transit operations in the United States. Nevertheless, street railway facilities—also known as streetcars, trams, and trolleys—are still utilized in many of the world's urbanized areas.

The following three sections of this chapter describe each of the rail transit modes considered applicable for the provision of primary transit service in the Milwaukee area. A critical distinction is the difference between the street railway and light rail transit modes. Although some of the technology—such as vehicle design—may be similar, or even identical, for the two modes, it is important to recognize that each mode possesses its own set of performance characteristics. Indeed, a light rail transit system is considered to offer a higher level of service than that offered by a street railway system because vehicle operation is performed over a greater proportion of the total system on reserved or exclusive rights-of-way—which may be either grade-separated or at-grade—instead of over rights-of-way shared with motor vehicle traffic.

LIGHT RAIL TRANSIT

Description

Light rail transit offers a lower level of service than does heavy rail rapid transit and commuter rail, but a higher level of service than that offered by the street railway mode. This mode is designed to fulfill capacity requirements above those possible with street railways or motor buses operating in mixed traffic, but below those required for heavy rail rapid transit. Because this mode operates at intermediate speeds relative to other modes, it has potential for use in corridors with requirements greater than those attainable by bus, but less than those required for heavy-rail rapid transit.

A major advantage of light rail transit is its wide variety of implementation and operational options. Like the street railway or surface bus mode, light rail transit can operate on surface streets, but it can also operate on a grade-separated alignment. Because of the absence of a need for full grade separation, the capital investment required for this mode is considerably lower than that required for a heavy rail rapid transit system. The key factor that allows light rail transit systems to provide a level of service approaching that offered by heavy rail rapid transit systems without the comparatively high capital investment is its ability to limit the separation of light rail vehicles from other surface traffic to highly congested areas and to locations where such separation is otherwise cost-effective. This is accomplished through utilization of a wide variety of alignment options.

Light rail transit permits a mix of routings, including operation on city streets in mixed traffic; on city streets over reserved lanes; in the median or along the side of surface streets; in the medians of freeways and expressways; through special activity centers including pedestrian malls; over rights-of-way shared with trunkline railways, other transit lines, or utilities; through parks and other open areas; and in subways or on elevated structures. Potential conflicts with vehicular traffic can be lessened or eliminated through application of traffic engineering measures and preferential treatment of the transit vehicles. Traffic engineering measures in this context refers to the use of lane markings and striping, signing, and lane channelization to reduce conflicts between modes. Preferential treatment refers to the redesigning of traffic signal cycles to incorporate special phases or traffic signal preemption provisions for light rail transit movements. Grade separation, such as underpasses and overpasses, and subway and elevated structures are options for congested areas such as activity centers and complex highway intersections. The degree of separation provided between the light rail transit vehicles and other motor vehicle, rail, and pedestrian traffic will determine the overall speed and level of service provided by the system. The amount and types of grade separation required will also determine the cost of the system.

Light rail vehicles are lightweight, electrically powered vehicles similar to streetcars, although current production models incorporate more recent technology with regard to control, performance, braking, ride quality, interior design, and safety. The most common light rail vehicle configurations are two- and three-unit articulated vehicles. Articulation allows the vehicle to "bend" on curves through use of a hinged joint over one or more sets of wheels. Most, but not all, recent vintage light rail vehicles are equipped for double-ended control and can be coupled into trains that are operated by one person.

Light rail stations are an important economic benefit of light rail transit systems. Light rail vehicles can be boarded and alighted both from street pavements or other ground-level areas or from high-level loading platforms. Although more elaborate station facilities may be employed at major terminals and transfer points, the majority of stops consist only of a simple loading area with a small shelter and appropriate signing. Because light rail transit generally utilizes an overhead contact wire system for electrical current distribution instead of a ground-level third rail, elaborate fencing and barriers to protect pedestrians from coming into contact with the power supply are not required.

Light rail transit is quite flexible in terms of signalization. Major interlocking and block signal installations are not necessary except in selected critical areas. Most light rail transit operations are able to minimize signalization of any kind and operate trains under visual sight rules. Preemptive traffic signal treatments can be provided to give light rail preference at major street intersections and other points of cross-traffic conflict.

Fare collection systems can also be adapted to individual system needs. Light rail transit relies generally on a less intensive system than does heavy rail rapid transit. Fares are normally collected on board the vehicles by the operator, eliminating the need for elaborate station facilities with ticket booths and turnstiles. A simpler method that is practiced in many European countries, especially West Germany, is self-service fare collection. Passengers are trusted to purchase tickets or passes from central offices or machines located at stations. Passengers cancel their own tickets on board, with random enforcement by a roving team of ticket checkers who sample the ridership and are empowered to levy fines.

Support requirements for light rail transit include vehicle storage facilities, vehicle maintenance facilities, guideway and station maintenance equipment and storage facilities, and the power supply system. Storage and maintenance facilities include the appropriate shops and equipment and material storage yards for vehicle, track, signal, and station maintenance. The extent of these facilities is dependent upon the particular system design. As already noted, the power supply for light rail transit is provided by an overhead contact wire system. Necessary auxiliary apparatus includes line substations and, more frequently, transformer/rectifier substations. Specialized equipment and maintenance crews are required for the track and power supply and distribution systems.

Definition

Light rail transit is widely accepted and popularly defined as a mode that utilizes predominantly reserved, but not necessarily grade-separated, rights-of-way. Its electrically propelled rail vehicles operate singly or in trains. Power supply is from an overhead wire and fare collection is on board the vehicle. Access to vehicles may be from ground level or from high-level platforms. Light rail transit provides a wide range of passenger capacities and performance characteristics at moderate costs.

For a primary transit system or facility to be considered a light rail transit system, most of the following conditions must be met:

1. Comparatively lightweight single or dual directional rolling stock is used.

2. There is overhead electric power distribution.

3. Rights-of-way are used jointly with other modes.

4. There is minimal application of grade separation.

5. There is low- or dual-level loading at stations or stops.

6. Fares are collected on-board, or a self-service system is used.

7. There is single-vehicle operation during off-peak periods, train operation during peak periods.

A major advantage of light rail transit is the variety of alignment options that are available for the guideway facilities. Therefore, depending upon the design of the system, and especially upon the degree to which route segments are reserved from or shared with other traffic, the system may approach at one extreme the characteristics of a street railway system, and at the other extreme the characteristics of a heavy rail rapid transit system. Some light rail transit systems which make particularly extensive use of grade-separated rights-of-way are described as "light rail rapid transit" systems.

There is a tendency to confuse light rail transit and streetcar operation because of the similarity between vehicles and certain route alignment features. These two modes are, however, different, with the major and probably most important distinction being that light rail transit is normally separated from and has priority over other traffic in congested areas. Although some light rail transit components may resemble street railway components, the level of service provided by light rail transit much more closely approaches that of heavy rail rapid transit. Indeed, the evolution of light rail transit into a mode separate and distinct from the street railway mode and from heavy rail rapid transit was one of the reasons for undertaking the Milwaukee area alternatives analysis.

Because of light rail's recent evolution into a separate mode and the wide variety of applications that it has been proposed for and used in, several other terms are sometimes used to denote the same mode. Although the term "light rail transit" or "LRT" has become the most commonly accepted term for this mode, others include semi-metro, limited tramway, subway-surface lines, stadtbahn, and light rapid transit.

Attributes

Light rail transit possesses several important attributes that require consideration in system planning and that are considered to be advantages over other primary transit modes. Inasmuch as the initial capital cost of fixed guideway systems is becoming an increasingly significant factor in public decision-making, light rail transit offers significant capital and operating cost savings as reflected in these items:

1. Light rail vehicles can be operated in trains with total passenger capacities of up to 1,000, producing a potential passenger-to-operator ratio of up to seven times that of buses. This has a significant impact on labor costs, the largest operating expense of most bus-operated transit systems. Because of this ability, multiple-unit vehicle capacity can be readily adjusted to meet various ridership demands and route headways, and the size of the required transit operating staff can be held to a relatively low, stable level.

2. Because of the wide variety of surface alignment options available, light rail transit systems need not involve the high capital costs of tunneling, elevated structures, and grade separation required for heavy rail rapid transit facilities. Moreover, criteria for grades and curvature and horizontal and vertical alignment of the facilities are much less restrictive than for heavy rail systems.

3. Because of the lower capital costs of not only the guideway but also the stations and support facilities, and because of the lower operating costs, a light rail transit network can be made denser than an equivalent heavy rail network and still provide a level of service close to that offered by heavy rail rapid transit.

4. Because a light rail transit system can be operated in mixed traffic on surface streets as well as over exclusive rights-of-way, access to certain high-density urban activity centers can be provided at a lower cost with such systems than with heavy rail rapid transit systems and light right transit systems can be constructed more quickly than can heavy rail transit systems.

5. Light rail vehicles utilize electric propulsion, and are thus not dependent on petroleum-based fuels.

6. Light rail transit systems can be more readily developed on an incremental basis to meet the needs of the urbanized area as those needs develop and are recognized, or as resources become available. An idea popular in certain Western European countries, especially West Germany, is to develop heavy rail rapid transit systems by utilizing light rail transit in an incremental, evolutionary manner, minimizing the immediate acquisition of costly right-of-way and construction of subway or elevated segments and staging future upgrading and development as the need develops. Light rail facilities can be installed in reserved lanes on city streets until increased ridership justifies a more exclusive alignment. Many route segment staging opportunities are available because of the easy implementation of surface alignments and the ready availability of rights-of-way.

7. All components and materials required for construction of light rail transit are proven and, therefore, readily available. Accordingly, system implementation time can be minimized.

Generic Application of Light Rail Transit

Light rail transit is the newest of all the conventional rail transit modes. Development of this mode was concentrated during the 1950's in Western Europe as many street railway facilities were upgraded either in whole or in part to light rail status. In such instances, light rail transit was generally designed to provide the basic skeletal network of public transit routes. Refinement of the mode occurred during the 1960's and 1970's as more upgrading took place, as did the conversion of some light rail facilities to heavy rail facilities. A light rail transit system used as an interim mode for staging full-scale rapid transit construction is known as a "pre-metro" system and is a significant attribute of the mode as cited above.

During the 1950's and 1960's light rail development was predominantly centered in the countries of West Germany, the Netherlands, Belgium, Sweden, Switzerland, and Austria, all of which pursued a policy of highway and transit improvement following World War II. During the late 1960's and early 1970's, urbanized areas in other countries took an active interest in maintaining and improving ridership trends and transit attitudes. More specifically, metropolitan areas in Canada, France, Great Britain, and Japan have either upgraded existing street railway systems or constructed new light rail systems to meet local primary transit demands. Finally, in the late 1970's, some metropolitan areas in the United States either upgraded existing street railway systems or constructed new light rail systems.

Because of its inherent design flexibility, light rail transit is able to function in a variety of public transit roles. The most common role is that of the basic or primary transit mode in medium and large urban areas. Typical networks in such areas consist of routes that branch out to outlying areas; thus, the mode provides its own feeder service. In some urban areas the light rail transit role of primary transit carrier is shared with surface motor buses and/or heavy rail rapid transit. In some lower-density, medium-size and smaller urban areas, light rail transit complements the basic surface bus network by providing service in a single heavily traveled corridor. This type of application is also common in areas that are in the initial stage of fixed guideway development. Light rail may also perform a feeder function to heavy rail or commuter rail facilities.

Light rail transit systems may also be used to provide shuttle or collector/distribution service at major activity centers and tourist attractions. However, light rail systems used to provide these services cannot be considered primary transit systems in a strict sense because of their specialized nature.

One remaining aspect that should be noted is the ability of light rail facilities to provide some local freight movement, provided standard gauge trackage is used. Although the mixing of passenger transit operation and carload freight movement is generally not desirable, provision for such mixed service can be made if the best or only alignment for a light rail transit facility is along an existing freight-only industrial spur or light-density branch line, where railway freight service must continue to be provided.

Geographic Extent of Light Rail Transit

Over 300 light rail transit and street railway systems are in operation throughout the world. The exact number of true light rail transit systems is difficult to determine since most inventories of these two modes are aggregated. It should be recognized, therefore, that probably half of this total consists of surface rail networks that operate either entirely or at least significantly in the street railway mode.

The majority of true light rail transit systems are presently concentrated in several Western European countries. West Germany, considered to be the showcase for the various configurations and stages of light rail transit development, perhaps has the largest number of systems—about 46—for a country its size. Light rail transit forms the basic transit network in the large urbanized areas of several other Western European countries, including Austria, Belgium, the Netherlands, and Switzerland. Eastern European countries rely even more heavily on light rail transit, as well as conventional street railway systems. More than 100 such systems are in operation in the U.S.S.R., and another 70 are in use in nearby Eastern European countries.

Two principal approaches to the application of light rail transit technology are taken on the European continent. One is the low-cost, low-impact approach—primarily employing traffic control measures to facilitate preferential treatment of transit—common to Dutch, Swiss, Swedish, and smaller West German systems. The high-investment, high-impact approach utilizes significant subway and grade-separation construction and is being pursued by some Belgium and West German systems. A trend appears to be emerging in Europe, however, for more extensive application of the low-impact, and therefore lower-cost, approach.

The majority of existing light rail transit systems in North America have grown out of street railway systems that have survived for a variety of reasons, an important one being extensive use of reserved right-of-way, critical to any light rail transit operation. Like most systems in Western Europe, most systems in North America are engaged in improvement and upgrading programs. In the United States and Canada, the urbanized areas of Boston, Cleveland, Edmonton, Newark, Philadelphia, Pittsburgh, and San Francisco have light rail transit systems currently in operation. A listing of these systems, together with certain characteristics of the systems, is provided in Table 36 and illustrated in Figures 69 through 75. Of particular interest is the newly opened line in Edmonton, the first light rail transit facility to be opened in North America since 1959. It should be noted that there are other systems in operation in North America that are sometimes identified as light rail transit systems, including those in Fort Worth, New Orleans, Philadelphia, and Toronto. However, since the alignment, equipment, location of stops, and overall speed for each of these systems are characteristic of either a predominantly street railway operation or a highly

Table 36

EXISTING LIGHT RAIL TRANSIT OPERATIONS IN THE UNITED STATES AND CANADA: 1980

Characteristic	Boston— Green Line	Boston— Manhattan-Ashmont Line	Cleveland— Shaker Division	Edmonton— North East Line	Newark City Subway	Philadelphia— Norristown High Speed Line	Philadelphia— Media-Sharon Hills Lines	Pittsburgh— South Hills Corridor	San Francisco— Muni Metro Lines
Operating Authority	Massachusetts Bay Transportation Authority	Massachusetts Bay Transportation Authority	Greater Cleveland Rapid Transit Authority	Edmonton Transit System	Transport of New Jersey	Southeastern Pennsylvania Transportation Authority/Red Arrow Division	Southeastern Pennsylvania Transportation Authority/Red Arrow Division	Port Authority of Allegheny County	San Francisco Municipal Railway
Number of Routes	4	1	2	1	1	1	2	4	5
Length of Route (miles)	33	3	19	4.5	4	14	14	45	72
Average Speed (mph)	12.4	12	23	18.6	20	31	14-17	13.7	9.5
Number of Revenue Service Vehicles	276	15	61	14	28	21	32	95	126
Type of Vehicles	PCC	PCC	PCC	U2	PCC	Brill Bullet	Brilliners	PCC	PCC
Annual Passengers Carried	41,000,000	3,900,000	4,720,000	1,800,000 (estimate)	2,450,000	2,750,000	4,000,000	7,000,000	10,000,000
Service Area Population[a]	282,000	N/A	91,000	128,000 (estimate)	47,000	66,000	110,000	157,000	275,000
Urbanized Area Population	641,000	Not applicable[e]	751,000	451,000	382,000[f]	Not applicable[e]	Not applicable[e]	520,000	716,000
Grade-Separated Operation[b] (percent)	55	99	53	22	99	100	--	3	17
Reserved Operation[c] (percent)	35	--	47	78	--	--	87	73	20
Mixed Traffic Operation (percent)	10	--	--	--	--	--	13	24	63
Average Stop Spacing (miles)	0.58	0.60	0.76	0.90	0.68	1.05	0.42	0.37	0.23
Daily Passengers Carried	151,000	14,000	18,500	18,000	12,000	10,000	14,000	24,000	35,000
Operating Cost[d] (per vehicle mile)	$11.16	$10.55	$2.90	$7.10	$2.86	$4.04	$4.04	N/A	N/A

NOTE: N/A indicates data not available.

[a] Based on census tracts served.

[b] Subway, elevated, and surface.

[c] Private rights-of-way, medians, or reserved lanes.

[d] Operating costs for 1976 through 1979 updated to 1979 dollars.

[e] Light rail line does not serve central city.

[f] Central city population.

Source: Modern Railroads, Rail Transit Magazine and SEWRPC.

specialized type of operation, these systems are not recognized herein as true light rail transit systems.

Several light rail transit systems are currently under development in North America. In addition, the mode appears to be a likely choice in a select group of cities currently completing an evaluation of primary transit alternatives. Table 37 briefly summarizes the status of these development efforts in Buffalo, Calgary, Portland, St. Louis, San Diego, San Jose, and Toronto.

Potential Application in Southeastern Wisconsin

The nature of light rail permits the mode to be applied in a wide variety of locations and alignments. Since there is no current application of this mode within the Southeastern Wisconsin Region (see Figure 76), location of a facility would not be constrained by extensions or refinements to an existing network. In addition to new exclusive right-of-ways, alignment options include boulevards and other wide streets, medians of proposed freeways, active and abandoned railway rights-of-way, and utility rights-of-way. Map 6 displays the extent of these possible light rail transit alignments within the Milwaukee urbanized area.

HEAVY RAIL RAPID TRANSIT

Description

Heavy rail rapid transit offers a higher level of service than does light rail transit, but a lower level of service than that offered by the commuter rail mode. This mode is designed to meet the highest demand requirements that may exist in corridors of high travel demand. Heavy rail rapid transit comprises the basic framework of most multimode transit networks in the largest urban areas, and is normally found in the most heavily traveled corridors of such areas. Average operating speeds and frequency of service throughout the day are relatively high. This mode is typically used for the line-haul portion of the longer home-to-work commuting trips in an urban area.

There are two distinct versions of heavy rail rapid transit: conventional heavy rail and modern heavy rail. Conventional heavy rail rapid transit is the more common of the two versions and is typified by the classic subway or elevated railway. Such systems were constructed in the United States from the 1890's through the 1920's and closely followed standard railway engineering practices of the

Figure 69

MASSACHUSETTS BAY TRANSPORTATION AUTHORITY—GREEN LINE

Boston's light rail transit system consists of five routes operating over 36 route miles of trackage. The various alignments utilize almost every type of guideway configuration, including operation in subway, on elevated structure, over exclusive right-of-way both at-grade and grade-separated, over former railroad rights-of-way, and in median areas of public streets, as well as in mixed traffic. As of mid-1980, the entire light rail system was in the process of undergoing rehabilitation of the trackage and power supply system, and new vehicles were being acquired. This view shows a train of Boeing-Vertol light rail vehicles at the Reservoir Station on the Riverside branch of the Green Line.

Photo by Otto P. Dobnick.

Figure 70

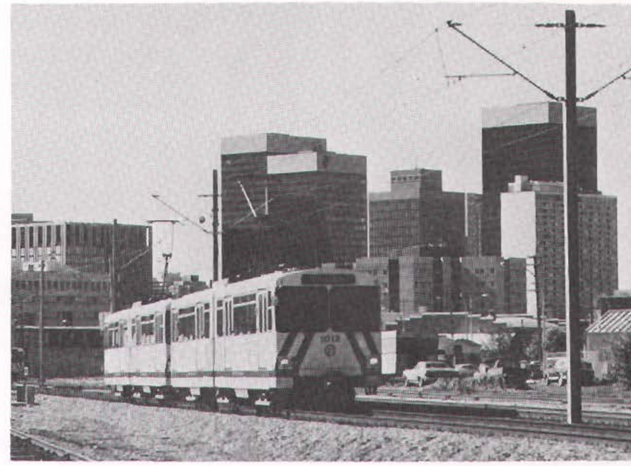
GREATER CLEVELAND REGIONAL TRANSIT AUTHORITY—SHAKER DIVISION

Cleveland's light rail transit system consists of two routes operating over 19 route miles of trackage extending from the former downtown intercity railway station in Cleveland to the suburb of Shaker Heights. As of mid-1980, the right-of-way, trackage, and power supply of the system were undergoing major improvements. Also, new vehicles were on order to replace the aging fleet of PCC streetcars. The two routes make extensive use of boulevard medians, which necessitates the crossing of many streets at-grade—as illustrated in this view at Shaker Square, the junction of the two routes.

Photo by Otto P. Dobnick.

Figure 71

EDMONTON TRANSIT SYSTEM—NORTHEAST LINE



Edmonton's 4.5-mile-long light rail transit line was the first such facility to be constructed in North America in more than 20 years. Constructed in what is considered by many to be record time for a major public works improvement—about four years—the transit line utilizes a subway in the downtown area and is located adjacent to a railway main line northeast of the downtown area. The line is in the process of being extended, and a second route in Edmonton has been approved for development by local officials.

Photo by Russell E. Schultz.

Figure 72

TRANSPORT OF NEW JERSEY—NEWARK CITY SUBWAY

The Newark City Subway is a single route about four miles in length which extends in a northerly direction from the former Pennsylvania Railroad station in downtown Newark. Acting primarily as a feeder to commuter rail and heavy rail rapid transit trains into the City of New York, this light rail transit line is all that remains of a once extensive street railway system. Upon exiting from the subway, the right-of-way is located in a grade-separated cut originally constructed for a canal. This view shows one of the system's PCC streetcars at a station adjacent to the route's only at-grade crossing of a public street.

Photo by Otto P. Dobnick.

Figure 73

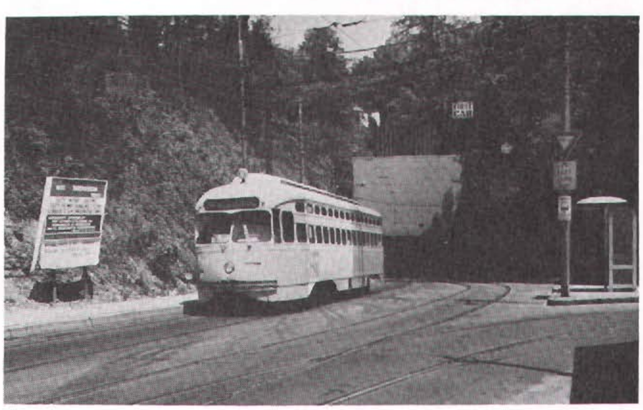
SEPTA RED ARROW DIVISION–MEDIA AND SHARON HILL LINES

The Southeastern Pennsylvania Transportation Authority (SEPTA) operates three light rail transit routes in the Philadelphia area as an integral part of an extensive system of heavy rail rapid transit, commuter rail, electric trolley bus, and street railway facilities. Two of the light rail routes make extensive use of exclusive right-of-way and side-of-the-road operation. The Media Line terminates at the end of approximately one mile of mixed traffic operation, as shown in this view. The third light rail transit line is a high-speed route to Norristown which, unlike the two other light rail transit routes that are wide gauge with an overhead power distribution system, is standard gauge and receives power from a third rail. All three light rail transit routes act as feeders to heavy rail rapid transit lines, connecting at the 69th Street terminal with a heavy rail rapid transit line into downtown Philadelphia.

Photo by Otto P. Dobnick.

Figure 74

PORT AUTHORITY OF ALLEGHENY COUNTY–SOUTH HILLS CORRIDOR



Following many years of controversy surrounding the replacement of Pittsburgh's remaining streetcar lines with an automated guideway transit system known as "Skybus," the existing street railway system in Pittsburgh's South Hills corridor is being upgraded to light rail transit status. In addition to track, power supply, and vehicle replacement, this extensive program includes some route relocation. There are currently four light rail transit routes serving the Pittsburgh area. These operate over a total of 45 route miles of trackage, most of which is located on a reserved or exclusive right-of-way, including a 3,500-foot-long tunnel under Mt. Washington between downtown Pittsburgh and South Hills junction.

Photo by Thomas A. Matola.

Figure 75

SAN FRANCISCO MUNICIPAL RAILWAY–MUNI METRO LINES

As of 1980, work was nearing completion on the conversion of the San Francisco street railway system to a light rail transit system. The system, which includes five routes operating over 72 route miles of trackage, was undergoing a major program of right-of-way upgrading, track and power supply system rehabilitation, and vehicle replacement. The rehabilitated system will use new Boeing-Vertol articulated light rail vehicles to provide fast and efficient service within the City of San Francisco. The guideway has been constructed in a wide variety of configurations which not only include extensive reserved lane operation, as shown in this view, but also operation in mixed traffic, over exclusive rights-of-way, through two existing tunnels, and through the newly constructed Market Street subway.

Photo by Russell E. Schultz.

period. Modern heavy rail refers to newer systems built since the mid-1960's. The rolling stock, guideways and other facilities of modern heavy rail do not follow standard mainline railway practice as much as do conventional systems. Since conventional heavy rail rapid transit technology is applicable only to existing systems, further discussion of this mode herein pertains only to modern, "state-of-the-art" applications.

Heavy rail rolling stock generally is similar to standard railway passenger equipment in length, width, and capacity. Electric propulsion is universal, with current distribution provided by an outside-mounted third rail. A typical vehicle configuration consists of two cars semi-permanently coupled into a pair. A control cab is located at the outside end of each car, creating bi-directional units. Trains commonly are made up of one or two pairs of cars during nonpeak travel hours, but up to five pairs during peak travel periods. A pair of such cars is significantly longer than an articulated light rail vehicle, thus achieving the highest capacity per unit of all rail transit systems.

As a practical matter, heavy rail rapid transit requires an exclusive, fully grade-separated right-

Table 37

PROPOSED LIGHT RAIL TRANSIT OPERATIONS IN THE UNITED STATES AND CANADA: 1980

Characteristic	Buffalo	Calgary	Portland	San Diego	San Jose	Toronto
Operating Authority	Niagara Frontier Transportation Authority	City of Calgary Transportation Department	Tri-Met Metropolitan Transportation District	Metropolitan Transit Development Board	N/A	Toronto Transit Commission
Number of Routes	1	1	1	1	1	1
Length of Route (miles)	6.4	8.1	14.4	15.9	12-14	4.4
Number of Revenue Service Vehicles	30	27	26	14	25-30	Not determined
Type of Vehicles	Not determined	U2	Not determined	U2	N/A	CLRV
Estimated Annual Passengers Carried	55,200,000[a]	Unknown	19,200,000[b]	Unknown	Unknown	6,000,000
Central City Population	463,000	470,000	383,000	697,000	446,000	Not applicable[c]
Grade-Separated Operation (percent)	81	8	N/A	- -	- -	N/A
Reserved Operation (percent)	19	91	N/A	100	N/A	N/A
Mixed Traffic Operation	None	None	None	100	N/A	N/A
Estimated Start of Operation	1984	1981	1985	1981	1986	1982
Project Status	Under construction	Under construction	Construction to begin during 1981	Under construction	Alternatives analysis phase II in progress	Construction to begin during 1980
Estimated Daily Passengers Carried	92,000[a]	N/A	53,000[b]	28,000[a]	25,000	N/A

NOTE: N/A indicates data not available.

[a] *1995 patronage estimate.*

[b] *1990 patronage estimate.*

[c] *Proposed light rail line does not serve central city.*

Source: Modern Railroads Rail Transit Magazine, American Public Transit Association, and SEWRPC.

of-way for operation. Because current collection is from an exposed third rail located at track level, heavy rail alignments must generally be grade-separated or fenced off along the entire length of surface operation. Grade separations generally must be provided at all street crossings. Conventional systems tend to be located either in subways or on elevated structures, and aligned along major streets, alleys, and railroad rights-of-way. Extensions of conventional systems through less intensively developed areas are often on new grade-separated locations not necessarily related to existing street or railroad locations. Freeway medians have also been used to achieve an exclusive, fully grade-separated right-of-way.

Stations for modern heavy rail systems are relatively elaborate facilities. Stations include high-level boarding platforms, necessary means of access to the platforms, fare collection facilities—since fares are usually collected before entering the platforms, and facilities for interface with other transit services. In many instances, a large area is provided for an attendant park-ride lot. Regardless of whether the heavy rail route is located in a subway or on an elevated structure, two-level stations are typical. One level consists of the actual station platforms and the second level consists of a concourse situated between the platform and street levels where fares are collected. Often, direct access between stations and various urban activity centers is provided.

Signalization systems are regarded as necessary for heavy rail operation because of the combination of high vehicle speeds, close headways during peak periods, and limited visibility in subway segments. On conventional systems automatic wayside block signal systems are gradually being modified by the addition of cab signals with some degree of fail-safe control of train spacing. Modern heavy rail systems employ full cab signaling, integrated with nearly complete automated train control.

Overall support requirements for heavy rail rapid transit are similar to those for light rail transit. Vehicle storage and maintenance facilities, guideway and station maintenance equipment and storage facilities, and a power supply system are all required. Specialized maintenance and shop crews are also necessary to perform work on rolling stock, track and roadway, fare collection devices, and the electrical system.

Definition

Heavy rail rapid transit is a mode that utilizes electrically propelled dual-rail vehicles—usually coupled into trains—operating on a predominantly

Figure 76

FORMER ELECTRIC RAILWAY TRANSPORTATION IN THE MILWAUKEE AREA

From 1900 to 1950, the Milwaukee area was well served by a very extensive electric street railway and electric interurban railway network. The electric interurban railway lines of The Milwaukee Electric Railway and Light Company radiated out of downtown Milwaukee in four directions; west to Waukesha, Oconomowoc, and Watertown; southwest through the Muskego Lakes area to Burlington and East Troy; south to Racine and Kenosha; and north to Port Washington and Sheboygan. As shown in this view of the interurban railway line to Sheboygan taken at the W. Silver Spring Drive station on the north side of Milwaukee, the electric interurban railway system was constructed and maintained to high engineering standards.

Photo by Kurt W. Bauer.

Of the electric railway transportation modes, light rail transit bears the closest resemblance to the now-obsolete electric interurban railway. Both technologies are capable of utilizing a wide variety of guideway configurations, including operation over exclusive right-of-way, over reserved lanes, and in mixed traffic operation. Both technologies also operate with relatively short trains of one to four cars and utilize an overhead power distribution system. Interurban trains from Watertown, East Troy, and Burlington operated to and from downtown Milwaukee over the "Local Rapid Transit Line," a 7.2-mile-high-speed facility constructed to very high electric railway engineering standards, being fully grade-separated over most of its length. The Local Rapid Transit Line was double tracked over its entire length and, as shown in this view at N. 60th Street, shared the right-of-way for about one mile with a double-track street railway line.

Photo by Kurt W. Bauer.

In addition to the interurban railway lines of The Milwaukee Electric Railway and Light Company, the Milwaukee area was served by the electric interurban and attendant street railway lines of the Chicago, North Shore & Milwaukee Railway Company which, like The Milwaukee Electric Lines, required extensive operation in mixed traffic to reach its terminal in downtown Milwaukee. This view shows a two-car Chicago-bound train on S. 5th Street south of W. Lincoln Avenue. While the last of the extensive network of interurban railway lines operated by The Milwaukee Electric Lines was abandoned in 1951, the North Shore Line continued operation into 1963.

Photo by Robert L. Genack.

The North Shore Line was known throughout its history for operation of high-speed trains between Milwaukee and Chicago, with average start-to-stop speeds between some stations reaching 60 miles per hour. During the early 1940's, two streamlined articulated trains known as "Electroliners" were designed and purchased for service in response to the introduction of modern "streamliners" by the competing steam railways. Each of these two trains made two and one-half round trips between Milwaukee and Chicago per day until 1963, when the interurban railway ceased operation. This view shows a southbound Electroliner leaving S. 5th Street to begin its run over a fully grade-separated, exclusive right-of-way through southern Milwaukee County.

Photo by Robert L. Genack.

Figure 76 (continued)

The Milwaukee Electric Railway and Light Company (The Milwaukee Electric Lines and later the Transport Company) operated an extensive street railway system in the City of Milwaukee, most of the trackage of which was located in the paved area of public streets and operated in mixed traffic. As shown in this view taken at the intersection of N. Holton Street and E. Meinecke Avenue, there was sometimes little additional pavement area left for motor vehicle traffic along streets used for railway operation. The addition of local transit buses to already congested streets served to further reduce the level of service offered by the street railway routes.

Photo courtesy of the City of Milwaukee, Bureau of Traffic Engineering.

This view typifies the appearance of a street railway facility in the City of Milwaukee during the late 1930's. The double-track railway line is located along the center of an arterial street, making safety islands necessary for the safe loading and unloading of passengers at busy intersections. This view looks west at the intersection of S. 35th Street and W. National Avenue. The Route 18 line—shown in this view—was a heavily patronized transit route in Milwaukee and required the use of high-capacity, articulated streetcars during the World War II years.

Photo courtesy of the City of Milwaukee, Bureau of Traffic Engineering.

Although most street railway trackage in the Milwaukee area was located on public street rights-of-way, 10 segments, totaling about 10.1 miles in length, were situated on private right-of-way and actually operated in what would now be termed light rail transit. The left view shows a segment of the Route 10—Wells Street-West Allis Branch car line which operated over 2.5 miles of private right-of-way between N. 52nd and W. Wells Streets and S. 70th Street and W. Greenfield Avenue. About one mile of this alignment was located adjacent to the Local Rapid Transit Line and was part of the last streetcar line to be replaced with motor buses in Milwaukee during 1958. The right view shows a portion of the one-mile segment of private right-of-way between S. 87th and W. Lapham Streets and the West Junction station of the Local Rapid Transit Line. This alignment was utilized by the Route 10 and later Route 18-National Avenue streetcar lines.

Photos by Kurt W. Bauer.

Map 6

POTENTIAL LIGHT RAIL TRANSIT GUIDEWAY ALIGNMENTS IN THE MILWAUKEE AREA

The location of light rail transit alignments within existing rights-of-way can significantly reduce the cost of alternative light rail system configurations. As shown on this map, there are a variety of rights-of-way within the Milwaukee area which have the potential to accommodate a light rail guideway. These rights-of-way include abandoned electric interurban railway rights-of-way, electric power transmission line rights-of-way, freeway rights-of-way, and active and abandoned railway rights-of-way. Light rail transit alignments also have the potential to be accommodated on certain standard surface arterial streets—namely, those standard arterial streets with medians and those standard arterial two-way streets of six lanes and one-way streets of three or more lanes.

Source: SEWRPC.

exclusive and fully grade-separated right-of-way. Heavy rail rapid transit is designed to serve urban corridors having a very high travel demand.

For a primary transit system or facility to be considered a heavy rail rapid transit system, most of the following conditions must be met:

1. Comparatively heavyweight dual-directional rolling stock, often operated in semi-permanently coupled pairs, is used.

2. The system relies on third rail electric power distribution.

3. Exclusive, fully grade-separated rights-of-way are used.

4. High-level loading platforms are used.

5. Fares are collected at stations.

6. Trains of up to five pairs of cars are operated during peak periods.

7. Cab signals with some degree of automated train operation are used.

Other terms used to describe heavy rail rapid transit include heavy rail transit, rapid transit, elevated ("El" or "L") railway, subway, metro, underground, and rapid rail.

Attributes

The following attributes of heavy rail rapid transit should be considered in system planning:

1. Heavy rail vehicles can be operated in trains with passenger capacities of up to 2,700, producing a potential passenger-to-operator ratio of up to 2.7 times that of light rail transit. The training ability permits ready adjustment of vehicle capacity to demand with a relatively stable operating staff. This mode is generally able to handle capacities greater than those which can be served by other primary transit modes.

2. Because it operates on exclusive, fully grade-separated rights-of-way, heavy rail rapid transit is capable of high speeds and a high level of reliability.

3. Automated operation can be utilized to the greatest extent practicable.

4. Heavy rail is, generally, the most capital-intensive primary transit mode, requiring a major investment to produce a usable segment.

5. The development of a heavy rail rapid transit system requires a lengthy implementation period. This is particularly true of systems with significant subway segments. Heavy rail construction also entails community disruption and long periods of negative impacts.

6. Heavy rail vehicles are electrically propelled, and are thus not dependent on petroleum-based fuels.

Generic Application of Heavy Rail Rapid Transit

Since the 1900's, heavy rail rapid transit has been the basic transit mode in the largest metropolitan areas. The earliest systems were constructed entirely as either subway or elevated railways. Nine cities constructed heavy rail rapid transit systems between 1863 and 1910—four of which are in the United States—with eight begun before 1936. The numerous system starts around the turn of the century were the result of a need for some means of providing rapid public transportation in densely developed metropolitan areas, coupled with contemporary breakthroughs in railway control and electrification.

The number of new heavy rail system development programs has increased since 1950 after 15 years of stagnation. Over 70 systems are now in operation throughout the world, with 15 additional systems under construction or design. With the exception of a few of the very largest systems, heavy rail rapid transit systems are radial in configuration, focusing on the central business district. Whether such systems are complex networks or just single routes serving the most heavily traveled corridor, their principal function is always to provide primary transit service.

Geographic Extent of Heavy Rail Rapid Transit

Like light rail transit use, heavy rail transit use is concentrated mainly in Europe, where over 30 systems are in operation. The remaining systems are scattered throughout the world, with small concentrations of systems in the U.S.S.R. and the United States. As already noted, since the 1950's the pace of heavy rail rapid transit development has significantly increased, with numerous extensions of conventional systems occurring in addition to new system start-ups. During this period, heavy rail rapid transit development has spread beyond North America and Europe to Japan, South America, and a variety of "third world" countries.

Table 38

CONVENTIONAL HEAVY RAIL RAPID TRANSIT SYSTEMS IN THE UNITED STATES AND CANADA: 1980

Characteristic	Boston	Chicago	Cleveland	New York City		Newark	Philadelphia	Toronto
Operating Authority	Massachusetts Bay Transportation Authority	Chicago Transit Authority	Greater Cleveland Transportation Authority	New York City Transit Authority	Staten Island Rapid Transit Operating Authority	Port Authority Trans-Hudson Corporation	Southeastern Pennsylvania Transportation Authority	Toronto Transit Commission
Number of Routes	3	6	1	32	1	4	3	2
Length of Route (miles)	32.9	89.4	19.2	229.8	14.5	13.9	23.9	26.6
Number of Revenue Service Vehicles	420	1,100	115	6,559	52	297	467	594
Estimated Annual Passengers Carried	80,200,000	149,200,000	11,757,000	1,056,187,000		54,385,000	105,443,000	198,200,000
Metropolitan Area Population	2,754,000	6,979,000	2,064,000	11,572,000		2,466,000	4,818,000	2,628,000
Average Station Spacing (miles)	1.4	0.6	1.0	0.5	0.6	1.1	0.4	0.6
Daily Passengers Carried	526,300	525,000	42,000	3,370,000	18,500	149,000	335,000	700,000
Operating Cost[a] (per vehicle mile)	\$8.85	\$2.61	\$2.12	\$3.01	\$5.99	\$5.51	\$3.08	N/A

NOTE: N/A indicates data not available.

[a] *Operating costs for 1976 through 1979 updated to 1979 dollars.*

Source: Modern Railroads Rail Transit Magazine, American Public Transit Association, and SEWRPC.

In the United States and Canada, conventional heavy rail rapid transit systems are located in the urbanized areas of Boston, Chicago, Cleveland, New York City, Philadelphia, and Toronto. A list of these facilities, together with selected system characteristics, is presented in Table 38, and the systems in the Cities of Boston and Chicago are illustrated in Figures 77 and 78. All of these systems are either carrying out or have proposed renovation and expansion plans. The systems in Boston, Chicago, New York City, and Philadelphia make extensive use of elevated segments in high-density areas, a type of facility that is common only in the United States.

Existing modern heavy rail rapid transit systems are located in and around the Cities of Atlanta, Montreal, Philadelphia, San Francisco-Oakland, and Washington, D.C. A list of these facilities, together with selected system characteristics, is presented in Table 39, and the systems in the Cities of Atlanta, Philadelphia, San Francisco-Oakland, and Washington, D.C. are illustrated in Figures 79 through 82. Several new heavy rail systems are either currently under construction or are close to construction. This group is also included in Table 39 and includes the cities of Baltimore, Honolulu, and Miami. Because heavy rail requires high population and employment densities in addition to a large capital investment, few American cities that are examining alternative fixed guideway systems are considering this mode.

Potential Application in Southeastern Wisconsin

The length of heavy rail rolling stock as well as vehicle speeds prohibit any alignments with sharp horizontal or vertical curves such as are possible with light rail transit. Outside of this consideration, however, there are no nonsite specific constraints that would limit heavy rail application to certain types of rights-of-way. Heavy rail rapid transit subway alignments are limited only by the placement of other underground utilities and by subsurface geophysical conditions. Elevated segments also appear not to be significantly restricted by surface infrastructure, although there is a tendency to locate heavy rail facilities adjacent to existing freeway and railway facilities.

COMMUTER RAIL

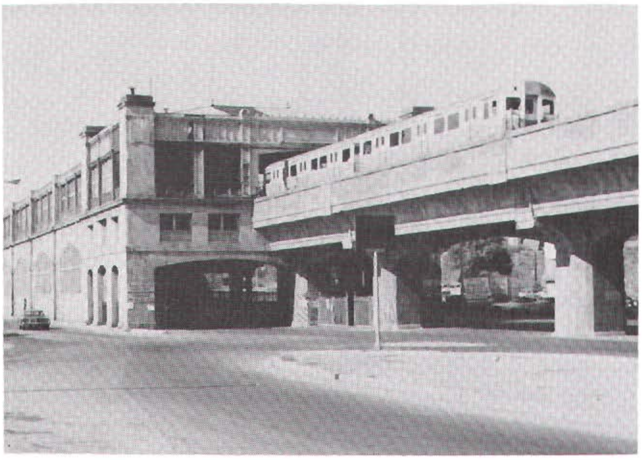
Description

At the highest quality end of the spectrum of rail transit modes is commuter rail, characterized by long average trip lengths, long distances between stations, and a high level of comfort. Trains are either electric or diesel-electric powered and are usually operated by railroad companies under contract over tracks also utilized for intercity passenger and freight service. Networks are generally radial, originating out of what is or was the intercity rail passenger station in or near the central business district. Traffic is extremely heavy during weekday rush hours.

Commuter rail utilizes the largest vehicles of all rail transit modes. Because such rolling stock shares trackage and rights-of-way with standard railway passenger and freight trains, car size and design are typical of mainline railroad requirements. While most commuter rail systems outside the United States and Canada are electrified, those within the United States and Canada rely on diesel-electric propulsion, with a few notable exceptions located

Figure 77

BOSTON–MASSACHUSETTS BAY TRANSPORTATION AUTHORITY



The Massachusetts Bay Transportation Authority operates three conventional heavy rail rapid transit routes in the Boston area totaling about 33 route miles in length. As shown in this view, terminals at the end of the older segments of Boston's heavy rail rapid transit lines are elaborate structures situated in the middle of wide street rights-of-way which were designed to facilitate transfer to local street railway and motor bus routes. This station, located at the Forest Hills terminal of Boston's Orange Line, is proposed to be replaced by an underground subway station.

Photo by Otto P. Dobnick.

Figure 78

CHICAGO–CHICAGO TRANSIT AUTHORITY

The Chicago Transit Authority operates an extensive conventional heavy rail rapid transit system. Although the system is undergoing an extensive modernization program, including vehicle replacement and traffic control system improvement, the guideway will continue to possess numerous sharp right-angle turns which restrict operating speeds and dictate the use of short vehicles. Elevated structures for conventional systems such as Chicago's were typically fabricated out of structural steel components and, while considered by some to be aesthetically unappealing as well as noisy, are considered by others to lend interesting historic character to "the loop," providing a unique and picturesque identity to downtown Chicago.

Photo courtesy of Chicago Transit Authority.

in extremely high-density corridors. The favored choice for modern commuter suburban equipment appears to be bi-level coach equipment because of the increased passenger capacity per car. However, many older systems, especially in the northeastern United States, are restricted to the use of single-level rolling stock because of limited vertical clearances.

Commuter rail fixed guideways consist of standard railroad track which is shared with intercity passenger and freight train movements. Facilities are usually double tracked for ease of bi-directional train movement. Since railroad rights-of-way utilized by commuter trains are located in populated areas, highway grade crossings are frequently protected by automatic grade-crossing warning signals or are grade-separated. With the exception of terminal areas, commuter rail guideway alignments possess high geometric standards, thus permitting high speeds between stations.

On-board fare collection is universal on commuter rail systems within the United States and Canada with two exceptions. Ticket sales procedures include the sales of various combinations of multiride tickets and passes along with single-ride tickets. Sales are either by mail or from the office at the main downtown station, and frequently tickets are sold at selected outlying stations as well. Fare collection is facilitated by crews of ticket collectors on board the trains. Exceptions to the use of this fare collection system are the barrier system utilized by "GO Transit" (Government of Ontario Transit) in Toronto and the Illinois Central Gulf suburban service in Chicago. Under these systems tickets are checked upon entering and exiting station platform areas, much as on typical heavy rail rapid transit systems.

The intensity of commuter rail station facility development depends upon whether park-ride lots, intermodal transfer, or ticket sales will be included at a particular location. The basic outlying commuter rail station need only consist of one or two platforms—which may be at ground level or raised—proper passenger access facilities, especially if the station is at a grade-separated highway crossing, and perhaps a small shelter. If tickets are to be sold

Table 39

MODERN HEAVY RAIL RAPID TRANSIT SYSTEMS IN THE UNITED STATES AND CANADA: 1980

Characteristic	Atlanta	Baltimore	Honolulu	Miami	Montreal	Philadelphia	San Francisco-Oakland	Washington, D. C.
Operating Authority	Metropolitan Atlanta Rapid Transit Authority	Baltimore Regional Rapid Transit Authority	Honolulu Area Rapid Transit	Metropolitan Dade County Transportation Administration	Montreal Urban Community Transit Commission	Port Authority Transit Corporation	Bay Area Rapid Transit District	Washington Metropolitan Area Transit Authority
Number of Routes in Completed System	4	6	1	1	3	1	3	5
Number of Routes in Service	1	--	--	--	2	1	3	2
Route-Miles in Completed System	53.3	71.0	23.0	50.1	51.0	14.5	71.5	100.8
Route-Miles in Service	6.7	--	--	--	23.7	14.5	71.5	30.7
Number of Vehicles in Service	100	72[c]	120[e]	136[e]	741	75	447	300
Metropolitan Area Population	1,390,000	2,071,000	629,000	1,268,000	2,743,000	4,818,000	3,110,000	2,861,000
Average Station Spacing (miles)	0.8	0.9	0.9	1.0	0.5	1.1	2.1	0.9
Daily Passengers Carried	110,000[b]	83,000[d]	209,000[f]	202,000[g]	560,000	40,000	150,000	270,000
Project Status	49 percent of Phase A in operation; remainder under construction	Section A totaling 8 miles is under construction	Alternatives analysis approved by UMTA; preliminary design to be completed in 1981	Stage I under construction—20.5 miles	Major extensions under construction	Examining potential of extensions	Adding third track under downtown Oakland	31.4 miles under construction
Initial Revenue Service Start-Up	1979	1982	After 1982	1983	1966	1967	1972	1976
Operating Cost[a] (per vehicle mile)	N/A	--	--	--	$2.37	$4.27	$3.99	$4.55

NOTE: N/A indicates data not available.

[a]Operating costs for 1976 through 1979 updated to 1979 dollars.

[b]1981 ridership estimate for completed Phase A.

[c]On order.

[d]1982 ridership estimate for Section A.

[e]Estimate.

[f]1990 ridership estimate.

[g]1985 ridership estimate for completed Stage I.

Source: Modern Railroads Rail Transit Magazine, American Public Transit Association, and SEWRPC.

an additional structure is required; usually this need is met by the existing railroad station, which is also utilized for other railroad operating functions. The addition of park-ride or intermodal transfer facilities may require additional platform and shelter capacity.

Signalization consists of the standard block and interlocking signals that are integrated with the rest of railroad operations. Application of centralized traffic control is common since most commuter operations are in heavily trafficked areas.

Support requirements for commuter rail are similar to those for other rail transit modes. Rolling stock storage and maintenance facilities are in many cases separate, but could be integrated with similar freight facilities. Track and roadway maintenance is generally performed by the owning railroad. Specialized power supply, distribution, and maintenance are required only where electric propulsion is used. On diesel-electric systems, such support requirements are minimal since the prime mover is on board the locomotive. Operating costs for facilities and services shared by both commuter rail and freight operators are usually split according to the amount of use by each.

Definition

Commuter rail is a rail transit mode that utilizes diesel-electric or electrically propelled trains made up of large railroad-sized passenger cars and operating over a right-of-way shared with rail freight movements. This mode is designed to serve the longest trips in metropolitan areas at high speeds with relatively few stations.

For a primary transit system or facility to be considered a commuter rail system, most of the following conditions must be met:

1. Heavy weight rolling stock of mainline railroad dimensions and design is used.

2. Diesel-electric locomotive propelled trains or self-propelled diesel-electric or electric vehicles are used.

Figure 79

ATLANTA–METROPOLITAN ATLANTA RAPID TRANSIT AUTHORITY

The first stage in the construction of Atlanta's modern heavy rail rapid transit system consists of portions of two routes totaling 11.8 route miles of line. The majority of this construction has been completed in 1980, with the remainder scheduled to be completed and open for service during 1981. These initial portions of the proposed regional system include subway segments constructed using both cut-and-cover and deep tunneling methods, elevated segments, and at-grade segments. Much of the grade alignment is located adjacent to an active mainline railway track. There are proposed to be 53.3 route miles of line in the completed system.

Photo courtesy of Metropolitan Atlanta Rapid Transit Authority.

Figure 80

PHILADELPHIA–PORT AUTHORITY TRANSIT CORPORATION

Opened for service in 1967, PATCO's high-speed Lindenwold Line was one of the first modern heavy rail rapid transit lines to be constructed in the United States or Canada. The system has been in continuous service since that time without any major operational problems, giving the system a reputation of being among the best designed and operated rapid transit lines in the world. The route, 14.5 miles in length, extends from suburban areas in New Jersey to downtown Philadelphia. As a highly successful example of rail transit automation, all trains have only one operator on board and stations are unmanned, with tickets dispensed from vending machines.

Photo courtesy of the Delaware River Port Authority.

3. Track and roadway are shared with intercity passenger and freight train operation.

4. Tickets and fares are collected on board.

5. The distances between stations are comparatively long.

6. Operation is concentrated in peak home-to-work commuting periods.

7. There is a predominance of low-level loading.

Other terms used to describe commuter rail systems include suburban train service and regional rail.

Attributes

Commuter rail possess the following attributes that require consideration in any system planning effort:

1. Rolling stock is built to maintain railroad suspension, noise insulation, and seating standards. This, together with relatively long station spacings, characterizes the mode as having a very high level of riding comfort.

2. Commuter rail utilizes standard railroad right-of-way and track work. Because such alignments are shared with intercity passenger and freight traffic, the mode does not need an exclusive guideway, resulting in capital and operating cost savings. New commuter rail routes or extensions are generally implemented using existing railroad roadway, structures, and rights-of-way, although rehabilitation of such fixed way facilities may be required prior to initiation of services. Thus, much of the potentially expensive right-of-way and fixed plant already exists.

Figure 81

**SAN FRANCISCO-OAKLAND–
BAY AREA RAPID TRANSIT DISTRICT**

Opened in stages during the 1970's, the Bay Area Rapid Transit (BART) system is considered by some to be a combination of modern heavy rail rapid transit and commuter rail service because of the station spacing and lengths of some of the routes which constitute the 71.5-mile-long system. Plagued by serious and costly start-up problems attributed to the desire to make numerous advances in the state-of-the-art of heavy rapid transit technology, BART now provides reliable service for approximately 150,000 passengers per day in the San Francisco-Oakland bay area.

Photo courtesy of Bay Area Rapid Transit District.

Figure 82

**WASHINGTON, D. C.–WASHINGTON
METROPOLITAN AREA TRANSIT AUTHORITY**

As of early 1979, Washington's Metro system consisted of two routes of a proposed five-route system, constituting about 31 miles of a proposed 101-mile system. Having been in operation for four years, the modern heavy rail rapid transit system is regarded as an unqualified success while enjoying phenomenal support among the area's residents. In addition to greatly shortening travel times within the District of Columbia and affecting land values and development along the routes, ridership on the system has exceeded expectations. The decreased travel times resulting from the availability of this system have contributed to the creation of a third rush hour during the midday in the Washington area.

Photo courtesy of Washington Area Metropolitan Transit Authority.

3. Because commuter rail in the United States and Canada is generally operated by railroad companies, crew sizes are a reflection of railroad policies and rules as opposed to transit labor practices.

4. Typical commuter rail service is heavily skewed to peak-period operation, creating idle investment during nonpeak periods. This means that such services have significant operating deficits if evaluated in isolation from other railway service. However, if evaluated as part of the complete urban transportation network for a metropolitan area, commuter rail may be regarded as reducing the need for investment in facilities to handle peak loads via other modes.

Generic Application of Commuter Rail

Commuter rail is the oldest of the rail transit modes discussed within this technical report. Nineteenth century railroad management discovered that long-distance trains could be stopped outside large cities to transport people who regularly work in the city. The extra revenues from such traffic was earned with negligible additional costs since the passenger trains were already in operation. In many large metropolitan areas such service quickly developed into large operations especially tailored for the daily suburban home-to-work market.

In the United States and Canada, two distinct intensities of commuter rail service developed. Some railroads developed large-scale operations with frequent service during peak periods—some of this as express or "skip-stop"—and a base service during nonpeak periods and on weekends. Other railroads felt that the demand for such service justified operation of only one or a few trains inbound during weekday mornings and outbound during weekday afternoons. This minimal type of service is rarely found today, with most of these services being discontinued by the railroads prior to the recent renewed interest in rail transit development.

The nature of commuter rail technology prohibits the mode from performing efficiently when station stops are too close together. Station location is therefore limited to high-activity areas, such as central business districts, suburban community centers, and centers of residential development. This makes the mode functional in two types of primary transit application. First, commuter rail functions as a principal means of transporting commuters into a central business district from outlying locations. Second, the mode can function as a high-quality means of serving other regional and long-distance urban trips that are not necessarily destined to or from the central business district. For example, in the Milwaukee urbanized area, central city residents could be transported to outlying concentrations of employment opportunities located to the northwest, west, and south of the older well-developed portions of the area. Traffic generated by such secondary attractions, however, probably does not by itself justify commuter rail service, but must be regarded as additional marketing opportunities for a system oriented to the central business district.

Geographic Extent of Commuter Rail

Like light rail transit and heavy rail rapid transit, commuter rail transit is more commonly found in major metropolitan areas outside the United States than in American metropolitan areas. In the United States and Canada, commuter rail service is available in the metropolitan areas of Boston, Chicago, Detroit, Montreal, New York City, Philadelphia, Pittsburgh, San Francisco, Toronto, and Washington, D.C. A list of these operations, together with selected system characteristics, is presented in Table 40, and the systems in the Cities of Boston, Chicago, Montreal, Philadelphia, Pittsburgh, and Toronto are illustrated in Figures 83 through 88. Certain routes operating into Chicago, Montreal, New York City, Philadelphia, and Washington, D.C., are electrified, the remainder utilizing diesel-electric locomotives. Outside North America, electrically powered multiple-unit operation appears to predominate.

Existing commuter rail services are generally continuations of services that have existed since before the 1900's. The only new service start-up within either the United States or Canada is the already mentioned "GO Transit" system, which began operation in 1967 and was designed as a replacement for conventional commuter services of the time. Other existing systems have improved service by initiating rolling stock replacement and facility improvement programs. There are not as many proposed commuter rail systems as there are proposed light rail transit or heavy rail rapid transit systems. Nevertheless, additional commuter rail routes have been proposed in the Detroit area, and the establishment of one or more routes out of Vancouver, British Columbia has been proposed.

It should be recognized that although it is not the intent of the National Railroad Passenger Corporation—Amtrak—to operate commuter or suburban services, certain Amtrak intercity trains are utilized for commuter-like travel. This is especially true in high-density intercity corridors, such as the Boston-Washington, Philadelphia-Harrisburg, and New York City-Albany corridors. In addition, several routes radiate out of Chicago, including one route to Milwaukee. A similar situation exists in Canada where, in the Montreal-Toronto-Windsor corridor, intercity passenger service is the responsibility of VIA Canada Ltd., an organization somewhat analogous to Amtrak.

Section 403-b of the public law that authorizes Amtrak provides that intercity passenger service beyond that included within the basic network can be requested by a state, regional, or local agency. Subject to the availability of equipment, federal funds, and an adequate passenger market, Amtrak must provide such service if the agency agrees to fund 50 percent of any capital improvements plus 20 percent of the operating deficit during the first fiscal year, 35 percent during the second fiscal year, and 50 percent during any subsequent year. Although it is not the intent of Amtrak to operate commuter service, it appears that the States of California and Michigan have utilized Section 403-b to implement a limited suburban-type service in the Los Angeles and Detroit areas, respectively.

Potential Application in Southeastern Wisconsin

At present, there is no commuter rail service in the Milwaukee urbanized area. Until July 31, 1972, the Chicago, Milwaukee, St. Paul & Pacific Railroad Company (the Milwaukee Road) operated one daily round-trip commuter train between Watertown and downtown Milwaukee (see Figure 89). Stops were made at Ixonia, Oconomowoc, Okauchee, Nashotah, Hartland, Pewaukee, Duplainville, Brookfield, Elm Grove, and Wauwatosa. The train operated daily except Saturdays, Sundays, and holidays, and was unofficially known as the "Cannonball." In its application for discontinuance of the train, the Milwaukee Road cited revenues of $20,674 and expenses of $96,524 during 1970, along with an average daily ridership of 39 passengers.

Table 40

COMMUTER RAIL OPERATIONS IN THE UNITED STATES AND CANADA: 1980

Characteristic	Boston	Chicago	Detroit	Montreal	New York City	Philadelphia	Pittsburgh	San Francisco	Toronto	Washington, D. C.
Operating Authority	Massachusetts Bay Transportation Authority	Regional Transportation Authority, Amtrak, Northwest Indiana Commuter District	Southeastern Michigan Transportation Authority	Canadian National, CP Rail	Metropolitan Transportation Authority, New Jersey Transit	Southeastern Pennsylvania Transportation Authority	Port Authority of Allegheny County, Pennsylvania Department of Transportation	Southern Pacific	Toronto Area Transit Operating Authority	Maryland Department of Transportation
Participating Railroads	Boston & Maine	Burlington Northern, Conrail, Chicago & North Western, Milwaukee Road, Illinois Central Gulf, Norfolk & Western, South Shore Line	Grand Trunk Western	Canadian National, CP Rail	Conrail, Long Island Rail Road	Conrail	Chessie System, Pittsburgh & Lake Erie	Southern Pacific	Canadian National, CP Rail, Government of Ontario	Chessie System, Conrail
Number of Routes	12	15	1	4	32	15[b]	2	1	3	3
Length of Route (miles)	205	594	26	152	1,043	483	49	47	111	150
Number of Stations	83	269	11	68	415	226	15	26	28	38
Diesel-Electric Locomotives	23	133	5	21[a]	N/A	3	3	24	25	5
Bi-Level Coaches	--	649	--	9	--	--	--	46	80	--
Single-Level Coaches	84	113	29	99	494	6	9	37	123	19
Multiple-Unit Electric Coaches	--	185	--	16	2,253	393	--	--	--	10
Self-Propelled Diesel Coaches	92	--	--	7	11	18	4	--	9	14
Metropolitan Area Population	3,455,000	7,612,000	4,434,000	2,743,000	16,468,000	7,077,000	2,401,000	4,174,000	2,628,000	4,932,000
Daily Passengers Carried	31,000	274,000	2,100	28,800	573,000	114,500	1,950	14,000	38,000	6,700
Operating Cost[c] (per car mile)	$6.84	$3.06 - $6.01	N/A	N/A	$2.99 - $5.22	$4.76	N/A	$7.08	N/A	N/A

NOTE: N/A indicates data not available.

[a] *Fourteen are straight electric.*

[b] *Data do not include ex-Pennsylvania-Reading Seashore Lines in New Jersey.*

[c] *Based on 1973 operating costs updated to 1979 dollars.*

Source: Modern Railroads Rail Transit Magazine and SEWRPC.

A limited amount of Chicago-based commuter rail train service is available in the extreme southern portion of the Region. The communities of Kenosha, Walworth, and Zenda are connected to the Chicago area via commuter rail routes. This service, however, has little or no impact on travel patterns in the Milwaukee urbanized area.

Because commuter rail service requires mainline quality railroad track and right-of-way for a guideway, implementation of such service is limited to those rail lines that have mainline alignment, and thus the potential for high-speed service. Such routes in the Milwaukee area are shown on Map 7. It should be recognized that the routes displayed are of a potential nature and may require substantial physical improvement prior to start-up of any passenger service.

TECHNICAL CHARACTERISTICS

Vehicle Technology

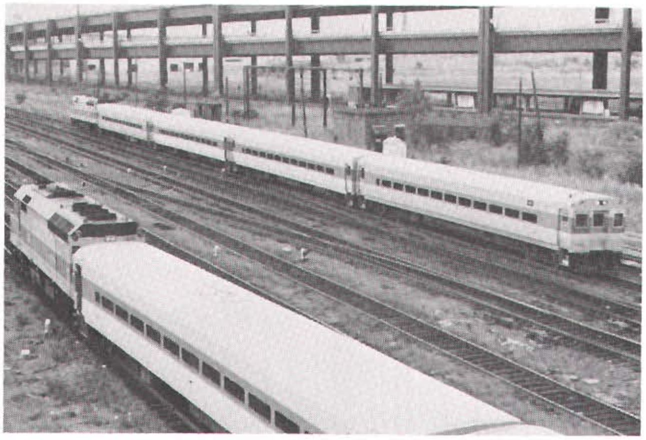
Each rail transit mode has physical and operating characteristics that differ enough to require a specific type of vehicle. The three rail transit modes considered herein are light rail transit, heavy rail rapid transit, and commuter rail. Critical vehicle characteristics include those pertaining to vehicle size and configuration, vehicle capacity, and vehicle performance.

Light Rail Transit: The typical light rail vehicle has three basic body configurations: a nonarticulated car, a single-articulated car, and a double-articulated car (see Figure 90). Articulation allows the vehicle to "bend" on joints usually supported by one or more two-axle nonpowered trucks when traversing both horizontal and vertical curves. Such design permits a single vehicle to possess a large seating capacity and yet to both traverse and retain a narrow profile on sharp curves, thus reducing civil engineering standards for the fixed guideway facilities and potential clearance and safety conflicts.

Nonarticulated light rail vehicles are exemplified either by conventional streetcars on systems that are in the process of upgrading to light rail transit, or by a select group of cars currently in production. In North America, nonarticulated vehicles are now being procured for street railway operation in Toronto and Philadelphia. Existing light rail transit systems as well as street railway systems in North America almost exclusively utilize PCC (Electric Railway President's Conference Committee) cars at present, although most of these

Figure 83

COMMUTER RAIL SERVICE IN THE BOSTON AREA



In the Boston area all commuter rail service is operated by the Massachusetts Bay Transportation Authority (MBTA), which contracts with the Boston and Maine Corporation for operation of the trains. The MBTA has pursued a vigorous policy of commuter rail system expansion and, as of 1979, operates 12 commuter rail routes over about 200 route miles of trackage in the Boston area. The lines reach out as far as 73 miles from downtown Boston. Rolling stock consists chiefly of standard, single-level railway coaches and former self-propelled coaches powered by diesel-electric locomotives and operated in a push-pull fashion. A limited number of self-propelled diesel coaches are also used.

Photo by Otto P. Dobnick.

Figure 84

CHICAGO–REGIONAL TRANSPORTATION AUTHORITY

Almost all commuter rail service in the Northeastern Illinois Region is operated by the Regional Transportation Authority, which contracts with six participating railroads for direct operation of the trains. With 15 commuter rail routes operated over almost 600 route miles of trackage, the extent of the Chicago commuter rail network is second only to that of New York City in the United States and Canada. The lines operated reach out as far as 74 miles from the Chicago "loop," with two lines terminating in southeastern Wisconsin—the Chicago & North Western line to Kenosha, and the Milwaukee Road line to Walworth. Except on three lines which are operated with multiple-unit electrified coaches, the commuter trains used typically consist of bi-level coaches assembled into push-pull trains powered by diesel-electric locomotives. The use of bi-level push-pull commuter trains was pioneered by Chicago area railroads during the early 1960's.

SEWRPC photo.

Figure 85

COMMUTER RAIL SERVICE IN THE MONTREAL AREA

Within the United States and Canada, the use of electrified rolling stock for commuter rail service is relatively rare outside the densely populated northeastern states. Other electrified commuter rail services exist only in Chicago and Montreal areas, as illustrated in this view. This service, operated by the Canadian National Railways, utilizes multiple-unit electrified coach and trailer combinations augmented by electric locomotive-hauled trains during peak periods. The 18-mile-long electrified suburban line gains access to downtown Montreal through a three-mile-long tunnel beneath Mt. Royal. Some commuter rail service is also provided in the Montreal area by CP Rail.

Photo by Otto P. Dobnick.

Figure 86

COMMUTER RAIL SERIVCE IN THE PHILADELPHIA AREA

The commuter rail system in and around the City of Philadelphia typifies the commuter rail services provided in eastern Pennsylvania, northern New Jersey, and the New York City area. Service is frequent and provided in many cases by electrified multiple-unit trains. Most of the 14 commuter rail routes in the Philadelphia area are operated with multiple-unit electric coaches, with some service provided by a small number of nonelectrified trains generally operated with self-propelled diesel coaches. The commuter routes in Philadelphia are operated out of one of two major downtown stub end railway terminals which are in the process of being interconnected via a new center city tunnel beneath the central business district.

Photo by Otto P. Dobnick.

Figure 87

COMMUTER RAIL SERVICE IN THE PITTSBURGH AREA

In contrast to the major commuter rail systems operated in such areas as Chicago and New York City, the system in Pittsburgh, Pennsylvania, offers only limited service throughout the day. Commuter trains generally consist of standard, single-level coaches no more than a few cars in length. Pittsburgh's Monongahela Valley commuter rail service consists of one diesel-electric locomotive-powered train and two rail diesel car (RDC) trains which make a total of eight daily round trips over an 18-mile route.

Photo by Otto P. Dobnick

Figure 88

TORONTO'S GO TRANSIT COMMUTER RAIL SYSTEM

The newest commuter rail system in North America is known as "GO (Government of Ontario) Transit" and is operated by the Canadian National Railways for the Toronto Area Transit Operating Authority. Regarded as one of the most efficient and effective rail commuter systems in North America, GO Transit was inaugurated in 1967 as a new regional transit service in the Toronto area. The initial route was about 42 miles in length extending both east and west from Toronto's Union Station along the shore of Lake Ontario. One-hour-headway service was provided during base periods and 20-minute-headway service was provided during peak periods. Trains are operated in push-pull fashion and fare collection is at stations, allowing a minimum-sized train crew. Since GO Transit was initiated, service has been expanded by the addition of two routes, with more planned. Single-level coaches have been largely replaced with double-deck coaches to increase capacity, and an extensive regional feeder bus system has been developed with schedules coordinated with the commuter train schedules.

Photo by Otto P. Dobnick.

vehicles are scheduled to be replaced within five to seven years.[1] Development and design of the PCC car was completed during the early 1930's by a committee whose members represented presidents of 25 electric railway companies. The PCC car proved to be very successful as a high-quality replacement street railway vehicle as more than 6,000 cars were constructed between 1936 and the mid-1950's (see Figure 91). Although these cars are no longer produced for use in the United States and Canada, licensed construction continues in Belgium and Czechoslovakia.

Single-articulated light rail vehicles appear to be the most popular contemporary configuration especially for application within the United States and Canada. A small decrease in performance is realized, resulting from the additional weight and the unpowered truck beneath the articulation joint. However, this is generally considered acceptable because of the greater passenger capacity afforded by this vehicle configuration while still requiring only one operator.

Light rail rolling stock that is double-articulated offers even less efficiency in performance than do single-articulated vehicles because of the additional body weight and unpowered truck. Many light rail systems in Europe had to be developed from existing street railways with narrow side clearances and track gauge. This led to the utilization of double-articulated vehicles that were constructed to be narrower but longer than most single-articulated vehicles in order to achieve comparable passenger capacities. However, if con-

[1] *As of the beginning of 1980, existing PCC vehicles utilized in Boston and San Francisco were to be replaced by Boeing-Vertol United States Standard Light Rail Vehicles.*

Figure 89

THE MILWAUKEE ROAD
"CANNONBALL" COMMUTER TRAIN

Until mid-1972, the Milwaukee area possessed limited commuter train service consisting of one weekday round trip between Watertown and Milwaukee over the Milwaukee Road main line. The train, unofficially known as the "Cannonball," was operated by the Chicago, Milwaukee, St. Paul & Pacific Railroad Company (the Milwaukee Road), which cited an average daily ridership of 39 persons in its application for discontinuance of the train. Shown in this view is the train's final run which occurred on July 31, 1972, with the addition of one coach more than normally used on the train.

Photo by Richard T. Volkmann.

structed to the same width as single-articulated vehicles, double-articulated light rail vehicles have larger capacities.

Table 41 presents a statistical analysis of the general physical and performance characteristics of 41 light rail vehicles. The range of values and the mathematical average are given for the various characteristics according to the vehicle configuration. While these characteristics are of an overall nature and relate to the light rail mode in general, Table 42 presents similar data on specific light rail vehicle models which typify the various configurations that are in current production as well as those models to be utilized on North American systems. Figures 92 through 94 illustrate those vehicles cited in Table 42.

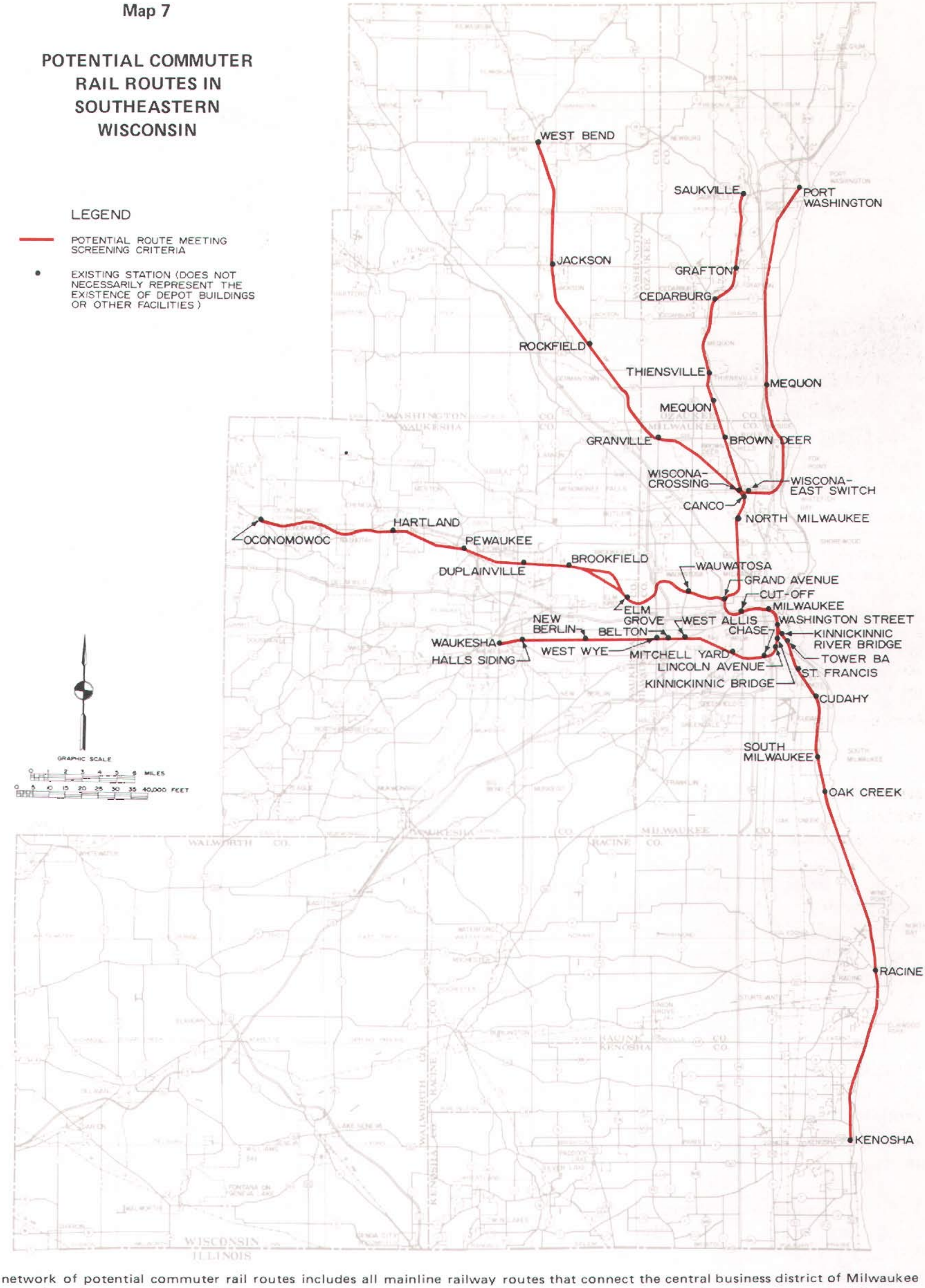
Light rail systems are generally propelled by relatively low voltage, generally between 600 and 650 volts direct current. The current is transmitted from the power source to traction motors attached to the vehicle tracks via an overhead trolley wire system. Pantographs are the preferred power collection device on board the vehicle as opposed to trolley poles because they offer a greater current collection capacity, less restrictive traveling requirements, and the need for a less complex overhead wire system. The physical properties of an overhead trolley wire system for current distribution restrict practical train length to three or four vehicles.

The systemwide average vehicle propulsion energy efficiency for light rail transit, based on the reported experience of selected transit operators in the United States, is summarized in Table 43. The wide variation in reported energy efficiency is a result of not only the type of vehicle used and its motor control system and weight and optional equipment, but also the characteristics of the routes operated, including average speed, frequency of stops, terrain, and weight of passenger loading. The energy efficiency is reported in Table 43 in terms of the vehicle miles traveled both per kilowatt-hours of electrical energy used and per British Thermal Units (BTU's) used. Because of conversion and transmission losses, the energy required to produce the electricity purchased for propulsion by a light rail system may be three to three-and-one-half times the energy represented by that electricity. Moreover, because of energy distribution losses in the overhead wire system of the light rail transit system, about 30 percent of the energy purchased for propulsion may be lost. As a result of these conversion, transmission, and distribution losses, the energy required for propulsion of a light rail system may be three-and-one-half to four times the energy actually used in light rail vehicle propulsion. These energy losses attendant to light rail vehicle propulsion have been included in the light rail propulsion energy requirements reported in Table 43.

The number of seat miles provided per unit of energy used is another important measure of the propulsion energy efficiency of light rail transit vehicles. Larger articulated vehicles capable of carrying more passengers may consume more energy per vehicle mile than will smaller single-unit vehicles; however, at high load factors, the energy consumption per seat mile may actually be less for larger vehicles than for smaller vehicles. Therefore, if demand is sufficient to warrant high load factors, a transit system may be able to operate at greater energy efficiency by using larger vehicles which provide more seat miles, and thereby potentially more passenger miles per unit of energy used. An example of such an increase in energy efficiency is that provided by a fully loaded Boeing

Map 7

POTENTIAL COMMUTER RAIL ROUTES IN SOUTHEASTERN WISCONSIN



A basic network of potential commuter rail routes includes all mainline railway routes that connect the central business district of Milwaukee with other major trip generators and with outlying concentrations of residential development. These routes radiate from downtown Milwaukee to Port Washington, Saukville, West Bend, Oconomowoc, Kenosha, and Waukesha.

Source: SEWRPC.

Figure 90

BASIC BODY CONFIGURATIONS OF LIGHT RAIL VEHICLES

As shown in these three views, light rail vehicles may have three basic body configurations: a nonarticulated car, a single-articulated car, and a double-articulated car. Any of these three vehicle designs would be acceptable for use on a new light rail system, although each configuration appears to be best adopted to certain operating conditions. Within North America, new nonarticulated vehicles have been procured for cities which are retaining street railway lines or which have light rail lines involving significant amounts of mixed traffic operation. For other North American light rail systems, as well as many foreign light rail systems, the single-articulated vehicle appears to be the most popular because of its combination of high capacity and favorable performance characteristics. Double-articulated vehicles have been widely applied on existing foreign systems that utilize a narrow track gauge and therefore narrower vehicles, which dictate the use of longer light rail vehicles to provide an acceptable vehicle capacity.

Photo (top) by ASEA Traction Department.
Photos (center and bottom) by Siemens Corporation.

Figure 91

TYPICAL PCC VEHICLE

Up to the late 1970's, all light rail transit systems, as well as almost all street railway systems in North America, had rolling stock rosters which consisted almost entirely of PCC streetcars, a vehicle designed by the Electric Railway Presidents' Conference Committee (PCC) in the early 1930's. Although the PCC car is being replaced in North America with modern light rail vehicles, small fleets of these reliable vehicles are expected to be maintained and reconditioned by many operators, including Philadelphia, as shown in this view.

Photo by Otto P. Dobnick.

Vertol standard single-articulated light rail vehicle, which provides about 50 percent more seats—68 seats compared with 46 seats provided by a typical single-unit nonarticulated Canadian Light Rail Vehicle (CLRV)—while consuming only about 20 percent more energy.[2]

For planning purposes, transit energy efficiency is best measured in terms of passenger miles per unit of energy used rather than vehicle miles or seat miles. At a load factor of 1.0—that is, with all seats occupied—energy consumption per seat mile and per passenger mile are equal. Transit systems in the United States, however, presently operate at load factors well below 1.0, as shown for selected light

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[2] *The Urban Transportation Development Corporation's Canadian Light Rail Vehicles (CLRV) procured by the Toronto Transit Commission have only recently been put into operation, and the propulsion energy requirements are not well established. Actual test data for the CLRV, however, indicate a consumption of from 15.5 to 17.8 vehicle miles per 100 kilowatt hours of power used, or an average of about 16.6 vehicle miles per 100 kilowatt hours.*

Table 41

GENERALIZED PHYSICAL AND PERFORMANCE CHARACTERISTICS FOR LIGHT RAIL VEHICLES

Characteristic	Nonarticulated		Single-Articulated		Double-Articulated	
	Range	Average	Range	Average	Range	Average
Length (feet)	44-53	47	58-88	69	78-91	86
Width (feet)	6-9	7.5	7-9	8	7-8.5	7.75
Height (feet)	9-11	9.75	9.75-11.5	10.25	10-11	10.5
Net Weight (pounds)	32,000-45,000	38,000	44,000-86,000	54,000	68,000-85,000	76,000
Maximum Speed (mph)	34-50	41	37.5-62	45	34-50	43
Maximum Acceleration (miles per hour per second)	1.8-4.3	3.4	1.8-3.6	2.7	2.2-2.7	2.4
Service Deceleration (miles per hour per second)	1.8-4.3	3.3	2.2-3.8	2.9	2.7-3.3	2.4
Emergency Deceleration (miles per hour per second)	5.2-8.2	6.5	5.2-7.5	6.4	6.1-6.8	6.6
Maximum Radius (feet)	39-66	53.5	32-82	54.5	48-66	54
Floor Height (inches)	33.1-36.2	34.7	33.5-39.4	35.4	33.1-39.4	35.8
First Step Height (inches)	8.5-19	12.8	7.9-18.8	13.7	9.3-15.7	13.7
Seating Capacity	16-48	32	29-72	46	46-64	54
Total Design Capacity	74-130	104	118-190	155	140-170	152

Source: Lea Transit Compendium and SEWRPC.

Table 42

SPECIFIC PHYSICAL AND PERFORMANCE CHARACTERISTICS FOR SELECTED LIGHT RAIL VEHICLES

Characteristic	President's Conference Commission Car[a]	United States Standard Light Rail Vehicle	Canadian Light Rail Vehicle	SEPTA Light Rail Transit Car	Shaker Heights Rapid Transit Vehicle	Articulated Pre-Metro Light Rail Vehicle	DuWag U2 Vehicle	DuWag Type B Vehicle	DuWag Hannover 6000 Vehicle
Length (feet)	43.5 to 50.5	71.0	50.7	53.0	79.9	83.6	75.4	88.2	88.6
Width (feet)	8.3 to 9.0	8.8	8.3	8.8	9.4	8.8	8.7	8.7	7.9
Height (feet)	10.1	11.5	10.7	10.8	12.4	12.6	7.5	11.0	10.9
Articulation	None	Single	None	None	Single	Single	Single	Single	Double
Net Weight (pounds)	33,000 to 42,000	67,000	52,000	54,000	84,000	83,600	66,000	86,000	85,000
Truck Centers (feet)	Varies	23.0	21.0	25.4	27.0	27.6	25.3	N/A	21.0
Minimum Horizontal Radius (feet)	Varies	42	36	60.0	100.0	65.6	82.0	82.0	59.0
Minimum Vertical Radius (feet)	Varies	310[b] 460[c]	800[e] 122[f]	N/A	3,900 3,788	656.0	1,640	N/A	492[b] 820[c]
Builder	Various	Boeing-Vertol Company	Hawker-Siddeley Canadian, Ltd.	Kawasaki Heavy Industries, Ltd.	Breda Costruzioni Ferroviarie	Bombardier, Ltd.	Waggonfabrik Uerdiggen A. B.	Waggonfabrik Uerdiggen A. B.	Waggonfabrik Uerdiggen A. B.
Approximate Design Year	1933	1973	1975	1979	1979	1977	1965	1971	1972
Steps/First Step Height (feet)	Low-N/A	High-Low/14.0	Low/10.0	Low-N/A	Low/12.3	High-10.0	High-N/A	High-Low/N/A	High-Low/15.3
Floor Height/Headroom (feet)	2.8/Varies	2.8/7.1	3.0/6.8	N/A	3.3/7.0	3.2/7.1	3.2/7.2	3.3	3.1/7.3
Door Type/Number per Side	Folding/2 or 3	Plug/3	Folding/2	Folding/2	Folding/3	Folding/4	Folding/4	Plug/6	Folding/5
Design Capacity Seats/Standees	49 to 69/Varies	68/151	42 to 47/90	50/50	84/138	58/193	64/98	72/108	46/118
Maximum Speed (mph)	50	50	50	50	55	50	50	60	49
Service Acceleration (miles per hour per second)	3.1	2.8	3.3	N/A	2.8	2.2	2.2	2.7	2.4
Service Deceleration (miles per hour per second)	3.1	3.5	3.5	N/A	3.5	2.7	2.7	2.7	3.5
Emergency Deceleration (miles per hour per second)	6.5	84.0-6.0	6.5	N/A	4.0-6.0	3.4	6.7	6.8	6.7
Maximum Design Grade (percent)	6.5	9.0	8.0	N/A	5.0	6.0	4.4	6.0	5.0
Capital Cost per Unit	$15,000-32,000[d]	$494,000	$502,000	$410,000	$759,000	N/A	$845,000	$1,300,000	$1,300,000
Systems Using Vehicles	Various	Boston, San Francisco	Toronto	Philadelphia (Red Arrow Division)	Cleveland	Rio de Janeiro	Frankfurt, Edmonton, Calgary, San Diego	Cologne, Bonn, Essen, Dusseldorf	Hannover

NOTE: N/A indicates data not available.

[a] *No longer in production, characteristics given for comparative purposes only since this vehicle is widely used in North America.*

[b] *Single vehicle.*

[c] *Coupled.*

[d] *Original cost; not updated to 1979 dollars.*

[e] *Concave.*

[f] *Convex.*

Source: Manufacturers' Literature and SEWRPC.

Figure 92

UNITED STATES STANDARD LIGHT RAIL VEHICLE

The United States Standard Light Rail Vehicle (SLRV) was designed and manufactured by the Boeing-Vertol Company. It incorporates many successful design features utilized by European light rail vehicle manufacturers. Intended as a replacement for PCC streetcars in the United States, the vehicle is now utilized by the Massachusetts Bay Transportation Authority in the Boston area (left) and by the San Francisco Municipal Railway (right). The SLRV's for Boston seat 52 passengers, have stepwells for low-level loading only, and include air conditioning. The SLRV's for San Francisco seat 68 passengers, have forced ventilation, have movable steps for either high- or low-level loading, and include cab signals and automatic train control capability.

Photo (left) by Otto P. Dobnick.
Photo (right) by Russell E. Schultz.

rail transit systems in Table 44. These low load factors are the result of operation during periods of limited, as well as peak, passenger demand in order to provide transportation services capable of meeting the needs of passengers for a variety of trip purposes throughout the day. During the peak morning and evening travel periods—when trips carried are being made primarily to and from work and school—it is not uncommon for passenger load factors to exceed 1.0 at the peak load point of transit routes in the peak direction. Because demand drops off past the peak load point as well as during other periods of the day, however, very high load factors are usually achieved only during the morning and afternoon peak travel periods and only over limited segments of the total transit system. Therefore, measures of transit vehicle energy efficiency need to be based in part on passenger miles per unit of energy used, determined on the basis of realistic load factors. Such load factors are a function of passenger demand which is, in turn, a function of specific route configuration, level of service, and adjacent land use type and intensity, among other factors. Therefore, unless specific route configurations and passenger demand are known and analyzed, comparisons of energy consumption expressed as passenger miles per unit of energy used can only be reported as a range based upon an assumed range of load factors. In order to illustrate the importance of passenger load factors in energy efficiency, the relationship between load factors and passenger miles per unit of energy used for propulsion for both standard new nonarticulated and single-articulated light rail transit vehicles is shown in Figure 95.

Vehicle speed is controlled by regulating the motor current and voltage using either a rheostatic or electronic solid-state method. The rheostatic method supplies power to the traction motors by varying resistance via either a hand-operated or motor-driven cam device. This approach is well established, reliable, and fairly rugged; however, energy is wasted as the resistors give off heat, making forced air a possible requirement for cooling.

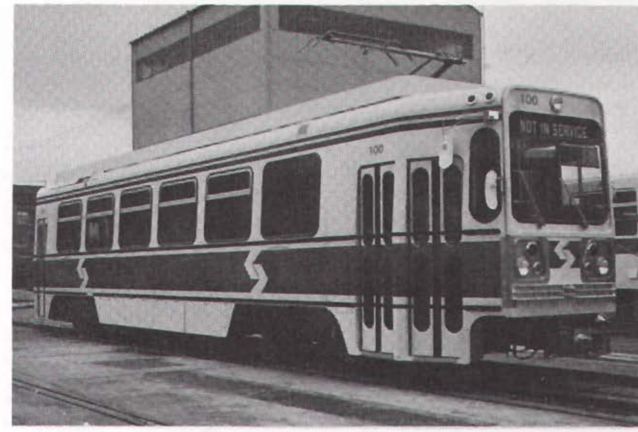
Many new vehicle designs utilize solid-state thyristor "choppers" to provide continuously variable motor control, the power to the motor being "chopped" or broken into pulses at a rate of a few hundred per second. The advantages of this type of control are that regenerative as well as dynamic braking can be achieved and there is very precise

Figure 93

CONTEMPORARY LIGHT RAIL VEHICLES UTILIZED ON NORTH AMERICAN LIGHT RAIL TRANSIT SYSTEMS

The Canadian Light Rail Vehicle (CLRV) was designed and developed by the Urban Transportation Development Corporation, Ltd., and is manufactured by Hawker-Siddeley Canada, Ltd., of Thunder Bay, Ontario. Although this vehicle design has multiple-unit capability, 196 vehicles have been purchased by the Toronto Transit Commission as replacements for PCC vehicles and are operated as single units in street railway service. The same car design, with a higher maximum speed, will be used in train service on the Toronto Transit Commission Scarborough light rail transit line, now under construction.

Photo by Otto P. Dobnick.



New nonarticulated light rail transit vehicles for the Southeastern Pennsylvania Transportation Authority (SEPTA) in the Philadelphia area are being manufactured by Kawasaki Heavy Industries, Ltd., of Japan. The order includes 141 single-ended vehicles to be operated on the street railway system as replacements for PCC vehicles, and 29 double-ended vehicles to be operated on the suburban Red Arrow Division routes. This figure shows one of the double-ended cars for suburban light rail transit service.

Photo courtesy of Kawasaki Heavy Industries, Ltd.

The DuWag/Siemens Model U2 light rail vehicle has been selected by three new light rail transit operations in North America—those in Edmonton and Calgary, Alberta in Canada and that in San Diego—because of its proven performance and "off-the-shelf" availability. Originally designed for use in Frankfurt, West Germany, the U2 vehicle is intended for operation in subways, over exclusive rights-of-way, and on transit malls and in mixed traffic. The vehicle can be coupled into trains and requires high-level loading of passengers. This view shows one of the vehicles to be operated on the City of Calgary light rail transit system, which is scheduled to begin operation in 1981.

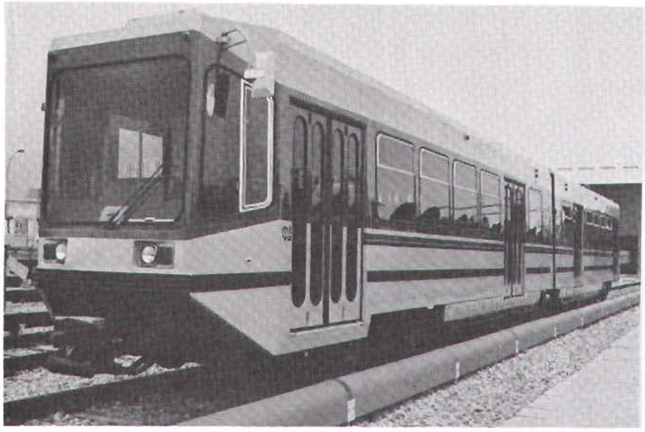
Photo courtesy of Siemens Corporation.

The new single-articulated light rail vehicles for the Greater Cleveland Rapid Transit Authority's Blue and Green Lines (former Shaker Division) were manufactured by Breda Construzioni Ferroviarie, an Italian manufacturer. The vehicles have multiple-unit capability and are designed for low-level boarding.

Photo courtesy of Greater Cleveland Rapid Transit Authority.

Figure 94

CONTEMPORARY LIGHT RAIL VEHICLES UTILIZED ON FOREIGN LIGHT RAIL TRANSIT SYSTEMS



These three photographs illustrate the appearance of typical light rail vehicles recently designed for foreign light rail systems. The top view shows the new articulated light rail vehicle manufactured for the Rio de Janeiro, Brazil pre-metro system. This vehicle has retractable steps for either high-level or low-level boarding and is manufactured by Bombardier, Ltd., of Quebec, Canada, in partnership with BN of Belgium. The center and bottom views show recent light rail vehicle designs manufactured by DuWag/Siemens for operation in various West German cities. The former shows what is known as a Type B vehicle which is operated in Cologne, Bonn, Essen, and Dusseldorf, while the latter shows a vehicle known as a Hannover 6000, operated in Hannover. All three of these vehicle designs are capable of operation over exclusive rights-of-way, including subways, as well as in mixed traffic on arterial streets.

Photo (top) courtesy of Bombardier, Ltd.
Photos (center and bottom) courtesy of Siemens Corporation.

Table 43

VEHICLE PROPULSION ENERGY EFFICIENCY FOR SELECTED LIGHT RAIL TRANSIT SYSTEMS: 1976-1978

System	Propulsion Energy Efficiency	
	Vehicle Miles per 100 KWHr	Vehicle Miles per Million BTU's
New Orleans Public Service, Inc.	24.3	21.3
Greater Cleveland Regional Transit Authority	23.3	20.4
Transport of New Jersey (Newark)	21.7	19.0
Southeastern Pennsylvania Transportation Authority (Philadelphia)	19.3	16.9
Port Authority of Allegheny County (Pittsburgh)	15.2	13.3
Massachusetts Bay Transportation Authority (Boston)[a]	13.5	11.8
San Francisco Municipal Railway	8.5	7.4

[a]*For Boeing Vertol single-articulated vehicles only.*

Source: American Public Transit Association; De Leuw, Cather & Company, Chicago; U. S. Department of Transportation; and SEWRPC.

vehicle control. The disadvantages are the potential for interference from control and communications signals, and the requirement for sophisticated maintenance equipment and skills. Although conventional rheostatic controllers are more prevalent, chopper control is being applied to many new vehicle designs.

Most recent light rail transit vehicle designs incorporate electric brake control because of the vulnerability of the traditional pneumatic systems to cold weather conditions. Primary deceleration is through the use of dynamic braking which utilizes the traction motors as generators. If regenerative braking capability is also incorporated (available only with chopper control), a 10 to 30 percent savings in power may be achievable because of the electric current being returned to the overhead power supply. Because dynamic braking becomes ineffective at low speeds, a secondary mechanical braking system is also required. Most modern designs employ disc brakes as opposed to brake shoes. In addition, electromagnetic truck brakes are now commonplace on most light rail vehicles. When activated, these brakes magnetically grip the track to prevent rolling when starting on an upgrade and also act as a very positive emergency brake. These braking systems give light rail equipment its outstanding braking capacity necessary for safe operation in and adjacent to street traffic without the extensive application of elaborate automatic protection.

The majority of new vehicle designs incorporate a single motor that drives both axles of each truck, as opposed to the traditional two-motor truck.

Table 44

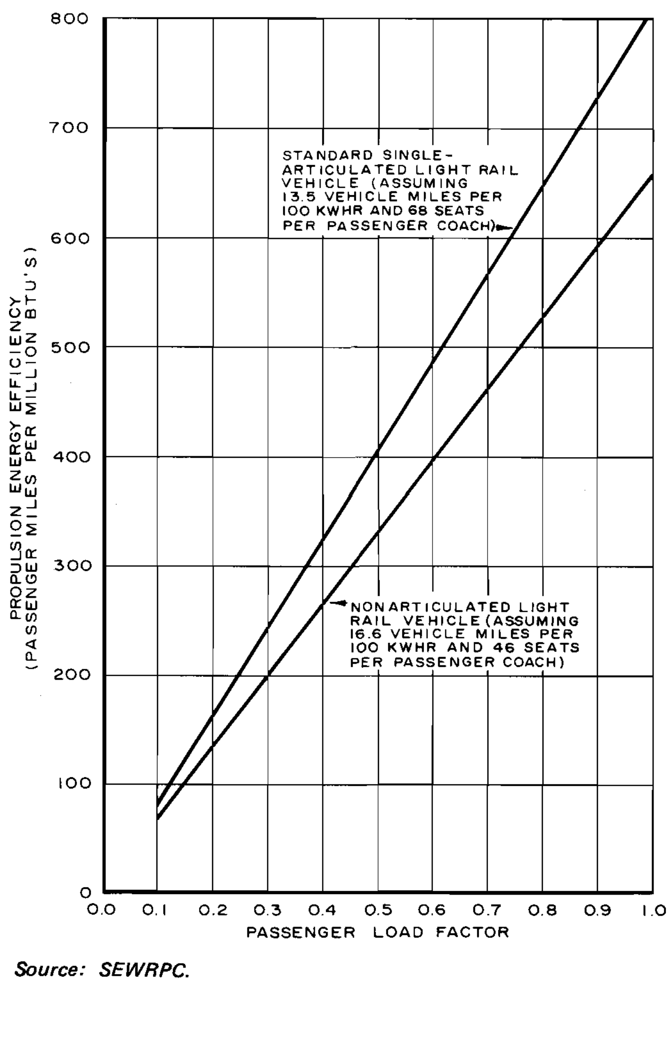
ESTIMATED VEHICLE OCCUPANCY AND PASSENGER LOAD FACTORS FOR SELECTED LIGHT RAIL TRANSIT SYSTEMS: 1977

System	Vehicle Productivity (passenger miles per vehicle mile)	Load Factor (passenger mile per seat mile)
Transport of New Jersey (Newark)	9.4	0.15
Southeastern Pennsylvania Transportation Authority (Philadelphia)	17.7	0.28
San Francisco Municipal Railway	23.6	0.37
Greater Cleveland Regional Transit Authority	26.5	0.42
Port Authority of Allegheny County (Pittsburgh)	27.8	0.44

Source: Congressional Budget Office, U. S. Department of Transportation, and SEWRPC.

Figure 95

VARIATION IN LIGHT RAIL TRANSIT PASSENGER MILES PER AMOUNT OF PROPULSION ENERGY USED VERSUS PASSENGER LOAD FACTOR



Source: SEWRPC.

This design saves both weight and costs and minimizes wheel slip. Nonarticulated vehicles are generally able to climb grades of about 10 percent. Because of the weight of additional unpowered wheels beneath articulation joints, articulated vehicles have a lesser grade-climbing ability.

Most modern light rail vehicles that are designed for operation on a variety of guideways are capable of multiple-unit operation. Multiple-unit capability allows two or more vehicles to be coupled together and controlled from a single console, raising line capacity and operator productivity.

Recent trends indicate a preference for bi-directional vehicles, the advantages of which are the smaller space and facility requirements for reversing vehicle direction—especially when underground operation is involved—and the ability to be loaded from either center or side platforms, since doors are required on both sides of the vehicle. A disadvantage of bi-directional equipment is that a set of doors is necessary on each side. This, along with the additional set of operator's controls, decreases the seating capacity and increases vehicle cost and complexity. There are also twice as many door mechanisms, assemblies that are particularly prone to failure. There is a trend to use single-direction vehicles only on smaller systems and those systems without subway operation.

Passenger access to the vehicle interior is generally through two, four, or six door openings per vehicle side. Several recent vehicle designs allow for both low- and high-level loading via movable steps. Although such apparatus enables a variety of station platforms to be used, the complexity, cost, and overall reliability of the light rail vehicles are adversely affected. High-level loading provides easy access into the vehicles for elderly and disabled persons and is also advantageous for rapid boarding of large passenger volumes. Low-level platforms, on the other hand, place constraints on vehicle door location. Stepwells for low-level loading must be placed away from the tracks, generally making the door position less than optimal.

Passenger doors on light rail vehicles are generally of the folding, or outside-hung plug, type. Various safety interlocks are utilized to prevent passengers from becoming trapped between doors and to prevent vehicle movement when any doors are in the open position. A common European practice is to have the doors equipped with pushbuttons, both inside and outside, which are operated by the passenger. Thus, all doors do not have to be opened at every stop, saving heat and air conditioning. Automatic door closure, which can save time during the boarding process, is photoelectric cell-activated.

Interior design is represented by a large variety of seat arrangements, with two-plus-two across seating being the most common arrangement in North America. On European systems, one-plus-two across seating is commonplace because of narrower vehicle widths. The latter arrangement may also be practical where a large ratio of standees to seated passengers is expected. Wider aisles not only afford a greater total capacity but also facilitate better loading, unloading, and interior flow during peak periods. The vehicle interior configuration and desired level of standing ridership will determine the overall vehicle capacity. Table 45 lists numerous levels of standee comfort. Individual seats are generally permanently installed so that half of the seats face one direction, and half the other direction. This alleviates the need for reversible seats in bi-directional vehicles.

Table 45

STANDARDS FOR TRANSIT STANDEE COMFORT

Standard[a]	Square Feet per Person	Persons per Square Foot
German Transit Crush Load	1.3	0.8
Elevator Crush Load (women)	1.5	0.7
Elevator Crush Load (mixed)	1.8	0.6
North American Transit Crush Load	2.0	0.5
UMTA Transit Design Load	2.5	0.4
German Transit Design Load	2.7	0.4
Crowded Elevator	3.0	0.3
Comfortable Elevator	3.5	0.3
"No-Touch" Crowd	7.0	0.1
Limited "No-Touch" Pedestrian Circulation	10.0	0.1

[a] *These levels of standee comfort are based upon widely quoted German standards, and upon research in pedestrian circulation and elevator loadings.*

Source: Tri-County Metropolitan Transportation District of Oregon and Oregon Department of Transportation, Banfield Transitway Project; Preferred Alternative Report.

Other important considerations in the physical design of light rail vehicles are the suspension and heating and air-conditioning equipment. Primary suspension is provided by either metal or rubber chevron springs, with secondary suspension usually employing air bags. Air suspension increases the vehicle cost and complexity, but automatically adjusts traction, braking, and vehicle level to varying passenger loads.

Heating is generally supplied by forced air from the starting and braking resistors (dynamic braking) and also from electric baseboard units. Air conditioning is principally used on North American systems. Very few European light rail vehicles are so equipped, although such units are available as options.

Heavy Rail Rapid Transit: The typical heavy rail rapid transit vehicle configuration is a single non-articulated design supported by two, two-axle trucks at both ends. The vehicle is of single direction operation with a control cab at one end. Most heavy rail systems semi-permanently couple two cars into "married pairs." Each pair of cars is then bi-directional. However, Philadelphia's Lindenwold Line and the MARTA system of Atlanta operate some single vehicles with control cabs at both ends. Both conventional and modern heavy rail vehicles are from 65 to 75 feet in length, approximately 10 feet in width, and about 11 to 12 feet in height.

Shorter vehicles are currently being produced for certain systems, notably those in Chicago and Boston, because of small radii on some curves. However, since it is desirable for new systems to utilize longer vehicles with greater passenger capacities, shorter vehicles will not be considered herein.

Heavy rail rapid transit vehicles, like light rail transit vehicles, are propelled by relatively low voltage, between 600 and 1,000 volts direct current. The current is transmitted to the electric traction motors via an energized third rail, mounted on the railroad track cross ties on the outside of and adjacent to one of the running rails. Third rail shoes attached to the vehicle trucks slide along the third rail for current collection. Use of a third rail is preferred for operation of high-capacity trains of more than four cars because of the rail's superior conduction properties as compared with overhead trolley wire. However, use of a third rail also necessitates complete grade separation for safety reasons. A very small number of heavy rail rapid transit systems utilize overhead trolley wire for current distribution, including Cleveland's system.

Modern heavy rail systems in the United States, as shown in Table 46, have reported systemwide average vehicle propulsion energy efficiencies of from 12 to 18 vehicle miles of travel per 100 kilowatts of electrical energy used. This variation in energy consumption is a result of not only the

Table 46

VEHICLE PROPULSION ENERGY EFFICIENCY FOR SELECTED HEAVY RAIL RAPID TRANSIT SYSTEMS: 1976

City	Vehicle Productivity (passenger miles per vehicle mile)	Load Factor (passenger mile per seat mile)
Port Authority Trans-Hudson Corporation	17.3	0.24
San Francisco Bay Area Rapid Transit	19.8	0.27
Port Authority Transit Corporation Lindenwold Line	22.5	0.31

Source: Congressional Budget Office, U. S. Department of Transportation, and SEWRPC.

Table 47

ESTIMATED VEHICLE OCCUPANCY AND PASSENGER LOAD FACTORS FOR SELECTED HEAVY RAIL RAPID TRANSIT SYSTEMS

System	Propulsion Energy Efficiency	
	Vehicle Miles per 100 KWHr	Vehicle Miles per Million BTU's
Port Authority Trans-Hudson Corporation	17.6	15.4
San Francisco Bay Area Rapid Transit	15.4	13.5
Port Authority Transit Corporation Lindenwold Line	12.2	10.7

Source: American Public Transit Association, U. S. Department of Transportation, and SEWRPC.

type of vehicle used and its motor control system and weight and optional equipment, but also the characteristics of routes operated, including average speed, frequency of stops, terrain, and weight of passenger loading. The energy efficiency is reported in Table 46 in terms of the vehicle miles traveled both per kilowatt hour, of electrical energy used and per British Thermal Units (BTU's) used. Because of the conversion losses and transmission losses, the energy required to produce the electricity purchased for propulsion by a heavy rail system may be three to three-and-one-half times the energy represented by that electricity. Moreover, because of energy distribution losses in the third rail power distribution system of the heavy rail rapid transit system, about 30 percent of the energy purchased for propulsion may be lost. As a result of these conversion, transmission, and distribution losses, the energy required for propulsion of a heavy rail system may be three-and-one-half to four times the energy actually used in heavy rail vehicle propulsion. These energy losses attendant to heavy rail vehicle propulsion have been included in the heavy rail propulsion energy requirements reported in Table 46.

The number of seat miles provided per unit of energy used is another important measure of the propulsion energy efficiency of heavy rail transit vehicles. Larger vehicles capable of carrying more passengers may consume more energy per mile than will smaller vehicles; however, at high load factors, the energy consumption per seat mile may actually be less for longer vehicles than for shorter vehicles. Therefore, if demand is sufficient to warrant high load factors, a transit system may be able to operate with greater energy efficiency by using larger vehicles which provide more seat miles, and therefore potentially more passenger miles per unit of energy used. An example of such an increase in propulsion efficiency is that provided by a fully loaded "modern" heavy rail vehicle manufactured by Rohr Industries for the San Francisco Bay Area Rapid Transit System. This vehicle provides 44 percent more seats—72 seats compared with 50 seats provided by a "conventional" heavy rail vehicle manufactured by Hawker Siddeley Canada, Ltd., for the Port Authority Trans-Hudson Corporation— while consuming only about 12 percent more energy.

For planning purposes, transit energy efficiency is best measured in units of passenger miles per unit of energy used rather than vehicle miles or seat miles. At a load factor of 1.0—that is, with all seats occupied—energy consumption per seat mile and per passenger mile are equal. Heavy rail systems in the United States, however, presently operate at load factors well below 1.0, as shown in Table 47. These low load factors are the result of operation during periods of limited, as well as peak, passenger demand in order to provide transportation services capable of meeting the needs of passengers for a variety of trip purposes throughout the day. During the peak morning and evening travel periods—when trips carried are being made primarily to and from work and school—it is not uncommon for passenger load factors to exceed 1.0 at the peak load point of transit routes in the peak direction. Because demand drops off past the peak load points, as well as during other periods of the day, however, very high load factors are usually achieved only during the morning and afternoon peak travel periods and only over limited segments of the total transit system. Therefore, measures of transit vehicle energy efficiency need to be based in part on passenger miles per unit of energy used, determined on the basis of realistic load factors. Such load factors are a function of passenger demand which is, in turn, a function of specific route configuration, level of service, and adjacent land use type and intensity, among other things. Therefore, unless specific route configurations and passenger demand are known and analyzed, comparisons of energy consumption expressed as passenger miles per unit of energy used can be reported only as a range, based upon an assumed range of load factors. In order to illustrate the importance of passenger load factors in energy efficiency, the relationship between load factors and passenger miles per unit of energy used for propulsion for both "modern" or larger and conventional or shorter heavy rail rapid transit vehicles is shown in Figure 96.

The heavy rail mode and the light rail mode use basically the same technology for vehicle acceleration and deceleration. Vehicle speed is controlled either by a rheostatic/mechanical method of varying the resistance, or by solid state chopper control. Braking capability is through dynamic braking and disc brakes. Electromagnetic track brakes are not used on heavy rail vehicles. Individual heavy rail rapid transit vehicles are equipped with four traction motors, one propelling each axle. Multiple-unit and bi-directional operation are universally mandatory for the provision of heavy rail rapid transit service.

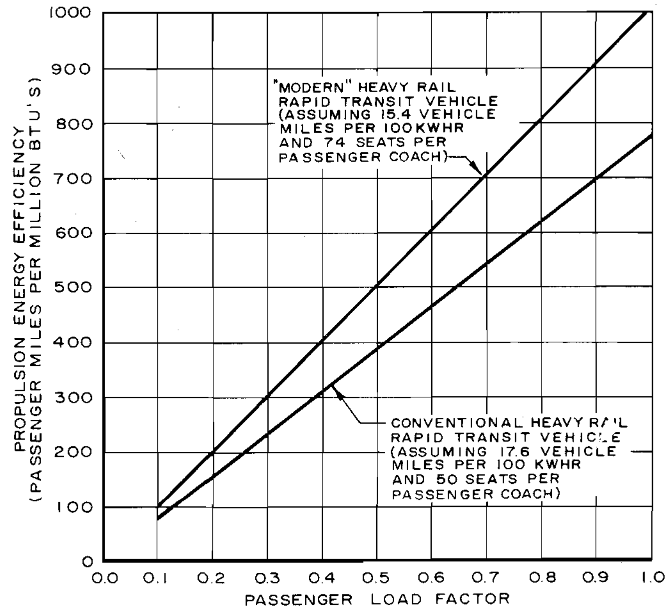
High-level platforms are employed for loading and unloading at stations. Since passengers do not have to negotiate any steps between the vehicle and platform, station dwell time for trains is minimized. Access for the elderly and disabled is also facilitated in this manner. If low-level loading were utilized, possible design problems could be encountered because of the conflict between stepwell and third rail placement.

Heavy rail vehicles have between two and four doors per side. Most doors are of the sliding type, with one-half of each door opening to each side of the doorway by pneumatic door opening mechanisms. Pressure-sensitive edges or photoelectric interlocks prevent the doors from closing on a passenger. Conventional systems use an attendant to control door closing, while modern system door closure is at least semi-automatic.

The interior seating arrangement of heavy rail vehicles, like that of light rail vehicles, is dependent upon policy toward standees. Many types of conventional vehicles are designed to accommodate large numbers of standees and thus have large open floor areas, and in some cases longitudinal seating. However, it would appear that modern heavy rail rapid transit vehicles are designed to accommodate as many seated riders as possible since the typical seating arrangement is transverse two-plus-two seating.

Figure 96

VARIATION IN HEAVY RAIL RAPID TRANSIT PASSENGER MILES PER AMOUNT OF PROPULSION ENERGY USED VERSUS PASSENGER LOAD FACTOR



Source: SEWRPC.

Table 48 presents data on contemporary heavy rail vehicles, both conventional and modern. Selected vehicles are illustrated in Figures 97 and 98.

Commuter Rail: Existing commuter rail rolling stock can be divided into two overall physical configurations based upon the form of propulsion: electrified multiple-unit equipment and diesel-powered equipment consisting of either unpowered passenger coaches pulled by diesel-electric locomotives or self-propelled diesel-mechanical coaches. Electrified commuter operations necessitate a very large initial investment because of the extreme requirements for their electrical power distribution system. As a consequence, all recent applications within the United States have been refurbishments and extensions. An electrified commuter rail

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[3] *Most electrified commuter rail facilities were built between 1907 and 1933, with a limited number of recent extensions constructed during the early 1970's. Electrification of such services occurred not only because of the inherent efficiencies for provision of high-density passenger service, but also because of smoke abatement situations resulting from steam locomotive operation in tunnels and central city areas.*

Table 48

PHYSICAL AND PERFORMANCE CHARACTERISTICS FOR SELECTED HEAVY RAIL RAPID TRANSIT VEHICLES

Characteristic	Conventional Massachusetts Bay Transportation Authority 1200 Series Car	Port Authority Transit Corporation Lindenwold 251 Series Car	Bay Area Rapid Transit District Vehicle	Washington Metropolitan Area Transit Authority 2000 Series Vehicle	Metropolitan Atlanta Rapid Transit Authority Vehicle	Baltimore Regional Rapid Transit Authority Vehicle[a]
Length (feet)	65.3	67.8	75.4[b]	75.0	75.0[b,c]	75.0
Width (feet)	9.2	10.1	70.0[c]	10.1	75.3[d]	10.2
Height (feet)	12.0	12.3	10.5	10.8	10.5	12.0
Net Weight (pounds)	67,000	74,000	59,000[b] 58,400[c]	72,000	76,000	77,000
Truck Centers (feet)	46.5	47.5	50.0	52.0	52.5	52.0
Minimum Horizontal Radius (feet)	120.0	125.0	400.0	225.0	350.0	250.0
Minimum Vertical Radius (feet)	2,000	2,000	1.5 percent per 100 feet	2,000	1.5 percent per 100 feet	2,000
Builder	Hawker-Siddeley Canada, Ltd.	Vickers Canada, Inc.	Rohr Industries	Breda Construzioni Ferroviarie	Societe' Franco-Belge de Materiel de Chamins de Fer	Budd Company
Year Built	1978-1979	1979	1970-1974	1980	1977-1978	1980
Floor Height/Headroom (feet)	3.7/7.1	3.8/7.1	3.2/7.2	3.3/6.8	3.7/6.8	3.6/7.2
Number of Doors per Side	3	2	2	3	3	3
Design Capacity Seats/Standees	58/162	80/20-120	72/48-144	68/119-164	68/72-182[b,c] 62/78-173[d]	74/90-199
Maximum Speed (mph)	65	75	80	75	75	70
Service Acceleration (miles per hour per second)	2.5	3.0	3.0	3.0	3.0	3.0
Service Deceleration (miles per hour per second)	2.75	3.0	3.0	3.0	3.0	3.0
Emergency Deceleration (miles per hour per second)	3.25	Above 3.0	3.0	3.2	3.5	3.2
Maximum Design Grade (percent)	N/A	N/A	4.0	4.0	3.0	N/A
Capital Cost per Unit	$586,000	$942,000	$642,000	$740,000[e] $792,000[f]	$719,000	$616,000

NOTE: N/A indicates data not available.

[a] *Vehicle also to be used by Metropolitan Dade County Transportation Administration.*

[b] *A car only.*

[c] *B car only.*

[d] *C car only.*

[e] *Cam control.*

[f] *Chopper control.*

Source: Manufacturers' Literature, American Public Transit Association, and SEWRPC.

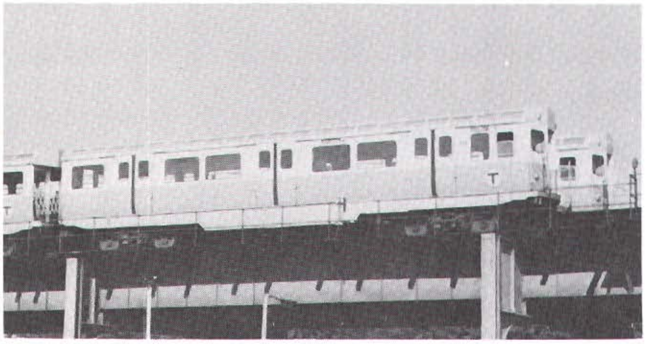
system in the Milwaukee area would require the construction of an overhead power distribution system along the railway lines to be used, including overhead wires, support towers, and substations; the construction of a specialized maintenance, repair, and servicing facility; and the acquisition of electrically propelled coaches and maintenance personnel. Such an investment in fixed plant for contemporary commuter rail operations can generally be justified only under the heaviest traffic loadings. In fact, within the United States, electrified commuter rail systems exist only in the Chicago, New York City, and Philadelphia areas. For this reason, electrified commuter rail is not further discussed herein.

Contemporary diesel-powered commuter train operation is characterized by the utilization of either bi-directional trains of locomotive-hauled coaches, or self-propelled coaches. Bi-directional trains are typically made up of locomotive and unpowered coach combinations, in what are termed "push-pull" train operations. Operation of a bi-directional train is provided in one direction from a control cab within the locomotive pulling the train from the front, and in the reverse direction from a control cab at the end of the rear coach with the locomotive pushing the train. This method of operation eliminates the need for physically turning or switching the train as well as the need for attendant facilities and crews, thereby reducing operating costs and potentially reducing turnaround and layover time.

Bi-level coaches are extensively utilized in the Chicago, San Francisco, and Toronto areas. Capacity is significantly increased over that of single-level equipment without any needed increase in train length and attendant station platforms. Commuter rail systems in the northeastern United States are frequently restricted in their use of bi-level equipment because of limited vertical clearances. In such

Figure 97

TYPICAL HEAVY RAIL RAPID TRANSIT VEHICLE FOR CONVENTIONAL SYSTEMS



Vehicles designed for "conventional" heavy rail rapid transit systems generally resemble standard railway passenger equipment more so than do vehicles designed for modern heavy rail rapid transit systems. Conventional vehicle designs are "squarish" in appearance and incorporate control and signal systems such that the vehicle will be compatible with older equipment already operated on the particular system. This view shows a 55-foot-long heavy rail vehicle typical of those used by the Massachusetts Bay Transportation Authority for operation on its Orange Line.

Photo by Otto P. Dobnick.

instances, and where demand does not justify large train capacities, single-level coaches are used. Single-level rolling stock exists in the form of both modern equipment designed for "push-pull" operation, and older vintage equipment consisting of ex-intercity long-distance coaches that have been either downgraded or remodeled.

In circumstances where the necessary train length and capacity are small, self-propelled coaches have proven to be popular. The seating capacity of such rolling stock is about the same as that of a typical single-level coach, but control cabs are located at each end, and propulsion equipment is mounted below the floor. Self-propelled coaches are bi-directional and have multiple-unit capabilities, although the training, or combining, of more than a few units is generally not considered to be as cost-effective as using a locomotive-hauled train.

At present, the Budd Company's Model SPV-2000 is the only self-propelled coach manufactured in the United States, although a British railbus is to be tested by the Federal Railroad Administration. The railbus vehicle, however, is considered to be as yet unproven, as discussed in Chapter V of this report. Passenger access to the coach interior of all commuter rail vehicles is through one or two doors per car side. Doorways on bi-level coaches are positioned at the car center or equidistant from the ends and are wider than those of single-level coaches to facilitate the larger passenger flows. Single-level coaches typically have doorways locate located at either end of the car. On modern rolling stock, doors are generally of the sliding type and are pneumatically operated, although manual doors are also in evidence. Low-level loading is more common than high-level loading, the latter being in evidence mainly at stations in the Northeast where there is third rail current collection. Interior arrangements are typically two-plus-two transverse seating, with pairs of seats facing each other or "walk-over"-type seating. Specific data on pertinent passenger coach characteristics are presented in Table 49.

Commuter trains are generally propelled by a separate diesel-electric locomotive. Fuel oil, the energy source, is carried on board and fed into the diesel engine, which turns a generator-alternator producing 600 volts direct current, which in turn is used to power the traction motors, typically hung one per axle. The diesel engine also drives the air compressor for the brake system and an auxiliary generator to supply on-board electrical power for the coaches. Because of the dependability of electrical heating during cold weather conditions, steam heating systems are no longer installed on passenger coaches. Except for minor modifications, diesel-electric locomotives used in commuter service are really no different than those used in intercity passenger and freight service.

Self-propelled rolling stock is diesel-mechanical powered. The diesel engine drives a hydraulic torque-converter which transmits power to the drive axles. This type of equipment is designed to operate only with similar vehicles, its performance suffering if used to pull unpowered coaches. Specific performance characteristics for a self-propelled commuter rail vehicle and a current model passenger locomotive are given in Table 50.

The systemwide vehicle fuel efficiency averages for four commuter rail systems in the United States are presented in Table 51. They range from about one to one-and-one-half vehicle miles per gallon of diesel fuel. This variation in fuel use is the result of not only the type of engine and number of cars in the passenger train, but also the characteristics of its route, including average speed, number of stops, and spacing between stops. The energy efficiencies are given in both vehicle miles per gallon of diesel

Figure 98

CONTEMPORARY VEHICLE DESIGNS FOR MODERN HEAVY RAIL RAPID TRANSIT SYSTEMS

PORT AUTHORITY TRANSIT CORPORATION
(PATCO) LINDENWOLD VEHICLE

Photo courtesy of Delaware River Port Authority.

BAY AREA RAPID TRANSIT
DISTRICT (BART) VEHICLE

Photo by Russell E. Schultz.

WASHINGTON METROPOLITAN AREA
TRANSIT AUTHORITY (WMATA) VEHICLE

Photo courtesy of Washington Metropolitan Area Transit Authority.

METROPOLITAN ATLANTA RAPID
TRANSIT AUTHORITY (MARTA) VEHICLE

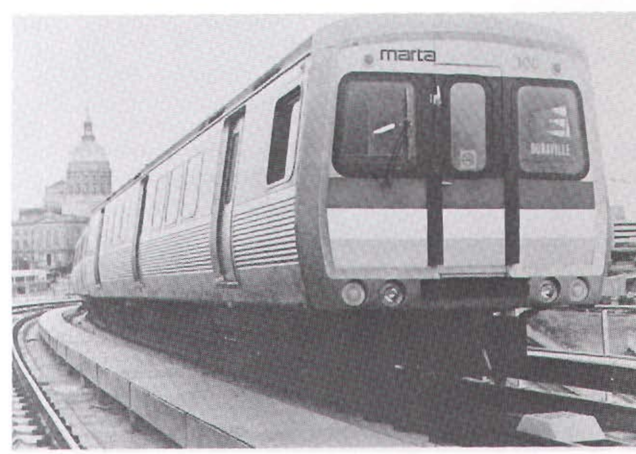


Photo courtesy of General Railway Signal Company.

Contemporary vehicle design for modern heavy rail rapid transit systems in North America typically has a streamlined exterior appearance compared with similar vehicles for older conventional heavy rail rapid transit systems. In addition to design features intended to reduce noise and improve suspension, careful attention is devoted to the aesthetics of the vehicle interiors. Like most conventional heavy rail rapid transit vehicles, modern heavy rail rapid transit vehicles are generally designed to be operated in pairs, thus reducing the amount of control equipment required for dual direction operation of trains.

fuel and vehicle miles per million British Thermal Units (BTU's) used. On the average, a train composed of an electric-diesel locomotive and five bi-level gallery coaches consumes about 0.8 gallon of diesel fuel per mile per passenger car.

The number of seat miles provided per gallon of fuel consumed is another important measure of energy efficiency for transit vehicles. Large trains capable of carrying more passengers may consume more fuel per mile than will smaller trains; however, at high load factors their fuel consumption per seat mile may actually be less than that of smaller vehicles. Therefore, a commuter rail system may be able to operate with greater fuel efficiency by using trains which provide more seat miles and, thus, potentially more passenger miles per unit of energy used. An example of such an increase

Table 49

CHARACTERISTICS OF SELECTED COMMUTER RAIL PASSENGER VEHICLES

Characteristic	Budd Company Model SPV-2000 Self-Propelled Vehicle	Budd Company Bi-Level Gallery Coach	Hawker-Siddeley Double-Deck Commuter Coach	Pullman-Standard Single-Level Push-Pull Coach
Length (feet)	85.3	85.0	85.0	85.0
Width (feet)	10.5	10.6	9.8	10.5
Height (feet)	14.3	15.9	15.9	12.7
Net Weight (pounds)	127,000	103,000[a] 107,000[b]	108,000	74,000[a] 78,000[b]
Truck Centers (feet)	59.5	59.5	64.0	59.5
Year Built	1978 to date	1950 to date	1977 to date	1974-1979
Number of Doors per Side	2 single	1 bi-parting	2 bi-parting	2 single
Design Capacity Seats	88	157[a] 147[b]	162	108[a] 104[b]
Floor Height/Headroom (feet)	4.4/6.7 low	N/A-N/A	2.1/6.6	4.2-N/A
Capital Cost per Unit	$960,000	$544,000[a] $627,000[b]	$685,000	$515,000[a] $605,000[b]

NOTE: N/A indicates data not available.

[a] *Straight coach.*

[b] *Coach with control cab.*

Source: Manufacturers' literature.

Table 50

CHARACTERISTICS OF SELECTED COMMUTER RAIL PROPULSION UNITS

Characteristic	Electro-Motive Division Model F40PH Diesel-Electric Passenger Locomotive	Budd Company Model SPV-2000 Self-Propelled Vehicle
Length (feet)	56.2	85.3
Width (feet)	10.7	10.5
Height (feet)	15.4	14.3
Weight (pounds)	259,000[a]	127,000[d]
Truck Center/Minimum Radius	33.0/315.0[b]	59.5-N/A
Year Built	1976 to date	1978 to date
Maximum Speed (mph)	65[c]	80
Service Acceleration (miles per hour per second)	N/A	0.5[e] 0.6[f]
Service Deceleration (miles per hour per second)	N/A	2.2
Emergency Deceleration (miles per hour per second)	N/A	3.0
Capital Cost per Unit	$929,000	$960,000
Multiple-Unit Capability	Optional	Yes
Horsepower	3,000	360 or 720

NOTE: N/A indicates data not available.

[a] *Loaded weight including fuel and other supplies.*

[b] *Coupled to 89-foot passenger car.*

[c] *Greater maximum speed is available with optional gear ratios.*

[d] *Ready-to-run, without passenger load.*

[e] *One-car train.*

[f] *Two-car train.*

Source: Manufacturers' literature.

Table 51

VEHICLE PROPULSION ENERGY EFFICIENCY FOR SELECTED COMMUTER RAIL SYSTEMS: 1979

System	Train Miles		Average Cars per Train	Vehicle Passenger Car Miles	
	Per Gallon[a]	Per Million BTU's		Per Gallon[a]	Per Million BTU's
Regional Transportation Authority (Chicago)					
Burlington Northern	0.195	1.41	5.5	1.08	7.79
Chicago & North Western	0.278	2.00	5.1	1.41	10.17
Milwaukee Road	0.257	1.85	4.1	1.05	7.57
Massachusetts Bay Transportation Authority (Boston)[b]	0.350	2.52	5.2	1.82	13.12

[a] *These figures include fuel consumed during running layovers and while deadheading equipment.*

[b] *Includes both locomotive-pulled trains and self-propelled vehicles.*

Source: Massachusetts Bay Transportation Authority and Regional Transportation Authority, Chicago.

in energy efficiency is that provided by a fully loaded four-car train which provides 33 percent more seats—628 seats compared with 471 seats for a typical three-car train—while consuming only 15 percent more fuel.[4]

For planning purposes, passenger miles per gallon of fuel consumed is a more important measure than is such consumption in terms of vehicle miles or seat miles. With a load factor of 1.0—that is, with all seats occupied—fuel consumption per seat mile and passenger mile are equal. Commuter rail systems in the United States, however, presently operate at load factors well below 1.0, as shown in Table 52. Therefore, measures of transit vehicle fuel efficiency need to be based in part on passenger miles per unit of energy consumed, determined on the basis of realistic load factors. Such load factors are a function of passenger demand which is, in turn, a function of route configuration, level of service, and adjacent land use and intensity. Therefore, unless specific route configurations and passenger demand are known and analyzed, comparisons of energy consumption expressed as passenger miles per gallon can be reported only as a range based on an assumed range of load factors. In order to illustrate the importance of passenger load factors and fuel efficiency, the relationship between load factors and commuter rail passenger miles per unit of energy consumed is shown in Figure 99.

Commuter rail rolling stock deceleration follows typical mainline railway practice of using an automatic air brake system to activate pneumatic cylinders which control the actual braking function. Diesel-electric locomotives and coaches of older design utilize tread brakes consisting of brake shoes attached to one pneumatic cylinder per car via a brake rigging system. Disc brakes are widely used on new commuter coach designs, usually in addition to tread brakes. The self-propelled coaches also employ dynamic braking furnished by engine brakes on the compression cycle combined with a retarder on the hydraulic transmission.

Typical rolling stock utilized in commuter rail service is illustrated in Figures 100 through 104.

[4] *This assumes the use of one diesel electric locomotive pulling bi-level gallery coaches. The U. S. Department of Transportation has estimated that, on the average, about 15 percent more energy would be consumed for each additional car added to a train for trains between three and seven passenger cars in length. For trains longer than seven cars, about 25 percent more energy would be consumed for each additional car.*

Table 52

ESTIMATED TRAIN AND VEHICLE OCCUPANCY AND PASSENGER LOAD FACTORS FOR SELECTED COMMUTER RAIL SYSTEMS: 1979

System	Train Productivity (passenger miles per train mile)	Vehicle Productivity (passenger miles per rail car mile)	Load Factor (passenger mile per seat mile)
Regional Transportation Authority (Chicago)			
Burlington Northern	334	60.4	0.40
Chicago & North Western	265	52.2	0.35
Rock Island Lines	208	66.4	0.43
Milwaukee Road	197	48.3	0.32
Massachusetts Bay Transportation Authority (Boston)[a]			
Boston & Maine Railroad	83[b]	26.1	0.26

[a] *Includes deadhead mileage.*

[b] *Self-propelled vehicle mileage is considered train mileage; therefore, trains of two or three self-propelled vehicles account for two or three train miles, respectively, while a locomotive propelling coaches accounts for only one train mile for each mile of travel.*

Source: Massachusetts Bay Transportation Authority and Regional Transportation Authority, Chicago.

Guideway Technology

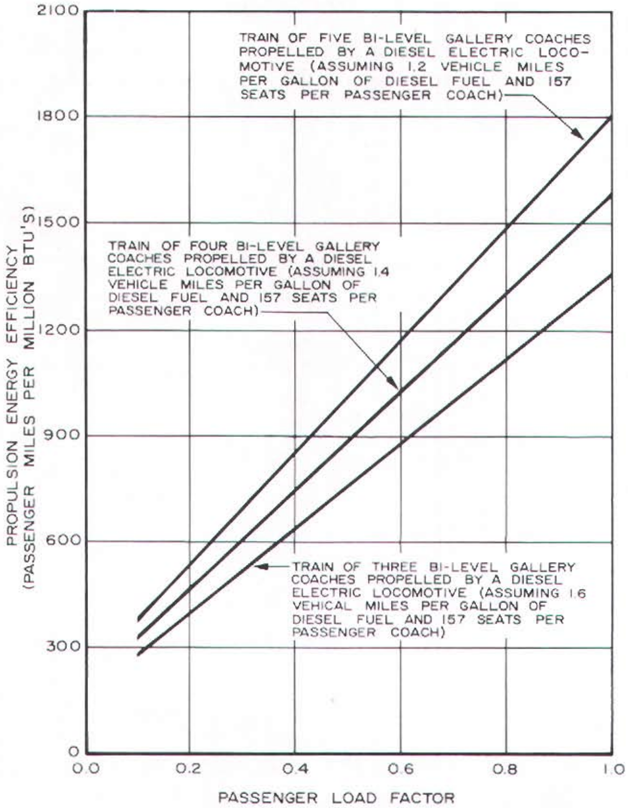
Guideway technology, like the vehicle technology for each of the rail transit modes, is significantly different for light rail, heavy rail, and commuter rail. Although all three modes utilize the basic guidance principle of the flanged steel wheel on steel rail, necessary guideway features vary considerably among the modes. Because of the wide variety of alignment options available for light rail transit facilities, the guideway characteristics of this mode are the most complex. Commuter rail guideway characteristics, on the other hand, are the least complex since only existing mainline railway facilities are normally utilized as a practical matter. Heavy rail guideway characteristics fall between these modes in complexity.

The most basic component common to all three rail transit modes is the track structure and roadbed. There are three basic types of track and roadbed: open track, fixed track, and paved track. Open track consists of steel T-rails attached to creosoted hardwood cross ties with steel tie plates and cut spikes, or of concrete cross ties with elastomeric tie pads and clip-type fasteners or bolts. The track itself is held in place by a layer of crushed stone ballast which holds the track to proper surface and alignment, prevents water from standing on and directly beneath the track, provides resiliency in response to the traffic load, and absorbs noise and vibrations. Open track constructed with hardwood cross ties is utilized for virtually all commuter rail service. Open track construction with concrete cross ties is used for modern heavy rail rapid transit. Reserved right-of-way surface applications of light rail transit utilize either type of cross ties.

The Federal Railroad Administration has promulgated a set of track safety standards that prescribe minimum engineering standards for safe operation of freight and passenger trains over railway lines that are a part of the general railway transportation system of the United States. These standards take into account such items as qualified inspection, roadbed condition, track geometry, and track structure. A total of six classes define specific track conditions—from Class 1 track, which permits a maximum operating speed for passenger trains of 15 mph, to Class 6 track, which permits a maximum operating speed for passenger trains of 110 mph. To adequately provide for commuter rail operation, tracks should meet at least Class 3 requirements, which allow passenger train speeds

Figure 99

VARIATION IN COMMUTER RAIL TRANSIT PASSENGER MILES PER AMOUNT OF PROPULSION ENERGY USED VERSUS PASSENGER LOAD FACTOR



Source: SEWRPC.

Figure 100

BUDD COMPANY SPV-2000 SELF-PROPELLED VEHICLE

The Budd Company SPV-2000 is the only self-propelled diesel rail car currently manufactured in the United States. Basically, this vehicle is a modernized version of the Budd Company's successful RDC (rail diesel car) series of self-propelled passenger coaches manufactured during the 1950's and 1960's. Marketed as being adaptable to all types of passenger train service—intercity, branchline, shuttle, and commuter—the interior of this vehicle can be arranged to seat from 86 to 109 people. The SPV-2000 has undergone demonstration runs in several United States metropolitan areas, including the Milwaukee area in 1980, and, as of late 1980, has been purchased by the Connecticut Department of Transportation for operation by Amtrak between New Haven and Springfield.

SEWRPC photo.

of 60 mph, per hour, and under most conditions, need not meet better than Class 4 requirements, which allow passenger train speeds of 80 mph.

Fixed track consists of steel T-rails attached directly to a concrete slab base with elastomeric pads and special tie plates placed between the rail and slab for noise dampening. Such application is normally used only on elevated structures or in tunnels where a concrete foundation is normally provided. Prevalent on heavy rail systems, light rail tunnels and subways sometimes use open track in place of fixed track. Trackage used for commuter rail must adhere to accepted mainline railway engineering practices; therefore, bridges and tunnels generally use open track.

Paved track is required wherever light rail transit shares the right-of-way with rubber-tired vehicles, such as in mixed traffic operation, reserved lane operation, transitways, pedestrian malls, and certain narrow street medians where ballasted track is not practical. Girder rail, which incorporates a built-in flangeway, is used with paved track, having either shallow grooves, for "streetcar" profile wheels, or deep grooves for railway profile wheels (see Figure 105). North American paved track is constructed in basically the same manner as is open track, using ties, ballast, and girder rail. Pavement is then placed over the ties and up to the top of the railhead, rigidly attaching the track to the pavement. Noise and vibrations are therefore transmitted to the pavement, resulting in a some-

Figure 101

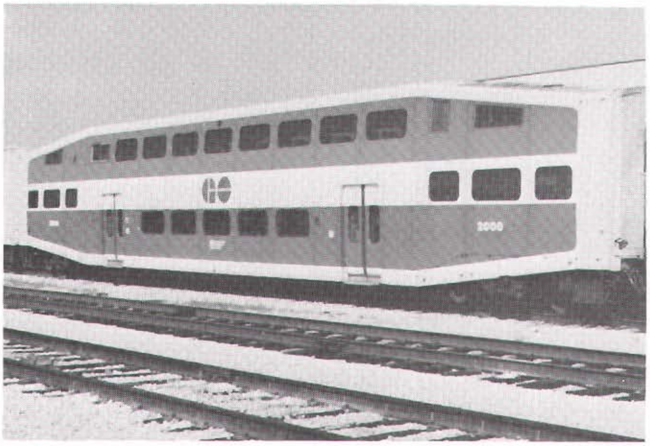
BUDD COMPANY BI-LEVEL GALLERY COACHES

Perhaps the most widely used modern commuter coach in the United States for diesel-electric locomotive-powered commuter train service is the bi-level gallery coach. This design consists of an 85-foot-long suburban coach with two-plus-two seating on the first level and a single row of seats along each side of the upper level, accessible from stairways in the center of the car adjacent to the doorways. A typical coach of this design manufactured by the Budd Company is shown in the photograph on the left. In order to facilitate push-pull train operation, the last coach on each train must be equipped with a control cab from which the train can be operated in the reverse direction. This design feature is shown in the photograph on the right. Bi-level gallery coaches are used in the Chicago, San Francisco, and Montreal areas.

SEWRPC photos.

Figure 102

HAWKER-SIDDELEY DOUBLE DECK COMMUTER COACH

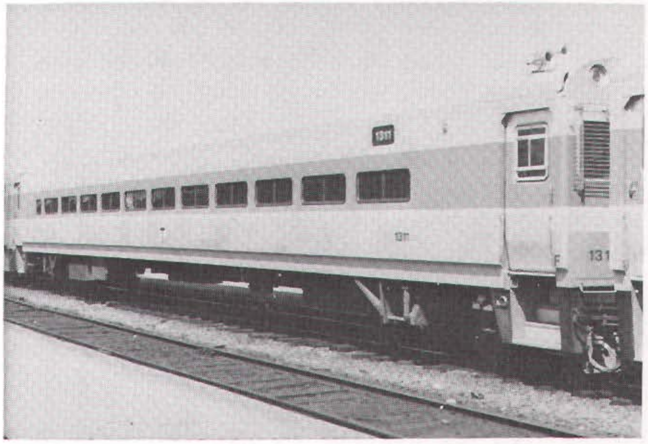


As passenger volumes steadily increased on Toronto's GO Transit system, greater passenger-carrying capacity was required but could not be achieved by increasing train length or frequency. To resolve this problem, Hawker-Siddeley Canada, Ltd., designed a double-deck coach which differs from a bi-level gallery coach in that both levels have two-plus-two seating, resulting in a larger passenger-carrying capacity.

Photo by Otto P. Dobnick.

Figure 103

SINGLE-LEVEL PUSH-PULL COACH



Because of restrictive vertical clearances, new commuter rail rolling stock for the Boston and northern New Jersey areas must be single level. To accommodate such requirements, Pullman-Standard has designed and manufactured a commuter coach for push-pull train operation which is now in service on commuter lines operated by the New Jersey Transit Corporation and the Massachusetts Bay Transportation Authority. This commuter coach design is now being manufactured by Bombardier, Ltd.

Photo by Otto P. Dobnick.

Figure 104

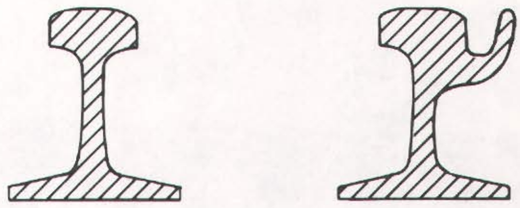
ELECTRO-MOTIVE DIVISION F40PH DIESEL-ELECTRIC PASSENGER LOCOMOTIVE

This diesel-electric locomotive manufactured by the Electro-Motive Division of General Motors Corporation is designed for both intercity and commuter train service, being capable of passenger train performance and speeds, as well as having the capability to supply electrical power for the heating and lighting of passenger coaches. In addition to being the principal diesel-electric locomotive used for Amtrak intercity passenger trains, this design is used for commuter rail service in the Chicago, Boston, and Toronto areas.

SEWRPC photo.

Figure 105

CROSS-SECTIONS FOR T-RAIL AND GIRDER RAIL



Source: SEWRPC.

what noisy track. The vibration and rail movement may also contribute to pavement deterioration.

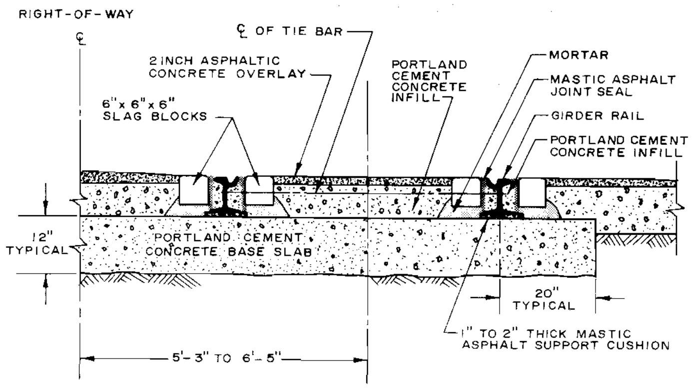
Contemporary European practice for construction of paved light rail transit trackage differs significantly from North American practice. Commonly referred to as "tieless track," European girder rail is rolled with a wider base and is laid directly on the ballast or a Portland cement concrete slab base, without cross ties. Track gauge is maintained by tiebars connecting the two rails, spaced about every 10 feet. The rails are situated within a jacket of mastic asphalt, which absorbs vibrations while supporting vehicle weight and accommodating thermal expansion without permanent distortion. Precast Portland cement concrete or slag blocks are placed between the pavement and the flexible mastic joint, the remaining area between and outside the rails being paved with conventional asphaltic or Portland cement concrete material (see Figure 106). A common German practice is to pave the entire track zone with slag blocks or concrete blocks. Paved track is not used in heavy rail rapid transit or commuter rail applications except to accommodate at-grade highway crossings and in terminal areas.

The size of rail is measured by weight in pounds per linear yard, with selection of the rail size being a function of axle loadings, design stiffness of the track, electrical requirements, cost, and availability. Since commuter rail trackage is also used for freight traffic, rail that is adequate for heavy loadings—usually ranging from 115 to 132 pounds per linear yard—is typically used. T-rails used for the heavy rail and light rail modes typically range from 100 to 115 pounds per yard. Girder rail utilized in paved area applications ranges from 104 to 128 pounds per yard, which matches 100-pound-per-yard T-rail. Contemporary track construction uses continuous welded rail, which provides a quieter and smoother ride, requires less maintenance than jointed rail, and eliminates the need for electrical rail bonding at joints.

Open track requires either hardwood or formed concrete cross ties to maintain track gauge and transfer the load from the rails to the ballast. The practice of attaching the running rails to concrete slabs for commuter and freight rail service is regarded as in the experimental stage. In fixed track applications of heavy rail transit, elastomeric pads or cushions placed directly underneath the rail help absorb vibration and sound transmission. In especially sensitive areas, such as tunnels, "floating" concrete slabs have been installed, although this practice is very expensive. "Floating" concrete slabs are concrete panels to which fixed track is anchored, all of which "floats" on a thin

Figure 106

CROSS-SECTION OF PAVED TRACK



Source: Light Rail Transit: A State of the Art Review, prepared for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago, 1976.

Table 53

TYPICAL TURNOUTS FOR RAIL TRANSIT SYSTEMS BY SHARPNESS OF FROG

Application	Typical Turnout Used		
	Light Rail Transit	Heavy Rail Rapid Transit	Commuter Rail
Yard Trackage.	No. 6	No. 6	No. 8
Low-Speed Crossovers	No. 6	No. 6-10	No. 12
Passing Tracks and Turnbacks. . .	No. 10	No. 10	No. 16
Mainline Junctions	No. 15[a]	No. 15	No. 20

NOTE: Maximum speeds for diverging routes are 10, 15, 25, 30, and 45 mph for number 6, 8, 12, 16, and 20 turnouts, respectively.

[a] *Turnouts in paved trackage may be significantly sharper to conform to available street widths.*

Source: SEWRPC.

layer of lubricant placed on the actual tunnel floor. The liquid lubricant prevents the transmission of vibrations from the trackage to the tunnel structure.

The most common track gauge utilized for new rail transit systems is "standard gauge" track, which is 4 feet 8½ inches between rails. Commuter rail is restricted to this gauge since the existing mainline railway network must be used. Standard gauge is desirable for new heavy and light rail because of the adaptability of existing maintenance and construction equipment, the availability of standardized track parts and supplies, and the ability to receive supplies and materials on-line from common carrier freight railways. Other track gauges do exist, but most are maintained for historic reasons, such as extensive use of a narrower or wider gauge which was never converted, or a desire by the local municipalities to prevent the movement of freight cars.[5]

Turnouts are assemblies that allow diverging tracks to turn out from tangent track. On commuter rail systems, heavy rail systems, and light rail systems where T-rail is utilized, the conventional split railway switch is installed. Consisting of two movable switch points, split switches generally have no speed restrictions on the tangent track. Where girder rail is used in paved trackage, a tongue and mate switch is normally used. A single movable point, the "tongue," is placed on the inside of the curve while the opposite rail has a nonmovable point. Advantages of the tongue and mate switch are its simplicity, low cost, and reduced maintenance. Frequent inspection and cleaning are necessary for turnouts in paved areas, however, and restricted speed is necessary. Typical turnouts used in rail transit are listed in Table 53.

In the design of any fixed guideway transit system, the most restrictive design components which must be considered are the amount of vertical and horizontal space required for each mode's guideway and the minimum clearances required for safe and efficient operation. Typical guideway cross-sectional data are set forth in Figures 107 through 116. However, this information should be recognized as preliminary and of a general systems planning nature. Actual guideway dimensions are dependent upon detailed site-specific designs that are created once a final choice has been made pertaining to mode and alignment.

Light Rail Transit: Of the rail transit modes discussed herein, light rail transit has the greatest variety of alignment options available (see Figures 107 through 111). It is therefore useful at this point

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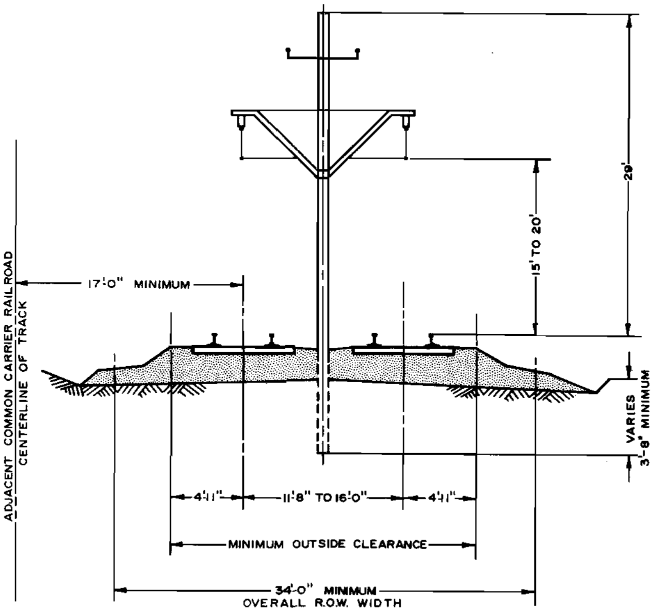
[5] *The San Francisco-Oakland Bay Area Rapid Transit System (BART) choose an unusual track gauge of 5'-6" because it provides a higher degree of lateral stability. New heavy rail systems constructed since BART have, however, returned to use of standard gauge.*

Figure 107

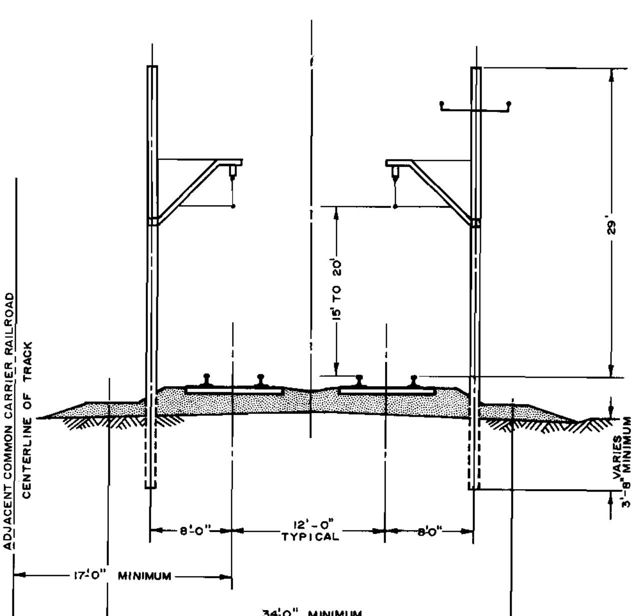
TYPICAL CROSS-SECTION FOR LIGHT RAIL TRANSIT OPERATION AT-GRADE WITH CENTER POLE



Source: SEWRPC.

Figure 108

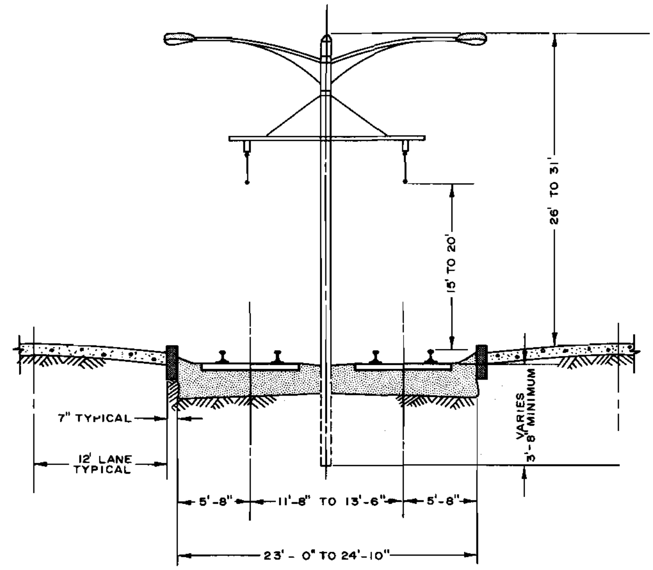
TYPICAL CROSS-SECTION FOR LIGHT RAIL TRANSIT OPERATION AT-GRADE WITH SIDE POLES



Source: SEWRPC.

Figure 109

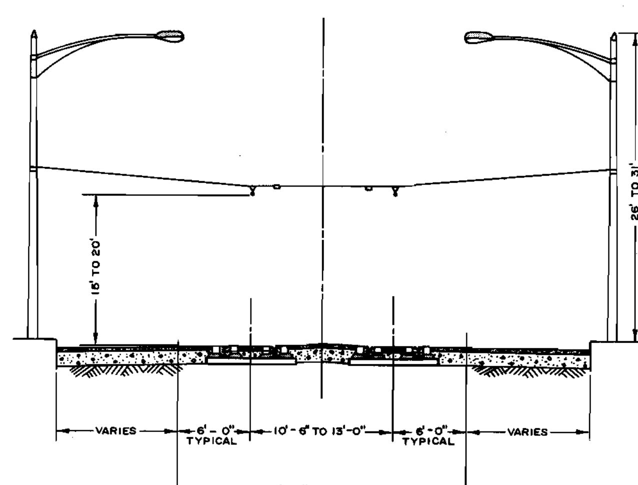
TYPICAL CROSS-SECTION FOR LIGHT RAIL TRANSIT OPERATION IN STREET MEDIAN



Source: SEWRPC.

Figure 110

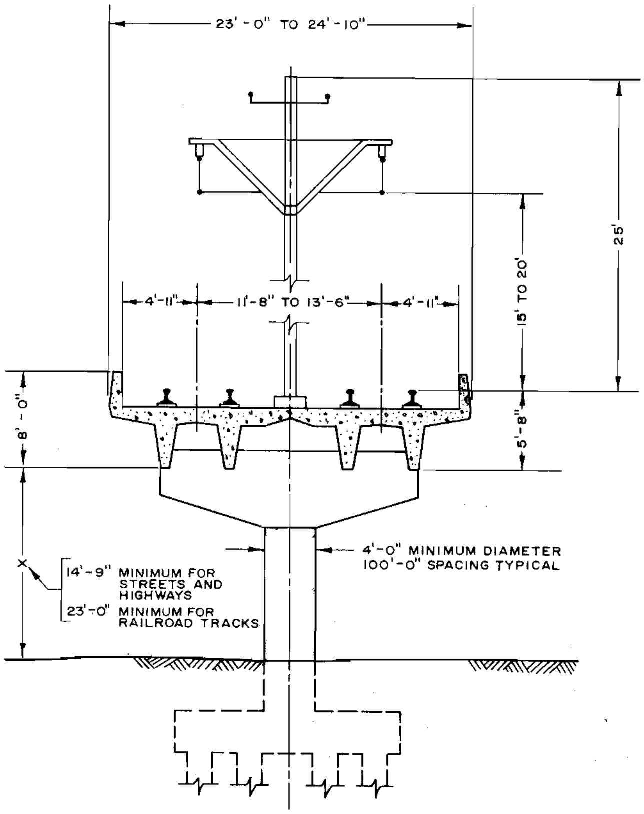
TYPICAL CROSS-SECTION FOR LIGHT RAIL TRANSIT OPERATION IN PAVED AREAS



Source: SEWRPC.

Figure 111

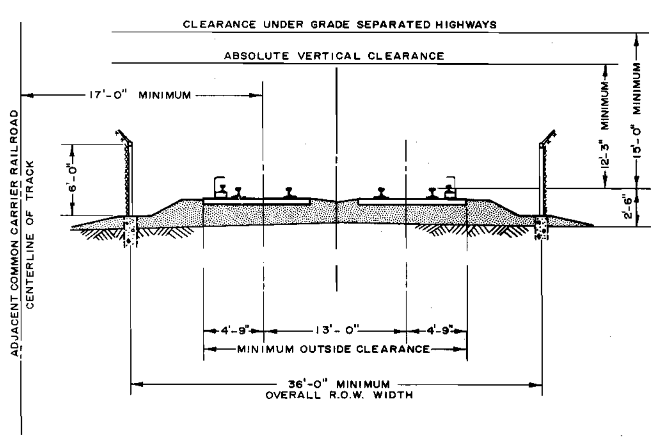
TYPICAL CROSS-SECTION FOR LIGHT RAIL TRANSIT OPERATION ON ELEVATED STRUCTURE



Source: SEWRPC.

Figure 112

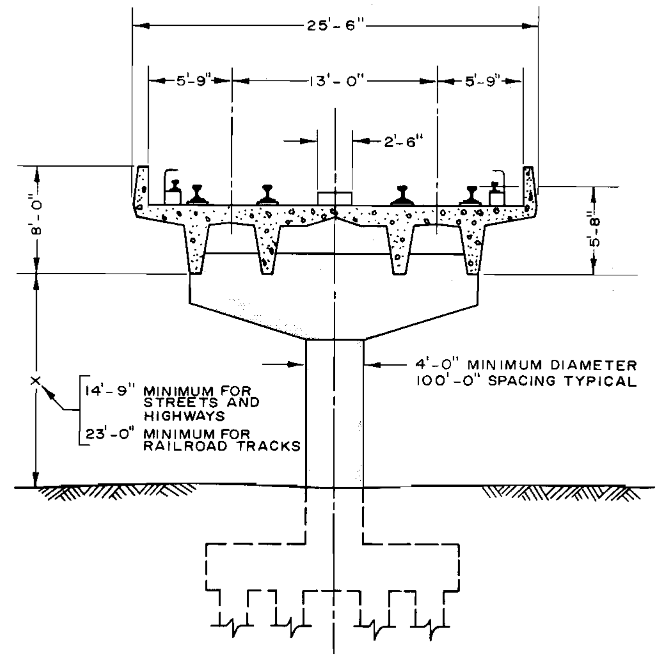
TYPICAL CROSS-SECTION FOR HEAVY RAIL RAPID TRANSIT OPERATION AT-GRADE



Source: SEWRPC.

Figure 113

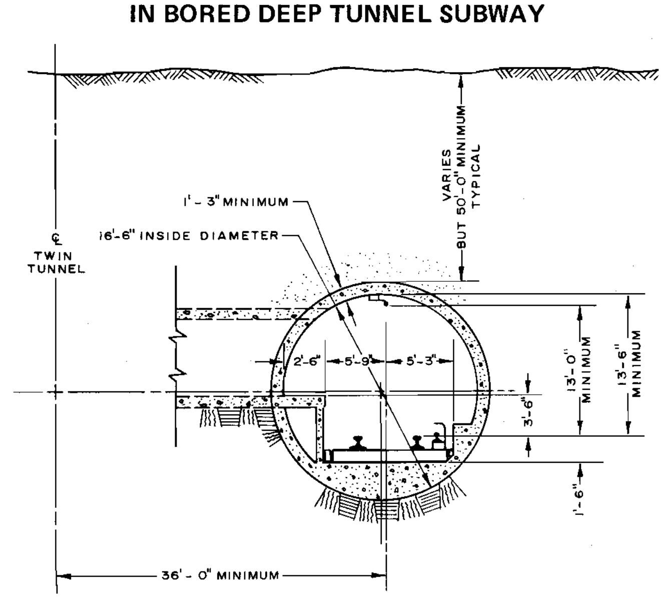
TYPICAL CROSS-SECTION FOR HEAVY RAIL RAPID TRANSIT OPERATION ON ELEVATED STRUCTURE



Source: SEWRPC.

Figure 114

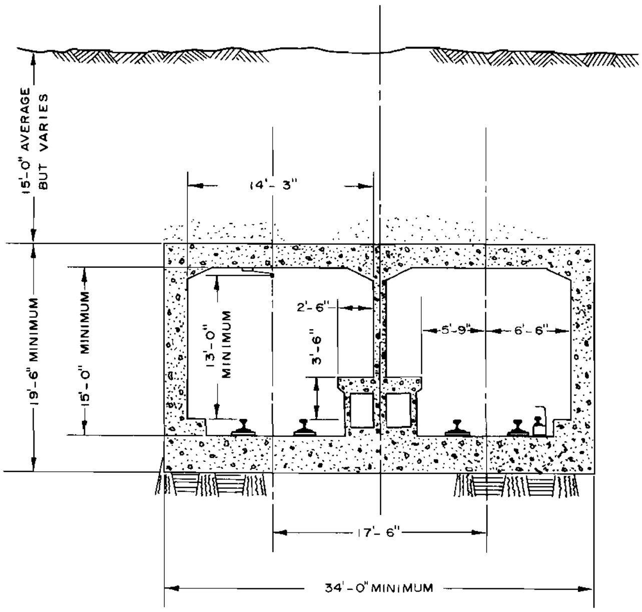
TYPICAL CROSS-SECTION FOR LIGHT OR HEAVY RAIL TRANSIT OPERATION IN BORED DEEP TUNNEL SUBWAY



Source: SEWRPC.

Figure 115

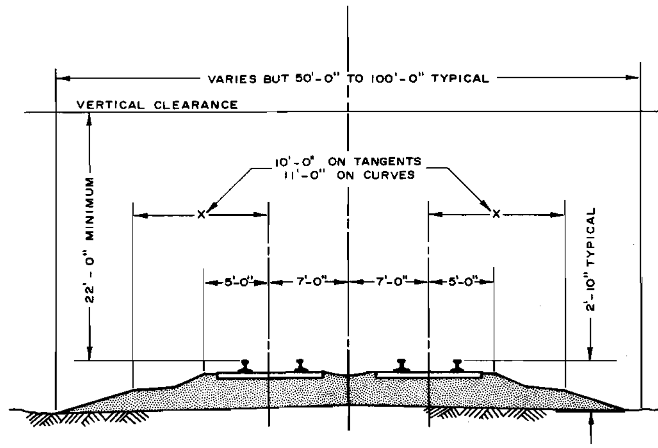
TYPICAL CROSS-SECTION FOR LIGHT OR HEAVY RAIL TRANSIT OPERATION IN CUT-AND-COVER SUBWAY



Source: SEWRPC.

Figure 116

TYPICAL CROSS-SECTION FOR COMMUTER RAIL OPERATION ON MAIN LINE OF RAILWAY



Source: SEWRPC.

to briefly discuss the different types of right-of-way location that could be implemented in a new light rail transit system.

Mixed Traffic Operation: The performance and service quality of light rail vehicles operating on paved trackage in mixed street traffic may be significantly affected by the same handicaps that affect urban transit motor bus operation, but with the additional disadvantage of lower maneuverability which results in even greater delays (see Figure 117). In the design of new light rail systems, mixed traffic operation that requires the guideway to be shared with rubber-tired vehicles should be minimized.

Reserved Transit Lanes: In areas where restricted street widths dictate a need for continuous access across the guideway for driveway or emergency access, paved track may be utilized that is restricted to light rail vehicles. Common treatments include solid striping separating the track zone from other lanes, diagonal striping across the track zone, or mountable concrete or asphalt medians on which the track is located. Such medians are typically raised several inches above the adjacent street pavement (see Figure 118).

Dedicated Street Right-of-Way: The alignment configuration most closely associated with the light rail mode is the reserved right-of-way located in the center of a street, avenue, or boulevard. This may be accomplished by the use of full curbs with a raised or lowered median area, or by separation of the track and street areas with bushes or other greenery, fencing, or concrete barriers. Sufficient width must also be provided in the median area for station areas. Dedicated street rights-of-way offer opportunities for improved operating speeds over those offered by mixed traffic and reserved lane operation since traffic interference and safety hazards are reduced (see Figure 119).

Pedestrian Malls: In many Western European countries, it is popular to use a major shopping street in a downtown area as a pedestrian and light rail transit thoroughfare. Track zones are typically delineated by either curbs, striping, or different-colored concrete blocks or slabs. Such transit malls facilitate light rail operation by removing motor vehicle interference and allowing ready access to the system, in spite of the comparatively low maximum speeds that must be observed for safety reasons (see Figure 120).

An important consideration in the utilization of streets for light rail guideways is the retention of ample motor vehicle capacity. If implementation of reserved lanes or median areas is considered, the remaining street right-of-way should be sufficient

Figure 117

OPERATION OF LIGHT RAIL TRANSIT IN MIXED TRAFFIC

The operation of light rail vehicles in mixed traffic implies the sharing of the right-of-way by the light rail vehicles with automobile, bus, and truck traffic. As shown in this photograph, mixed traffic operation can result in interference with motor vehicle traffic, a situation that can hamper transit system performance during peak travel periods. In fact, extensive mixed traffic operation was one of the important factors contributing to the abandonment of street railway systems in the United States. Light rail transit guideways should be located in mixed traffic where no other reasonable alternative exists and where motor vehicle traffic during rush hours is not severely congested.

Photo by Otto P. Dobnick.

Figure 118

OPERATION OF LIGHT RAIL TRANSIT IN RESERVED TRANSIT LANES

Reserved transit lanes for light rail transit normally consist of paved trackage from which motor vehicle traffic is excluded by pavement markings such as solid lane striping or diagonal striping across the track zone, as shown in this view. Such an application permits access across the guideway for entrance to and exit from marginal access driveways, and for operation of public works, utility, and emergency vehicles.

Photo by Otto P. Dobnick.

to allow at least two driving lanes in each direction, since most light rail routes tend to be located on high-volume streets. This may necessitate the elimination of parking to obtain extra lane capacity.

Although street rights-of-way provide access to most traffic generators likely to be served by a light rail system, a more efficient routing may be achieved through the location on an independent right-of-way, particularly in high-density areas and corridors. Where street rights-of-way are utilized, horizontal curvature and gradients are largely dependent upon the adjacent street pattern and physical development. Use of independent rights-of-way affords more design choices, the minimum horizontal curvature and maximum grades being determined principally by vehicle constraints. Maximum grades are generally from 4 to 9 percent, depending on the vehicles used. Minimum radii on horizontal curves are similarly dependent upon vehicle selection; however, a typical minimum centerline of track radius for a mainline light rail guideway is 750 feet, which translates into an approximately eight-degree curve.

Because fixed guideways for light rail transit can be constructed on a wide variety of rights-of-way, ranging from existing public streets within densely developed urbanized areas to fully grade-separated, exclusive alignments, such guideways may be classified into two categories, such as has been done for busways (see the section entitled "Guideway Technology" in Chapter II, "Motor Bus Technology"). The first category—Class A guideways—provides for high-speed operation over an exclusive, but not necessarily fully grade-separated, right-of-way, which incorporates gentle horizontal curves and gradients. A light rail transit system which makes generous use of Class A guideways should be capable of providing an overall level of service similar to that of Class A busways and approaching that of a heavy rail rapid transit system. The second

Figure 119

DEDICATED STREET RIGHT-OF-WAY FOR LIGHT RAIL TRANSIT OPERATION

A street right-of-way can be dedicated for light rail transit operation in a number of ways, including the use of an existing median area, the creation of a new median area, the separation of the track and street areas by bushes or other greenery, the removal of pavement in the track zone, or the placement of concrete curbs. The photograph on the left illustrates a practice utilized by the San Francisco Municipal Railway; the track zone has been raised by several inches yet left paved for access by emergency vehicles and use for turning movements into and out of marginal access driveways. The pavement, however, has a rough texture to discourage motorists from using the track zone as a driving lane. The photograph on the right illustrates the use of a median area for light rail transit operation.

Photo (left) courtesy of San Francisco Public Utilities Commission.
Photo (right) by Otto P. Dobnick.

Figure 120

OPERATION OF LIGHT RAIL TRANSIT IN PEDESTRIAN MALLS

Particularly good locations for light rail transit guideways in congested commercial areas are public streets which can be converted into what are referred to in Western Europe as a "tram-pedestrian mall." Experience has shown this measure to create a desirable pedestrian-oriented environment in shopping areas as well as to enhance the performance of the light rail transit operation because of the elimination of conflicting motor vehicle traffic. Track zones on such rights-of-way are typically delineated by either curbs, pavement markings, landscaping, or changes in the color and texture of the pavement surface.

Photo (left) courtesy of Siemens Corporation.
Photo (right) by Otto P. Dobnick.

category—Class B guideways—provides a somewhat lower level of service because of the greater utilization of arterial street rights-of-way as well as the utilization of sharper horizontal curves and steeper gradients in order to minimize community disruption attendant to right-of-way acquisition for, and construction of, grade-separated guideways. Preferential treatment at controlled intersections should be provided with Class B guideways so that the transit vehicles can achieve acceptable average speeds. As with busways, Class A and Class B alignments may be combined within a single system or route.

Freeway Rights-of-Way: Alignments may be located on either side of a freeway or expressway between the shoulder and edge of the right-of-way, or within the median area, the latter generally being viable in newer outlying freeways where there is a sufficiently wide median. Considerations for such an application include proper pedestrian access, space for parking facilities, and integration of the light rail line with existing highway geometrics and structures.

Railway Rights-of-Way: Existing railway rights-of-way represent a ready-made alignment in built-up urban areas. Typically, where such rights-of-way are utilized, separate light rail transit trackage is installed to avoid many of the institutional, operational, and engineering problems which would arise from joint use of trackage with conventional freight operations. In some instances, light rail implementation may require the existing track to be shifted, industrial spur leads to be rearranged, and selected portions of the right-of-way to be widened for transit stations (see Figure 121).

Joint use of existing railway track by light rail and standard railway freight operations, while possible, is generally avoided because of potential conflicts between the two types of operations and the safety hazards involved. The expectation of cost savings through the use of existing track is seldom found, due to the low quality of common carrier track found on many present day railway lines. Problems inherent in the joint use of new facilities include, but are not limited to, significant differences in vertical and lateral clearance requirements, in gradients, in axle loading requirements for track construction, in train lengths and speeds and therefore signal requirements, and in deceleration characteristics which affect grade-crossing protection requirements.

Figure 121

OPERATION OF LIGHT RAIL TRANSIT ON RAILWAY RIGHTS-OF-WAY

If adequate cross-sectional area is available, existing railroad rights-of-way may represent an economical alignment option for light rail transit guideways, especially in developed urban areas. In North America the new light rail transit systems in Calgary and Edmonton and in San Diego utilize railroad rights-of-way for significant portions of their routes.

Photo by Russell E. Schultz.

Grade Separations: In designing light rail transit systems, it may be desirable to employ grade separations at certain points of potential traffic conflict. At complex or high-volume street or highway intersections, under- or overpasses could be developed. Depressed grade separations are generally preferred for operational, cost, and aesthetic reasons. Since light rail vehicles are capable of negotiating 4 to 9 percent grades, approaches can be considerably shorter than those required for heavy rail or commuter rail systems. Because of the delays that would be attendant to at-grade location at active railway lines, grade separations at active railway lines are preferred. Light rail system overpasses require a minimum 23-foot clearance to pass over a railway right-of-way, as opposed to a minimum 14-foot 9-inch clearance to pass over a street or highway, making railway overpasses both longer and more costly. Lengthy aerial segments are not common on light rail systems. It should be remembered that while grade separations positively affect the quality of transit service, they are the most costly alignment option outside of subways.

Subways: Subways are frequently utilized to gain exclusive right-of-way in high-density locations, system bottlenecks, and some downtown distribution segments. Light rail subway construction is generally similar to heavy rail rapid transit subway construction (see Figure 115). Cut-and-cover is the more common practice, although bored tunnels are constructed where geophysical conditions allow. If eventual conversion of the subway alignment to heavy rail operation is contemplated, the underground facility must be designed and built to "pre-metro" standards in order to facilitate the underground structure's ultimate use. An important factor to remember is that the high cost of underground guideways can negate a major cost advantage of selecting light rail as the primary transit mode.

Other Rights-of-Way: There are various other alignment options for a potential light rail system because of its predominant application as a surface mode. Abandoned electric interurban and trunkline railway rights-of-way may offer a ready-made alignment if the rights-of-way are intact. Several recent light and heavy rail extensions have been constructed on abandoned railway rights-of-way. Utility rights-of-way may be used in a similar manner if they coincide with the transit corridor. Subject to certain design and environmental considerations, parks and other open spaces present yet another location option.

Heavy Rail Rapid Transit: The guideway alignment options for heavy rail rapid transit are far less complex than those for light rail transit. Typical cross-sections of the guideway types available for heavy rail rapid transit are illustrated in Figures 112 through 115. Because the current distribution system utilizes an electrified third rail, surface portions are typically fenced off, with no grade crossings with streets or railways. New systems tend to utilize either expressway medians or railroad rights-of-way for surface segments because of the expense and impacts of acquiring right-of-way in built-up areas. Use of railroad rights-of-way frequently entails the rehabilitation of the existing railroad roadway and structures. When railroad right-of-way is utilized, aerial guideway segments are commonly used to provide for grade-separated crossings of the main line and numerous sidings and industrial spur tracks. Elevated guideway segments are also utilized in congested areas and along streets and highways when no other nearby right-of-way is readily available (see Figure 122).

Modern heavy rail subway segments are typically used in central business districts, established built-up areas, and other major activity centers. Subway alignments in such areas tend to be located directly

Figure 122

TYPICAL GUIDEWAY CONFIGURATIONS FOR HEAVY RAIL RAPID TRANSIT

Because heavy rail rapid transit alignments must be fully grade-separated, lengthy elevated structures are found on most systems. As shown above, complicated structures are frequently required to allow the transit guideways to pass over existing street and railway rights-of-way, as on MARTA's East Line in Atlanta.

Photo by Otto P. Dobnick.

In the United States, railway rights-of-way have become a popular location for new heavy rail rapid transit guideways, particularly in intensively developed urbanized areas. However, as was the case in Atlanta, the use of such rights-of-way may entail expensive relocation of existing railway tracks and structures.

Photo by Otto P. Dobnick.

Where sufficient cross-sectional area exists, freeway and expressway rights-of-way offer economical locations for heavy rail rapid transit facilities. The Chicago Transit Authority has pioneered the use of this concept and has constructed segments of three heavy rail rapid transit routes in freeway medians.

SEWRPC photo.

below major streets, deviating only to provide gentle curves so that major operating speed reductions are not necessary.

Absolute minimum horizontal curvature depends upon the specifications of the vehicles selected. Minimum track centerline radii for modern heavy rail vehicles vary between 200 and 400 feet, although such curvature is restricted to storage yards and emergency crossovers between double tracks. Typical mainline minimum horizontal curvature for heavy rail is similar to that for commuter and common carrier freight trackage, with values usually ranging between one and seven degrees—radii of 5,729 and 818 feet, respectively.

Maximum grades are also dependent upon vehicle specifications, modern heavy rail vehicles generally being able to climb 3 to 4 percent gradients.

Commuter Rail: By definition, implementation of any new commuter rail system is limited to the existing mainline common carrier railway network that radiates out of the central business district. Therefore, the completed guideway is already in place, making further detailed discussion unnecessary, although it should be noted that upgrading of the condition of individual tracks to be utilized is generally necessary to some extent.

Nevertheless, a typical double-track mainline cross-section is illustrated in Figure 116 so that a comparison may be made of the guideway requirements for the various rail transit modes. Additional grade separations for existing railway main lines would not be anticipated solely on the basis of commuter rail service implementation.

Horizontal curvature for railway main lines in southeastern Wisconsin typically ranges from zero to two degrees—2,864-foot radius—with sharper curves of up to 12 degrees—477-foot radius—only in yards, at junctions, and in terminal areas. Maximum grades on such track typically range between one-half and 1 percent, although several other factors must be considered, including, importantly, the length of the grade.

Station Characteristics

Detailed characteristics, such as dimensional data and land requirements, of rail transit stations cannot be provided without site-specific information on individual facilities. Therefore, only general dimensions and considerations are discussed herein.

Of the three rail modes, heavy rail rapid transit utilizes by far the most elaborate, costly, and areally demanding stations. Typically spaced from 0.3 mile to 1.2 miles apart, facilities constructed for modern heavy rail generally consist of two levels. The platform level is equipped with high-level boarding platforms—either side or center islands—seating, transit information, and radiant heaters if winter climatic conditions warrant such devices. The second or concourse level contains facilities for fare collection and interface with other transit routes. The practice of providing newstands and other small convenience shopping facilities within transit stations is common in Europe, but rare in the United States. The concourse level is situated either at ground level or between the ground and track levels for guideways located either at-grade or on aerial structures, while subway station concourses are usually located beneath the street level but above track level. The various levels are connected by stairways and escalators or moving sidewalks. In addition, recent requirements necessitate elevators for use by the elderly and handicapped. Because heavy rail stations are usually enclosed, security equipment such as closed circuit cameras and communications devices are often necessary (see Figure 123).

Heavy rail stations vary from 300 to 700 feet in length, depending upon the longest train length which must be accommodated at the platforms. Overall widths are generally a minimum of 45 feet, with concourse levels sometimes being wider in subway segments. Actual platform width should be no less than 12 feet. A common feature of some underground stations is direct pedestrian access via passageways to adjacent activity centers such as shopping areas, convention complexes, and other business establishments.

The space requirements and total cost of heavy rail stations, as well as of commuter and light rail stations, are dependent upon how the rail transit line is integrated with other transportation services. Most new systems are designed to utilize transit feeder routes and park-ride lots to attract substantial ridership. Transit feeder routes require berthing facilities for motor buses as well as sheltered walkways and waiting areas for passengers transferring between modes (see Figure 124). In order to attract park-ride customers large parking lot capacities are required, which in turn necessitate large land parcels if single-level structures are used, or a large capital investment if multiple-level structures are used. The actual size of a specific lot depends upon the ridership anticipated at the station. For single-level parking lots with intermeshed multiple parking lanes, the gross area required per parking space typically varies between 246 and 255 square feet, depending upon the parking angle. For self-parking multiple-level parking garages, the gross area varies from 350 to 400 square feet per parking space.

Figure 123

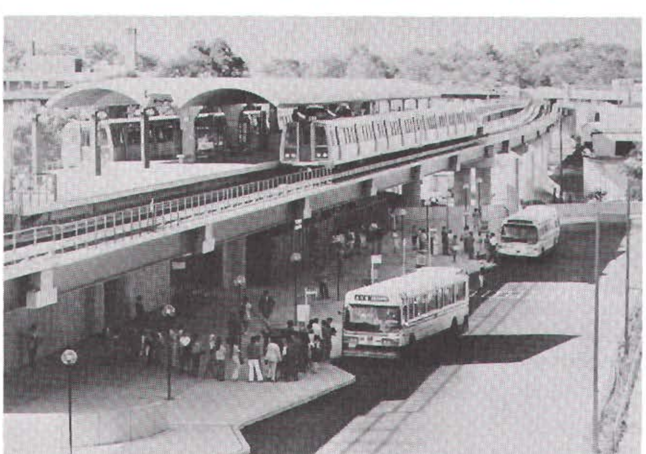
TYPICAL HEAVY RAIL RAPID TRANSIT STATIONS

In most instances, stations for heavy rail rapid transit are elaborate facilities resulting from the need to accommodate long trains with high-level boarding of passengers, in addition to fare collection and intermodal transfer facilities. The photograph on the left shows the West Lake Station on MARTA's West Line in Atlanta prior to the facility's opening, and exemplifies a large station design for either at-grade or elevated alignment. The photograph on the right shows the interior of the Pentagon City Station on the Metro Red Line in the Washington, D. C., area. Subway stations in urbanized areas can be very expensive and usually require three to four years for construction.

Photo (left) by Otto P. Dobnick.
Photo (right) courtesy of Washington Metropolitan Area Transit Authority.

Figure 124

TYPICAL INTERMODAL TRANSFER FACILITY



Most outlying stations for light rail transit, heavy rail rapid transit, and commuter rail systems are designed to facilitate the transfer of passengers to and from both automobiles and feeder buses. This view of the Rhode Island Avenue Station on Washington's Metro system illustrates the accommodation of connecting feeder buses with individual bus bays constructed at the station entrance and exit.

Photo courtesy of Washington Metropolitan Area Transit Authority.

Station configurations for the light rail mode can be chosen to conform to the desired capital investment. Light rail stations are typically spaced at 0.2 to 0.5 mile intervals and basically fall into two categories: those at grade and those with controlled access.

Because the light rail mode frequently uses on-board or self-service fare collection procedures, only simple facilities are used for at-grade stations at low-volume locations and on right-of-way widths that are constricted, such as where the guideway is situated in reserved street lanes or in street medians. Such stations are relatively simple, generally consisting of the platform, signing, lighting, a small amount of shelter, and proper pedestrian access. Platform length should be able to accommodate the longest light rail trains, with typical lengths ranging from 100 to 330 feet. Platform widths vary between 6 and 12 feet. In heavily trafficked areas where either large volumes of riders are expected or several light rail routes share the same track, station and platforms may have to be designed for simultaneous loading of more than one train or vehicle (see Figure 125).

Figure 125

TYPICAL LIGHT RAIL TRANSIT STATIONS

These photographs illustrate typical station facilities that exist on the San Francisco Municipal Railway (left) and the Massachusetts Bay Transportation Authority (right) light rail transit systems. Such station facilities can be very simple and, except for the need for loading platforms, are very similar to local bus stops, with little more in the way of facilities than proper signing, access, and possibly a shelter.

Photo (left) courtesy of San Francisco Public Utilities Commission.
Photo (right) by Otto P. Dobnick.

Controlled access stations are employed at major transfer stations or where large passenger volumes are anticipated. Such facilities largely incorporate heavy rail rapid transit station design. Controlled access stations are utilized whenever the light rail alignment is located in a subway. Where the "pre-metro" concept is used, stations must be designed for ultimate use as heavy rail facilities. Platforms for underground stations may be 300 or more feet long (see Figure 126).

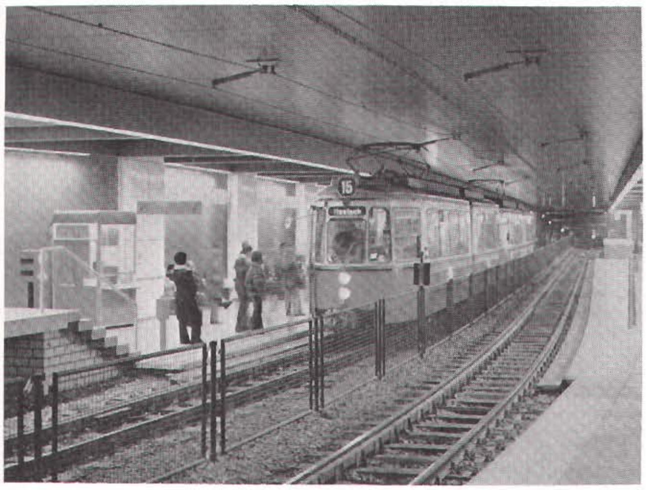
In designing a light rail system, an important decision is whether to use high-level, low-level, or dual-level loading, since platform height affects not only the station design, but also vehicle design, system performance, and rider accessibility. High-level loading and unloading offers the advantages of shorter station dwell times and ready access for the elderly and handicapped, assuming that ramps are used for platform access instead of steps. Although high-level loading involves a greater initial investment than does low-level loading, the difference may be able to be offset by the cost of the less complex vehicles that will be required since stepwells or movable steps are not needed (see Figure 127).

The location of stations or stops when the light rail guideway is located on a public street right-of-way deserves special attention because of the potential impacts on motor vehicle and pedestrian traffic (see Figure 128). Where a median already exists, this median must be widened, and where the guideway is located in reserved lanes, a safety island must be installed both to physically protect people boarding or alighting from the transit vehicles, and to prevent delays to motor vehicle traffic. Where heavy volumes of left-turn traffic are expected, either a special left-turn lane can be installed or the boarding island can be placed on the far side of the intersection. These actions presume the dedication of either driving or parking lanes to light rail usage near stations and intersections. In special cases, the left-turn movements may be allowed from the track lane. Where the median area is of sufficient width, the guideway can be placed on a reverse curve through the intersection to gain space for the platforms. Turnaround loops, layover tracks, and stations at major transfer points are typically located on off-street parcels. It should be apparent that any light rail guideway designed for use on street right-of-way will require detailed traffic engineering studies so that any impacts on pedestrian and motor vehicle traffic resulting from land or intersection modification can be appropriately treated.

Commuter rail stations are the least complicated of those used by the three rail modes and have the largest spacing, ranging from 0.7 mile to 2.8 miles. The actual facilities in many instances include only

Figure 126

LIGHT RAIL TRANSIT STATION DESIGNED FOR PRE-METRO OPERATION



In situations where light rail transit facilities are proposed to be eventually upgraded to heavy rail rapid transit operation, stations must be designed for this ultimate use. Such light rail transit facilities are termed "pre-metro." Pre-metro light rail transit subways have been constructed in Western Europe and employ a low-level platform that can be readily raised upon conversion to heavy rail rapid transit. In this view of an underground light rail transit station in Stuttgart, West Germany, note the stairway leading from the high-level platform to the low-level platform.

Photo courtesy of Brown Boveri Canada, Ltd.

platforms, generally one on each side of the double track, as opposed to a center platform. If there is a major station structure, it is probably a railroad passenger station that is also used for freight or intercity passenger operations. Some recent commuter station renovation projects have installed transit waiting shelters. Besides lighting and signing, parking space is a major component of commuter rail stations since commuter rail depends upon a large park-ride attraction (see Figure 129).

Since commuter trains are often lengthy, long platforms may be required to accommodate the entire train length. Typical platform lengths vary between 500 and 1,000 feet. Low-level loading may be used, requiring only low-level platforms.

Support Requirements

Support requirements for all three rail transit modes consist of five principal elements: vehicle storage and maintenance, guideway and structure maintenance, power supply and distribution, traffic control, and fare collection procedures. The extent to which each of these ancillary elements is applied to any new system depends upon the site and operational specifics of that system which evolve from a detailed engineering design. The information presented in the following sections is considered sufficient for consideration of support requirements for systems planning.

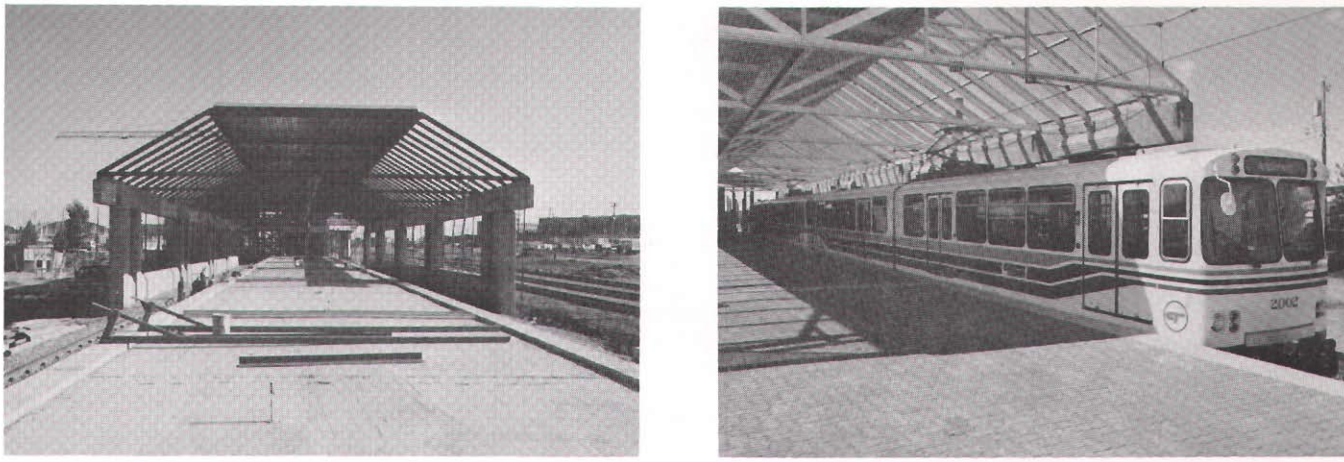
Vehicle Storage and Maintenance: Vehicle storage for light rail transit and heavy rail rapid transit systems consists of storage yards large enough to hold all vehicles not in service during the system's least active operating period. If the system is relatively small, or contains only a single route, vehicle storage and shop/maintenance facilities are generally combined at a single location in order to avoid the cost of multiple buildings and facilities. On larger systems, it may be necessary to provide storage capacity at several locations because of the extensive land requirements combined with the need to minimize nonrevenue operation of trains. When locating more than one vehicle storage yard, the outer ends of routes are generally chosen. Light rail yards, and to a lesser extent heavy rail yards, are sometimes combined with, or located adjacent to, motor bus garage facilities. Commuter rail rolling stock is simply stored on side tracks at the outermost station of each route. During midday layover periods, commuter rolling stock not in use either remains at the downtown station or is held in a nearby coach yard.

Because light and heavy rail vehicles are propelled by electric motors, as opposed to internal combustion engines, indoor storage is not mandatory. Commuter rail equipment is invariably stored outside. Storage yards should include the appropriate apparatus for daily servicing. Such servicing would include fare removal, sanding, washing, interior cleaning, and light inspection.

Shop facilities for light and heavy rail vehicle transit systems are usually designed to handle both light or "running" repairs and heavy maintenance and repairs. Appropriate components for a shop facility include diagnostic equipment, underfloor pits, wheel-trueing equipment, apparatus for either jacking or lifting the vehicle bodies, a drop table for truck removal, a machine shop for mechanical and electrical work, an electronic shop, and a paint booth. Major inspection and repairs for commuter rail rolling stock are usually handled by the common carrier railway that is directly involved. The principal construction items for maintenance

Figure 127

TYPICAL LIGHT RAIL STATION FOR HIGH-LEVEL LOADING



High-level boarding has been selected for use in the new light rail transit systems in Calgary, Edmonton, and San Diego. These views of one of the outlying stations on Calgary's system—which was still under construction as of 1980—illustrate the simple design possible for light rail transit stations even with high platforms and at major stops. Similar high-level-loading stations can be accommodated in downtown areas with narrower platforms, and shelter for pedestrians can be provided by awnings instead of the canopy shown here.

Photos courtesy of the City of Calgary Transportation Department.

facilities include site preparation, earthwork, drainage and utilities, buildings and shops, shop equipment, parts storage, staff facilities, track work, electrification, landscaping, and security.

Guideway and Structure Maintenance: The major elements of guideway and structure maintenance are apparatus, personnel, and operations which are necessary to maintain and repair the track structure and roadway. Specialized equipment and expertise must be available to the system for such tasks as cross-tie replacement, rail repair, pavement and grade-crossing repair, track surfacing and aligning, bridge maintenance and repair, and snow removal. Machinery would be the same as is required for all rail transit modes. These requirements may be satisfied in one of two ways. If a system is comparatively large, economies of scale may dictate that the majority of routine maintenance and repair tasks be carried out by internal forces. Smaller systems may find it to be more cost-effective to handle only minor items internally and to contract for extensive maintenance and major repairs. Regardless of how much work is contracted for, a certain level of staff and equipment will be required, not only for minor guideway repairs but also for right-of-way maintenance and sanitation, station and sign repair, and general grounds-keeping activities.

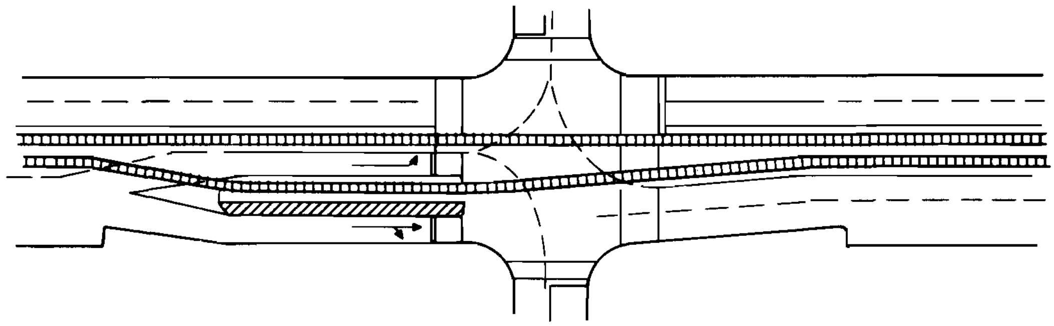
Depending upon the size and responsibilities of the maintenance staff, space will have to be allocated for personnel facilities, shop facilities, material storage, and motor vehicle storage. Depending on the size of the motor vehicle fleet, it is likely that a garage and mechanic will be necessary for truck servicing and repair. These facilities are typically located adjacent to the rail vehicle shop or storage yard.

Track, roadbed, right-of-way, and structure maintenance and repair for commuter rail operations are the responsibility of the railway company over which the service is run. Since the trackage is usually shared with freight train movements, the percentage of maintenance expenses attributable to commuter service is generally prorated according to predefined terms stipulated in a purchase-of-service agreement between the railway company and the transit operating authority. Station upkeep may or may not be the responsibility of the transit operator, depending upon utilization of the specific site by each party.

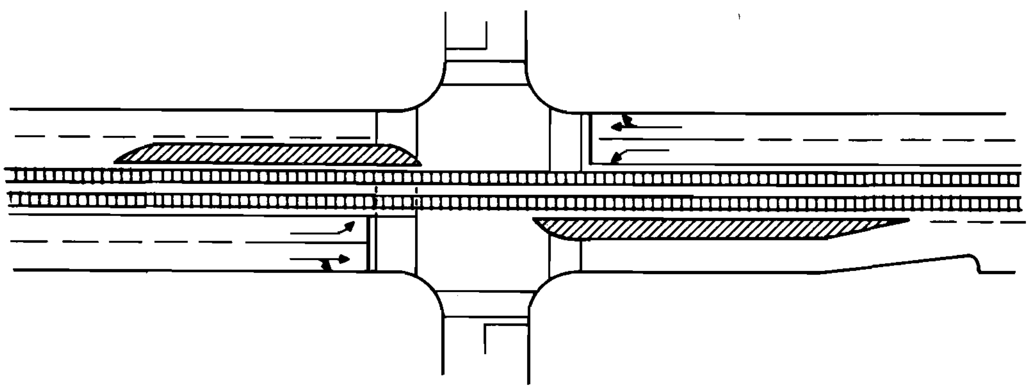
Power Supply and Distribution: All three rail transit modes, with the exception of self-propelled commuter rail vehicles, operate on low-voltage direct current supplied to the traction motors, which turn the wheels. However, the physical apparatus neces-

Figure 128

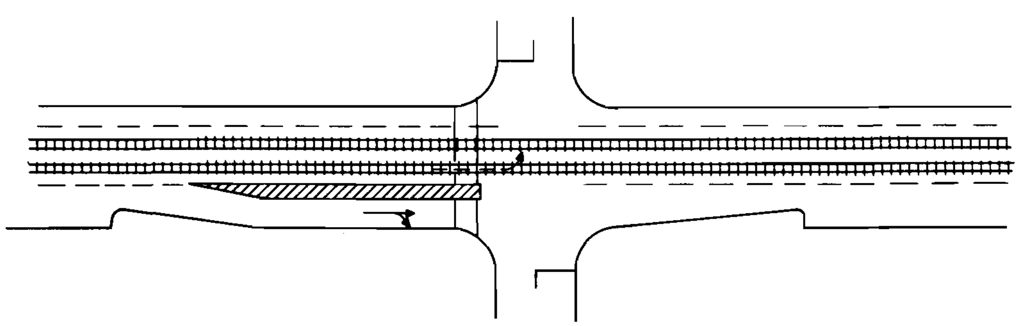
STATION LAYOUTS FOR LIGHT RAIL
TRANSIT WITHIN STREET RIGHTS-OF-WAY



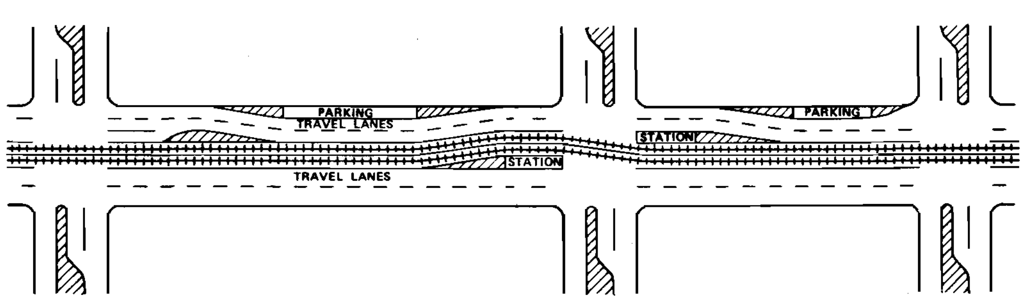
SPECIAL LEFT TURN LANE



FAR-SIDE BOARDING ISLAND



COMMON LEFT-TURN AND TRANSIT LANE



STATIONS ON REVERSE CURVE

Source: *Light Rail Transit: A State of the Art Review, prepared for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago, 1976 and SEWRPC.*

Figure 129

TYPICAL COMMUTER RAIL STATION

Except at the ends of commuter rail routes and in the central business district, commuter rail stations in many instances may consist solely of one or two platforms with appropriate signing and access facilities plus parking space for automobiles. Such a simple station design is illustrated in this view of the Wood Dale, Illinois, station on the Regional Transportation Authority's commuter line from Chicago to Elgin.

SEWRPC photo.

sary to transmit this power to the vehicles differs significantly between the three modes.

Electrical current is distributed to the vehicles used in light rail systems through an overhead contact wire system. One type of overhead wire system consists of a simple contact wire hung from either cross span wires or bracket arms, both of which are supported by line poles. Contact wire systems are simple, lightweight, and relatively inconspicuous compared to catenary systems. However, such overhead must be supported about every 100 feet, has a limited current-carrying capacity, and has a tendency to sag, and the stiffness of the wire varies throughout its span. Single-wire overhead is practical where speeds are below 45 miles per hour and in areas where aesthetics are especially sensitive, such as pedestrian malls.

The other type of overhead contact wire system is a catenary system which consists of a contact wire attached to hangers suspended from a messenger wire. The messenger wire is suspended either directly from bracket arms supported by line poles or some type of portal structure, or from cross span wires supported by line poles. With a catenary overhead system the contact wire is maintained in a level position that is parallel to the rails. Catenary systems are recommended for high-speed operations of above 45 miles per hour. Also, the electrical properties of the catenary system are superior to those of the single-wire system because of the larger cross-section, and the catenary system requires fewer line poles or other overhead system supports. Most contemporary railway and transit electrification projects that call for an overhead power distribution system utilize a catenary system. Distance between support columns ranges from 150 to 300 feet.

Because light rail requires an overhead power distribution system, the cross-sectional area of the guideway may require a greater vertical area than that required by other rail transit modes. Typical contact wire heights are between 15 and 20 feet above top-of-rail. Typical line pole heights range from 25 to 30 feet above top-of-rail. On portions of the guideway that do not have sufficient vertical clearance to permit installation of the entire line pole assembly, such as underneath overhead bridges and in subways, the contact wire can be attached "directly" to the overhead obstruction.

A frequently cited disadvantage of light rail transit is the visual intrusion of the overhead power distribution system into the surrounding aesthetics. Several design considerations are available to minimize such an impact:

1. Power feeders, signal circuits, communication lines, and cables other than those essential for power collection by the vehicles can be placed underground.

2. Carefully thought out landscaping has been successfully utilized to mitigate the visual impact of overhead wires and line poles. Since wires are conspicuous primarily in silhouette, such "blending" with surrounding trees may help to obscure the wires, especially in pedestrian mall or boulevard settings.

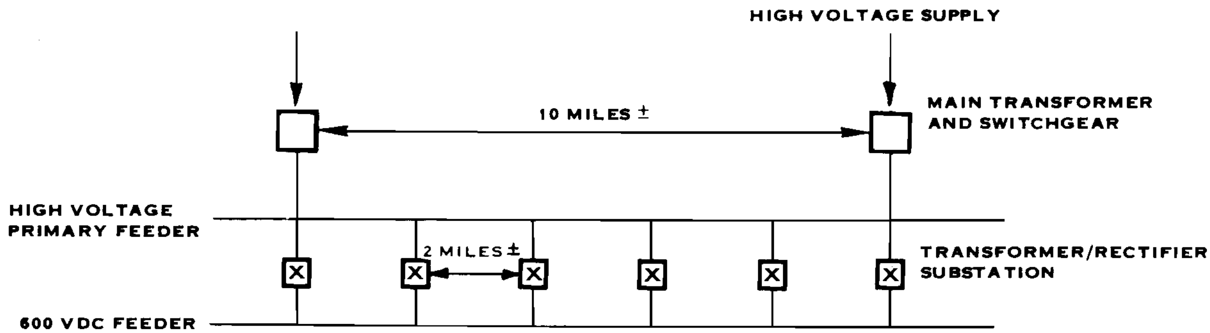
3. Existing buildings or other structures can be substituted for line poles to support the overhead wiring.

4. Combining overhead wiring, street illumination, and traffic signals on the same poles can reduce the number of poles and standards necessary on public street rights-of-way.

To transmit power to the overhead wire system, power is purchased commercially and is tapped from the high-voltage supply at intervals of several

Figure 130

POWER DISTRIBUTION AND CONVERSION SYSTEM



Source: Light Rail Transit: A State of the Art Review, prepared for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago, 1976.

miles. At these locations, the main transformers and switchgear transform the power into the primary feeder voltage and feed it into the primary feeder system. These primary substations are normally spaced several miles apart so that different zones of the public power supply can be tapped, lessening the chance of a total transit system shutdown should a partial failure occur in the public power system. At shorter intervals throughout the system, the primary feeder connects to substations, each containing the rectifier unit consisting of a rectifier transformer, the rectifier, and the necessary switchgear. Here the power is transformed into the operating voltage and converted to direct current (see Figure 130). The older apparatus necessary to perform this function—rotary converters and attendant switchgear—has been supplanted by automatic solid-state devices which are much smaller and can be left unattended since supervision is by remote control.

Substantial buildings for these substations are no longer required, the solid-state devices being located either in underground vaults or in small enclosures. The main substations may be located approximately 10 miles apart, and the secondary substations, two miles apart. Operating voltages greater than the typical 600 volts direct current may be appropriate for a completely new system since operating efficiency and substation spacing can be increased.

Low-voltage direct current is preferred for light rail transit systems because vehicle size does not allow space for the equipment necessary to rectify and step down high-voltage alternating current to a range suitable for powering electric traction motors. While transmission losses occur over long distances for direct current as compared with alternating current, the relatively short power transmission distances for urban rail transit do not justify use of alternating current, which does not suffer from such large power losses. On systems powered with direct current, the power supply and distribution facilities are fairly complex, involving substations and a substantial feeder system, since the current is delivered at low voltage. On the other hand, the components on board the vehicles are comparatively simple. These factors and others make direct current distribution very practical for intensively used systems such as light and heavy rail systems, which operate lightweight equipment making numerous starts and stops.

It should be recognized that the extent and complexity of the power supply and distribution system are dependent upon the power required per train. Electrical capacity must be available to deliver adequate power for the greatest-length trains to be operated on the shortest headway anticipated. Larger capacity or more frequent substations may be required where traffic demands will be greater, such as where two or more routes converge.

Heavy rail rapid transit power supply and distribution are very similar to light rail supply and distribution. Similar direct-current voltages, primary feeders, and substations are utilized, the major difference being that an outside third rail is used for power distribution instead of an overhead contact wire. Vehicle current collection is through a third rail shoe which slides along the energized third rail. Because a third rail possesses a larger cross-section, and therefore greater current capacity, it can be used with fewer feeders, or can handle longer trains. Indeed, the longest heavy rail rapid transit trains are from eight to 10 cars long while the longest light rail transit trains are three to four vehicles long.

On segments of heavy rail guideway above ground, a third rail is less conspicuous than are overhead wires. Because of safety and clearance problems, rail transit systems that utilize a third rail must have an exclusive, grade-separated right-of-way as well as high-level platforms. Substation equipment for modern heavy rail is typically located within the station structures.

Utilization of an electrified power supply and distribution system for any rail transit mode requires specialized maintenance forces. These include not only appropriate staff, but also parts and materials inventory, vehicles, and tools specifically for overhead repair and maintenance.

Power requirements for dieselized commuter rail service are contained on board the locomotive, making no attendant guideway apparatus necessary. Adequate fueling facilities must be provided, these usually being shared with the mainline railway over which such service is operated. If these facilities are inadequate or located too far from commuter train layover stations, separate facilities may be warranted to decrease deadheading expenses. In addition, standby electric power should be available for coaches at equipment layover locations.

Traffic Control: Traffic control apparatus commonly used for rail transit applications can be categorized by function. The principal functions of rail traffic control systems are to control the speed and spacing of traffic moving along a guideway in the same direction, to protect against conflicting movements, to control points of interface with other modes, and to control routings within the system.

Vehicle speed and headway control is the most complex function performed by the heavy rail rapid transit mode. Modern heavy rail systems in the United States employ automatic train operation, whereby almost all functions of train operation are automated. An operator is on board to monitor vehicle performance, communicate with the central control facility, and close the vehicle doors which activate the automatic operation sequence. A communications system, as part of the train control system, carries a continuous flow of traffic information to the central control complex, which monitors the movement of all trains. The on-board operator is also present to operate the train manually, should the automated system temporarily fail. Automated train operation is contingent upon provision of a fully grade-separated, exclusive guideway.

Conventional heavy rail systems rely more on manual control by the operator of each train, although other train control equipment is commonplace. Automatic train protection detects the position of trains in successive track segments ("blocks") and relays this information to the operator either via cab signals directly on the operating console, or via wayside signals positioned adjacent to the track. Automatic train stop or "overspeed protection" automatically applies the vehicle brakes if safe speeds are exceeded or if a train comes too close to the one ahead of it. Automatic vehicle monitoring systems identify trains for purposes of route control and passenger information display boards at stations through a code contained on the vehicle which activates a trackside detector. These latter control systems are typically included within an automatic train operation system.

The majority of existing light rail systems use manual or visual sight rules, similar to those used by street railway systems. Some form of simple automatic train protection is employed on segments with restricted visibility. Such areas are usually in subways, and the typical control devices used are simple wayside block signals.

Following distances and train speeds for a new commuter rail service would most likely be governed by whatever signal system is already in place on the existing common carrier railway. Automatic block signals are typically used to control train spacing on double-track main lines. On single-track main lines and on heavily trafficked double-track lines, centralized traffic control is common whereby signal aspects and turnouts for an extensive section of railway are controlled by a dispatcher seated at a central console. Train movements on the remaining railway lines, including secondary and branch lines, are usually governed by established operating rules that relate to superiority of certain trains, timetable authorization, and written train orders issued by the dispatcher.

On heavy rail systems, traffic control at junctions and at-grade crossings is generally integrated with other signal and train control systems. Automatic train operation systems control turnouts where tracks diverge, with each train's routing being preset at the control center. Modern heavy rail systems are designed so that routes do not cross at-grade. On commuter rail systems, traffic control at junctions and at-grade crossings is under the direction of a dispatcher where centralized traffic control is in service. On other parts of the commuter rail system, junctions are under the supervision of an operator in an adjacent tower who must "line" the proper routing for each movement by operating the signals and turnouts. At-grade crossings are either controlled by a manned tower or automatically controlled. In all cases, electrical and/or mechanical interlocking mechanisms prevent the aligning of signals and switches for conflicting movements. Turnouts for commuter rail in yards and at storage tracks are manually controlled, requiring a switchman.

Where light rail routes diverge, turnouts are activated by the operator from inside the vehicle. To accomplish this, contactors are placed parallel to the overhead contact wire. When the vehicle's pantograph passes the contacts, the switch motor or solenoid that moves the switch points is activated based on whether the propulsion power is on or off at that moment. These mechanisms are being superseded by new techniques on some Western European systems. One recently adopted system utilizes on-board transmitters which relay signals to wayside detectors. The detectors align turnouts for proper vehicle routing and confirm that the aligned route is clear of conflicting movement. This system provides for greater safety and also greater vehicle speeds if turnout alignment permits them.

Points of at-grade intersection between rail transit modes and other modes present special traffic control considerations. Heavy rail rapid transit guideways are completely grade-separated, therefore eliminating the need for signalization. Commuter rail utilizes the common carrier railway freight system, with public street and highway crossings typically being protected within urbanized areas by automatic warning signals. Such signals are activated when a train occupies a signal circuit adjacent to the crossing. Automatic grade-crossing signals consist of flashing lights along with crossing gates in many instances. Public road crossings outside built-up areas may be protected only by crossbucks. The addition of commuter trains on a particular route may warrant the installation of automatic signals or, where signals are already in place, the installation of gates that lower as the train approaches.

Movable drawbridges present another potential point of conflict for commuter rail service. When located on main lines, such bridges are protected by signals and interlocking mechanisms similar to those used at railway junctions and at-grade crossings.

Light rail transit guideways probably require the most complex at-grade protection. Since light rail is located largely on the surface without the benefit of lengthy aerial or subway segments, some sort of preferential treatment must be provided if high-speed, high-quality service is to be provided. In addition, since typical guideway applications are in street or boulevard medians, the form of preferential treatment for light rail transit must mesh with the existing traffic control system on the street network.

Three basic strategies are available that afford light rail preference over adjacent motor vehicle surface traffic. Priority treatment may be achieved by grade separation of the transit guideway, prohibition of cross traffic where light rail utilizes the street right-of-way, and modification of existing motor vehicle traffic control devices to accommodate transit movements.

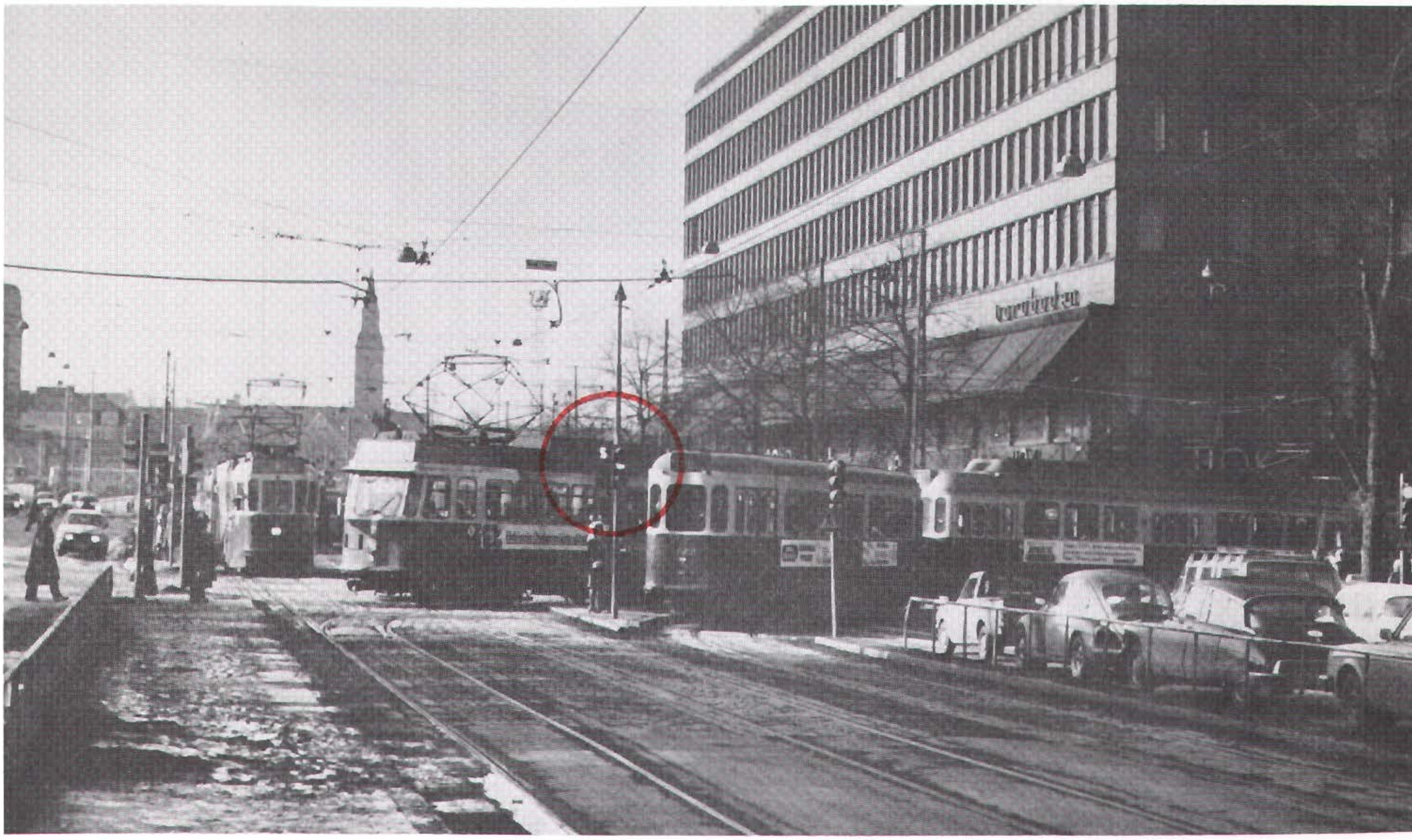
Grade separation of congested locations is the most positive priority measure, but is also the most costly. Prohibition of cross traffic—including left turns—where the guideway utilizes public street rights-of-way may not be desirable in congested areas and, in any case, provision may have to be made to continue pedestrian access across the guideway. Modification of traffic control systems is the most popular option as it can be implemented in a variety of ways, listed here in ascending order of positive control:

- Stop or yield signs for cross traffic may be installed where traffic volumes are low.

- Standard traffic signals with fixed-time cycles may be utilized where light rail traffic is subject to the same control as is motor vehicle traffic operating in the same direction. Left turns may be handled in the manner as described under the "Station

Figure 131

FIXED-TIME TRAFFIC SIGNALIZATION WITH SPECIAL PHASES FOR LIGHT RAIL VEHICLE MOVEMENTS



In addition to the conventional traffic signals at major intersections, special signal phases can be installed to facilitate transit movements, especially where light rail vehicles must make turning movements through an intersection. As shown, the special phases indicated by white signal aspects (circled) allow light rail transit trains to proceed through busy intersections without having to wait for motor vehicle traffic to clear. This practice is widely used on West European light rail transit systems.

Photo by Otto P. Dobnick.

Characteristics" section of this chapter, and directional signal phases may possibly be required (see Figure 128).

- Standard traffic signals with fixed-time cycles and special phases for light rail transit movements may be utilized. The aspects may show white arrows providing priority in one or more directions. Faster and safer transit movements are allowed, although the intersection's total capacity is reduced because of the additional phases (see Figures 131 and 132).

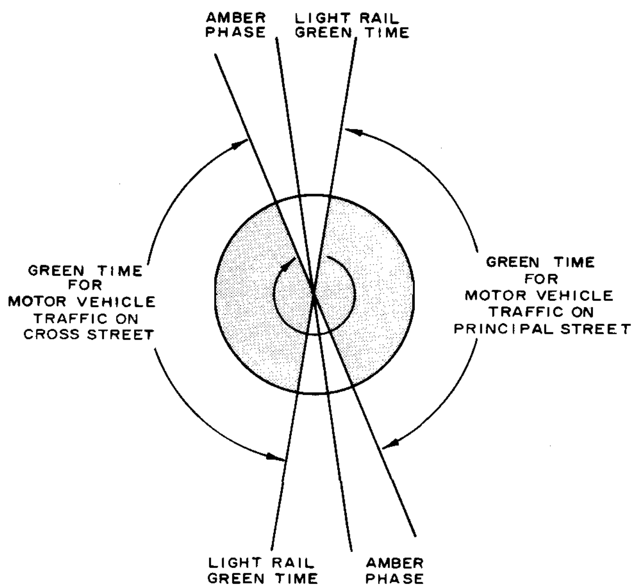
- Traffic signals can be equipped with special phases such that light rail movements can actuate either additional leading green time or additional lagging green time as part of the signal cycle. Such an arrangement assures a higher probability of light rail vehicles reaching an intersection during a green phase (see Figure 133).

- Signal preemption can be used to eliminate all cross traffic delays for light rail, but will disrupt other traffic. While this option may not be desirable at intersections where cross traffic and turning traffic volume-to-capacity ratios are high, it would be viable for minor street crossings.

- Full preemption with barriers or gates to more fully protect against motor vehicle conflicts will increase driver obedience and

Figure 132

FIXED-TIME TRAFFIC SIGNAL CYCLE WITH TRANSIT PHASE

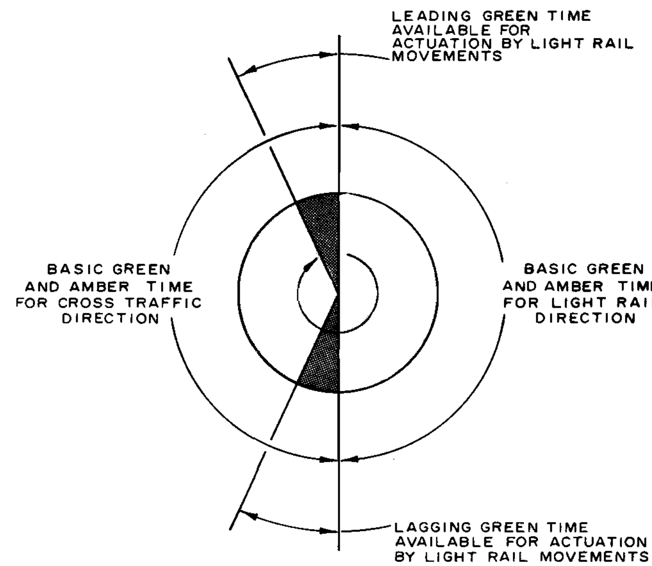


AT CERTAIN SIGNALIZED INTERSECTIONS, LIGHT RAIL MOVEMENTS MAY WARRANT INDIVIDUAL FIXED-TIME PHASES WHICH PERMIT TRANSIT VEHICLES TO MOVE THROUGH THE INTERSECTION UNOBSTRUCTED BY EITHER TURNING THROUGH OR CROSSING MOTOR VEHICLE TRAFFIC. SINCE THIS MEASURE WILL REDUCE TOTAL INTERSECTION CAPACITY, IT IS MOST APPLICABLE TO INTERSECTIONS WHERE LIGHT RAIL VEHICLES WILL BE ARRIVING DURING MOST, IF NOT ALL, SIGNAL CYCLES.

Source: SEWRPC.

Figure 133

TRAFFIC SIGNAL CYCLE WITH ON-CALL TRANSIT PHASE



NORMALLY, EACH DIRECTION AT THE INTERSECTION WILL HAVE AN EQUAL AMOUNT OF GREEN TIME AVAILABLE. DURING PERIODS WHEN LIGHT RAIL VEHICLES ACTUATE BOTH THE LEADING AND LAGGING GREEN TIME, NET AVAILABLE GREEN TIME FOR THE CROSS TRAFFIC WILL BE SIGNIFICANTLY REDUCED.

Source: SEWRPC.

safety. These barriers are similar in physical appearance to typical railway crossing gates. Street capacity will be affected when the barriers are actuated. On new light rail segments that are on or adjacent to active railway rights-of-way, this type of protection may be incorporated into the crossing protection already in place at the railway grade crossing.

It should be recognized that priority signal treatments designed to increase the quality of light rail transit service may have significant impacts on adjacent street traffic patterns as available capacity is reduced.

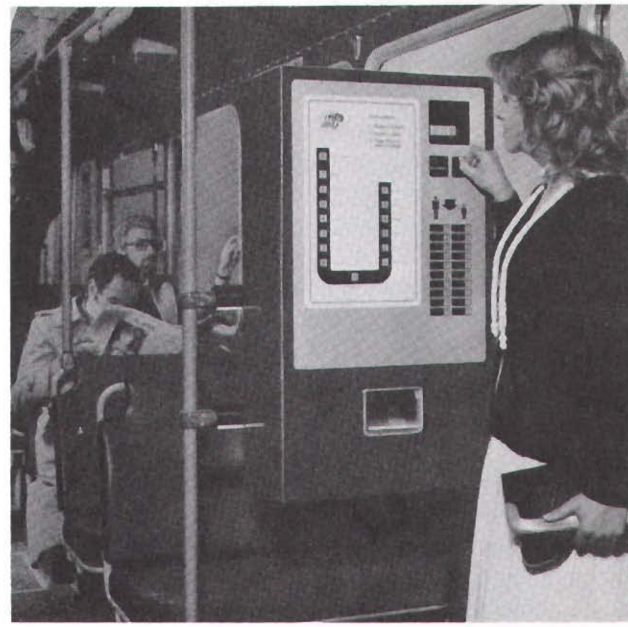
Station location relative to grade-crossing location can also affect light rail system performance. Signal progression along a street which contains a light rail guideway within the right-of-way can be used to improve transit flow. This requires that the station spacing be located such that the trains can travel across several controlled intersections within the green band progression. Arranging stations so that near-side stops are alternated with far-side stops may permit light rail movements to cross an additional intersection within the signal progression. On guideways located in street medians, it may be beneficial for stations to be located at major intersections since—depending on the type of traffic control—light rail vehicles may have to stop at such major intersections in any case.

Preemptive signalization can be actuated by either automatic track circuits, overhead wire contactors, or a signal transmitted from the vehicle. Track circuits are insulated segments of track that, when occupied by a train, permit the preferential signal sequence to be activated. Overhead wire contactors perform the same function when activated by a pantograph passing over them.

The signal transmission system may be implemented with different devices. A system devised in Western Europe specifically for light rail requirements utilizes transponders installed underneath the vehicles which, when passing over an inductive detection loop installed in the guideway, transmit a signal to a wayside interrogator. This signal identifies the type of vehicle, route numbers, and vehicle identification number. The signal can directly trigger traffic lights or transmit the information to a central control center which supervises the traffic lights and turnout operation. Other technology is also available, such as the transmission of signals via radio or optical scanners.

Figure 134

TYPICAL TICKET VENDING MACHINE



Many West European light rail transit systems utilize self-service ticketing in which riders purchase tickets from vending machines located either at stations or on board the vehicles. The passengers are responsible for validating their tickets and are subject to on-the-spot fines by inspectors for noncompliance.

Photo courtesy of Shepard Transitron, Inc.

<u>Fare Collection Procedures:</u> Fare collection can be categorized into four basic types, each applicable chiefly within the context of one of the four rail transit modes: pay-as-you-enter, controlled access, on-board ticket collection, and self-service procedures.

Public transit operations in the United States and Canada normally use the pay-as-you-enter system for fare collection on motor buses, street railways, and light rail transit. Passengers deposit either coins, tickets, or tokens into a farebox upon entering the vehicle or present a weekly or monthly pass to the operator for inspection. If light rail service uses trains, an operator or agent must be present in each vehicle. Exact fare is almost universally required for security and operator safety. A variation of this method is fare collection upon boarding vehicles destined for the downtown area, and upon alighting the vehicle in the outbound direction. This procedure reduces station dwell times where boarding is heavy and congested.

Controlled access fare collection is handled entirely off the vehicle. Fares are collected in the stations as passengers pass through turnstiles or by ticket agents. This type of fare collection is utilized on all modern heavy rail rapid transit systems and in some instances on light rail transit systems when the system is located in subways or on other exclusive alignments. This arrangement allows station dwell time and train crew size to be minimized. Modern heavy rail systems operating with a zoned-fare structure employ vending machines which accept coins and paper money, dispensing magnetically coded tickets that are inserted into the turnstiles. This system is designed to facilitate unmanned stations, thereby reducing operating expenses. However, such stations in many instances have been subsequently staffed to provide greater security and assistance to passengers in purchasing tickets.

On-board ticket collection is typical of commuter rail service in North America. Single-ride and multiple-ride tickets or monthly passes are purchased from ticket agents in stations or through the mail. Tickets are inspected by ticket-collecting personnel on board the train. Train crew size can be kept to a minimum if controlled-access fare collection is handled at stations.

Self-service ticketing, also known as "barrierless" and "honor system" ticketing, is a popular, if not the predominant, fare collection system utilized on light rail transit systems throughout Western Europe. The basic technology includes two types of devices: a ticket vending machine and a ticket canceling machine. Ticket vending machines are either freestanding or wall-mounted at stations, or are located on board the vehicle (see Figure 134). Ticket validation equipment is also located on board or at stations. Passengers must purchase tickets and validate them at the time of use. Compliance with this system is maintained by a staff of checkers who typically sample 5 percent of the daily vehicles operated, and are legally empowered to fine offenders on the spot. Reported levels of noncompliance range between 0.1 and 3 percent, with 1 percent being typical. According to a recent study, this range compares well with estimates of the extent to which conventional fare collection systems are defrauded. A recognized key to the success of self-service fare collection systems appears to be the capability to impose on-the-spot financial penalties, avoiding costly and time-consuming court procedures.

Self-service ticketing is readily accepted by the public in Europe. In fact, authorities attribute much of the success of light rail systems there to adoption of these techniques, since they serve to reduce the number of operators required to collect fares on board, thus reducing dwell times and increasing overall operating speeds. The extent to which such a system would succeed or fail in the United States is speculative at this time, since such procedures are not presently used anywhere in the nation. The Urban Mass Transportation Administration is considering funding demonstration projects in selected cities to gain experience with self-service fare collection in the United States. Two Canadian cities—Edmonton, where light rail is in service, and Calgary, where light rail is under construction—are seriously considering implementation of this type of fare collection.

PERFORMANCE CHARACTERISTICS

System performance characteristics for light rail transit, heavy rail rapid transit, and commuter rail may be defined in terms of three critical factors: speed, headway, and capacity. These factors are important determinants of the level of public acceptance and patronage of a new primary transit system.

Speed Characteristics

Rail transit speeds may be expressed as absolute vehicle speeds, typical operating speeds, or average speeds over an entire transit route. Absolute vehicle speeds are determined by the capabilities of the individual vehicles. Light rail vehicles generally have maximum attainable speeds of about 50 miles per hour (mph), while modern heavy rail vehicles have maximum attainable speeds of about 75 mph. Diesel-electric passenger locomotives in commuter rail service have maximum attainable speeds of 65 mph,[6] while a current production model of a self-propelled diesel coach is geared for a maximum attainable speed of 80 mph.

Typical operating speeds are constrained by the type and configuration of the guideway as well as by adjacent land uses. Heavy rail rapid transit systems possess the least constraints in this regard. Because of the exclusive grade-separated right-of-way, maximum vehicle speeds on the main line can be achieved except when traversing some curves and when passing through stations. Commuter rail trains, when operating through areas that are not intensely developed, can also attain the maximum speeds for which the rolling stock is designed. Most commuter rail operations, however, must operate through terminal and railway switching yard districts as well as through intensely developed areas which may have many grade crossings. Both of these factors tend to limit speeds from 30 to 40 mph.[7]

Because of their location and placement on the guideway, light rail systems are subject to the greatest constraints on operating speeds of the three modes considered herein. Maximum vehicle speeds can be obtained on a right-of-way which either is fully grade-separated or has fully protected crossings. On reserved rights-of-way that are shared with public streets, operating speeds are limited to those of the surrounding traffic. On Western European systems, typical operating speeds under such circumstances range from 30 to 40 mph. Mixed traffic operation generally requires that both motor vehicle and transit traffic operate at the same speeds. Pedestrian malls demand an even greater reduction in speed for safety reasons, 15 to 20 mph being typical. Localized speed restrictions may be necessary to accommodate sharp curves and turnouts.

Light rail speed limits on North American systems are similar to those on European systems. The Public Utilities Commission of the State of Cali-

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[6] *Maximum speeds of 101 mph are attainable by current production diesel-electric locomotives if supplied with one of several optional gear ratios.*

[7] *Such speed restrictions along potential commuter rail routes in the Milwaukee area are discussed more fully in Chapter VII of SEWRPC Technical Report No. 23, Transit-Related Socioeconomic, Land Use, and Transportation Conditions and Trends in the Milwaukee Area.*

Table 54

MAXIMUM SPEEDS PERMITTED ON VARIOUS LIGHT RAIL TRANSIT ALIGNMENTS

Alignment Classification	Crossing or Intersection Control	Train Protection	Maximum Permitted Speed (mph)
Exclusive	- - - - - -	ATP and ATS ATP only None required	No limit[a] 55 45[b]
Fenced Right-of-Way with at Grade Crossings	Between crossings	Train protection and maximum permitted speed as for exclusive alignment classifications	
	At crossings Flashing lights and gates Flashing lights and gates Flashing lights and gates Traffic signal or other approved device	 ATP and ATS ATP only None required - -	 No limit[a] 55 45[b] - -[c]
Street Median or Side Alignment with 6-Inch Curb and Fence	Between crossings	None required	Legal speed of parallel traffic plus 10 mph[b,d]
	At crossings Flashing lights and gates (side alignment only) Traffic signal or other approved device	 None required None required	 Legal speed of parallel traffic plus 10 mph[b,d] Legal speed of parallel traffic but not to exceed 35 mph[b]
Street Median or Side Alignment with 6-Inch Curb	Traffic signal or other approved device	None required	Legal speed of parallel traffic but not to exceed 35 mph[b]
Mountable Curb or Transit Lane	Traffic signal or other approved device	None required	Legal speed of parallel traffic but not to exceed 35 mph[b]
Mixed Traffic	Traffic signal or other approved device	None required	Legal speed of parallel traffic but not to exceed 35 mph
Pedestrian Mall	Traffic signal or other approved device	None required	20 mph[e]

NOTE: ATP denotes automatic train protection system requirement and ABS denotes automatic train stop requirement.

[a] *Speed is limited only by vehicle or alignment characteristics.*

[b] *Provided adequate stopping sight distance is available.*

[c] *Traffic signal or other approved device at crossings on fenced right-of-way with at-grade crossings may be authorized only in special locations where speeds do not exceed 25 mph, such as at stations.*

[d] *Maximum speed 55 mph unless ATP and ATS are provided. Maximum speed 45 mph unless ATP is provided.*

[e] *Lower speed may be required for malls paved flush with the tracks.*

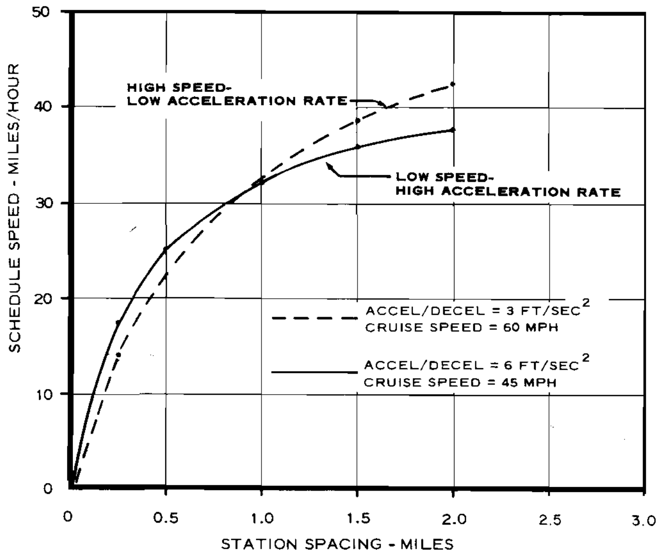
Source: Public Utilities Commission of the State of California.

fornia recently adopted general regulations for the design, construction, and operation of light rail transit and street railway systems within the State. Set forth in this order are applicable speed limits for most alignments, as shown in Table 54.

Average speeds for rail transit systems are dependent upon the acceleration and deceleration characteristics of the vehicles, station spacings, and, in the case of the light rail transit mode, the extent of priority over conflicting traffic. For vehicles

Figure 135

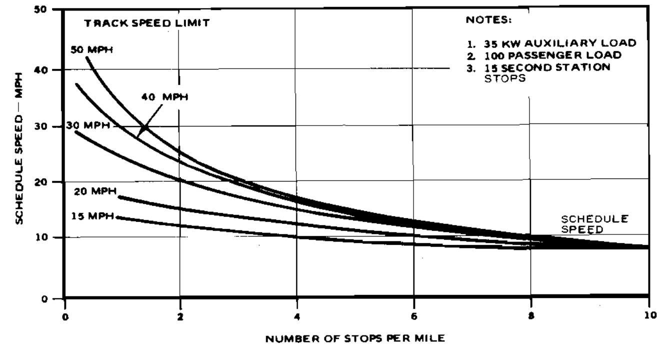
EFFECTS OF VEHICLE PERFORMANCE AND STATION SPACING ON AVERAGE SPEEDS



Source: Light Rail Transit: A State of the Art Review, prepared for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago, 1976.

Figure 136

STANDARD LIGHT RAIL VEHICLE PERFORMANCE



Source: Boeing Vertol Company.

operating with frequent stops and starts, the acceleration and deceleration characteristics may have a greater impact on the average speed than does the maximum speed of which the vehicle is capable. Figure 135 illustrates that given certain vehicle performance characteristics, high operating speeds are more important in determining average speeds when the station spacing is greater than one mile, but high acceleration rates are more important when the station spacing is less than one mile.

Station spacing is an important factor in determining average system speeds, as shown in Figure 136. Although this graph is based on the performance of the United States Standard Light Rail Vehicle, similar relationships between station spacing and operating speeds are evident for heavy rail and commuter rail vehicles. In fact, in order for commuter rail to achieve an acceptable average speed, station spacings must be large, relative to station spacings for the light and heavy rail modes, because of the low rates of acceleration and deceleration of diesel-electric-powered passenger trains.

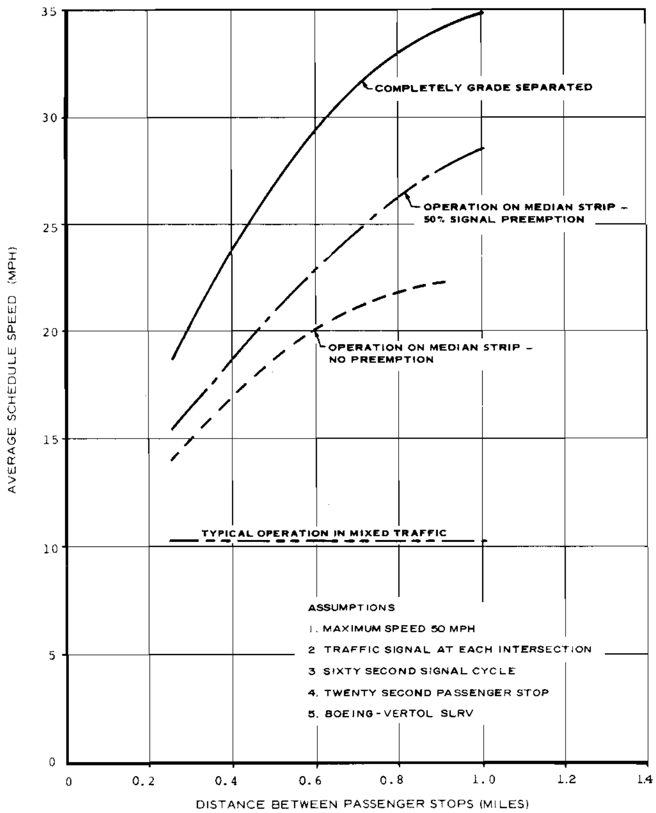
The amount of preferential treatment afforded light rail transit installations also has a bearing on average speeds. Figure 137 shows the maximum performance available under a set of given assumptions for four different guideway configurations. The performance indicated for mixed traffic operations readily illustrates the need for light rail to be given, to the maximum extent possible, priority over adjacent motor vehicle traffic. For example, Cologne, West Germany—which exhibits a wide variety of alignment configurations—reports average speeds of 10 to 13 mph in mixed traffic operations, 15 to 20 mph in median strip operations, and up to 25 mph in exclusive right-of-way operations.

Average speeds for all three rail transit modes vary widely. Typical speeds for light rail transit vary from 9.9 to 18.6 mph depending on the station spacing, as shown in Table 55. These figures represent European average speeds which have undergone significant improvements during the 1960's and 1970's, when many street railways were upgraded to the light rail mode. For example, in Bremen, West Germany, average speeds on new segments are 15 to 17 mph, compared with previous speeds of 11 to 12 mph. Separation of a route in Amsterdam from other traffic by installation of concrete curbs and priority at 17 traffic signals raised the average speed from 4 to 10 mph.

Again recognizing the critical importance of station spacing for light rail operations, stations on United States systems tend to be located farther apart than are stations on European systems, resulting in average speeds that are somewhat greater than those on European systems. For example, the

Figure 137

EFFECTS OF GUIDEWAY CONFIGURATION ON LIGHT RAIL AVERAGE SPEEDS



Source: *Light Rail Transit: A State of the Art Review, prepared for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago, 1976.*

Table 55

AVERAGE LIGHT RAIL TRANSIT SPEEDS

Average Station Spacing (miles)	Range of Average Speeds[a] (mph)
0.00-0.25	9.9-14.3
0.25-0.50	9.3-18.6

NOTE: Light rail data from U. S. Cities (Boston, New Orleans, Pittsburgh, San Francisco, Philadelphia, and Cleveland) indicate speeds of 6 to 11 mph in mixed traffic and 10 to 20 mph on partial grade separations.

[a] *Based on light rail speed data from Rotterdam, the Netherlands; Dusseldorf, West Germany; Frankfurt, West Germany (30-40 percent grade-separated); Stuttgart, West Germany (40 percent grade-separated); Hanover, West Germany; Gothenburg, Sweden (70 percent grade-separated); Cologne, West Germany (63 percent grade-separated); and Bielefeld, West Germany (40 percent grade-separated.*

Source: D. B. Sanders and T. A. Reynen, et. al., Characteristics of Urban Transportation Systems—A Handbook for Transportation Planners (National Technical Information Service, Springfield, Virginia, 1979) compiled for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago.

Shaker Heights Rapid Transit System in Cleveland operates at an average speed of 23 mph, the Newark rapid transit system operates at 20 mph, and Edmonton's new line operates at 18 mph.

Although there is no light rail transit system in the Southeastern Wisconsin Region, two former electric railway routes did provide service over what might today be considered light rail routes. These two routes were the Route 10 street railway line, which maintained an average speed of between 14 and 21 mph over a 3.5-mile segment of reserved and exclusive right-of-way with some mixed traffic operation, and the Route 2 "Local Rapid Transit Line," which maintained an average speed of 24 mph over a 7.2-mile segment consisting almost entirely of exclusive right-of-way.

Average speeds for heavy rail rapid transit based on modern systems operating in the United States range from 20 to 55 mph, depending on station spacing, as shown in Table 56. Since this mode operates on an exclusive, grade-separated right-of-way, guideway configuration is not a major determinant of average speed, and thus maximum vehicle speeds and station dwell time are the critical factors. The effect of these factors is represented by the data set forth in Table 57, which provides theoretical average speeds attainable for the heavy rail mode.

Average commuter rail speeds are largely dependent upon station spacing, as shown in Table 58. Other contributing factors are dwell time at stations and rates of acceleration and deceleration. Where commuter trains are long, dwell times may reach several minutes. Also, because commuter trains are typically combinations of locomotives and nonpowered coaches, in contrast to light and heavy rail trains which are made up of powered vehicles, acceleration and deceleration are slower if trains are long. Commuter rail service formerly

Table 56

AVERAGE HEAVY RAIL RAPID TRANSIT SPEEDS

Average Station Spacing (miles)	Range of Average Speeds (mph)
0-1	20-25
1-2	35-40
2-3	45-50
Over 3	50-55

Source: D. B. Sanders and T. A. Reynen, et. al., Characteristics of Urban Transportation Systems—A Handbook for Transportation Planners (National Technical Information Service, Springfield, Virginia, 1979) compiled for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago.

operated between Milwaukee and Watertown maintained an average speed of approximately 41 mph over the entire run.

Headway Characteristics

Rail transit system headways may be given in terms of theoretical limits and actual experience. Actual headways on existing operations seldom approach the theoretical limits except in some instances where several transit routes operate over common trackage.

Vehicle speed and the degree of automatic train protection largely determine how short a headway can be safely achieved. For safety reasons, high speeds dictate longer headways than do lower speeds. Automatic train protection systems also regulate train spacings and include built-in safety margins which prohibit short headways that may be possible under visual/ manual control.

Theoretical maximum rail transit headways per unit time are the most frequent with light rail and the least frequent with commuter rail. Table 59 shows such value ranges on the basis of both frequency per hour and headway measured in minutes. Even on the highest density systems such headways occur only for brief periods during weekday peak periods, and especially where more than one route uses the same trackage.

Actual observed headways provide a more realistic perception of the scheduling that has been designed for contemporary rail transit systems. Scheduled headways for light and heavy rail services are typically quite similar to headways for urban motor bus transit services. Light rail headways vary from 5 to 10 minutes during weekday peak periods, 10 to 15 minutes during weekday midday periods, and 15 to 30 minutes during weekday evenings. Saturday service is typically similar to weekday service except that peak-period headways are not as frequent as on weekdays. The frequency of owl service—service provided during early a.m. hours—is usually once an hour, if such service is provided at all.

Actual headways for heavy rail rapid transit vary between operations, but may be typified by two modern systems in the United States: Philadelphia's Lindenwold line and Washington, D.C.'s Metro system. The Lindenwold line has operated 24 hours per day, 7 days per week continuously since service commenced. Headways are from 2 to 5 minutes during peak periods, 7.5 minutes during the midday, 10 minutes during evenings, and 60 minutes between midnight and 6 a.m. On Sundays, there is a 15-minute headway.

Washington's Metro system provides headways of 5 minutes during peak periods and 10 minutes during nonpeak periods. The system presently operates from 6:00 a.m. to midnight on weekdays and from 8:00 a.m. to midnight on Saturdays. Sunday service was begun in September 1979. Some degree of partial service, such as operation on weekdays only, is typical of new heavy rail systems in the United States because of break-in periods which are felt to be necessary. Actual headways and hours of operation for any new light on heavy rail system should be recognized as being determined by local discretion.

The concept of headways may or may not be applicable to commuter rail scheduling. Large-scale operations have headways of 20 to 60 minutes during weekday peak periods, with one- to two-hour base service during midday and evening periods. Saturday and Sunday frequencies range from one to three hours. Hours of operation are generally 6:00 a.m. to midnight, with service being reduced somewhat on weekends. In some instances a commuter service may consist of only one or two trains inbound on weekday mornings and outbound on weekday afternoons. Under these circumstances, headway definition becomes unimportant. Actual commuter service schedules and headways for any new service should be recognized as a function of local demands and conditions.

Table 57

THEORETICAL SPEEDS ATTAINABLE BY HEAVY RAIL RAPID TRANSIT SYSTEMS

Maximum Speed Achieved (mph)	Dwell Time[a] (seconds)	Average Speed per Distance Between Stations (mph)					
		0.5 Mile	1.0 Mile	1.5 Miles	2.0 Miles	2.5 Miles	3.0 Miles
50	0	34.2	40.6	43.3	44.8	45.8	46.4
	10	28.7	36.5	40.1	42.2	43.5	44.5
	20	24.8	33.1	37.3	39.9	41.5	42.7
	30	21.8	30.3	34.9	37.8	39.7	41.1
60	0	36.0	45.0	49.1	51.4	52.9	54.0
	10	30.0	40.0	45.0	48.0	50.0	51.4
	20	25.7	36.0	41.5	45.0	47.4	49.1
	30	22.5	32.7	38.6	42.4	45.0	47.0
70	0	36.7	48.2	53.7	57.1	59.2	60.8
	10	30.5	42.5	48.9	52.9	55.6	57.5
	20	26.1	38.0	44.8	49.3	52.4	54.7
	30	22.8	34.4	41.4	46.1	49.5	52.0
80	0	36.7	50.2	57.3	61.7	64.7	66.8
	10	30.5	44.1	51.8	56.8	60.3	62.9
	20	26.1	39.3	47.3	52.7	56.5	59.4
	30	22.8	35.4	43.5	49.1	53.2	56.3
90	0	36.7	51.4	60.0	65.5	69.2	72.0
	10	30.5	45.0	54.0	60.0	64.3	67.5
	20	26.1	40.0	49.1	55.4	60.0	63.5
	30	22.8	36.0	45.0	51.4	56.2	60.0

NOTE: Above data are based on assumed acceleration and deceleration rates of three miles per hour per second on tangent track alignment with 0 percent grades.

[a]San Francisco's BART system, with a maximum allowable speed of 80 mph (average run of 47 mph), has an average 10-second station dwell time; Chicago's CTA, with a maximum allowable speed of 70 mph (average run 30 mph), has an average 20-second dwell time; Boston's MBTA (Red Line), with a maximum allowable speed of 70 mph (average run 32 mph), has an average 15-second dwell time; New York's NYCTA Second Avenue route, with a maximum allowable speed of 70 mph (average run of 28 mph), has an average 30-second dwell time; PATCO, with a maximum allowable speed of 75 mph (average run 39 mph), has an average 20-second dwell time; and Washington's Metro has a maximum allowable speed of 80 mph.

Source: D. B. Sanders and T. A. Reynen, et. al., Characteristics of Urban Transportation Systems—A Handbook for Transportation Planners (National Technical Information Service, Springfield, Virginia, 1979) compiled for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago.

Capacity Characteristics

The maximum passenger-carrying capacity of any rail transit system is dependent upon vehicle capacity, train length, and headway. In addition, certain other design, policy, and institutional considerations which reflect local conditions have a bearing on capacity. For example, the capacity of a new heavy rail rapid transit system is governed principally by initial guideway design constraints, while light rail transit and commuter rail must attend to additional factors because they lack a fully exclusive guideway. Light rail capacities will depend on the type of right-of-way and constraints imposed by at-grade operation, while commuter rail capacities may be affected by freight traffic operating over the same trackage.

Data on the system capacity attainable under efficient operation by the three rail transit modes vary somewhat. Light rail transit is generally cited as being able to meet peak-hour demands ranging from 6,000 to 20,000 passengers per hour, while

Table 58

TYPICAL AVERAGE COMMUTER RAIL SPEEDS

Average Station Spacing (miles)	Range of Average Speeds (mph)
0-2	20-30
2-3	28-35
3-5	33-40
5-6	38-45

NOTE: These speeds reflect current commuter rail speeds; speeds include typical dwell times. Above data are based on analyses of commuter rail systems operated by the Penn Central, Pennsylvania-Reading Seashore Lines, Southern Pacific, Chessie System, New York Metropolitan Transportation Authority, and several lines of the Southeastern Pennsylvania Transportation Authority.

Source: D. B. Sanders and T. A. Reynen, et. al., Characteristics of Urban Transportation Systems—A Handbook for Transportation Planners (National Technical Information Service, Springfield, Virginia, 1979) compiled for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago.

Table 59

MINIMUM THEORETICAL HEADWAYS FOR RAIL TRANSIT MODES

Mode	Maximum Frequency per Hour	Headway in Minutes
Light Rail Transit	40-90	1.5-0.6
Heavy Rail Rapid Transit . . .	20-40	3.0-1.5
Commuter Rail	10-30	6.0-2.0

Source: George E. Gray and Lester A. Hoel, ed., Public Transportation: Planning, Operations and Management (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1979).

heavy rail rapid transit is cited as being able to meet peak-hour demands of from 10,000 to 40,000 passengers per hour. Commuter rail is generally cited as being able to meet demands of from 8,000 to 35,000 passengers per hour. These data assume double-track guideways, one track for each direction of travel.

Tables 60 through 62 provide data on the range of passenger-per-hour capacities attainable under various vehicle and operational configurations, based upon recent vehicle designs. Extreme values in each matrix would be reached only under unusual circumstances, and are therefore unrealistic when applied to normal operating conditions. Maximum capacities for light rail will depend, at least partially, on the type of alignment. Large numbers of grade crossings and integration of light rail signal systems with those controlling motor vehicle traffic at street intersections may act to constrain light rail performance by causing additional delays and speed restrictions. Table 63 indicates the relative maximum capacity that could be expected under various alignment alternatives.

Energy Intensity of Rail Transit Systems

Energy requirements for transportation systems are frequently reported in terms of vehicle propulsion energy efficiency—that is, the number of vehicle miles per unit of energy. However, vehicle energy efficiency is only one aspect of transit system total energy consumption. In addition to the energy required to propel vehicles, an analysis of transit energy requirements may include the energy needed to maintain vehicles and to operate stations and other system facilities, and the energy expended in the construction of the system and manufacture of the vehicles. This more comprehensive consideration of energy requirements provides a basis for comparison of transit systems which may differ with regard to vehicle, guideway, and system types, system configuration, and energy source, as well as vehicle fuel consumption.

The separation of energy requirements into operation and construction requirements permits consideration of potential future as well as current availability and cost of energy sources. Systems which require relatively small amounts of construction energy but relatively large amounts of operating energy may be less desirable in the future than systems which require less operating energy, or which use energy sources other than petroleum, but require more energy for construction. Data on construction energy intensity are not as readily available as are data concerning vehicle propulsion energy consumption.

For the purpose of this analysis, system operating energy is defined as the propulsion energy required by the transit vehicles and the energy required to operate stations and maintain vehicles and system facilities. System construction energy is defined as the energy required for guideway construction and vehicle manufacture. Together, these elements constitute the total energy requirements, or energy intensity, of light rail transit, heavy rail rapid transit, and commuter rail systems.

Vehicle propulsion energy requirements constitute the majority of energy consumed and account for most of the variation in the overall energy utiliza-

Table 60

THEORETICAL SYSTEM CAPACITIES PER HOUR FOR LIGHT RAIL TRANSIT

Headway in Minutes	System Capacity per Number of Vehicles in Train[a]			
	1	2	3	4
1	8,820	17,640	26,460	35,280
2	4,410	8,820	13,230	17,640
5	1,764	3,528	5,292	7,056
10	882	1,764	2,646	3,528
15	588	1,176	1,764	2,352
20	441	882	1,323	1,764
30	294	588	882	1,176
60	147	294	441	588

[a] *Assumes use of a single-articulated light rail vehicle having a total design capacity of 147 passengers, including 68 seated passengers and 79 standees.*

Source: SEWRPC.

tion of rail transit systems. The propulsion energy requirements of rail transit systems, based on the experience of transit operators in the United States, were discussed in earlier sections of this chapter. With respect to the second element of system operating energy—the energy used to maintain vehicles and to maintain and operate stations—relatively few data are available since data on maintenance and station energy requirements are rarely segregated from overall energy consumption data by transit operators. Moreover, there has been relatively little research to identify these requirements. Energy used to maintain vehicles and stations typically constitutes from 10 to 20 percent of the propulsion energy required per vehicle mile. Maintenance requirements for heavy rail rapid transit and light rail transit are estimated at about 2,000 British Thermal Units (BTU's) per vehicle mile. Commuter rail is estimated to have much higher energy requirements, about 3,800 BTU's per vehicle mile, than do the other three modes.

The amount of energy required to operate stations varies widely among the three rail transit modes, being particularly high only for heavy rail rapid transit, which normally has elaborate grade-separated stations with air conditioning and escalators. Such stations require an average of 12,000 BTU's per vehicle mile, about twice as much as do other fixed guideway systems. Energy requirements for other stations vary from nothing for stations consisting of only small paved areas marked with appropriate signing to 5,100 BTU's per vehicle mile for light rail transit stations and to 3,200 BTU's per vehicle mile for commuter rail stations, both of which typically consist of specially constructed platforms, lighting and support facilities such as telephone service, rest rooms, and fare collection facilities, and a heated shelter building.

Guideway construction and vehicle manufacture energy can constitute a significant proportion of the energy requirements of primary transit. Construction energy requirements are similar for light rail and heavy rail rapid transit guideways and vary by type of guideway. Recent studies have reported that a surface guideway requires an average of 24.6 billion BTU's per mile of dual light or heavy rail rapid transit guideway. Construction of a grade-separated segment of guideway has been estimated to approach 111 billion BTU's per dual guideway mile for elevated portions and 234 billion BTU's per dual guideway mile for subway sections. Even more energy is consumed in the construction of commuter rail guideways—about 30 billion BTU's

Table 61

THEORETICAL SYSTEM CAPACITIES PER HOUR FOR HEAVY RAIL RAPID TRANSIT

Headway in Minutes	System Capacity per Number of Vehicles in Train[a]					
	1	2	4	6	8	10
1	13,320	26,640	53,280	79,920	106,560	133,200
2	6,660	13,320	26,640	39,960	53,280	66,600
5	2,664	5,328	10,656	15,984	21,312	26,640
10	1,332	2,664	5,328	7,992	10,656	13,320
15	888	1,776	3,552	5,328	7,104	8,880
20	666	1,332	2,664	3,996	5,328	6,660
30	444	888	1,776	2,664	3,552	4,440
60	222	444	888	1,332	1,776	2,220

[a] *Assumes use of a heavy rail rapid transit vehicle having a total design capacity of 222 passengers, including 74 seated passengers and 148 standees.*

Source: SEWRPC.

Table 62

THEORETICAL SYSTEM CAPACITIES PER HOUR FOR COMMUTER RAIL

Headway	System Capacity per Number of Coaches in Train					
	1	2	4	6	8	10
5 Minutes						
Self-Propelled Vehicles with Seated Capacity of 88 per Coach	1,056	2,112	4,224	6,336	8,448	10,560
Single-Level Push-Pull Train with Seated Capacity of 108 in Straight Coaches and 104 in Coach with Control Cab	1,248	2,544	5,136	7,728	10,320	12,912
Train with Bi-Level Gallery Coaches, Total Seated Capacity of 157 in Straight Coaches and 147 in Coach with Control Cab	1,764	3,648	7,416	11,184	14,952	17,640
10 Minutes						
Self-Propelled Vehicles with Seated Capacity of 88 per Coach	528	1,056	2,112	3,168	4,224	5,280
Single-Level Push-Pull Train with Seated Capacity of 108 in Straight Coaches and 104 in Coach with Control Cab	624	1,272	2,568	3,864	5,160	6,456
Train with Bi-Level Gallery Coaches, Total Seated Capacity of 157 in Straight Coaches and 147 in Coach with Control Cab	882	1,824	3,708	5,592	7,426	8,820
20 Minutes						
Self-Propelled Vehicles with Seated Capacity of 88 per Coach	264	528	1,056	1,584	2,112	2,640
Single-Level Push-Pull Train with Seated Capacity of 108 in Straight Coaches and 104 in Coach with Control Cab	312	636	1,284	1,932	2,580	3,228
Train with Bi-Level Gallery Coaches, Total Seated Capacity of 157 in Straight Coaches and 147 in Coach with Control Cab	441	912	1,854	2,796	3,738	4,410
30 Minutes						
Self-Propelled Vehicles with Seated Capacity of 88 per Coach	176	352	704	1,056	1,408	1,760
Single-Level Push-Pull Train with Seated Capacity of 108 in Straight Coaches and 104 in Coach with Control Cab	208	424	856	1,288	1,720	2,152
Train with Bi-Level Gallery Coaches, Total Seated Capacity of 157 in Straight Coaches and 147 in Coach with Control Cab	294	608	1,236	1,864	2,492	2,940
60 Minutes						
Self-Propelled Vehicles with Seated Capacity of 88 per Coach	88	176	352	528	704	880
Single-Level Push-Pull Train with Seated Capacity of 108 in Straight Coaches and 104 in Coach with Control Cab	104	212	428	644	860	1,076
Train with Bi-Level Gallery Coaches, Total Seated Capacity of 157 in Straight Coaches and 147 in Coach with Control Cab	147	304	618	932	1,246	1,560

Source: SEWRPC.

Table 63

COMPARISON OF CAPACITIES FOR VARIOUS LIGHT RAIL TRANSIT ALIGNMENTS

Type of Alignment	Approximate Design Capacity (passengers per hour)
Exclusive, Grade-Separated Subway, Aerial, or Surface Guideway	20,000-30,000
Reserved Surface Guideway, Median, or Side of Road, Reserved Lane, or Transit Mall	10,000-20,000
Mixed Traffic Operation	5,000-10,000

Source: Peter Strauss, "San Francisco Also has MUNI," Progressive Railroading, August 1978.

per dual guideway mile. The energy used in the rehabilitation of commuter rail guideways can be expected to constitute some proportion of the energy needed for construction, that proportion depending on the extent of rehabilitation required.

Vehicle manufacturing energy is estimated at 5,500 BTU's per vehicle for heavy rail rapid transit and 4,100 million BTU's per vehicle mile for light rail transit. Commuter rail vehicles require the largest amount of manufacturing energy, about 6,800 million BTU's per vehicle.

ECONOMIC CHARACTERISTICS

Within the context of this report, the term "economic characteristics" pertains primarily to the capital and operating costs of each transit mode. This section presents such cost data relevant to system planning for all three rail transit modes. The cost data presented represent generalized, nonsite-specific information compiled from data collected on actual systems operating in selected urban areas of the United States. No special attempt was made to obtain cost data for European light and heavy rail facilities since adequate data were available from within the United States. The cost data are intended to be utilized at the systems planning level for comparing alternative primary transit system plans.

Capital Costs

Capital costs are those investments required to acquire and construct the physical facilities—both fixed guideway and rolling stock—necessary for the operation and maintenance of a rail transit system. Capital costs thus include the cost of acquiring right-of-way and vehicles; the costs of constructing the guideway, stations, power distribution system, signalization and communication system, and maintenance and storage facilities; agency costs; and contingencies.

Right-of-Way: Right-of-way acquisition costs include all costs entailed in obtaining easements over, or fee simple title to, all real property required for the construction and operation of the rail transit system. In the design of both light and heavy rail systems there is a tendency to utilize available public rights-of-way and alignments to the greatest extent possible. There may be instances, however, where insufficient right-of-way is available, especially for heavy rail, which requires less severe gradients and greater horizontal curvature than does light rail. Although right-of-way acquisition costs are difficult to estimate in the absence of a specific system design and definitive knowledge of local real estate values, some measure of those costs is provided in Table 64. Land for major stations and parking facilities must be estimated separately on a per-acre or per-parking-space basis. When the proposed alignment requires that structures, utilities, or other transportation facilities be relocated, such relocation can become a major element in the total right-of-way cost.

Vehicles: The cost of vehicles is a function of the sophistication of various vehicle subsystems. Included within this item are the costs of vehicle delivery, on-board control, and any special equipment. Over the past several years, vehicle costs have been escalating at a more rapid rate than have most other capital cost items, implying that vehicle costs should be estimated with particular care and caution. Some light rail vehicles as well as commuter rail rolling stock involve the use of proven, "off-the-shelf" technology that should require a minimum of presystem start-up testing. Recent cost data are presented along with other vehicle data under the section above entitled "Vehicle Technology" (see Tables 42, 48, 49, and 50).

Guideway Construction: The guideway generally accounts for the major portion of the total cost of light rail transit and heavy rail rapid transit construction. Guideway costs are difficult to generalize since they are greatly affected by the horizontal and vertical alignment. Therefore, unit costs based on a number of critical items are provided in the absence of a preliminary engineering plan, relating such costs to a subway, surface, or elevated con-

Table 64

LAND COSTS IN MILLIONS OF DOLLARS PER MILE FOR LIGHT RAIL TRANSIT AND HEAVY RAIL RAPID TRANSIT RIGHTS-OF-WAY

Location[a]	Land Costs per Population of SMSA's[b] (in millions of dollars)					
	Less Than 50,000	50,000-100,000	100,000-250,000	250,000-500,000	500,000-1 Million	More Than 1 Million
Central Business District . . .	1.34	1.34	1.61	2.02	2.68	4.14[c]
Central Business District Fringe Area.	1.34	1.34	1.45	1.61	2.02	2.68
Residential Area.	1.19	1.19	1.34	1.34	1.71	2.39

[a] *Based on data extrapolated from highway land costs and expressed in terms of two-track rail facilities where at-grade and open cut right-of-way cross-sections average 36 feet and elevated, cut-and-cover, and tunneling cross-sections average 30 feet. Data are expressed in 1979 dollars.*

[b] *SMSA = Standard Metropolitan Statistical Area.*

[c] *Caution is warranted in using this figure since there is a wide variation in actual values.*

Source: D. B. Sanders and T. A. Reynen, et. al., Characteristics of Urban Transportation Systems—A Handbook for Transportation Planners (National Technical Information Service, Springfield, Virginia, 1979) compiled for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago.

figuration for the guideway. Guideway costs for commuter rail are normally minimal since the trackage is already in place. Upgrading, rehabilitation, and construction of some ancillary trackage may, however, be necessary prior to initiation of commuter service over existing railway lines.

The guideway costs cited within Tables 65, 66, and 67 include the cost of all structures necessary to support the trackage. Items included in the unit costs of at-grade, on-street guideways include pavement removal, utility and drainage adjustment, base construction, trackwork, and pavement restoration. The unit costs of off-street guideways include earthwork, the subbase, drainage, trackwork, fencing, and landscaping. Items included in the unit cost of aerial structures include foundations, footings, columns, the superstructure, drains, trackwork, utility adjustments, street restoration, and landscaping. Items included in the unit costs of underground segments include pavement removal, underpinning, utility maintenance and relocation, excavation, shoring, dewatering, concrete tunnel structure, and track work. Underground segments for heavy rail rapid transit guideways assume the use of cut-and-cover tunneling.

Stations: The costs of station facilities, like guideway costs, depend upon the particular requirements of a specifically designed system. Commuter rail and surface applications of light rail usually require minimal facilities. Heavy rail rapid transit stations, on the other hand, are complex structures, especially if located on elevated or underground alignments. Light rail stations that are located on either elevated or underground segments will tend to approach the magnitude of heavy rail stations in design and cost. A major determinant of any particular station cost is its physical dimensions, which must be related to projected passenger volumes, train size, and the fare collection system. Other factors requiring consideration include the location of loading platforms, the elevation of the platforms, architectural treatment, security requirements, intermodal facilities, and park-ride facilities (see Tables 68, 69, and 70).

Power Distribution: The power distribution system includes those facilities required to provide electrical power for vehicle propulsion and operation of fixed facilities. Basically, this component consists of the necessary complement of substations and an overhead contact wire system for light rail service, or a third rail system for heavy rail service. This cost component is not applicable to diesel-electric-propelled commuter rail services.

Signals and Communication: The size and cost of the signalization and communication component will vary with the mode. Traffic control is the most

Table 65

UNIT CONSTRUCTION COSTS FOR LIGHT RAIL TRANSIT FIXED GUIDEWAYS

Item	Construction Costs (in 1979 dollars—agency and contingency costs are not included)									
	Medium Density			High Density				Central Business District		
	At-Grade on Private Right-of-Way	Elevated on Fill or Structure	Retained Cut	At-Grade on Private Right-of-Way or Median	Aerial Structure	Retained Cut	Elevated on Fill	At-Grade on Median or in Transit Mall	Aerial Structure	Cut-and-Cover Subway
Grading (per mile)	$ 362,000	$ 393,000	$ 1,812,000	$ 181,000	$ 906,000	$ 1,812,000	$ 393,000	$ 181,000	$ 906,000	$14,049,000
Drainage	18,000 per stream crossing	30,000 per stream crossing	120 per linear foot	169,000 per mile	--	120 per linear foot	30,000 per stream crossing	169,000 per mile	--	604,000 per mile
Utilities (per crossing)	6,000 each highway	24,000 each highway	72,000 each highway	12,000 each railroad and highway[c]	24,000 each railroad and highway	72,000 each railroad and highway	24,000 each railroad and highway	18,000 each railroad and highway[c]	24,000 each railroad and highway[c]	72,000 each railroad and highway[d]
Structures—Primary (per miles)	--	12,756,000	15,946,000	--	15,100,000	15,946,000	12,756,000	--	--	--
Structures—Other (per crossing)	362,000 each railroad and river	362,000 each railroad, highway, and river, if required	362,000 each railroad, highway, and river	362,000 each railroad, highway, and river, if required	--	362,000 each railroad, highway, and river	362,000 each railroad, highway, and river, if required	--	--	--
Traffic Handling (each railroad and highway crossing)	6,000	48,000	48,000	18,000	60,000[e]	60,000	60,000	30,000	60,000[e]	266,000[f]
Demolition (per building)[a]	9,000	9,000	9,000	--	12,000	12,000	12,000	--	12,000	12,000
Fencing (per mile)	133,000	133,000	133,000	--	--	133,000	133,000	--	--	--
Trackage (per double-track mile)	815,000	897,000	897,000	1,067,000	989,000	989,000	989,000	1,334,000	1,087,000	1,087,000
Special Trackwork (per mile)	91,000	100,000	100,000	141,000	110,000	110,000	176,000	176,000	121,000	121,000
Electrification (per mile)	1,329,000	1,329,000	1,329,000	1,329,000	1,329,000	1,329,000	1,329,000	1,329,000	1,329,000	1,329,000
Signals and Communication (per mile)[b]	414,000	414,000	414,000	414,000	414,000	414,000	414,000	--	414,000	414,000
Grade-Crossing Protection	54,000 per highway crossing	--	--	54,000 per highway crossing[g]	--	--	--	--[g]	--	--

[a]If building is greater than three stories in height, then number of buildings equals the number of stories minus two.

[b]Does not include on-board equipment and storage yard control.

[c]If not located on street right-of-way, use $604,000 per mile.

[d]If not located on street right-of-way, use $3,624,000 per mile.

[e]If not located on street right-of-way, use $966,000 per mile.

[f]If not located on street right-of-way, use $326,000 per railroad and highway crossing.

[g]For median or boulevard operation, use $15,000 per arterial street intersection for preemptive signals. Do not use preemptive signals on private rights-of-way or transit mall applications.

Source: U. S. Department of Transportation, Urban Mass Transportation Administration; and SEWRPC.

Table 66

UNIT CONSTRUCTION COSTS FOR HEAVY RAIL RAPID TRANSIT FIXED GUIDEWAYS

Item	Construction Costs (in 1979 dollars—agency and contingency costs are not included)								
	Medium Density			High Density				Central Business District	
	At-Grade	Elevated on Fill or Structure	Retained Cut	Cut-and-Cover Subway	Elevated on Fill	Aerial Structure	Retained Cut	Cut-and-Cover Subway	Aerial Structure
Grading (per mile)	$453,000	$ 393,000	$ 1,812,000	$14,049,000	$ 393,000	$ 906,000	$ 1,812,000	$14,049,000	$ 906,000
Drainage	17,000 per stream crossing	30,000 per stream crossing	120 per linear foot	604,000 per mile	30,000 per stream crossing	--	120 per linear foot	604,000 per mile	--
Utilities (per crossing)	24,000 each highway	24,000 each highway	72,000 each highway	72,000 each railroad and highway[c]	24,000 each railroad and highway	72,000 each railroad and highway[d]	72,000 each railroad and highway	72,000 each railroad and highway[c]	24,000 each railroad and highway[d]
Structures—Primary (per mile)	--	12,756,000	15,946,000	15,946,000	12,756,000	15,100,000	15,946,000	15,946,000	15,100,000
Structures—Other (per crossing)	362,000 each railroad, highway, and river	362,000 each railroad, highway, and river, if required	362,000 each railroad, highway, and river	--	362,000 each railroad, highway, and river	--	362,000 each railroad, highway, and river	--	--
Traffic Handling (each railroad and highway crossing)	36,000	48,000	48,000	266,000[e]	60,000	60,000[f]	60,000	266,000[e]	60,000[f]
Demolition (per building)[a]	9,000	9,000	9,000	12,000	12,000	12,000	12,000	12,000	12,000
Fencing (per mile)	133,000	133,000	133,000	--	133,000	--	133,000	--	--
Trackage (per double-track mile)	815,000	897,000	897,000	989,000	989,000	989,000	989,000	1,087,000	1,087,000
Special Trackwork (per mile)	91,000	100,000	100,000	110,000	110,000	110,000	110,000	121,000	121,000
Electrification (per mile)	906,000	906,000	906,000	906,000	906,000	906,000	906,000	906,000	906,000
Signals and Communication (per mile)[b]	827,000	827,000	827,000	827,000	827,000	827,000	827,000	827,000	827,000

[a] If building is greater than three stories in height, then number of buildings equals the number of stories minus two.

[b] Does not include on-board equipment and storage yard control.

[c] If not located on street right-of-way, use $3,624,000 per mile.

[d] If not located on street right-of-way, use $604,000 per mile.

[e] If not located on street right-of-way, use $326,000 per railroad and highway crossing.

[f] If not located on street right-of-way, use $966,000 per mile.

Source: U. S. Department of Transportation, Urban Mass Transportation Administration; and SEWRPC.

Table 67

UNIT RAILWAY TRACK STRUCTURE AND ROADBED REHABILITATION COSTS FOR COMMUTER RAIL SERVICE

Item	Construction Cost[a] (in 1979 dollars)
Cross Tie Replacement	$35 per tie
Crushed Rock Ballast	$12-21 per cubic yard, including alignment and surfacing[b]
Alignment and Surfacing Only	$21-120 per track mile
Earthwork and Drainage	Item
Roadbed Widening	Item
Continuous Welded Rail	$165,000-181,000 per track mile[c]
Rail Joint Renewal	$15 per joint
New Trackage	$65-73 per linear foot[c]
Turnout Rehabilitation	$23,000-33,000 per turnout[c]
New Turnouts	$19,700-33,000 per turnout[d]
Power Turnout Machinery	$30,000 per turnout
New Crossing Diamond	$35,000 per turnout
Signal Work	Item
Grade-Crossing Work	Item
Grade-Crossing Protection	$60,000 for single-track crossing $140,000 for double-track crossing
Supervision	5 percent

[a] *All costs subject to variation depending upon site-specific conditions.*

[b] *Dependent upon depth of new crushed rock plus extent of alignment and surfacing.*

[c] *Dependent upon weight of rail and ease of installation.*

[d] *Dependent upon turnout size.*

Source: SEWRPC.

complex for the heavy rail rapid transit mode, being governed by such systems as automatic train control, automatic train operation, and automatic train protection. The apparatus necessary for such systems includes track circuits, wayside detectors, interlocking equipment, data transmission equipment, central control facilities, and applicable software. Also included within this cost component is the communication system between the control center, supervisory and maintenance personnel, stations, and trains, and the public address systems at stations. The cost of similar apparatus for light rail systems varies greatly with system design. Generally, light rail communications equipment needs are similar to those of heavy rail systems, although the cost of such equipment is a relatively minor portion of the cost of the entire component. Traffic control will more than likely cost less with automatic train protection, being normally limited to some wayside block signalization and preemptive traffic signals at intersections. The capital costs, if any, of a signalization system for commuter rail service will be dependent on the type of signalization installed on the existing railway lines and its ability to safely handle the combination of freight and/or passenger trains and the proposed commuter train traffic.

Maintenance and Storage: Initial costs incurred in the construction of vehicle storage yards, maintenance and servicing facilities, and repair shops relate directly to the size of the completed system and to the extent to which certain functions are performed by in-house forces. In many cases, the central traffic control center and special administrative facilities will be at the same location as the storage and repair facilities. Costs are difficult to determine in the absence of at least a conceptual layout (see Tables 71, 72, and 73).

Agency Costs: Agency costs are the unallocated allowances for engineering and administration during project implementation. Specific tasks covered under this item include engineering and architectural design, construction management, cost estimation and control, construction supervision, inspection and testing, and system start-up. Fifteen percent of total capital costs is typically allotted to cover these needs. This cost does not apply to vehicle acquisition.

Contingencies: Contingencies are an unallocated allowance that is intended to cover unforeseen and unpredictable conditions that may arise during detailed design or construction. Values for this item, which applies to all capital cost items except vehicle acquisition, range between 20 and 35 percent, and depend upon the depth of the preliminary engineering studies.

Summary: Tables 65 through 73 provide capital construction cost data in a form convenient for use in estimating rail transit facility capital costs for systems planning purposes. Tables 65, 68, and 71 pertain to light rail transit, and present costs for guideway, station, and storage and maintenance facility construction, respectively. Tables 66, 69, and 72 pertain to heavy rail rapid transit and again present costs for guideway, station, and storage and maintenance facility construction, respectively. Tables 67, 70, and 73 pertain to commuter rail and present costs for railway track rehabilitation and upgrading, station construction, and the upgrading of storage and maintenance facilities, respectively.

Several basic observations can be made regarding rail transit capital costs. First, initial investment in commuter rail may be expected to be considerably lower than that required for either light

Table 68

UNIT CONSTRUCTION COSTS FOR LIGHT RAIL TRANSIT STATIONS

Item	Construction Costs (in 1979 dollars—agency and contingency costs are not included)									
	Medium Density			High Density				Central Business District		
	Exclusive At-Grade Right-of-Way	Elevated on Fill or Structure	Retained Cut	Exclusive At-Grade Right-of-Way	Shared Street Right-of-Way	Elevated on Fill or Structure	Retained Cut	Shared Street Right-of-Way or in Transit Mall	Aerial Structure	Cut-and-Cover Subway
Awning per Two-Car Train.	$ 97,000[a]	$ 97,000[a]	$ 97,000[a]	$ 97,000	$ --	$ 97,000	$ 97,000	$ --	$ 97,000	$ --
Parking per 75 Autos.	139,000[a]	139,000[a]	139,000[a]	139,000[a]	--	139,000[a]	139,000[a]	--	--	--
Access per 75 Autos	174,000[b]	242,000[c]	242,000[c]	174,000[b]	--	242,000[d]	242,000[d]	--	906,000 plus 293,000 per each additional 1,800 people	731,000 plus 322,000 per each additional 1,800 people
Platform per Two-Car Train	18,000	155,000	181,000	18,000	18,000	155,000	181,000	18,000	193,000	532,000
Shelters per 360 People	6,000	12,000	12,000	6,000	6,000	12,000	12,000	6,000	--	--
Station Facility	--	--	--	--	--	--	--	--	435,000 plus 284,000 per each additional 1,800 people	977,000 per 1,800 people

[a] *Optional if included in station layout design.*

[b] *Do not include if there is no parking included.*

[c] *If no parking is included, use $30,000 plus $30,000 per 360 people.*

[d] *If no parking is included, use $36,000 plus $36,000 per 360 people.*

Source: U. S. Department of Transportation, Urban Mass Transportation Administration; and SEWRPC.

Table 69

UNIT CONSTRUCTION COSTS FOR HEAVY RAIL RAPID TRANSIT STATIONS

Item	Construction Costs (in 1979 dollars—agency and contingency costs are not included)								
	Medium Density			High Density				Central Business District	
	At-Grade	Elevated on Fill or Structure	Retained Cut	Cut-and-Cover Subway	Elevated on Fill	Aerial Structure	Retained Cut	Cut-and-Cover Subway	Aerial Structure
Parking per 75 Autos.	$139,000[a]	$139,000[a]	$139,000[a]	$139,000[a]	$139,000[a]	$139,000[a]	$139,000[a]	$ --	$ --
Access									
Per 75 Autos if Between 75 and 300 Autos	295,000[b]	$271,000[c]	271,000[d]	483,000 plus 242,000 per each additional 600 people	254,000 per 600 people	254,000 per 600 people	480,000 per 1,000 people	1,208,000 plus 604,000 per each additional 1,800 people	664,000 per 3,000 people
Per 150 Autos if Between 301 and 750 Autos	469,000[b]	592,000[c]	592,000[d]						
Platform per Two-Car Train . . .	72,000	43,000	242,000	425,000	193,000	193,000	425,000	483,000	193,000
Station Facility	87,000 per 360 people	87,000 per 360 people	127,000 per 360 people	302,000 per 600 people	145,000 per 600 people	145,000 per 600 people	302,000 per 600 people	3,866,000 plus 1,148,000 per each additional 1,800 people	435,000 per 1,800 people
Awning per Two-Car Train. . . .	97,000	97,000	97,000	--	97,000	97,000	--	--	97,000

[a] *Optional if included in station layout design.*

[b] *If no parking is included, use $121,000 per 360 people.*

[c] *If no parking is included, use $181,000 per 360 people.*

[d] *If no parking is included, use $242,000 per 360 people.*

Source: U. S. Department of Transportation, Urban Mass Transportation Administration; and SEWRPC.

Table 70

UNIT CONSTRUCTION COSTS FOR COMMUTER RAIL STATIONS

Item	Construction Costs (in 1979 dollars—agency and contingency costs are not included)		
	Suburban, Low, and Medium Density	High Density	Central Business District
	At-Grade	At-Grade	At-Grade
Platform per Two-Car Train	$11,000	$11,000	$11,000[a]
Station Facility per 150 People	10,000	10,000	10,000
Parking per 30 Autos.	49,000	--	--
Awning per Two-Car Train.	97,000[a]	97,000[a]	97,000[a]

[a] *Optional if included in station layout design.*

Source: U. S. Department of Transportation, Urban Mass Transportation Administration; and SEWRPC.

Table 71

UNIT CONSTRUCTION COSTS FOR LIGHT RAIL TRANSIT STORAGE YARDS AND REPAIR SHOP FACILITIES

Item (per 60 cars)	Construction Costs (in 1979 dollars—agency and contingency costs are not included)	
	Storage Yard	Shop Facilities
Grading	$411,000 plus 236,000 per each additional 60 cars	$ 302,000
Drainage	846,000	181,000
Utilities	966,000	242,000
Trackage	2,126,000 plus 978,000 per each additional 60 cars	1,317,000
Buildings	85,000 plus 39,000 per each additional 60 cars	6,523,000 per 100 cars
Electrification and Power	2,054,000	1,108,000
Fencing	36,000 plus 21,000 per each additional 60 cars	36,000

Source: U. S. Department of Transportation, Urban Mass Transportation Administration; and SEWRPC.

Table 72

UNIT CONSTRUCTION COSTS FOR HEAVY RAIL RAPID TRANSIT STORAGE YARDS AND REPAIR SHOP FACILITIES

Item (per 60 cars)	Construction Costs (in 1979 dollars—agency and contingency costs are not included)	
	Storage Yard	Shop Facilities
Grading	$411,000 plus 236,000 per each additional 60 cars	$ 302,000
Drainage	846,000	181,000
Utilities	966,000	242,000
Trackage	2,126,000 plus 978,000 per each additional 60 cars	1,317,000
Buildings	85,000 plus 39,000 per each additional 60 cars	6,523,000 per 100 cars
Electrification and Power	1,401,000	707,000
Fencing	36,000 plus 21,000 per each additional 60 cars	36,000

Source: U. S. Department of Transportation, Urban Mass Transportation; and SEWRPC.

Table 73

UNIT CONSTRUCTION COSTS FOR COMMUTER RAIL STORAGE YARD AND REPAIR SHOP FACILITIES

Item	Construction Costs[a] (in 1979 dollars—agency and contingency costs are not included)	
	Storage Yard	Shop Facilities
Drainage (per 20 cars)	$ 29,000	$121,000
Trackage (per 20 cars)	304,000	368,000
Buildings (per 20 cars)	49,000 plus 25,000 per each additional 20 cars	668,000 plus 325,000 per each additional 20 cars
Fencing (per 60 cars)	13,000	40,000

[a] *Costs reflect upgrading of existing facilities.*

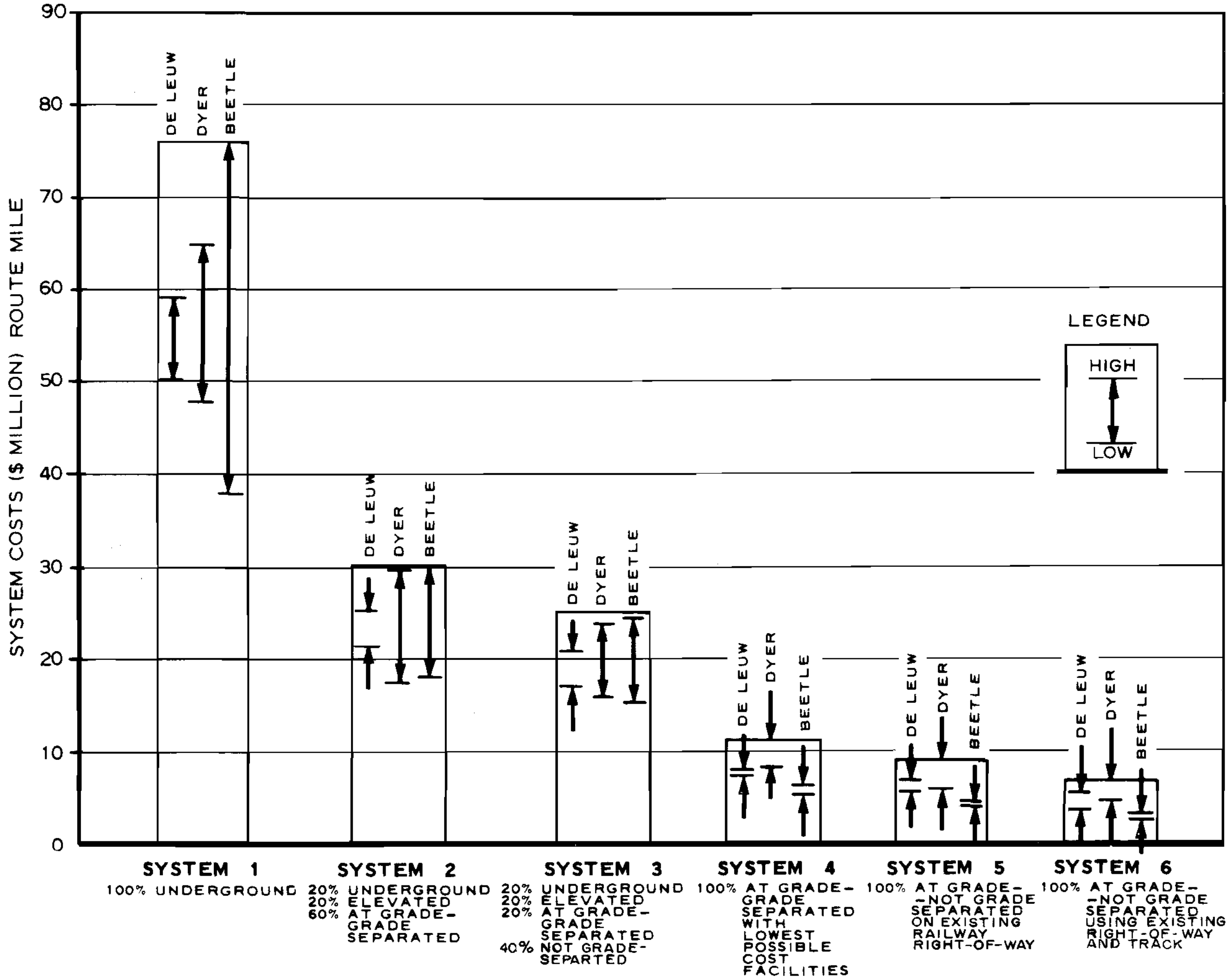
Source: U. S. Department of Transportation, Urban Mass Transportation; and SEWRPC.

or heavy rail. The ready availability of a right-of-way and guideway transfers the major share of capital investment to rolling stock and stations, which are typically nonintensive facilities. The similarities between commuter rail and the other two rail transit modes are, however, limited, since commuter rail systems are oriented toward a different set of travel demands.

Second, there are large differences in the costs associated with different vertical guideway alignments. Elevated segments cost two to five times more than surface segments, and underground segments cost two to five times more than elevated segments. The costs of surface guideway construction are highly variable, depending upon whether the alignment is exclusive, reserved, or in mixed traffic. The decision as to what vertical configuration is desirable for a new system is fundamental to the system's ultimate cost, and may be more important than the choice of mode. As shown in Figure 138, a comparison of unit cost ranges developed by the consulting firms of De Leuw, Cather & Company, Thomas K. Dyer, Inc., and George R. Beetle indicate little or no difference between major items of construction for selected systems of specified configurations. However, as these hypothetical system configurations show, a predominantly grade-separated—or Class A—light rail transit system with sophisticated train control and elaborate station facilities will approach the cost of a heavy rail rapid transit system. A more austere light rail transit system design—using Class B alignments—which includes shared rights-of-way,

Figure 138

EFFECT OF VERTICAL CONFIGURATION ON FIXED GUIDEWAY CAPITAL COSTS FOR LIGHT RAIL TRANSIT SYSTEMS



Source: Light Rail Transit: A State of the Art Review, prepared for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago, 1976.

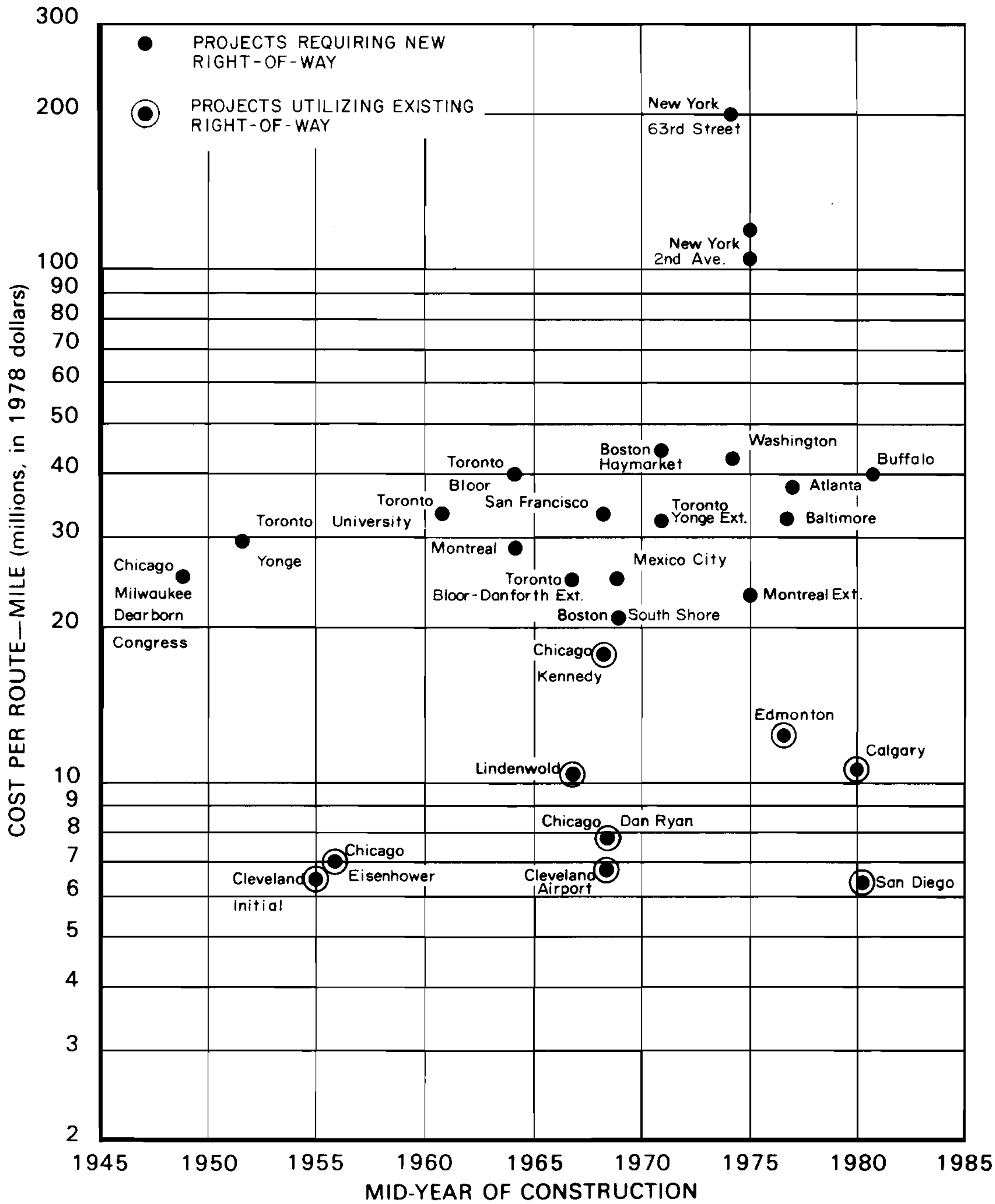
at-grade crossings, minimal train control and signal systems, and simple waiting shelters at stations will show significant cost savings over the former type of system.

Third, the availability and use of existing rights-of-way has a significant effect on total costs. Figure 139 shows that projects utilizing railway or freeway rights-of-way are generally completed at a significantly lower cost per route mile than are projects utilizing new right-of-way. Use of existing rights-of-way minimized costs for land acquisition, earthwork, and structures for cross streets and highways. Although this figure predominantly shows heavy rail rapid transit projects constructed since 1945, recent light rail transit start-up costs have been added for comparison.

Fourth, light rail transit cost advantages over heavy rail transit can be exploited only when extensive use is made of nonexclusive surface alignments, while minimizing investment in stations and sophisticated train control. When light rail is designed with elaborate stations and a predominantly grade-separated right-of-way, the distinction between the two modes becomes blurred and the costs become quite similar.

Figure 139

EFFECT ON COSTS OF UTILIZATION OF EXISTING RIGHTS-OF-WAY FOR RAIL TRANSIT PROJECTS



Source: San Diego Metropolitan Transit Development Board, Final Report—Guideway Planning Project; and SEWRPC.

Operating Costs

Operating and maintenance costs are normally expressed in units of dollars or cents per vehicle mile or vehicle hour. Typical operating and maintenance costs for light and heavy rail systems are shown in Tables 74 and 75, based upon the operating experience of selected United States operations. In addition, a slightly more detailed comparison of the operating costs of American and European light rail systems is presented because

Table 74

TYPICAL OPERATING AND MAINTENANCE COSTS FOR LIGHT RAIL TRANSIT

Item	Range of Costs per Car Mile[a]	Typical Cost per Car Mile[a]
Maintenance of Way and Structures	$0.28-$0.86	$0.63
Vehicle Maintenance . . .	$0.25-$0.69	$0.52
Power.	$0.12-$0.53	$0.37
Transportation	$0.96-$1.44	$1.20
General and Administrative	$0.59-$1.10	$0.76
Total	$2.70-$3.80	$3.48

[a] *Costs are based on 1975 data adjusted to reflect 1979 prices.*

Source: D. B. Sanders and T. A. Reynen, et. al., Characteristics of Urban Transportation Systems—A Handbook for Transportation Planners (National Technical Information Service, Springfield, Virginia, 1979) compiled for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago.

Table 75

TYPICAL OPERATING AND MAINTENANCE COSTS FOR HEAVY RAIL RAPID TRANSIT

Item	Range of Costs per Car Mile[a]	Typical Cost per Car Mile[a]
Maintenance of Way and Structures	$0.23-$1.13	$0.46
Vehicle Maintenance . . .	$0.32-$0.73	$0.38
Power.	$0.17-$0.49	$0.39
Transportation	$0.65-$1.60	$1.23
General and Administrative	$0.41-$2.38	$0.49
Total	$2.32-$4.81	$2.95

[a] *Costs are based on 1975 data adjusted to reflect 1979 prices.*

Source: D. B. Sanders and T. A. Reynen, et. al., Characteristics of Urban Transportation Systems—A Handbook for Transportation Planners (National Technical Information Service, Springfield, Virginia, 1979) compiled for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago.

of the current interest in European light rail operations (see Table 76). There are five principal categories of operating and maintenance costs for light and heavy rail as defined below. These categories conform to accepted transit accounting practices within the United States.

Maintenance of Way and Structures: Maintenance of way and structure costs are the expenses required to maintain fixed facilities, including the right-of-way, guideway and trackage, stations, electrical and control equipment, power systems, fare collection equipment, escalators, landscaping, fencing, and parking lots, and the administrative costs of this activity.

Maintenance of Vehicles: Maintenance of vehicle costs are the expenses required to maintain, inspect, clean, and repair vehicles, plus the administrative costs of this activity.

Power: Power costs are the expenses required to provide traction power for the propulsion of transit vehicles, and auxiliary power for the illumination of stations, yards, and shops and the operation of machinery in stations, yards, and shops. Energy unit costs for existing rail transit systems vary widely, necessitating the use of local rates for detailed estimation.

Transportation: Transportation costs are the wages for the personnel responsible for train operation. Such personnel include operators and other train attendants, station attendants, the security force, and other employees required to perform functions such as scheduling and dispatching. The total cost of this category can vary widely for the light rail mode, depending upon the fare collection system used and the extent to which vehicles are coupled into trains during peak periods. These factors will affect the number of employees required at stations and on board vehicles.

General and Administrative: General and administrative costs are the indirect expenses for such items as advertising and marketing, public information, insurance, safety, legal matters, accounting, taxes, and operating rents where applicable. An allowance for this category is generally made, based on the other direct operating and maintenance costs.

The categories of commuter rail operating and maintenance costs are based on the accounting practices utilized by major railway companies in the United States. The format used is the Uniform System of Accounts for Railroad Companies, as prescribed by the Interstate Commerce Commission. Major categories are entitled: Maintenance

Table 76

COMPARISON OF OPERATING AND MAINTENANCE COSTS OF AMERICAN AND EUROPEAN LIGHT RAIL TRANSIT SYSTEMS

System	Number of Vehicles Owned	Annual Vehicle Miles in Thousands	Total Operating Expenses per Vehicle Mile (in 1979 dollars)
Cleveland	55	1,042	$3.44
Philadelphia	424	22,812	1.64
Newark	27	462	5.94
San Francisco	115	3,304	6.06
Basel, Switzerland	375	10,320	5.21
Bern, Switzerland	84	1,850	6.16
Nuremberg, West Germany	351	8,910	3.02
Brunswick, West Germany	53	1,400	3.86
Gothenburg, Sweden	358	9,560	6.50
Munich, West Germany	630	11,750	4.37
Stuttgart, West Germany	467	15,535	3.27

NOTE: Information in this table is based on 1972 and 1973 data, and costs have been converted to dollars from foreign currencies.

Source: Light Rail Transit: A State of the Art Review, prepared for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago, 1976.

of Roadways and Structures and Maintenance of Equipment, which correspond to similar categories for light and heavy rail transit; Transportation, which includes the items under the power and transportation categories for light and heavy rail; Traffic, which includes advertising, superintendence, and employee benefits; and Other Costs, which are comprised of the usual overhead items. Typical costs for commuter rail are provided in Table 77.

Amortization Periods

The determination of suitable amortization periods for major components of a new rail transit system should be properly related to the expected service life. Amortization periods typically utilized for primary transit systems planning are set forth in Table 78.

SUMMARY

Rail transit technology is comprised of four distinct fixed guideway modes, three of which are described within this chapter along with pertinent characteristics necessary for systems level planning. These three modes are light rail transit, heavy rail rapid transit, and commuter rail. The fourth mode—the street railway—is only briefly mentioned since its use is considered to be largely obsolete within the United States.

Light rail transit is defined as a mode that utilizes predominantly reserved, but not necessarily grade-separated, rights-of-way. Its electrically propelled dual-rail vehicles operate singly or in trains. Power supply is from an overhead wire system and fare collection is on board the vehicle. Access to vehicles may be from ground level or from high-level platforms. An advantage of this mode is that it allows for a wide range of passenger capacities and performance characteristics at moderate costs.

The light rail mode is able to function in a variety of public transit roles, the most common being that of the primary transit system in medium-sized metropolitan areas. Typical network configurations consist of either a single route in a heavily traveled corridor, with feeder routes to other forms of primary transit service; or routes that branch out to outlying areas, thus providing their own feeder service.

Initially developed during the 1960's, light rail evolved into a separate mode as many street rail-

Table 77

TYPICAL OPERATING AND MAINTENANCE COSTS FOR COMMUTER RAIL

Category	Range of Costs per Car Mile[a]	Typical Cost per Car Mile[a]
Maintenance of Roadways and Structures	$0.29-$1.27	$0.59
Maintenance of Equipment	$0.68-$1.73	$1.18
Transportation	$2.70-$5.78	$4.15
Traffic	$0.01-$0.09	$0.05
Other	$0.17-$0.29	$0.31
Total	$4.14-$8.64	$6.28

[a] *Costs are based on 1972 data adjusted to reflect 1979 prices.*

Source: D. B. Sanders and T. A. Reynen, et. al., Characteristics of Urban Transportation Systems—A Handbook for Transportation Planners (National Technical Information Service, Springfield, Virginia, 1979) compiled for the Urban Mass Transportation Administration by De Leuw, Cather & Company, Chicago.

Table 78

TYPICAL AMORTIZATION PERIODS FOR RAIL TRANSIT COMPONENTS

System Component	Amortization Period in Years
Light Rail Vehicles	20-30
Heavy Rail Rapid Transit Vehicles	25-30
Commuter Rail Rolling Stock	30
Right-of-Way	100
Guideways[a]	20-30
Structures	50
Stations, Including Parking	30
Power Distribution	30-40
Control and Communication Equipment.	30
Maintenance and Storage Facilities	30-40
Contingency and Agency Costs	30

[a] *Does not account for freight service utilization.*

Source: SEWRPC.

way systems in Western Europe were upgraded to light rail standards and methods of operation. During the 1970's, active interest in the mode gained momentum as urban areas outside Europe—including the United States—started projects of either upgrading remaining street railway systems or constructing new light rail systems. It is important to recognize that although some light rail components resemble those of street railways, the level of service more closely matches that of heavy rail rapid transit because of the priority provided over other traffic in congested areas. Therefore, light rail's inherent performance characteristics distinguish it as a separate rail transit mode.

Heavy rail rapid transit is defined as a mode that utilizes dual-rail vehicles propelled by electricity transmitted through a side-running third rail, and operating on an exclusive, grade-separated right-of-way. Typical attributes of heavy rail rapid transit include the use of paired vehicles coupled into trains, high-level platform loading, and fare collection at stations. Automated train operation is commonplace on modern heavy rail systems.

The principal function of this mode is the provision of primary transit service that can meet the travel demands of the most heavily traveled corridors. Heavy rail rapid transit normally exists only in the largest areas. Heavy rail networks are generally radial in nature. Conventional systems were constructed from the 1890's through the 1920's. After a two-decade suspension, interest in such facilities increased sharply during the 1970's. Contemporary system start-ups exhibit an advanced level of automated train control and follow standard mainline railway practices far less than do older, conventional systems.

Commuter rail is characterized by relatively large peak-hour volumes, long average trip lengths, long distances between stations, and a high level of comfort. Trains share mainline railway trackage with freight traffic, the common practice in the United States and Canada being the use of diesel-electric locomotives and coaches as opposed to electrified multiple-unit equipment. Attraction of park-ride passengers is important.

Commuter rail is the oldest of the rail transit modes, but presently exists only where there are substantial passenger trip origins in outlying suburban areas with destinations in the central business district. Because of this basic traffic requirement, commuter rail systems are found only in about 10 cities within the United States and Canada. Only one of these systems has been instituted in recent years, and that was a replacement for conventional commuter services.

The critical characteristics of each mode pertaining to vehicle size and configuration, capacity, and performance vary significantly. Thus, each rail mode requires its own type of vehicle. Contemporary light rail vehicles are available in nonarticulated, single-articulated, and double-articulated versions. Articulation allows the vehicle to bend on joints supported by a two-axle truck when traversing curved trackage. Such design allows a larger vehicle capacity, while retaining a narrow profile on curves for clearance and safety purposes.

Light rail vehicles are available in a wide range of physical and operational configurations. The length and width vary from 44 to 91 feet, and from 6 to 9 feet, respectively. Vehicle height to the top of roof is normally 11 feet or less. Net weight ranges from 16 to 43 tons. Seating capacity ranges from 16 to 72 passengers, while total capacity ranges from 74 to 190 passengers. Even greater capacity is available if "crush" loads are permitted. Vehicle performance may be measured by maximum attainable speed, and by maximum acceleration and deceleration. These values range from 34 to 62 miles per hour (mph), from 1.8 to 4.3 miles per hour per second and 1.8 to 8.2 miles per hour per second, respectively.

Light rail power is typically provided by 600- to 650-volt direct current, collected by a pantograph on the vehicle roof from an overhead trolley wire system. Vehicle speed is controlled by regulating the motor current and voltage using either a rheostatic method or new solid-state designs which allow regenerative braking and thereby contribute to power economies.

Current truck design incorporates a single motor for driving both axles. This design reduces weight and cost but adversely affects speed, acceleration, and grade-climbing ability. Brake systems are usually all-electric, employing dynamic braking and disc brakes. The incorporation of a magnetic track brake for emergency stopping provides light rail equipment with high rates of deceleration, necessary for nonexclusive guideway operation.

Recent trends indicate a preference for bi-directional vehicles, which offer greater operational flexibility—especially in underground segments. Multiple-unit operation permits one operator to control a train of up to four vehicles, raising line capacity and operator productivity. Interior design and passenger amenities are dependent upon local preferences and the desired load factors. Door design and location depend on whether high-level or low-level loading, or both, is used.

The typical heavy rail rapid transit vehicle configuration is sets of two cars semi-permanently coupled with a control cab at one end of each car. Vehicles generally range from 65 to 75 feet in length, are about 10 feet wide, and are approximately 11 to 12 feet in height. Net weight varies between about 28 and 41 tons per car. Seating capacity ranges from 58 to 80 passengers, with design capacities of from 200 to 325. The typical maximum speed is 75 mph, and service acceleration and deceleration values range from 2.5 to 3.5 miles per hour per second.

The electrical requirements of heavy rail propulsion are similar to those of light rail propulsion, although current is collected from an energized rail instead of an overhead wire. Because of this and the use of automated train control on modern systems, there should not be any grade crossings along the guideway.

For safety reasons, passenger access to vehicles is via high-level platforms. These also expedite boarding and alighting. Modern heavy rail seating arrangements are generally two plus two transverse to accommodate as many seated riders as possible.

Contemporary diesel-powered commuter train operation is characterized by the use of either bi-directional locomotive-hauled trains or self-propelled coaches. Bi-level coaches are extensively utilized in certain metropolitan areas, significantly increasing train capacity without enlarging train length. In circumstances where relative demand is not as great, self-propelled coaches may be preferred. Similar to an unpowered single-level coach, control cabs are located at both ends, and propulsion equipment is mounted beneath the floor.

Because commuter rail rolling stock operates on trackage shared with common carrier intercity freight and passenger trains, overall design and construction is similar to that of typical railway passenger rolling stock. Coaches are 85 feet long by 10½ feet wide by about 14 to 16 feet high. Net car weights range between 37 and 64 tons. Seating design capacities range from 88 to 162 passengers.

Diesel-electric locomotives used in commuter service are similar to those used in regular railway operations. Self-propelled rolling stock is diesel-mechanical powered, employing no electric traction motors.

Of the rail transit modes considered herein, light rail transit has the most complex guideway technology because of the wide variety of alignment options available. Guideway characteristics are the least complex for commuter rail since existing facilities are utilized. Traditional open trackage consisting of T-rails attached to cross ties anchored in crushed stone ballast, is used for all commuter rail service, and for surface applications of the light and heavy rail modes. To adequately provide for commuter rail operation, trackage should meet at least Class 3 requirements, as prescribed by the Federal Railroad Administration track safety standards, which allow passenger train speeds of 60 mph.

Fixed track, which consists of T-rails fixed directly to a concrete slab base with special elastomeric tie pads for noise control, is applied on elevated structures and in subways of light and heavy rail systems. Paved track is required whenever light rail transit shares the right-of-way with rubber-tired vehicles, such as in mixed traffic operation, transitways, and pedestrian malls. Girder rail, which incorporates a built-in flangeway, is used with paved track. To date, North American practice includes the placement of pavement over open track construction, resulting in the truck being rigidly attached to the pavement and transmitting noise and vibrations. Contemporary European paved-track construction differs in that girder rail is laid directly on the ballast or concrete slab base without cross ties, the gauge being maintained by tiebars. The rail is supported and surrounded by a jacket of mastic asphalt which deadens noise and vibration transmission. The remainder of the track zone is paved with one of several possible materials, such as concrete blocks. "Standard gauge" track of 4 feet 8½ inches is typical for all new rail transit system start-ups.

Of the three modes, light rail transit has the greatest variety of alignment options available, including mixed traffic operation, reserved transit lanes, dedicated street rights-of-way, pedestrian malls, freeway rights-of-way, railroad rights-of-way, and subways. Fixed guideways for light rail transit may be categorized as either Class A or Class B alignments. Class A alignments provide for high-speed operation with gentle gradients and horizontal curves, while Class B alignments accommodate a somewhat lower level of service because of the extensive utilization of shared rights-of-way and sharp horizontal curves. Heavy rail guideways have a less flexible set of alignment options available, being totally grade-separated. Modern heavy rail rapid transit systems often utilize a subway in a major activity center, including the central business district, and either surface or elevated segments in other areas. Because of the expense and impacts of constructing right-of-way in built-up areas, new systems tend to utilize either expressway medians or railroad rights-of-way in such areas. Commuter rail normally uses existing mainline railway alignments and trackage.

Actual guideway dimensions are dependent upon detailed site-specific designs that are created once the mode and alignment have been selected. Minimum right-of-way widths for double-track surface applications of light and heavy rail vary between 24 and 34 feet, depending on the alignment particulars. A typical commuter rail right-of-way is 100 feet wide. Distances between track centers range from slightly less than 12 feet for light rail to 14 feet for standard mainline railway design. Side clearances are usually a minimum of about 5 feet from track center. Overall, the smallest minimum lateral clearances pertain to light rail transit, while the largest minimum clearances are required for commuter rail because of the need to adhere to common carrier railway practices. The minimum clearances for heavy rail rapid transit fall between those of these two modes.

The minimum vertical area required for light rail guideways is largely determined by the design of the overhead electrical current distribution system. Contact wire height must be between 15 and 20 feet from the top of rail for satisfactory pantograph performance. Line poles for supporting the contact or catenary wire system may be located either between or to the outside of the tracks and are generally 24 to 29 feet in height. In some areas, it may be appropriate to suspend the overhead wiring from street light standards or adjacent buildings. Where restrictive vertical clearances do not permit installation of complete line pole assemblies, the contact wire can be attached directly to the overhead obstruction.

Aerial and underground guideway construction is nearly identical for light and heavy rail with regard to the structures necessary. Minimum vertical clearances for aerial structures are 14 feet 9 inches over streets and highways, and 23 feet over railway tracks. Support column spacing is typically at 100-foot intervals. Underground segments can be constructed by either the cut-and-cover or deep tunnel-bored method. For cut-and-cover construction a trench must be dug, which severely affects surface activity. The subway casing is then poured, the trackage installed, and the trench filled in. Overall dimensions for the underground structure might be 34 feet in width with 17 feet 6 inches between track centers, and a minimum of 19 feet

6 inches in height. A bored subway tube can be expected to have an inside diameter of 16 feet 6 inches and a one-foot three-inch minimum wall thickness. Track centerlines are 36 feet apart. The distance between the top of structure and ground level varies, but typical values are 15 feet for cut-and-cover construction and 50 feet for a bored deep tunnel.

With regard to the potential application of the three rail transit modes within the Southeastern Wisconsin Region, there are no restrictions resulting from existing system constraints. Light rail transit application would be constrained only by the availability of suitable surface rights-of-way. Heavy rail rapid transit alignments would be subject to even less constraints since underground and elevated guideway alignments can be used. Commuter rail system implementation is constrained by the existing location of mainline common carrier railway routes. This, however, also works to the mode's advantage, since the right-of-way, structures, and guideway are already in place.

Heavy rail rapid transit utilizes the most elaborate, costly, and areally demanding stations of the three transit modes. Typically spaced from 0.3 mile to 1.2 miles apart, each facility normally has two levels: the platform level equipped with either center or side island platforms and the concourse level for fare collection and interface with other modes. Overall lengths vary from 300 to 700 feet, with a 60-foot minimum width. Actual platforms should be at least 10 to 12 feet wide. Parking lots and facilities for feeder buses can significantly influence station design and cost.

Stations for light rail transit vary in complexity depending upon the desired level of investment. Typically spaced from 0.2 to 0.5 mile apart, simple at-grade facilities need to consist only of platforms, signing, lighting, a small shelter, and proper pedestrian access. Platform lengths range from 100 to 300 feet, and widths from 6 to 10 feet. Controlled access stations are employed at major transfer points or where large passenger volumes are anticipated. The layout and cost of such stations may approach that of heavy rail stations, especially in subway alignments. Where the "pre-metro" concept of using light rail as an interim mode is implemented, stations may have to be designed for ultimate use as a heavy rail facility. Also important to station design are local conditions and whether high- or low-level loading is used.

Commuter rail stations are usually the least complicated, the distance between stations ranging from 0.7 mile to 2.8 miles. In many instances, actual facilities include only platforms of 500 to 1,000 feet in length. An additional major item is parking lot space since commuter rail depends upon a large park-ride attraction.

Support requirements for all three rail transit modes consist of five elements. Vehicle storage and maintenance for light rail and heavy rail consists of storage yards large enough to hold all vehicles not in service during the system's least active operating period, as well as adequate shop and repair facilities. Storage yards must include appropriate apparatus for daily servicing, while the shop facilities should be able to handle routing inspection maintenance, as well as heavy repairs. Similar facilities for commuter rail consist of outside storage tracks at outlying stations, with maintenance and repairs normally handled by the railway over which the service is operated.

The second element, guideway and structure maintenance, consists of the apparatus, personnel, and operations necessary to maintain and repair the track structure, guideway, right-of-way, stations, and other fixed facilities. Comparatively large systems may find it advantageous to carry out all such functions—both minor and major—with in-house forces. Smaller systems, on the other hand, may determine that contracting outside for such tasks would be more cost-effective. Roadway and structure maintenance for commuter rail is generally the responsibility of the operating railway, with the costs of commuter train operation being prorated according to the terms of a purchase-of-service contract.

Power supply and distribution relate only to the light rail and heavy rail modes. The light rail mode requires an overhead contact wire system consisting of either a simple contact wire or a catenary system suspended from supports. A simple contact wire is practical where speeds are below 45 miles per hour, or in areas where aesthetics are especially sensitive. The wiring must be supported at approximately 100-foot intervals. Catenary overhead is recommended for high-speed operation and is more complex, but requires support columns only every 150 to 300 feet.

A frequently cited disadvantage of light rail transit is the visual intrusion created by the overhead power distribution system. This impact may be mitigated by placing nonessential wiring and cables underground, blending line poles and wires with surrounding trees and other landscaping, substituting line poles with overhead wire support from existing buildings and other structures, and combining overhead wiring, street illumination, and traffic signals on the same masts to reduce the number of poles necessary on public street rights-of-way.

Power is purchased commercially and transformed into the operating voltage through a system of substations and primary feeders. Primary substations are typically located at 10-mile intervals and secondary substations at 2-mile intervals. Operating voltages greater than the typical 600-volts direct current may be appropriate for a completely new system since operating efficiency and substation spacing can be increased. It should be recognized that the extent and complexity of the power supply and distribution system are dependent upon the power required per train. Electrical capacity must be available to deliver adequate power for the greatest-length trains to be operated on the shortest headway anticipated.

Heavy rail rapid transit power supply and distribution is very similar to light rail power supply and distribution except that vehicle current collection is through a third rail shoe which slides along an energized third rail. The larger cross-section of the third rail allows a greater current capacity, which in turn permits longer trains to be operated than can be handled by light rail transit.

Power requirements for dieselized commuter rail service are contained on board the locomotive, making no attendant guideway apparatus necessary. Such service generally shares fueling facilities with the railway over which operations occur.

The principal functions of rail traffic control apparatus are to control the speed and spacing of traffic along the guideway, to protect against conflicting movements, to control points of interface with other modes, and to control routings within the system. Modern heavy rail systems in the United States employ automatic train operation, whereby almost all functions of train operation are automated. The majority of existing light rail systems rely on manual or visual sight rules, with some automatic train protection on segments with restricted visibility. Safe following distances and train speeds for a new commuter rail service would be governed by whatever signal system is already in place—either automatic block signals, which control train spacing, or centralized traffic control, whereby heavily trafficked trackage is controlled from a central location.

Grade-crossing protection for light rail transit systems deserves special attention. Since the mode is located largely on the surface without the benefit of lengthy aerial or underground segments, some sort of preferential treatment must be acquired if high-speed, high-quality service is to be provided. Basic strategies to facilitate this are prohibition of cross traffic, costly grade separation, or modification of the existing motor vehicle traffic control systems to give special signal phases to, or permit preemption by, transit vehicles.

There are four basic fare collection procedures that are relevant to rail transit operations. Most common is the pay-as-you-enter system which is normally used on motor bus systems, street railways, and light rail transit systems in the United States and Canada. Controlled access fare collection is handled in stations and is common to heavy rail rapid transit systems within the United States. On-board ticket collection is typical of commuter rail service in North America. The fourth fare collection procedure is self-service ticketing; passengers purchase tickets from a vending machine and validate them at the time of use. Compliance with this system is maintained by a staff of checkers who are legally empowered to fine offenders on the spot. Self-service ticketing is popular in Western Europe but remains untried in the United States.

System performance characteristics for light rail transit, heavy rail rapid transit, and commuter rail may be defined in terms of three factors—speed, headway, and capacity. These three factors are important determinants of the level of public acceptance and patronage of a new primary transit system. Absolute vehicle speeds are a function of the individual vehicle capabilities. Typical maximum speeds are approximately 50 mph for light rail vehicles, 75 mph for modern heavy rail rapid transit vehicles, 65 mph for diesel-electric-propelled commuter trains, and 80 mph for contemporary self-propelled diesel coaches.

Typical operating speeds are constrained by the type of guideway, traffic control, surrounding land uses, and, especially, the extent to which the guideway is grade-separated or reserved. Heavy rail and commuter rail systems can operate at maximum speeds except where horizontal curvature, grades, switching districts, and station areas impose specific speed restrictions. Light rail operates at maximum speed only on grade-separated or fully protected surface alignments. On reserved rights-of-way that are shared with public streets and in mixed traffic, speeds are held at or near those speeds allowed of the surrounding traffic. For safety reasons, pedestrian malls demand an even greater reduction in speed, usually to 15 or 20 mph.

Average speeds for rail transit are dependent upon the acceleration and deceleration characteristics of the vehicles, station spacings, and, in the case of light rail transit, the extent of priority over conflicting traffic. Typical speeds for light rail systems from 10 to 18 mph; for heavy rail, from 20 to 55 mph; and for commuter rail, from 20 to 45 mph. Exclusive rights-of-way are a critical factor in the determination of average system speeds.

Vehicle speed and the degree of automatic train operation largely determine how short a headway can safely be achieved. Minimum theoretical headways range from 0.6 minute to 1.5 minutes for light rail, from 1.5 to 3.0 minutes for heavy rail, and from 2.0 to 6.0 minutes for commuter rail. Actual headways are normally greater and reflect service scheduling policies. While light and heavy rail headways typically vary from 5 to 30 minutes throughout the day, commuter rail headways vary from 20 to 60 minutes except in cases where only one or two trains per weekday are operated.

Data on the system capacity attainable under efficient operation by the three rail transit modes vary somewhat. Light rail transit is generally cited as being able to meet peak-hour demands ranging from 6,000 to 20,000 passengers per hour, while heavy rail rapid transit is cited as being able to meet peak-hour demands of from 10,000 to 40,000 passengers per hour. Commuter rail is generally cited as being able to meet demands of from 8,000 to 35,000 passengers per hour. These data assume double-track guideways, one track for each direction of travel.

Capital costs are those investments required to acquire and construct the physical facilities required for the operation and maintenance of a rail transit system. Capital costs thus include the costs of acquiring right-of-way and vehicles; the costs of constructing the guideway, stations, power distribution system, maintenance and storage facilities, and signalization and communication system; agency costs; and contingencies.

A light rail transit guideway varies in cost between $4 million and $8 million per mile for at-grade facilities, and between $6 million and $19 million per mile for elevated facilities, not including stations or rights-of-way. Light rail guideway costs per mile for underground alignments are similar to heavy rail subway costs. Light rail station costs may vary from a negligible amount to about $7.5 million per facility, depending upon design and location.

The overall construction costs for heavy rail facilities depend upon the vertical configuration of the guideway and the type of surrounding urbanized area. Guideway costs per mile range from $4 million to $50 million, depending upon whether the facility is at-grade, elevated, or underground. Typical station facility costs range from $0.5 million to $14.5 million. The initial investment in both light and heavy rail systems depends greatly on what alternative vertical alignment is chosen, as well as on the availability of right-of-way. In contrast, commuter rail capital investment normally does not require the purchase of a right-of-way or the construction of a guideway, making the initial investment for this mode considerably less than that required for the other two rail transit modes.

Operating costs for light rail and heavy rail include maintenance of way and structure costs, vehicle maintenance costs, and power and transportation costs, as well as general and administrative costs. Total operating expenses range from $2.70 to $3.80 per car mile per year for light rail systems, and from $3.32 to $4.81 per car mile per year for heavy rail systems.

The categories of commuter rail operating and maintenance costs are based on standard railway accounting practices in the United States. Major categories differ somewhat from those cited above, but are analogous. Total operating expenses for commuter rail operations range from $4.14 to $8.64 per car mile per year.

The energy requirements of rail transit technologies include not only the energy required to propel vehicles, but also the energy needed to operate stations and maintain vehicles and system facilities and the energy required to construct the system and manufacture the vehicles.

Vehicle propulsion energy constitutes the majority of energy consumed and accounts for most of the variation in overall energy utilization of rail transit systems. In terms of propulsion energy per vehicle mile, the commuter rail mode has the highest energy requirements, ranging from 98,300 to

132,100 British Thermal Units (BTU's) per vehicle mile for bi-level gallery coaches propelled by a diesel-electric locomotive. Heavy rail rapid transit and light rail transit propulsion energy requirements were estimated to range from 64,900 to 93,400 BTU's per vehicle mile and 46,900 to 135,000 BTU's per vehicle mile, respectively.

Energy used to maintain vehicles and stations typically constitutes from 10 to 20 percent of the propulsion energy required per vehicle mile. Commuter rail vehicle maintenance needs are the highest, estimated at 3,800 BTU's per vehicle mile. Maintenance requirements for heavy rail rapid transit and light rail transit are estimated at 2,100 and 2,000 BTU's per vehicle mile, respectively.

Energy for station operation varies widely among the rail transit modes, being particularly high for heavy rail rapid transit, which normally has elaborate grade-separated stations with air conditioning and escalators. Such stations are estimated to require an average of 12,000 BTU's per vehicle mile, about double the energy required by stations on other fixed guideway systems. Station energy requirements for the other rail modes vary from nothing for stations consisting of only small paved areas to 3,200 BTU's per vehicle mile and 5,100 BTU's per vehicle mile for larger station facilities for commuter rail and light rail systems, respectively.

Light rail transit and heavy rail rapid transit guideway construction energy requirements are similar, and are estimated at 24.6 billion BTU's per dual guideway mile for at-grade segments, about 111 billion BTU's per mile for elevated segments, and 234 billion BTU's per mile for subway sections. The energy consumed in the construction of commuter rail guideways is estimated at 30 billion BTU's per dual guideway mile.

Finally, vehicle manufacturing energy is estimated at 5,500 million BTU's per vehicle for light rail transit and 4,100 million BTU's per vehicle for heavy rail rapid transit. Commuter rail vehicles require about 6,800 million BTU's per vehicle.

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Chapter IV

ELECTRIC TROLLEY BUS TECHNOLOGY

INTRODUCTION

By a strict definition of the terms "primary," "secondary," and "tertiary" transit service, the electric trolley bus mode usually is applied only in the provision of a tertiary level of service. This is because the operation of electric trolley buses is, as a practical matter, usually restricted to standard surface arterial streets. However, it must be recognized that even though the electric trolley bus utilizes arterial streets for the guideway, the mode has the ability to provide a high-quality line-haul service, as do light rail transit and arterial express bus systems. With special design provisions, there is no reason why the mode could not be applied to the provision of a secondary level of service—that is, express service over reserved lanes of surface arterials. Although the maximum operating speed of the electric trolley bus presently precludes its use for high-speed primary service over exclusive guideways, there is really no reason why the mode could not be so used if lower operating speeds were acceptable or if, for example, severe motor fuel shortages required the electrification of existing busways. For these reasons, and because of the current limited interest in the resurgence of this mode, electric trolley bus technology is included within this inventory of alternative primary transit technology.

DESCRIPTION, DEFINITION, AND ATTRIBUTES

The electric trolley bus mode consists of rubber-tired buses which operate on existing surface arterial streets and highways, generally in mixed traffic. The vehicles are propelled by electric motors which receive power through power collection poles attached to the vehicle roof that slide along a pair of overhead contact wires. The electric trolley bus mode, therefore, represents a mixture of the motor bus and light rail transit technologies. Like the motor bus mode, electric trolley buses do not require a special guideway, as they can operate on existing public roadways and are therefore able to maneuver around many obstacles such as barricades and stopped motor vehicles. Like light rail transit vehicles, electric trolley buses require an overhead power distribution system, which prevents the vehicle from being able to deviate from the established routes.[1] The boarding or alighting of passengers generally occurs at typical street corner bus stops, although pedestrian islands and some station facilities may be employed at special locations. Fare collection procedures are generally identical to those used in the motor bus mode, as are the support requirements except for the overhead power distribution system.

The electric trolley bus mode can be defined as the operation of electrically propelled rubber-tired transit buses over paved roadways. The electrical power is transmitted to the vehicles via an overhead contact or "trolley" wire system. For a transit service to be considered an electric trolley bus operation, most of the following conditions must be met:

1. Electrically propelled rubber-tired transit buses, either standard single-level or articulated design, are used.

2. Electric power is transmitted to the vehicles through an overhead network of trolley contact wires.

3. Operation is generally in mixed traffic on public streets and highways.

4. Fares are collected on board.

Other terms are often used to denote the electric trolley bus mode, including "trolley coach" and "trackless trolley."

[1] *Hybrid vehicles, which employ internal combustion engines in addition to the electric motors, do permit operation away from the overhead power distribution system for short periods of time. This type of modification is more fully discussed in the "Technical Characteristics" section of this chapter.*

Electric trolley bus systems possess several attributes that require consideration in any system planning effort, including:

1. Electric trolley bus systems typically use existing paved roadways, making the construction of a new fixed guideway unnecessary.

2. The overhead power distribution system does not permit immediate route changes or detours, although the individual vehicles have a limited ability to move laterally under the overhead contact wires.

3. The overhead wire system and other electrical support facilities represent a major construction element requiring some period for implementation as well as possibly resulting in some community disruption, including the undesirable visual impact of the overhead wires.

4. The quality of service will be affected by surrounding traffic conditions since this mode typically operates in mixed traffic.

5. Electric trolley buses utilize electric propulsion and are thus not dependent on petroleum-based fuels.

6. There is no significant difference in the performance characteristics of electric trolley buses and conventional diesel motor buses.

7. Electric trolley bus vehicles cannot overtake each other without removal of the power collection poles from the contact wires or without additional overhead wires and switches.

GENERIC APPLICATION AND GEOGRAPHIC EXTENT OF ELECTRIC TROLLEY BUS OPERATION

In the past, the elctric trolley bus mode was seen as offering an intermediate capacity and level of service, or a capacity and level between that offered by the street car mode and the motor bus mode. The first electric trolley bus system in the United States was placed in service during 1910, with several additional crude systems becoming operational from 1910 to 1920 and in the early 1920's. Following this experimental period, the mode was adopted by the transit industry and has been or currently is utilized on a total of 49 systems in the United States, 14 systems in Canada, and 2 systems in Mexico. Most of the United States systems were installed during the 1930's, while most of the Canadian systems were installed during the late 1940's.

There are several significant reasons for the introduction of this mode in the 65 North American cities, among them:

- During the 1930's, many street railway systems reached the end of their economic life. With falling passenger volumes and the depression economy, many transit operators chose to replace the street railway lines with a less capital-intensive mode.

- Also during the 1930's, the trolley bus in many instances possessed performance capabilities superior to those of either the streetcar or the motor bus. Older pre-PCC era streetcars lacked similar performance capabilities and had to contend with worn-out trackage. On heavily traveled lines, the electric trolley bus could out-perform the gasoline and early diesel motor buses, especially when stops were frequent. Also, many electric trolley buses were larger, had a larger seating capacity than did the early motor buses, and were quieter as well. Finally, the excellent electric trolley bus performance was well accepted by passengers.

- The ability to utilize existing electric power facilities and technology was also a factor. The sizable investment in the power distribution system could be utilized for the electric trolley bus since the substations, feeder lines, and some of the overhead wire components required little or no modification. In addition, maintenance and repair facilities already in place for street railway technology did not require renovation, and the staff didn't require extensive retraining.

- The cost savings realized from conversion from the street railway mode was usually significant because of the elimination of the fixed guideway and associated maintenance functions. Also, certain operating cost characteristics favored the electric trolley bus over the motor bus. Electric trolley buses utilized a much simpler propulsion system which required less maintenance, effort, personnel, and inventory; generally had a more favorable power or fuel cost, especially compared with that of gasoline-powered motor buses; and could frequently handle heavily patronized routes with fewer vehicles because of the electric trolley buses' larger size and superior performance. These cost savings, however, were partially offset by the maintenance costs of the power distribution system.

The utilization of electric trolley buses in North America peaked during the early 1950's, when well over 50 systems were in operation. Beginning in the late 1940's, and continuing through the mid-1960's, almost all electric trolley bus systems in the United States were converted to diesel motor bus operation. During the late 1960's and early 1970's, a majority of the Canadian systems were similarly converted. The major reasons for the discontinuance of this mode are:

- The changing pattern of the urban infrastructure, partly caused by the wide spread use of the automobile, caused much low-density suburban development to occur. At the same time, the increased automobile usage generated highway relocations, freeway construction, and the institution of one-way streets. In the face of declining ridership and attendant increasing headway intervals, transit operators could not justify the capital investment required to either extend electric trolley bus routes into suburban areas or relocate routes to conform to changes in land use and street patterns.

- During the 1950's, most electric trolley bus systems had reached or passed their anticipated economic life, which was considered to be 20 to 25 years. The poor financial position of many transit operators during this period precluded the borrowing of funds for system renewal.

- Also during the 1950's, as well as the 1960's, the economics of operating transit systems forced the various managements to seek any and all ways to reduce costs in order to remain profitable. The costs of maintaining the fixed-power distribution system, the separate maintenance facilities and forces, plus spare parts inventories for more than one type of propulsion became targets for fiscal conservation on the part of operators, most of whom had converted or were in the process of converting from street railway systems to diesel motor bus operations. Also, fleet standardization became important in the quest for cost savings.

- The decline in transit ridership following World War II reduced the market value of transit systems, with many being subsequently sold to holding companies for less than book value. In many cases, the new management—which did not have to contend with the same level of capitalization—would use the salvage value from street railway and electric trolley bus systems to cover all or a substantial portion of the purchase price. If the dismantled facilities had book value remaining, tax credits could also be generated. In addition, the separation of electric utility and transit companies—forced by the Securities and Exchange Commission—eliminated the benefits of shared costs and arbitrary allocations for fixed electrical power distribution facilities.

The electric trolley bus mode was fairly well dispersed throughout the United States and Canada. Although the 63 systems within the United States and Canada were generally located in the major urbanized areas—including Milwaukee—several smaller cities, such as Duluth, Minnesota; Fort Wayne, Indiana; Greensboro, South Carolina; Rockford, Illinois; Shreveport, Louisiana; and within the Region—Kenosha, Wisconsin, were served by the mode. In contrast, electric trolley buses were notably absent from some large metropolitan areas such as Houston, Miami, Minneapolis-St. Paul, Pittsburgh, St. Louis, and Washington, D.C.

Electric trolley bus technology in Europe developed at about the same time as in the United States. The mode, however, was adopted much more quickly, with numerous systems in operation by 1910. The electric trolley bus mode then followed much the same course as in North America, with new systems being placed in operation up to the 1950's, much of the activity occurring immediately after World War II. The 1950's and 1960's witnessed the conversion to motor bus of many systems in most western European countries. For example, the last electric trolley bus system in the British Isles was converted in 1972, and in Germany, where such systems numbered more than 70 following World War II, only three remain in West Germany and three in East Germany. Two exceptions are Switzerland, which has retained and is upgrading virtually all of its electric trolley bus systems, and the Soviet Union, which is expanding its existing systems and installing new ones. In 1979 more than 200 urbanized areas outside North America utilized the electric trolley bus as part of the public transportation network.

There is currently a renewed interest in the electric trolley bus mode. All the systems in North America that survived past the mid-1970's have undergone, or are currently undergoing, some degree of system renovation. Such renovation ranges from the rebuilding of vehicles to the replacement of the entire power distribution system. Reasons for retaining the remaining electric trolley bus systems include not only the advantageous operating and maintenance costs, which in some cases include the cost of relatively inexpensive hydroelectric power, but also the widespread citizen support stemming from environmental protection and energy conservation considerations. In one case—Dayton, Ohio—the electric trolley bus network represents about 75 percent of the total system fleet, and in most cases the urbanized area is also served by electrically propelled rail transit. It should be recognized that the current "revival" of the electric trolley bus mode within North America is generally limited to vehicle replacement, fixed plant renewal, and route expansion within transit systems that are already utilizing the mode. Only one completely new electric trolley bus system is being implemented in North America. This system consists of two new routes in Guadalajara, Mexico placed in service during 1976. This system was precipitated by the availability of inexpensive surplus vehicles from Chicago plus the fact that a downtown tunnel which has been designed for eventual conversion to light rail transit was available for use.

As of October 1979 there were 11 electric trolley bus systems in operation in North America, including five in the United States, four in Canada, and two in Mexico. In the United States, electric trolley bus systems are in operation in the urbanized areas of Boston, Dayton, Philadelphia, San Francisco, and Seattle. In Canada, the mode is used in the metropolitan areas of Edmonton, Alberta; Hamilton and Toronto, Ontario; and Vancouver, British Columbia. Mexico's two electric trolley bus systems are operated in Guadalajara and Mexico City. A list of these operations, together with selected system characteristics, is presented in Table 79 and illustrated in Figures 140 through 144. There are no known proposals for the establishment of completely new electric trolley bus systems within North America.

Generically, the electric trolley bus mode appears to be best suited for performing a tertiary level of transit service, operating over surface arterial streets. Express operation of electric trolley buses on limited-access highways in mixed traffic has not, to date, been attempted. This is partially due to the fact that most electric trolley bus systems predated the widespread construction of expressways and freeways. In addition, there appear to be certain feasibility problems caused by the overhead power distribution system and the fact that available vehicles are designed for a maximum operating speed of about 40 miles per hour (mph). A more severe problem is the inability of electric trolley bus vehicles to weave through traffic at high speeds, as may be necessary in mixed traffic freeway applications. High-speed movements away from the overhead contact wire are likely to result in dewirement. If multiple routes utilized the same freeway segment, overhead contact wire switches would have to be employed, which limit maximum speeds to 25 mph on typical North American systems. These speed restrictions, along with the greater probability of dewirements, make switches impractical in freeway operation. Finally, rewiring the trolley poles would place the driver in an extremely hazardous position on a heavily traveled freeway. For these reasons, the operation of electric trolley buses in mixed traffic on high-speed limited-access roadways appears to be feasible only on short segments such as a bridge which connects two parts of a route located largely on surface arterial streets. Operation would be restricted to the outside curb lane.

The provision of a primary level of transit service through the operation of trolley buses over reserved surface street lanes or over exclusive guideways would also be constrained by the maximum operating speed of currently available vehicles, the maximum speed permitted by the currently used rigid overhead power distribution system, and the restrictions on speed which are imposed by any trolley bus overhead power distribution wires because of the overhead contact wire switches, crossovers, and electrical insulators. However, an electric trolley bus route could be developed along any motor bus guideway and could be designed to achieve a performance similar to that offered by the diesel bus. This would require use of a vehicle with a higher maximum operating speed, use of a flexible overhead power distribution system, and minimization of the number of overhead wire switches, crossovers, and electrical insulators.

Table 79

EXISTING ELECTRIC TROLLEY BUS SYSTEMS IN NORTH AMERICA

Characteristic	Boston	Dayton	Edmonton	Guadalajara	Hamilton	Mexico City	Philadelphia	San Francisco	Seattle	Toronto	Vancouver
Operating Authority	Massachusetts Bay Transportation Authority	Miami Valley Regional Transit Authority	Edmonton Transit System	N/A	Hamilton Street Railway	Sistema de Transporte Collective (Metro)	Southeastern Pennsylvania Transportation Authority	San Francisco Municipal Railway	Municipality of Metropolitan Seattle	Toronto Transit Commission	British Columbia Hydro and Power Authority
Number of Routes	4	8	9	2	3	18	5	15	10	8	13
First Year of Operation	1936	1933	1938	1976	1950	1951	1930	1935	1940	1946	1947
Total Revenue Service Vehicles	61	80	80	47	50	600[b]	130	345	56	151	312
Vehicles Purchased Since 1970											
Quantity	50	65	37	--[a]	43	--	110	343	109	151	50
Year	1976	1974	1973	--	1972/1978	--	1977	1976	1977	1972	1974
Manufacturer	Flyer Industries, Ltd.	Flyer Industries, Ltd.	Flyer Industries, Ltd.	--	Flyer Industries, Ltd.	--	AM General Corporation	Flyer Industries, Ltd.	AM General Corporation	Flyer Industries, Ltd.	Flyer Industries, Ltd.
Percentage of New Vehicles in Fleet	82.0	81.3	46.3	--	86.0	--	84.6	99.4	--	100.0	16.0
Urbanized Area Population	641,000	686,000	451,000	2,075,000[c]	312,000[d]	11,943,000[c]	4,021,000	716,000	1,238,000	2,628,000[c]	410,000[d]

NOTE: N/A indicates data not available.

[a] *Fleet purchased second-hand from Chicago Transit Authority.*

[b] *Approximation. Fleet consists almost entirely of second-hand vehicles purchased from various United States cities, including Milwaukee.*

[c] *Metropolitan area population.*

[d] *Center city population.*

Source: SEWRPC.

POTENTIAL APPLICATION IN SOUTHEASTERN WISCONSIN

At present, there are no electric trolley bus systems in operation within the seven-county Southeastern Wisconsin Region. Both the Cities of Milwaukee and Kenosha, however, did in the past employ this mode. The Milwaukee Electric Railway & Light Company—later The Milwaukee & Suburban Transport Corporation—operated electric trolley buses over 10 trunkline routes totaling 80.9 route miles in length, all of which were converted directly from the street railway mode. The electric trolley buses operated in and around the City of Milwaukee from 1936 to 1965 (see Figure 145). In the City of Kenosha, the electric trolley bus system consisted of four routes operated by the Wisconsin Gas & Electric Company. A total of 18.2 route miles were operated in the period from 1932 to 1952. Since electric trolley buses generally operate over roadways which are already in existence, reinstitution of the mode within the Milwaukee urbanized area would be limited only by the configuration of the existing street and highway network.

TECHNICAL CHARACTERISTICS

Vehicle Technology

The typical electric trolley bus has two basic body configurations: a single-unit nonarticulated vehicle

Figure 140

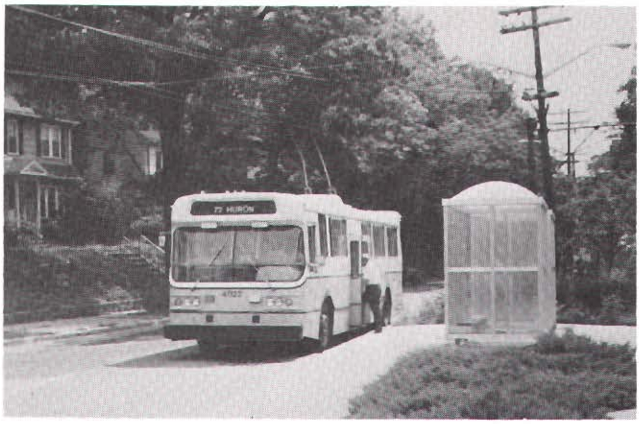
ELECTRIC TROLLEY BUS SERVICE IN THE DAYTON AREA

Dayton, Ohio, is one of five cities in the United States that in 1980 used electric trolley buses in daily transit service. In the mid-1970's, approximately 80 percent of Dayton's aged electric trolley bus fleet was replaced with modern vehicles manufactured by Flyer Industries, Ltd., of Canada. The MVRTA system is one of only four systems in North America wherein the electric trolley bus provides the backbone of all service. In the Dayton area, 8 of the 15 transit routes are equipped for such operation. Diesel motor buses are chiefly utilized for routes which extend into the suburban areas and a single crosstown route, and to augment the electric trolley bus vehicles during rush hours.

Photo by Thomas A. Matola.

Figure 141

ELECTRIC TROLLEY BUS SERVICE IN THE BOSTON AREA



Boston's four electric trolley bus routes operated by the Massachusetts Bay Transportation Authority originate at Harvard Square in the Cambridge area. While the remainder of Boston's once extensive electric trolley bus network was converted to diesel motor bus operation, these four routes were maintained because of the problems associated with the buildup of diesel exhaust in the tunnels utilized beneath Harvard Square. An unusual feature of Boston's electric trolley bus vehicles are the left-hand doors for the boarding of passengers in the Harvard Square tunnel and along a segment of Route No. 72—Huron Avenue, where some waiting platforms are located in the median area, as shown in this view.

Photo by Otto P. Dobnick.

Figure 142

ELECTRIC TROLLEY BUS SERVICE IN THE SEATTLE AREA

As of 1980, the City of Seattle was nearing completion of an extensive program to modernize and expand its electric trolley bus system operated by the Municipality of Metropolitan Seattle. The program included the replacement of all overhead wires and switches in the old 32-route-mile system, as well as the construction of 26 new neighborhood power substations to create a feederless power supply system. Also included in the project were an additional 23 miles of routes to be electrified, and the acquisition of 109 new electric trolley bus vehicles. Completion of this project will give Seattle a total of nine rehabilitated, and in some cases extended, electric trolley bus routes plus seven new electric trolley bus routes. In addition to offering quiet, pollution-free operation, the trolley buses have been found to have excellent hill-climbing capability on the many steep hills on Seattle's transit system.

Photo courtesy of the Municipality of Metropolitan Seattle.

Figure 143

ELECTRIC TROLLEY BUS SERVICE IN THE SAN FRANCISCO AREA

Unlike the electric trolley bus systems in most other cities where they are operated, San Francisco's system has remained relatively stable since the early 1950's and presently consists of 15 routes. In 1976 the entire fleet of vehicles was replaced by 343 new electric trolley buses manufactured by Flyer Industries, Ltd., of Canada. A recently completed study by the San Francisco Municipal Railway recommends several improvements, including three completely new routes, route changes, and complete rehabilitation of the electrical power conversion and distribution system. The electric trolley bus has been retained as a basic component of the urban transit system in San Francisco, as in other cities in North America, in part because of the availability of relatively inexpensive hydroelectric power.

Photo by Russell E. Schultz.

Figure 144

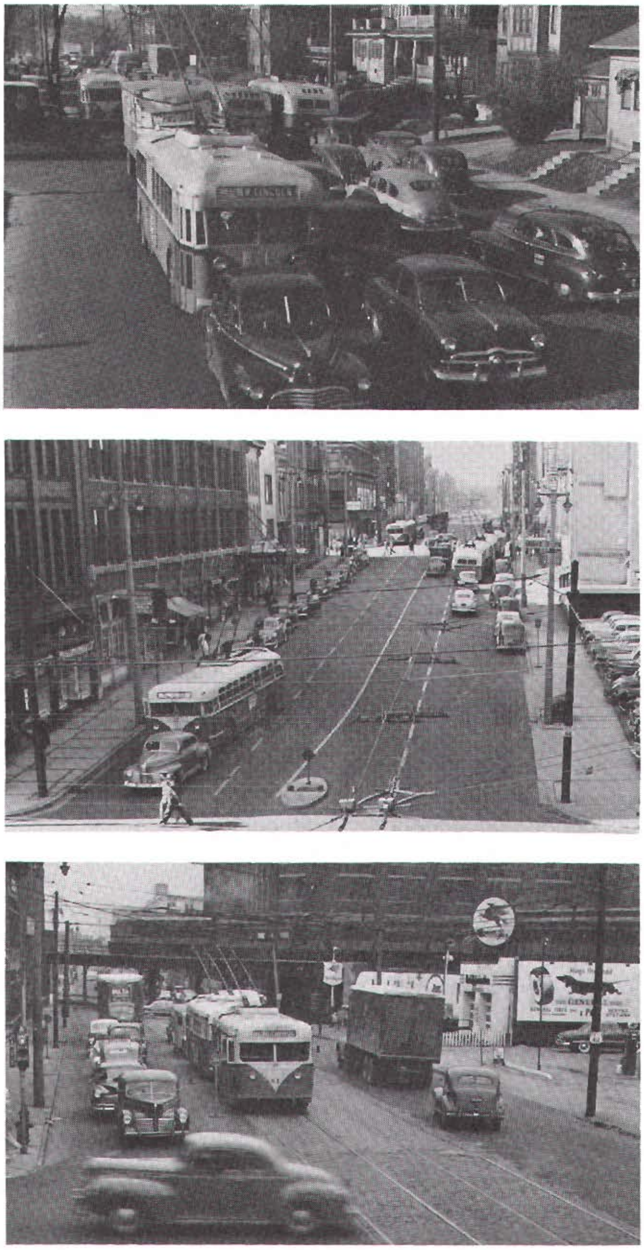
ELECTRIC TROLLEY BUS SERVICE IN THE VANCOUVER AREA

Presently, the British Columbia Hydro and Power Authority operates 19 electric trolley bus routes serviced by about 285 electric trolley buses in the Vancouver area. In 1977 practically all electric trolley bus routes in the central business district of Vancouver were moved onto the new Granville Street shopping mall, on which all service except for two diesel motor bus routes is provided by electric trolley buses. Vancouver also has one of only two North American electric trolley bus systems--the other being in Philadelphia--which utilize more than two sets of overhead wires on certain routes for the provision of express service. Such an overhead wire configuration is illustrated here on the Granville Street viaduct in Vancouver, where there are four pairs of overhead wires.

Photo by Russell E. Schultz.

Figure 145

FORMER ELECTRIC TROLLEY BUS OPERATION IN MILWAUKEE, WISCONSIN



The Milwaukee Electric Lines—and later the Transport Company—operated electric trolley buses in the Milwaukee area from 1936 to 1965. All trolley bus routes operated in mixed traffic on arterial streets and were, therefore, subject to the effects of traffic congestion during peak periods, as shown in the top view taken shortly after 4:30 p.m. at the intersection of N. 35th Street and W. State Street. The center view, taken from the intersection of E. Michigan Avenue and N. Milwaukee Street, shows the complex overhead wire construction required at junctions, as well as a lineup of electric trolley buses at E. Wisconsin Avenue. Without passing sidings built into the overhead wire system, an electric trolley bus cannot readily overtake and pass another such bus on a line. Electric trolley bus technology is designed for boarding passengers at curbside, as was typically done in Milwaukee. The Milwaukee system, however, frequently made use of safety islands originally designated for passengers waiting to board streetcars, as shown in the bottom view.

Photos courtesy of City of Milwaukee, Bureau of Traffic Engineering.

configuration and a two-unit articulated vehicle configuration. The standard single-unit nonarticulated electric trolley bus is by far the more common of the two configurations presently used on systems throughout the world and is the only configuration presently in use within North America. The typical modern vehicle used within the United States and Canada consists of a single-unit body with an overall length of 40.0 feet, a width of 8.5 feet, and a height of 10.3 feet. Within North America such nonarticulated vehicles are now being manufactured only by Flyer Industries, Ltd., and Diesel Division-General Motors of Canada, Ltd., although the AM General Corporation of Wayne, Michigan, produced modern electric trolley bus vehicles during the late 1970's. Unlike older electric trolley bus designs, currently available models throughout the world use a body design similar to that used for urban diesel buses, the only major differences between the two vehicle types being the propulsion and control systems. Table 80 sets forth selected technical characteristics for the standard nonarticulated electric trolley bus vehicle, including characteristics for three North American models and two European models. Figures 146 and 147 illustrate three of the modern North American vehicles. The characteristics of discontinued models have not been included, although some of these models may still be in use. All systems in the United States and Canada have replaced substantial portions of their original vehicle fleets with relatively new vehicles. A minimum of 80 percent of the total revenue vehicles in use on systems in the United States were manufactured after 1974.

The second basic electric trolley bus body configuration, the articulated vehicle, is an extra-length vehicle able to "bend" when traversing horizontal and vertical curves. Such a design permits a single vehicle with a single operator to provide a large seating capacity and yet be able to negotiate typical city street networks without vehicle clearance and overhang problems. The high capacity of such a vehicle is attractive from a transit operator's point of view because of the reduction in operating costs per passenger attributable to the vehicle's larger capacity, which may be especially important on high-density routes. The typical vehicle consists of two body units with an overall length of 54.1 feet, a width of 8.2 feet, and an average height of 10.3 feet. Articulated electric trolley buses have two axles supporting the front unit, an articulation joint located behind the second axle, and a third axle supporting the rear unit. The second axle propels the vehicle while the first and third axles perform the steering function. Like the nonarticulated standard version, currently available articulated electric trolley buses are similar to standard diesel bus designs but have a different propulsion and control system. While articulated electric

Table 80

PHYSICAL AND PERFORMANCE CHARACTERISTICS OF SELECTED ELECTRIC TROLLEY BUSES—STANDARD CONFIGURATION

Characteristic	AM General 10240-E	Flyer E900	GM of Canada, Ltd./ Brown, Boveri, Canada, Ltd.	Swiss Standard FBW 91T	Daimler-Benz OE 305[a]
Length (feet)	40.0	40.0	40.0	37.4	36.4
Width (inches)	102.0	102.0	101.8	98.4	98.4
Height (inches)	123.6	122.4	135.9	117.6	115.2
Gross Weight (pounds)	N/A	N/A	N/A	N/A	N/A
Net Weight (pounds)	23,500	23,000	N/A	26,019	24,271
Wheelbase (inches)	284.4	284.4	284.8	216.0	220.8
Minimum Turning Radius (feet)	37.2	37.2	42.0	N/A	34.4
Builder	AM General Corporation, Wayne, Michigan	Flyer Industries, Ltd., Winnipeg, Manitoba	Diesel Division—General Motors of Canada, Ltd./ Brown, Boveri, Canada, Ltd.	FBW/HESS Switzerland	Daimler-Benz, West Germany
Door Type /Number	NA/2	NA/2	NA/2	NA/3	NA/2
Front Door Width (inches)	30.0	30.0	30.0	N/A	49.2
Design Capacity Seats/Standees	50/25	51/26	53/27	29/60	44/61
Maximum Speed (mph)	37	40	37	37	43.5
Motor Type	GE 1213	GE 1213	N/A	Secheron 4EL62553	--[b]
Horsepower	155	155	N/A	197	--
Service Acceleration (miles per hour per second)	3.5	3.5	2.5	N/A	4.0
Service Deceleration (miles per hour per second)	N/A	N/A	N/A	N/A	N/A
Emergency Deceleration (miles per hour per second)	N/A	N/A	N/A	N/A	N/A
Capital Cost per Vehicle	$148,000	$146,000	$178,000	N/A	N/A

NOTE: N/A indicates data not available.

[a]*Prototype vehicle.*

[b]*Available with either electric and diesel or electric and battery propulsion systems.*

Source: Manufacturers, U. S. Department of Transportation, and SEWRPC.

trolley buses are used in some European cities, there are currently no articulated electric trolley buses in service within North America, although the Seattle system is considering the use of such vehicles. Specifications for selected articulated electric trolley buses—mostly of European design—are presented in Table 81, with accompanying illustrations in Figures 148 and 149.

Brief comments are warranted on two other, unusual, electric trolley bus body configurations. One configuration is a double-decked electric trolley bus, a design which has never seen application within the United States or Canada. This configuration was once popular in Great Britain, but disappeared with the discontinuance of electrification on all urban bus systems in the country. The second unusual configuration is a standard two-axle electric trolley bus towing a trailer. The use of trailers is not widespread—they are used only in Lausanne and St. Gall, Switzerland—and such application is apparently limited to special situations. The above cities are very hilly and there is concern about the ability to operate articulated vehicles on heavy grades on ice and snow conditions. The operation of trailers is subject to very restrictive safety regulations in Switzerland and is presently prohibited in some other countries. In addition, the use of trailers would require either the implementation of a self-service fare system or the addition of a second operator for manning the trailer.

Propulsion of electric trolley bus systems is achieved with relatively low-voltage—generally 600 volt—direct current (DC). The current is transmitted from the power source to traction motors attached to the vehicle axle via an overhead power distribu-

Figure 146

AM GENERAL CORPORATION
MODEL 10240-E VEHICLE

During the late 1970's, the AM General Corporation manufactured about 220 contemporary electric trolley bus vehicles for systems operating in Philadelphia and Seattle. These vehicles employed a body design identical to that used by AM General in the manufacture of its line of diesel motor buses, with solid-state chopper propulsion control supplied by Randtronics Transit Control Division. Subsequent to the delivery of these vehicles, AM General indicated that it would no longer respond to bid requests for new electric trolley buses.

Photo by Russell E. Schultz.

tion system. On nonarticulated designs the motor is attached to the rear axle; on articulated designs, to the second axle. The power collection device aboard the vehicle consists of two power collection poles because of the need for both positive and negative overhead contact wires. The overhead contact wires restrict the lateral distance that a vehicle may move away from the contact wires in order to pass obstructions or to stop at curbside loading points. This distance, sometimes referred to as the "touring distance," is generally between 12 and 15 feet from the centerline of the two overhead wires, although the exact distance is a function of the trolley pole length, the height of the contact wires, and the speed of vehicle travel.

Vehicle speed is controlled by regulation of the motor current and voltage using one of three basic types of control equipment systems: a rheostatic system, an electronic solid-state system, or a pulse width modulation system using alternating-current (AC) motors. The rheostatic system supplies power to the traction motor by applying varying resistance to the motor. This resistance is governed by the position of the accelerator pedal, which is controlled by the operator. This approach is well established, having been used for over 90 years in

Figure 147

FLYER INDUSTRIES, LTD., ELECTRIC TROLLEY BUS VEHICLES

Flyer Industries, Ltd. (formerly Western Flyer) of Thunder Bay, Ontario, is responsible for manufacturing most of the new electric trolley bus vehicles in service on North American systems. The Model E700 (left) and the more recent Model E800 (right) utilize the same vehicle bodies as do the Model D700 and Model D800 diesel motor buses manufactured by Flyer Industries.

Photo (left) by Otto P. Dobnick.
Photo (right) by Russell E. Schultz.

Table 81

PHYSICAL AND PERFORMANCE CHARACTERISTICS OF SELECTED ELECTRIC TROLLEY BUSES—ARTICULATED CONFIGURATION

Characteristic	Ikarus 280T3	Swiss Standard FWB 91GTL	Daimler-Benz[a] OE-305G	M.A.N GE-110/54/57 A
Length (feet)	54.1	59.0	56.6	54.1[b]
Width (inches)	98.4	98.4	98.4	98.4
Height (inches)	124.8	118.8	115.2	135.6
Gross Weight (pounds)	N/A	N/A	N/A	N/A
Net Weight (pounds)	26,901	34,177	29,856	28,665
Wheelbase Front/Rear (inches)	212.4/363.6	216.0/282.0	220.8/242.4	225.6/214.8
Minimum Turning Radius (feet)	N/A	N/A	34.4	34.1
Builder	Crown Coach Corporation	FBW/HESS Switzerland	Daimler-Benz, West Germany	M.A.N. Truck & Bus Corporation
Door Type/Number	NA/4	NA/4	N/A	NA/4
Door Width (inches)	49.2	N/A	49.2	49.2
Design Capacity Seats /Standees	35/104[c]	44/115	49/135	31/100
Maximum Speed (mph)	37	37	43.5	37
Motor Type	Secheron	Secheron	--[d]	Keipe
Horse Power	224	197	--	N/A
Service Acceleration (miles per hour per second)	N/A	N/A	4.0	N/A
Service Deceleration (miles per hour per second)	N/A	N/A	N/A	N/A
Emergency Deceleration (miles per hour per second)	N/A	N/A	N/A	N/A
Capital Cost per Vehicle	N/A	N/A	N/A	N/A

NOTE: N/A indicates data not available.

[a]Prototype vehicle.

[b]Also available in 59-foot length.

[c]European seating configuration. American seating configuration for this vehicle is 73 passengers.

[d]Available with either electric and diesel or electric and battery propulsion systems.

Source: Manufacturers, U. S. Department of Transportation, and SEWRPC.

all types of electric transportation, and is reliable and fairly rugged. However, energy is wasted as the resistors give off heat during acceleration.

Some new vehicle designs utilize solid-state thyristor choppers to provide continuously variable motor control, the power to the motor being "chopped" or broken into pulses at a rate of a few hundred per second. Advantages of this type of control are that regenerative, as well as dynamic, braking can be achieved.

Pulse width modulation is a power conversion technique with many similarities to chopper control. The principal difference is that the output is three-phase AC with a variable frequency in voltage. This theoretically permits the use of a standard AC induction motor, which is a mass-produced item in common use. This motor is lighter and cheaper than a DC motor, and requires less maintenance. However, in practice the mass-produced motor may not be durable enough for transit applications. A determination of any advantages of using the pulse width modulation method on electric trolley bus vehicles must await actual experience in revenue operation. European manufacturers have taken advantage of the improved component performance and reduced costs and have developed several systems for rail transit applications which may make this technique attractive for use on certain European systems.

Figure 148

IKARUS ARTICULATED ELECTRIC TROLLEY BUS MODEL 280T3

The Ikarus Model 280T3 electric trolley bus—marketed in the United States by Crown Coach Corporation—utilizes the same basic body components utilized by the Ikarus 286 diesel motor articulated bus and, therefore, has similar dimensions and capacities. Available with two, three, or four doors for passengers to board and alight, the vehicle is also equipped with electronic solid-state chopper control and a gasoline engine for limited propulsion capability away from the overhead wire system.

Photo courtesy of Crown Coach Corporation.

Figure 149

SWISS STANDARD ARTICULATED ELECTRIC TROLLEY BUS

In part because of the availability of relatively inexpensive hydroelectric power, interest in electrically propelled urban transportation systems has never lapsed in Switzerland. In 1970 the trolley bus committee of the Association of Swiss Transport Operators (VST) approached the manufacturers and suggested the development of a standard electric trolley bus because of the large number of such vehicles due for replacement at that time as well as the pending enlargement of some fleets. The resulting vehicle design incorporates an auxiliary power supply for operation independent of the contact wire, a high level of passenger comfort, simple and standardized components, and electronic chopper control which has resulted in reduced maintenance and more economical power consumption. This view shows the articulated version, there also being a conventional two-axle version. Six major Swiss cities are utilizing vehicles of this standard design.

Photo courtesy of Brown Boveri Canada, Ltd.

The performance capabilities of the electric traction motor provide high starting torque, and thus the motor can be overloaded for short periods of time. The performance characteristics of the electric trolley bus have remained essentially unchanged for many years, since most North American electric trolley buses built since 1940 have utilized the General Electric 1213 traction motor or an equivalent. This is the only motor specifically manufactured in North America for use in electric trolley buses.

The rate of acceleration for electric trolley buses is dependent upon loaded vehicle weight, roadway conditions, and the roadway gradients. The typical rate of acceleration is approximately 3.5 miles per hour per second for standard nonarticulated North American designs, but rates vary between 2.1 miles per hour per second and 4.0 miles per hour per second for various European vehicle designs. Maximum vehicle speeds approximate 40 mph.

It is generally accepted that the acceleration capability and overall operating performance of the electric trolley bus is superior to those of the diesel or gasoline bus. During the peak period of use of electric trolley buses—the late 1930's through the late 1950's—they offered the following advantages over diesel and gasoline buses.

1. The trolley coach was propelled by a DC electric motor which provided high torque throughout its operating range and therefore a high acceleration rate;

2. The DC electric motor had a significant overload capability that could deliver high operating performance on most grades that are encountered in normal transit operations;

3. The propulsion systems available for motor coaches—either gasoline- or diesel-powered—

were not mature products and were not designed to comparable performance standards; and

4. Electric trolley buses were generally larger vehicles and were equipped with wider doors, which reduced passenger stop and station dwell times. This reduction in turn lowered the running times and increased the average speed of operation.

During the early 1970's the performance of the diesel motor bus was greatly improved with the introduction of the Detroit Diesel 8V-71 engine. This prime mover provided greater acceleration and power and overcame many of the performance deficiencies of the 6V-71 and the older 6-71 engines built by Detroit Diesel. Utilization of the same body configurations for both electric trolley buses and diesel buses negates any advantage previously enjoyed by trolley coaches because of larger sizes or wider doorway openings. A review of electric trolley bus and diesel motor bus performance data suggests that the former is still a slightly superior vehicle in terms of acceleration provided; however, the top speed does not exceed 40 mph. The determinants of overall speed on a typical urban transit route, however, include factors other than the propulsion system performance such as traffic volumes, incidence of traffic signals, cycle time for the traffic signals, turning movements, double parking, street geometry, and dwell time. These factors can negate the electric trolley bus's slight performance advantage. Another factor that affects electric trolley bus performance is the overhead wire system. Overhead wire switches and crossings at intersections and junctions—referred to as "special work"—may limit both speed and acceleration and therefore affect overall performance. When electric trolley buses and diesel motor coaches are compared for typical urban transit route applications, they can be considered to have identical performance characteristics and can be treated as interchangeable vehicles. Transit operators in Edmonton, Vancouver, Seattle, and San Francisco all contend that the two types of vehicles are interchangeable from an operational point of view.

Most recent electric trolley bus designs incorporate electric brake control, which reduces mechanical brake maintenance to about one-third that of an equivalent-size diesel motor bus. Primary deceleration is achieved through the use of dynamic braking which utilizes the traction motors as generators. If regenerative braking capability is also incorporated—available only with chopper control—a 10 to 30 percent savings in power may be achievable because of the regenerated electric current being returned to the overhead power supply. However, this return of power is only possible when the line is receptive. Receptivity is a function of the closeness of another power absorbing source—usually an accelerating trolley coach—although reverse flow substations are possible. The regenerating electric trolley bus must return power to the line at a voltage higher than that of the line to "force" power into the line. This voltage must not be allowed to get too high, however, as it may damage components both on the generating vehicles and on any leading or following vehicles. Arrangements must therefore be made to monitor and reduce the line voltage if it rises too high. When the line is unreceptive, the braking energy must be switched from the line to the on-board resistors—that is, from regenerative to dynamic braking. Because dynamic braking becomes ineffective at low speeds, a secondary mechanical braking system is also required. Most modern designs employ disc brakes, as opposed to brake shoes, activated by an air break system which is identical to that of a diesel motor coach.

Various options are readily available to permit different degrees of off-wire electric trolley bus operation. However, such options provide limited performance and range capabilities, being applicable only for bypassing route blockages, crossing wire gaps or intersections, or moving around garage or storage areas without overhead wire.

The technology for off-wire operation currently involves energy storage either in the form of batteries or internal combustion engines. Battery operation involves three or four additional 24-volt batteries per vehicle which are constantly charged. When required to supply power to the traction motor, a switch changes the power connection from parallel to series, giving a 72-volt or 96-volt supply. The range is limited to about one mile, and speed is under 10 mph, but the additional space and weight for the batteries are modest.

Gasoline engines and diesel generators are provided on many Swiss and French electric trolley buses for emergency and nonrevenue purposes. The engines do not accumulate many operating hours and are small. Maximum speeds are generally 15 to 27 mph, and the maximum range is generally 30 miles or less. As with off-wire battery operation, the equipment for emergency movements increases vehicle weight and reduces vehicle performance and grade-climbing abilities. During off-wire operation, all nonessential auxiliary loads—such as air conditioning and heating—are turned off to maximize power to the traction motors.

The use of electric trolley buses with off-wire capabilities in daily revenue service is generally regarded as a fairly new concept. In fact, however, the Public Service Coordinated Transport Company of New Jersey operated a large fleet of electric trolley engines for extensive off-wire operation in and around the City of Newark during the 1930's and 1940's This type of operation has never since been attempted in North America. Such operation would require significant energy storage capacity, using either batteries, flywheels, or internal combustion engines. This type of operation is considered to be in the experimental stage and is discussed more fully in Chapter V of this report. Although off-wire flexibility is common in some European countries, there are, at present, no North American vehicles so equipped.

The reported experience of selected transit operators in the United States with respect to electric trolley bus transit vehicle propulsion energy efficiency is summarized in Table 82. The energy efficiency is presented in terms of the vehicles miles traveled per kilowatt hour of electrical energy and per British Thermal Units (BTU's) used. The variation in power use among these systems may be attributed not only to the type of vehicles used—with the attendant types of traction motors, motor control systems, vehicle weight, and optional equipment—but also to the characteristics of the routes involved, including the average speed, frequency of stops, degree of traffic congestion, terrain, and weight of the passenger loading. The energy losses attendant to electricity production, the trunkline power transmission necessary to the supply of energy to a trolley bus system, and the energy losses associated with power transmission and distribution of electric power in the overhead trolley bus wire system have been included in the tabulated propulsion energy requirements. Of the total energy required for the propulsion of electric trolley buses, about 70 percent is lost in the generation and trunkline distribution of electric power and about 7 percent is lost in the transmission and distribution of the electric power in the overhead trolley wire system.

Table 82

VEHICLE PROPULSION ENERGY EFFICIENCY FOR SELECTED URBAN ELECTRIC TROLLEY BUS SYSTEMS: 1978

Urbanized Area	Propulsion Energy Efficiency	
	Vehicle Miles per 100 KWHr	Vehicle Miles per Million BTU's
San Francisco . . .	32.2[a]	28.2
	27.0[b]	23.7
	22.2[c]	19.5
Dayton.	27.7	24.3
Seattle	20.0	17.5
Philadelphia	17.8	15.6

[a] *Vehicles equipped with solid-state thyristor chopper motor control.*

[b] *Vehicles equipped with conventional switched resistor motor control.*

[c] *Newest vehicles purchased in 1978 with conventional switched resistor motor control.*

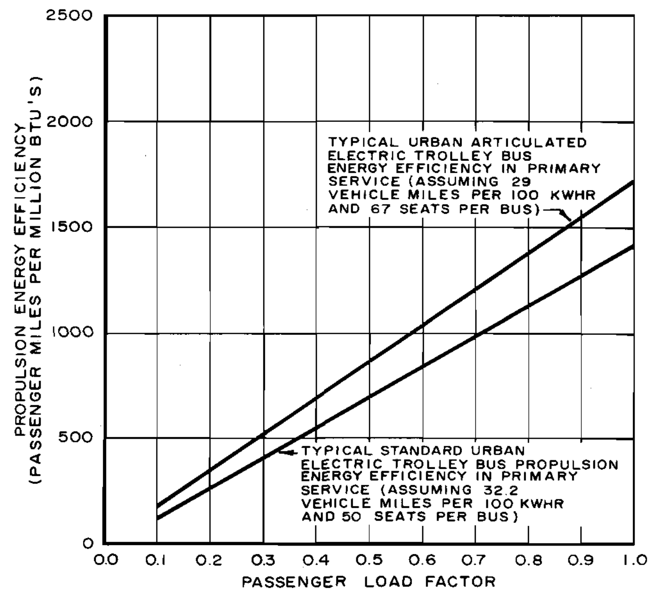
Source: U. S. Department of Transportation, American Public Transit Association, and SEWRPC.

The number of seat miles provided per unit of energy used is an important measure of the propulsion energy efficiency of electric trolley bus transit vehicles. Large articulated electric trolley buses capable of carrying more passengers may consume more energy per vehicle mile than smaller single-unit vehicles; however, at high load factors, the energy consumption per seat mile may actually be less than that of the smaller vehicle. Therefore, if sufficient demand exists to achieve high load factors, a transit system may be able to operate with greater propulsion energy efficiency by using electric trolley buses which provide more seat miles—and therefore potentially more passenger miles—per unit of energy used. An example of such an increase in propulsion energy efficiency is that provided by a fully loaded Ikarus articulated trolley bus, which provides 34 percent more seats—67 seats compared with 50 seats provided by a typical single-unit electric trolley bus vehicle—while consuming only about 15 percent more energy.[2]

For planning purposes, transit propulsion energy must also be estimated in terms of passenger miles per unit of energy used rather than just in terms of vehicle miles or seat miles per unit of energy used. At a load factor of 1.0—that is, with all the seats occupied—propulsion energy consumption per seat mile is equal to propulsion energy consumption per passenger mile. Electric trolley bus transit systems in the United States, however, are presently operating at load factors well below 1.0. For electric trolley bus systems operating in the United States in 1978, the overall vehicle occupancy was estimated to be 14.2 passenger miles per vehicle mile. Assuming an average seating capacity of 50 seats per vehicle, a vehicle load factor of 0.28 may be estimated. This low load factor is the result of operation during periods of limited, as well as peak, passenger demand in order to provide transportation services throughout the day. During the peak morning travel period—when the trips carried are being made primarily to and from work and school—it is not uncommon for passenger load factors to exceed 1.0 at the peak load point of the transit routes in the peak direction. However, because demand drops off sharply past the peak load point, as well as during other periods of the day, load factors are usually high only during morning and afternoon peak travel periods and only over limited segments of the total transit system. Therefore, measures of transit vehicle fuel efficiency need to include estimates of passenger miles per unit of energy consumed based upon realistic load factors. Such load factors are a function of passenger demand, which is, in turn, a function of specific route configuration, levels of service, and adjacent land use type and intensity, among other factors. Therefore, unless specific route configuration and passenger demand are known

Figure 150

VARIATION IN ELECTRIC TROLLEY BUS PASSENGER MILES PER AMOUNT OF PROPULSION ENERGY USED VERSUS PASSENGER LOAD FACTOR



Source: U. S. Department of Transportation, Urban Mass Transportation Administration.

and analyzed, comparisons of energy consumption expressed as passenger miles per unit of energy can be reported only as a range based upon an assumed range of load factors. In order to illustrate the importance of passenger load factors in propulsion energy efficiency, the relationship between load factors and bus passenger miles per unit of energy used for electric trolley bus propulsion is shown in Figure 150.

Passenger access to electric trolley buses depends upon the vehicle configuration as well as upon the method of fare collection utilized. Standard, single-unit configuration vehicles generally have two doors on the same side, one located at the front and the second located midway along the length of the vehicle. Articulated buses, of which several designs exist in Europe, typically have three doors per side, two in the front unit and one in the rear unit. A third door on standard, single-unit configuration trolley buses and a fourth door behind the rear axle on articulated models is available as an

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[2] *The standard single-unit nonarticulated vehicle is the only configuration presently in use in North America, although the Seattle system is considering the use of articulated vehicles. Actual test data for articulated vehicles in Seattle and Vancouver indicate that articulated vehicles would require on the average of about 15 percent more energy to operate.*

option. A third door facilitates rapid loading and unloading when a self-service fare collection system is utilized. Self-service fare collection has not as of yet been attempted within the United States. Because of this, the articulated buses currently being used in selected American cities have only two doors, one on each vehicle unit, so that boarding passenger flows can be directed past the operator and fare collection apparatus. Passenger doors on electric trolley bus vehicles are generally of the folding or swinging type. Sensing edges are usually used to prevent the doors from closing on obstructions. Some European designs are equipped with pushbuttons to be activated by the passengers for opening.

Interior design is almost always represented by a two-plus-two across seating arrangement. Some designs incorporate one-plus-two across seating or some longitudinal seating in order to gain additional space for standees and thus a larger maximum vehicle capacity. Such variations are more common on foreign vehicles than American vehicles. Individual seats are permanently installed so that all seats face forward.

Other important features of the physical design of electric trolley bus vehicles, such as the suspension, interior climate control equipment, and wheelchair lifts, are identical to those of conventional diesel motor buses. On current-model electric trolley buses, outside air is heated by a 600-volt electrical resistance unit, instead of a heating core off the engine's coolant, to furnish interior heat. The electric trolley buses have the ability to use brake and accelerator resistance heat for this purpose, but the complexity of adapting the existing heat duct systems has deterred such use. If air conditioning is required, a small DC motor is installed to operate the compressor. Air conditioning, although widely used in the United States, is considered optional on most foreign vehicle designs, which rely instead on open window and forced air ventilation.

Since an electric trolley bus is a rubber-tired vehicle, it can develop an electrical potential to ground. Shocks can be obtained as passengers enter or alight from the vehicle unless all doors and handrails reachable while standing outside the vehicle are insulated. The electric trolley bus can also be equipped with a meter that measures potential to ground, with the coach then being removed from service if unsafe levels are recorded.

Guideway Technology

Transit modes which incorporate electric trolley bus technology employ the basic guidance principle of rubber-tired vehicles operating over roadway pavements. The guideway requirements of the electric trolley bus mode, therefore, are identical to those of the motor bus mode. (Such guideway requirements are considered under the "Guideway Technology" section of Chapter II, "Motor Bus Technology.") From a practical standpoint, however, the trolley bus probably must be considered as being unable to operate in mixed traffic over freeways because of its limited top speed. This limitation is a result of the potential for dewirement and necessity of restricted speeds through overhead wire switches and crossings. Electric trolley buses, however, are physically able to operate on primary transit guideways of reserved lanes, on arterial streets, and on exclusive busways.

With respect to the operation of electric trolley buses on exclusive guideways, two considerations should be noted. First, electric trolley buses have performance characteristics similar to those of current-model diesel motor buses. Therefore, the vertical and horizontal alignment of exclusive guideway as well as the operation on such facilities would be similar. However, certain design differences do exist, the most significant being the need to provide ventilation in an underground guideway facility designed for diesel motor buses. The cost differential of such a design component would be dependent upon the particular alignment and design; however, significant cost savings may result from not requiring the installation of ventilation facilities for an underground fixed guideway intended for the sole use of electrically propelled vehicles.

Second, greater vertical clearance is required for electric trolley bus operation. Compared with an exclusive busway constructed for a diesel motor bus operation, an exclusive busway constructed for electric trolley bus operation would require a greater vertical clearance because of the roof-mounted power collection equipment on electric trolley bus vehicles and the space required for overhead wire construction. In addition, guideway design must provide for gradual transitions between varying wire heights.

Electric trolley buses have not been extensively employed in fixed guideway systems. The only significant example of such a system is that in Guadalajara, Mexico. This system consists of a 3.2-

mile-long subway—constructed in the mid-1970's—in the central business district, including five intermediate stations plus one at each portal. Until recently, the electric trolley bus system in Boston, Massachusetts, utilized a subway segment underneath Harvard Square.[3] Short exclusive right-of-way segments for electric trolley buses have been used in the past in other cities such as Memphis, Tennessee. In many cases, these segments were shared with street railway routes.

Station Characteristics

The station requirements of the electric trolley bus mode are almost identical to those of the motor bus transit modes. Because electric trolley buses typically operate in a tertiary level of transit service, existing station stops are generally located at street corners, where the vehicles can pull up to a curb to alight and board passengers. Safety islands are yet another station location option, but are generally not preferred because of the inherent safety hazards. Safety islands may be required at stop locations where the route must make a left turn at a busy intersection, because the overhead contact wires must be located in left-turn lanes.

More intensive station facilities for the electric trolley bus mode may be required in two situations. First, such facilities may be required at transit centers where more than one mode or several routes converge for the purpose of passenger transfer. The design of a facility to serve such a location would be highly dependent on the specifics of the location and the individual system; however, such a facility should be designed to minimize or eliminate backup movements of electric trolley bus vehicles, since such maneuvers may increase the possibility of dewirement. Second, such facilities may be required at turnaround points where the trolley bus vehicles must reverse direction. The overhead contact wires must be arranged so as to enable the vehicle to turn around in either a wye or loop configuration. The loop configuration is preferred since a backup maneuver by the vehicle would not be required. Such loops can either encircle a typical city block or be located on a special turnaround driveway, in which case a shelter and other passenger amenities may be provided.

Other system design considerations pertinent to electric trolley bus stations are identical to those of the motor bus transit mode. These considerations are discussed in the "Station Characteristics" section of Chapter II.

Support Requirements

The support requirements for the electric trolley bus mode consist of a selected group of principal elements: vehicle storage and maintenance, guideway and structure maintenance, traffic control, fare collection, and power supply and distribution. The elements related to guideway and structure maintenance, traffic control, and fare collection are quite similar to the support requirements of motor bus transit systems, and the elements related to vehicle storage and maintenance and power supply and distribution are similar to the support requirements of the light rail transit mode. The extent to which each of these ancillary elements is applied to any new system or system modification depends upon the site and operational specifics of the system. The information presented herein is considered sufficient for consideration of support requirements at the system planning level.

Vehicle Storage and Maintenance: Vehicle storage for electric trolley bus systems consists of garages and/or paved lots large enough to hold all vehicles not in service during the least active operating period of a system. On larger systems, more than one garage location may be required. Because electric trolley bus vehicles are propelled by electric motors, as opposed to internal combustion engines which are sensitive to the low temperatures experienced in northern climates of the United States and Canada, indoor storage is not necessary and represents a potential advantage of trolley buses over diesel motor buses. Electric trolley buses when operated in the Milwaukee area were stored outside. In fact, a majority of North American trolley bus operations utilize outdoor storage which consists of a paved lot with parallel lane storage. During cold weather months it may be desirable to heat the vehicles prior to the morning pullout; however, this is easily accomplished since the vehicles are electrically heated and do not rely upon the prime mover as the heat source. Garages and storage facilities should include the appropriate facilities and equipment for daily servicing, including lubrication; fare removal; washing; interior cleaning; light inspection; tire, battery, and brake maintenance; and lockers and washrooms and other driver facilities.

[3] *The operation of electric trolley buses in the Harvard Square subway has been temporarily discontinued as of 1979 because of the extension of a nearby heavy rail rapid transit subway facility.*

Electric trolley bus vehicles require less maintenance than do diesel motor buses of a similar age. This is principally due to the electric propulsion system of the electric trolley bus, which has fewer moving parts and a longer life. Electric trolley buses also require less servicing since they don't need fuel and certain lubricants. The addition of the electric trolley bus mode to a system which relies solely on diesel-powered vehicles will require a change in key maintenance department functions because of the important differences in the propulsion system. Such a change would require the addition of specialized maintenance equipment, retraining of the staff, and an increased inventory of spare parts. Specialized diagnostic equipment would be required if vehicles contain chopper propulsion control systems. Heavy maintenance and repairs, including major unit overhauls, are usually provided at a central shop facility. Central maintenance facility functions would include major bodywork necessitated by accidents or a rebuilding program, chassis and suspension system repairs, painting, and unit remanufacturing. Appropriate components for such a shop facility would be similar to those required for a major shop facility for diesel motor buses. Should implementation of electric trolley buses require an increase in fleet size, a significant expansion of shop facilities may be required.

Guideway and Structure Maintenance: Since the electric trolley bus mode would utilize roadways and other guideways utilized by the motor bus transit modes, maintenance requirements would be no different than ordinary freeway and arterial street maintenance requirements. Since the electric trolley bus mode predominantly uses public roadways, the responsibility for maintenance of such facilities will usually lie with municipal, county, or state authorities. If an exclusive guideway is utilized, major guideway maintenance tasks would include wearing surface repairs, bridge repairs, and the repair or replacement of signs and other traffic control devices. The responsibility for guideway, station, garage, shop, and grounds upkeep may or may not lie with the transit operator, depending upon the cost-effectiveness of the arrangements involved and upon the extent to which such areas are shared with other public or private uses.

Traffic Control: Because the electric trolley bus mode will use the same types of guideways and roadways used by the motor bus transit modes, traffic control apparatus and procedures will be identical. Such procedures and requirements apply not only to electric trolley buses operating on public arterial streets but also to the mode when operating on exclusive guideways and to traffic signal priority at intersections. These matters are discussed more fully under the "Traffic Control" section of Chapter II.

Fare Collection Procedures: The electric trolley bus mode utilizes one of two basic types of fare collection procedures: pay-as-you-enter and self-service. These types of fare collection are discussed under the "Fare Collection Procedures" sections of Chapter II and Chapter III.

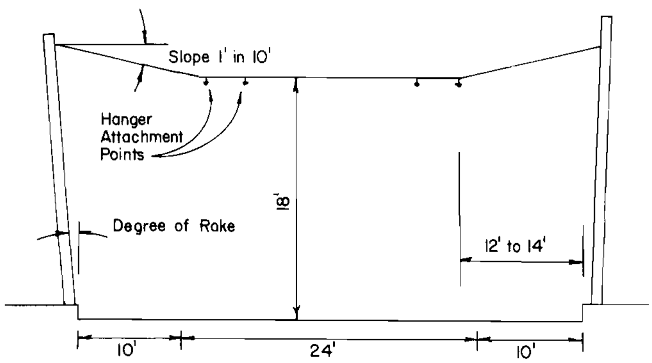
In Europe, the widespread use of articulated electric trolley buses is part of an overall program to increase operating staff productivity. Overall operating speeds and thus the level of service afforded passengers is increased because of the reduction in dwell time at stops resulting from passengers entering and exiting through door openings that are located throughout the length of the vehicle. To successfully implement this type of program, a self-service fare system must be implemented, with a high percentage of fares being converted to bulk purchases through appropriate sales outlets. The driver's duties are then reduced to driving the vehicle, as he is no longer required to verify correct payment of fares by the patrons.

The standard fare collection procedure in the United States and Canada is pay-as-you-enter, requiring all passengers to enter by the front door. The use of articulated electric trolley buses in a tertiary level of service on North American systems, which typically have a high passenger turnover, may create dwell time problems which would negate the articulated vehicles' contribution to productivity.

Power Supply and Distribution: For electric trolley buses to operate, low-voltage DC must be supplied to the traction motors which turn the vehicles' driver axles. Electrical power is transmitted to the vehicles through an overhead contact wire system, which represents the major investment for the electric trolley bus mode outside of the vehicles themselves. The basic contact wire assembly consists of a pair of grooved contact wires horizontally spaced 24 inches apart and hung from 16 to 22 feet above the roadway surface, 18 feet being a typical height. The contact wires are suspended either from span wires across the roadway or from bracket arm assemblies and are usually positioned from 12 to 14 feet from the curb (see Figure 151). If the street has two traffic lanes in each direction,

Figure 151

TYPICAL CROSS-SECTION FOR ELECTRIC TROLLEY BUS OVERHEAD CONTACT WIRE SYSTEM



Source: U. S. Department of Transportation, Urban Mass Transportation Administration.

the wire would normally be positioned over the right-hand traffic lane to provide access to the left-hand lane for passing and to the curb lane for bus stops. The contact wires are typically suspended from either the span wires or the bracket arm at intervals ranging between 100 and 140 feet. Specialized components and assemblies are required for horizontal curve alignments, switches, and crossings. Such components differ from those required for street railway or light rail transit power distribution systems. Because of differing electrical polarities, crossings of positive and negative contact wires must be insulated.

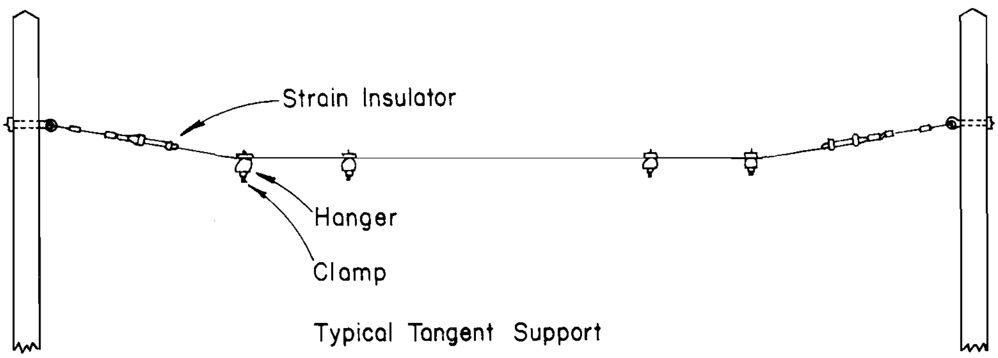
The typical overhead contact wire configuration for electric trolley bus systems employs a pair of contact wires in each direction of travel on a given route. Additional overhead special work is required for turnaround loops, emergency routings, garage and storage area wiring, and routes with express service. Loops are required at the end of routes to turn vehicles in the opposite direction, and should be equipped with a siding so that vehicles can pass without the need to remove and rewire poles. Turnaround loops at the ends of routes are generally located off-street. Flexibility dictates that vehicles be able to turn short of their normal terminals to accommodate emergencies or to return a late vehicle to its schedule. Loops which encircle a typical city block or wye configurations at intersections can be used to serve this purpose. Similarly, emergency downtown routings can be quite helpful in the event of a wire break, fire, major accident, or occasional parade. Garage wiring can consume a vast amount of special work such as switches, crossovers, and curve segments if every necessary movement is to be wired. The amount of overhead wiring can be reduced by having two or three storage lanes share one set of common overhead wires.

Arterial express service using electric trolley buses can be accomplished in three ways which differ in the configuration of the overhead wiring. One way is to install passing sidings at intervals, allowing express buses to pass local buses. The disadvantage of this method is that unexpected service delays can cause a disruption and a loss of time savings. Another way is to install a set of three wires down the middle of the street, with the positive contact wire in the center. This method would allow a peak-period express service to operate over its own set of wires but only in one direction at any given time. The system in Philadelphia currently uses such a method on one of its routes. The third method is to install two additional complete sets of wires to allow bidirectional express service. This arrangement is necessary on wider streets and when reverse peak express service is necessitated. This method is currently utilized on the system in Vancouver which operates express service in both peak and base periods on weekdays. Some United States cities have used this method in the past.

The overhead contact wire systems currently available fall into one of two categories: rigid systems and elastic systems. Such classification relates to the method of suspension and the contact wire's ability to work with the current collector to avoid loss of contact at fixed suspension points. In rigid systems, the contact wire assumes a parabolic shape which changes as the vehicle passes between the two fixed suspension points. As the vehicle nears the midpoint in a span, the wire is flat and then rises at an increasing angle as the suspension point is approached. Between suspension points, the current collector will exert sufficient force to deflect the wire and remaining contacts. As the suspension point is reached, the collector must accelerate upward to overcome the angular rise of the wire. When an angle of sufficient magnitude is encountered, the collector cannot accelerate fast enough and will momentarily leave the wire. Since the suspension point is rigid, the wire cannot deflect downward to meet the collector. The amount of disengagement between the wire and the collector is a function of the speed of the collector, the

Figure 152

TYPICAL CROSS-SECTION FOR RIGID OVERHEAD CONTACT WIRE SYSTEM



Source: U. S. Department of Transportation, Urban Mass Transportation Administration.

configuration of the wire and amount of tension, the length of the span, and the pressure exerted by the collector. At points where the collector leaves and then returns to the wire, small welding pearls are formed and subsequently may cause wear on the collector. Wear will also occur on the wire at the point of return. Rigid systems are currently used on all electric trolley bus systems within the United States and Canada and represents the only system available from a United States manufacturer of overhead contact wire components (see Figure 152).

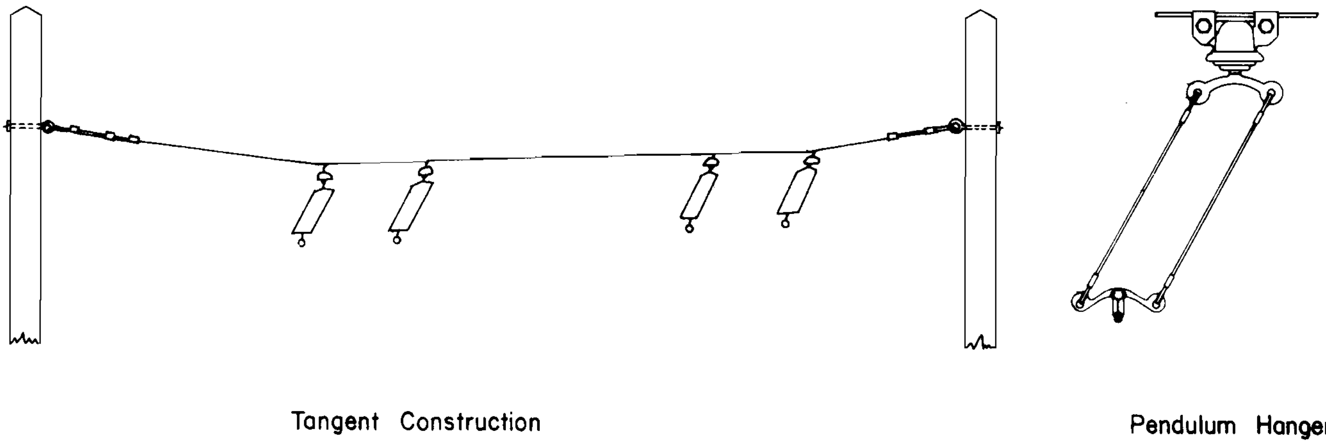
In the elastic systems, the vertical configuration of the contact wire is similar to that of the rigid system and the behavior of the wire and the current collector is also similar until the collector reaches the immediate vicinity of the suspension point. When the pressure between the collector and wire decreases because of the angular ascent of the wire, the suspension system senses this difference and the wire descends to prevent momentary dewirement. While the contact wire is clamped directly to a hangar which is suspended from a span wire on fixed systems, elastic systems employ a movable pendulum hangar to attach the contact wire to the cross span assembly (see Figure 153). There are several advantages of the elastic system over the rigid system, including a lesser potential for dewirement, a minimization of radio disturbances, less wire wear, and less collector wear. In addition, operating speeds of up to 50 mph are attainable with the elastic system, while rigid systems generally allow for maximum speeds of only 35 or 40 mph. It should be recognized that regardless of the type of overhead wire construction, maximum vehicle operating speeds can be maintained only if the horizontal angle between the wire and the trolley poles does not exceed approximately 10 degrees. Operation at angles in excess of 10 degrees greatly increases the chances of dewirement when the driver does not accelerate and brake in a smooth manner, when the driver makes sudden turning movements, or when rough pavement is encountered.

A frequently cited disadvantage of electric trolley bus systems is the visual intrusion of the overhead power distribution system into the surrounding aesthetics. In order to minimize the impact of the overhead wires, the same design considerations that apply to overhead power distribution systems for the light rail transit mode are applicable. Such considerations include the underground placement of feeder cables and communication lines, the careful planning of landscaping, the blending of surrounding trees and other amenities with line poles, and the placement of overhead contact wires, street illumination, and traffic signals on the same poles to reduce the overall number of poles on the public street right-of-way.

To transmit power to the overhead contact wire system, power is purchased commercially and is tapped from the voltage supply at intervals of several miles. At these locations, the main transformers and switchgear transform the power into the primary feeder voltage that feeds into the

Figure 153

TYPICAL CROSS-SECTION FOR ELASTIC OVERHEAD CONTACT WIRE SYSTEM



Source: U. S. Department of Transportation, Urban Mass Transportation Administration.

primary feeder system. These primary substations are normally spaced several miles apart so that different zones of the public power supply can be tapped, lessening the chance of total transit system shutdown should a partial failure occur in the public power system. At shorter intervals throughout the system the primary feeder connects the substations, each containing a rectifier unit consisting of a rectifier transformer, a rectifier, and the necessary switchgear. Here the power is transformed into the operating voltage and converted to direct current. The older apparatus necessary to perform this function—rotary converters and attendant switchgear—have been supplanted by automatic solid-state devices which are much smaller and can be left unattended since supervision is by remote control. Substantial buildings for these substations are no longer required, the devices being located in either underground vaults or small enclosures.

PERFORMANCE CHARACTERISTICS

Electric trolley bus system performance may be defined in terms of three critical characteristics: speed, headway, and capacity. These factors are important determinants of the level of public acceptance and patronage of a new primary transit system.

Speed Characteristics

Transit speeds may be expressed as absolute vehicle speeds, as typical operating speeds, or as average speeds over an entire route. Absolute or maximum vehicle speeds are determined by the capabilities of individual vehicle design. Standard, nonarticulated configuration electric trolley buses designed for urban transit operations generally have maximum attainable speeds of 40 mph. This compares with a maximum attainable speed of 50 to 55 miles per hour for typical diesel-powered transit buses. Utilization of a lower gear ratio should produce higher maximum speeds, although acceleration and the maximum grade capability may be reduced and power consumption increased. The maximum rate of acceleration for such vehicles varies between 2.9 miles per hour per second to 4.0 miles per hour per second, with 3.5 miles per hour per second being a typical value. This compares with typical acceleration rates of 2.5 miles per hour per second to 2.7 miles per hour per second for diesel motor buses. The maximum speeds and maximum rates of acceleration for articulated electric trolley buses are slightly lower. Maximum speeds for these vehicles generally range from 35 to 40 mph.

Figure 154 shows the acceleration rates for electric trolley buses and a conventional motor bus. The electric trolley bus outperforms the acceleration of the V8 engine-equipped motor bus at speeds below 30 mph. However, the diesel-powered motor bus is capable of a top speed of over 50 mph while the electric trolley bus is limited to a maximum speed of 37 mph. Therefore, although the electric trolley bus may be able to outperform the diesel motor bus in local service over arterial streets, overall it may be slower because of the maximum speed limitations when operating on reserved lanes or exclusive busways.

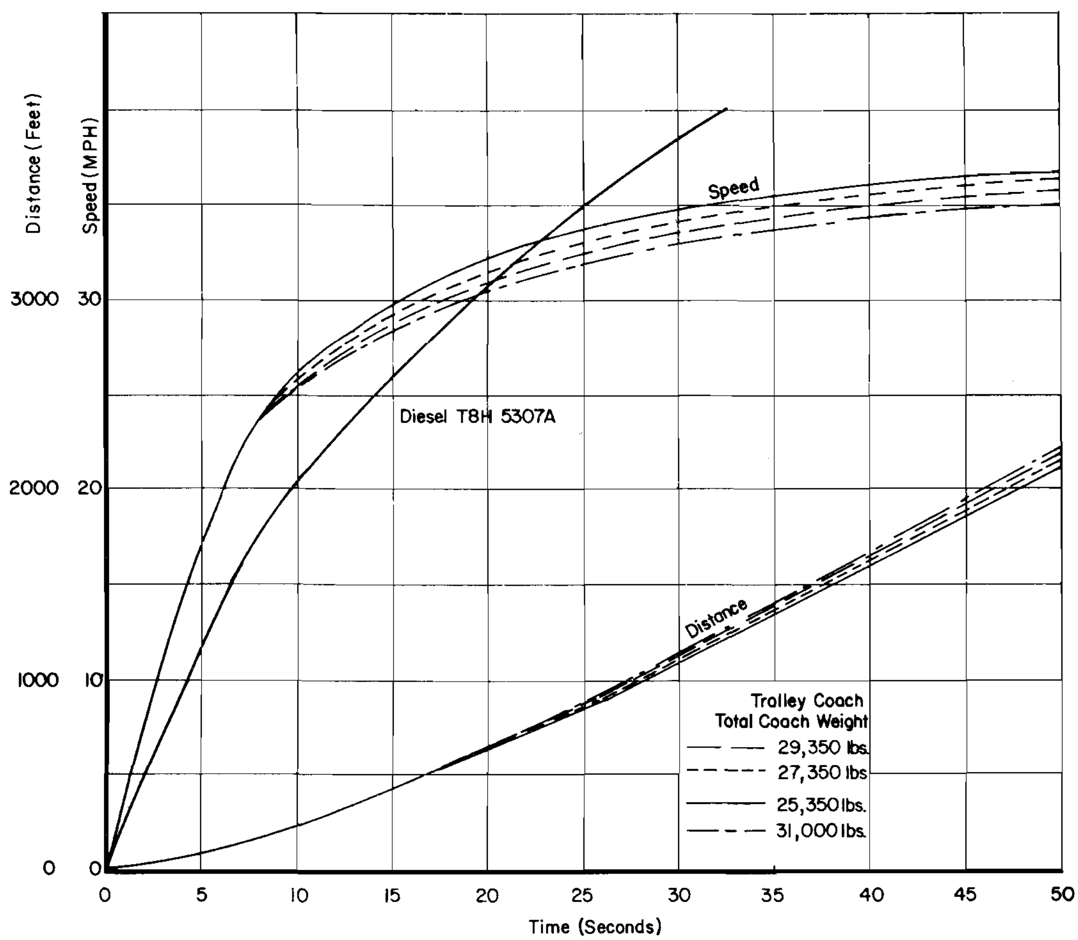
Figure 154

COMPARISON OF ACCELERATION RATES FOR ELECTRIC TROLLEY BUSES AND DIESEL MOTOR BUSES

Trolley Coach Operating Characteristics
Single Motor - 48-50 Passenger Coaches

Weight of Coaches	18,000	20,000	22,000	23,500
Average Pass. Load	7,350	7,350	7,350	7,500
Totals	25,350	27,350	29,350	31,000

Motor Type - GE-1213	Average Voltage - 550	Leeway - 10% of time in motion
Gear Ratio - 11.59 to 1	Grade - Level	Accelerating & Brake Rate - 3.5 MPHPS
Wheel Dia. - 42 inches	Average Stop - 7 secs.	



Source: U. S. Department of Transportation, Urban Mass Transportation Administration.

Typical operating speeds for electric trolley buses will primarily be dependent upon posted speed limits, existing traffic volumes, and street geometry. These regulatory factors govern not only bus traffic but also all other traffic on roadways that are shared by all types of vehicles. These factors will generally restrict the operating speeds to below that attainable by individual electric trolley bus vehicles. In low- and medium-density areas, and along major arterial streets, such speeds will typically range from 30 to 35 mph. In densely developed areas near the fringe of the central business district and on narrow arterial streets in older portions of the city, posted speed limits can be expected to range from 25 to 30 mph. Bus streets or malls in downtown areas should have maximum speeds of 20 or 25 mph because of the pedestrian environment. Maximum attainable speeds can be permitted only on reserved lanes or on exclusive guideways where bus movements can be facilitated for substantial distances without interference from cross traffic or the need for frequent stops.

A factor unique to the electric trolley bus mode that affects performance is the overhead contact wire system. Special work at intersections will limit both the speed and acceleration of the vehicles. The effect on performance may be significant if switches and crossings are frequently encountered. Rigid overhead wire contact systems generally allow operating speeds of up to 35 or 40 mph, with speeds through overhead special work limited to about 25 mph. Elastic overhead contact wire systems which are in common use throughout Europe generally permit speeds of up to 50 mph, with maximum speeds of 35 mph through overhead special work. For both types of overhead system, increased vehicle speeds will increase the possibility of dewirements.

Average speeds over an entire route of an electric trolley bus system are dependent upon the surrounding traffic volumes, the incidence of traffic signals, traffic signal cycle times, turning movements, the incidence of double parking, street geometry, and dwell time at stops. As noted earlier, several cities which operate electric trolley bus systems have found the vehicles to be interchangeable with diesel motor buses over arterial street routes. This fact has been demonstrated in cities where diesel motor buses have been substituted temporarily for electric trolley buses or have been added to routes to expand the peak-hour fleet.

The difference in the performance of the electric trolley bus mode and the diesel motor bus in arterial street service is within the level of variation that can normally be expected among various types of vehicles in a street transit operation, and thus may be ignored. Only if electric trolley bus operation is extensively employed on reserved lanes or on exclusive guideways will average speeds differ, being a function of the speed restrictions imposed by current vehicle design and the overhead wire system.

Headway Characteristics

Headways for electric trolley bus systems may be given in terms of theoretical limits and actual experience. Actual headways realized on existing systems seldom approach the theoretical limits except under exceptionally high travel demand conditions. Vehicle spacing is not controlled by a centralized, automatic, or automated traffic control system, as it is for rail transit modes. Vehicle spacing is under the direct control of the driver of each vehicle, making headways dependent upon visual and manual control. For safety reasons, higher speeds require increased distances between vehicles.

As the number of electric trolley buses in a section of overhead contact wire increases, the demand for electrical current will increase. Each additional vehicle in the same section of overhead wire may have an effect on the headway as well as overall performance since a large number of vehicles could overload the system, resulting in insufficient power available for each vehicle to accelerate. In addition, the overhead contact wires could be damaged through overheating. Therefore, sufficient electrical capacity must be available to deliver adequate power for the greatest number of vehicles operating on the shortest headway anticipated.

Actual observed headways based on existing operation provide a more realistic perception of schedules that have been designed for contemporary electric trolley bus systems. The minimum observed headways for electric trolley buses in North America are reported to be that currently provided on the Granville Street Mall in Vancouver and that which was provided at the former Harvard Square underground station in Boston. Eighty-three vehicles per hour on seven routes are scheduled to and do use the Granville Street Mall in the peak direction. The Harvard Square station had 74 vehicles per hour on five routes scheduled in the peak direction. At both locations, a mix of electric trolley buses and diesel motor buses has been used. According to Milwaukee County Transit System officials, the most heavily used electric trolley bus route in the City of Milwaukee had minimum headways of under 30 seconds, with 100 vehicles being operated during both the morning and evening peak hours. Within a 20-minute period, as many as 50 vehicles were scheduled to pass a given location. The capacity of this type of facility is a function of both the number of vehicles and the number of routes. It is believed that a location on a grade-separated facility unaffected by adjacent intersections could accommodate a greater number of vehicles. Up to 940 trolley buses or diesel motor buses per hour could theoretically be accommodated under these conditions without excessive delays caused by queuing, given a relatively even flow of vehicles.

Depending on local demand, electric trolley bus service may have a scheduled peak-period headway of from 3 to 10 minutes. Because the power distribution system of electric trolley bus routes represents a significant investment, this mode is generally utilized only on trunkline routes where daytime off-peak headways can be expected to be no longer than 10 or 15 minutes. Headways on service provided on evenings, Saturdays, Sundays, and holidays can be expected to be similar to daily nonpeak frequencies.

Capacity Characteristics

The maximum passenger-carrying capacity of an electric trolley bus system is dependent upon vehicle capacity, vehicle configuration, and headway. In addition, certain other design, policy, and institutional considerations which reflect local conditions may have a bearing on capacity.

Because vehicle body designs of currently available electric trolley buses are identical to those of currently available diesel motor buses, and because the headway characteristics for these two types of buses are quite similar, the capacity of each of the modes can be expected also to be similar. The electric trolley bus mode, which predominantly utilizes arterial street rights-of-way, can generally be expected to meet peak demands ranging from 2,000 to 10,000 passengers per hour.

Table 83 illustrates the range of passenger-per-hour capacities obtainable under various vehicle and operational configurations based upon recent vehicle designs. Extreme values in the matrix would not be expected to be reached except under unusual circumstances. It should be noted that unit capacity is limited to that of one vehicle, since it is not currently practical to couple electric trolley buses into trains such as may be done with rail transit vehicles. These capacity considerations are applicable only in a line-haul context. Should stops be required of most vehicles along a designated route, station or bus stop design becomes critical. Because headways may be very small on facilities with large peak demands, the necessary dwell time per vehicle at the stop may be greater than the headway, causing bus queues to form outside the stop area if an insufficient number of berths is available.

A further consideration which is applicable only to the electric trolley bus mode is that capacity may be restricted by the inability of the electric trolley bus vehicles to pass each other when operating on a single pair of wires. A similar condition will occur when either electric trolley buses or diesel motor buses are operated through single-lane streets or other facilities where there is insufficient lane width for passing. Such a situation could be rectified by the installation of two sets of wires for operation in the same direction, with loading islands to serve the center set of wires. This action would essentially double the capacity of a single-lane electric trolley bus route.

Table 83

THEORETICAL PASSENGER CAPACITIES PER HOUR FOR ELECTRIC TROLLEY BUS TRANSIT

Headway	System Capacity	
	Standard Single-Unit Configuration[a]	Articulated Configuration[b]
30 seconds	6,120	8,760
1 minute	3,060	4,380
2 minutes	1,530	2,190
3 minutes	1,020	1,460
4 minutes	765	1,095
5 minutes	612	876
10 minutes	306	438
12 minutes	255	365
15 minutes	204	292
20 minutes	153	219
30 minutes	102	146
60 minutes	51	73

NOTE: All calculations are based upon full-seated capacities. Passenger loads that include standees may be calculated by multiplying the theoretical capacity by the desired load factor.

[a] *Assumes use of conventional single-unit vehicle with seated capacity of 51 passengers.*

[b] *Assumes use of articulated vehicle with seated capacity of 73 passengers.*

Source: SEWRPC.

ECONOMIC CHARACTERISTICS

Within the context of this report, the term "economic characteristics" pertains primarily to the capital and operating costs of each transit mode. This section presents such cost data relevant to systems planning for the electric trolley bus mode. The cost data presented represent generalized, nonsite-specific information developed from data collected on actual systems operating in selected urban areas of the United States. The cost data are intended to be utilized at the systems planning level for comparing alternative primary transit system plans.

Capital Costs

Capital costs are those investments required to acquire and construct the physical facilities—both fixed facilities and vehicles—necessary for the operation and maintenance of an electric trolley bus system. Capital costs include the costs of acquiring vehicles; the costs of constructing stations, the power distribution system, and maintenance and storage facilities; agency costs; and contingencies. In addition, depending upon the proposed specifics of the system, the capital costs may include right-of-way acquisition costs, guideway construction costs, and the costs of installing signal and communication equipment.

Vehicles: The cost of vehicles is a function of the basic vehicle configuration chosen plus the options selected by the transit operator. Included within this item are the costs of vehicle delivery and any special equipment such as wheelchair lifts. The procurement of electric trolley bus vehicles could involve the use of proven, "off-the-shelf" technology that should require a minimum of presystem start-up testing. If a domestic electric trolley bus vehicle becomes available and is purchased, then a preliminary break-in and testing period is likely to be required. Vehicles purchased using federal funds may be subject to certain yet unspecified requirements should the U. S. Department of Transportation reach a final decision concerning transit bus requirements. Some recent costs are presented along with other vehicle data under the "Vehicle Technology" section above.

Stations: Other than at route turnaround points or major transfer points, stations for electric trolley bus routes which are located on arterial street rights-of-way will generally consist of nothing more than normal bus stops with or without shelters. Major transfer points and turnaround points may require more intensive facilities, while any electric trolley bus systems which utilize exclusive busways may require expensive stations similar to those required for light rail transit systems. Otherwise, the same considerations and costs which are applicable to the motor bus technologies discussed in Chapter II of this report apply to the electric trolley bus mode.

Power Distribution: The power distribution system includes those facilities required to provide electrical power for vehicle propulsion and operation of any fixed facilities that may be required. Basically, this component consists of the necessary complement of substations, overhead contact wires, feeder wires, and control apparatus required to supply power to the vehicles. The power distribution element will represent the largest nonvehicle capital cost of a new electric trolley bus system constructed in the same manner as those systems already in existence.

Maintenance and Storage: At least a portion of the necessary maintenance and storage facilities of a new electric trolley bus system will likely be integrated with the existing facilities designed for diesel motor bus servicing. The expansion of existing facilities or the construction of additional garage or storage space may be necessary in order to obtain sufficient storage area for an expanded fleet. In addition, the maintenance and repair facilities specifically required for electrically powered vehicles would have to be added. Actual costs for these facility expansions are difficult to determine in the absence of at least a conceptual layout. However, such costs may be expected to be similar to storage yard and repair shop costs for a diesel motor bus fleet except for the cost of outdoor instead of indoor storage and the cost of the power distribution system.

Agency Costs: Agency costs are the unallocated allowances for engineering and administration during project implementation. Specific tasks covered under this item include engineering and architectural design, construction management, cost estimation and control, construction supervision, inspection and testing, and system start-up. Fifteen percent of total capital costs is typically allotted to cover these needs. This cost does not apply to vehicle acquisition.

Contingencies: Contingencies are an unallocated allowance that is intended to cover unforeseen and unpredictable conditions that may arise during detailed design or construction. Values for this item, which applies to all capital cost items except vehicle acquisition, range between 20 and 35 percent, and depend upon the depth of the preliminary engineering studies.

Right-of-Way Acquisition and Guideway Construction: Existing applications of the electric trolley bus mode do not normally require the use of exclusive guideways, which would necessitate the acquisition of suitable right-of-way and the construction of busways. Therefore, the capital costs represented by these items are not normally associated with the implementation of a new electric trolley bus system. Should such an alignment be included with the new system proposal, facility costs for the guideway would be similar if not identical to those cited in Chapter II of this report for the various motor bus technologies. The only significant difference would be an appropriate adjustment for the cost of tunnel ventilation, which is not required for transit services that are to be operated exclusively with electrically propelled vehicles.

Summary of Capital Costs: Overall capital construction costs for the electric trolley bus mode apply principally to three elements: the purchase of vehicles, the construction of the power distribution system, and adequate maintenance and storage facilities. Unit construction costs applicable for the overhead power system are presented in Table 84. These costs are based on the experience of selected North American cities which have recently expanded or rebuilt their electric trolley bus systems.

It is also possible that the implementation of a new electric trolley bus system would include segments of exclusive busways, reserved lanes, or other traffic engineering measures to grant preferential treatment for the transit vehicles. While these elements could represent a sizable portion of the capital investment, their costs can be expected to be identical to those of the same facilities that would be utilized for a typical diesel motor bus primary transit system. The costs of such items are set forth in Chapter II of this report and can be added to the cost of the electric trolley bus vehicles and power distribution system should such additional improvements be warranted.

Table 84

UNIT CONSTRUCTION COSTS FOR ELECTRIC TROLLEY BUS OVERHEAD POWER DISTRIBUTION SYSTEMS

Item	Cost of Material and Installation (1979 dollars)
Two-Way Tangent Overhead Line Installation Using Cross Spans (per mile)	
Existing Poles	$141,000
New Wooden Poles	228,000
New Steel Poles	413,000
50 Percent New Wooden Poles	185,000
50 Percent New Steel Poles	277,000
New Eyebolts	228,000
Typical Overhead Special Work Configurations Using Steel Poles[a]	
Single 90° Curve	$ 20,000
Double 90° Curve	28,000
Single Switch	41,000
Double Switch	75,000
Single Switch with Crossing	51,000
Wye	82,000
T Intersection	159,000
One-Half Grand Union Configuration	215,000
One-Quarter Grand Union Configuration	136,000
Double Crossing	35,000
Single 90° Curve with Crossing	28,000
Substation Including Installation	
Typical 500-Kilowatt Feederless Station	$174,000[b]
Typical 1,500-Kilowatt Station for Conventional Feeder System	122,000[c]
Feeder Cables Enclosed in Conduit	344,000 per mile

[a] *The use of wooden poles would reduce costs, but would require guy lines.*

[b] *Includes housing for outdoor placement.*

[c] *Does not include DC switch gear ($40,000 per DC circuit), and assumes availability of indoor placement.*

Source: U. S. Department of Transportation and SEWRPC.

Operating Costs

Operating costs for an electric trolley bus system consist of the daily costs of operating the vehicle fleet regardless of the type of guideway utilized, and the costs associated with the routine operation of any bus priority facilities such as reserved lanes or exclusive busways. Normally expressed in monitary units by type of operating cost, the daily costs will be similar to those for systems which exclusively operate diesel motor buses. These costs can be broken down into six categories: transportation expenses, which includes the costs of drivers and supervisory personnel and station expenses; maintenance and garage expenses, which include the maintenance and storage costs as well as the costs of repairing and maintaining the overhead power distribution system, along with the costs of the attendant labor required for both of these functions; power costs, which replaces the motor fuel costs; administrative and general expenses, which include insurance and safety and management costs; operating taxes and licenses; and miscellaneous costs, which include the costs of such items as depreciation and amortization.

Many of the operating costs incurred by electric trolley bus systems will be identical to typical operating costs incurred by diesel motor bus systems. Based on analyses for the transit system in Vancouver, British Columbia, conventional electric trolley bus nonlabor costs were estimated to total 84 percent of conventional diesel motor bus nonlabor costs. The operating costs of systems in other cities in North America which operate both forms of buses were found to be similar. Although such costs are aggregated on a vehicle-mile basis, it should be recognized that major transit operators allocate expense accounts for vehicle operations on the basis of four variables: vehicle hours, vehicle miles, peak of vehicle needs, and system revenue. Vehicle hours are used to allocate wage expenses for drivers and supervisory personnel, since such wages are paid on an hourly basis. This expense represents by far the largest single cost for most transit operators. Expenses for power, tires, vehicle parts, and vehicle taxes are a function of vehicle use and therefore are logically allocated on the basis of vehicle miles. Many costs—such as the cost of operation and maintenance facilities, including the costs of the service equipment and of maintaining these facilities—are related to the maximum fleet size and thus are allocated on the basis of peak vehicle needs. Finally, system revenue is used as a parameter of many general or systemwide costs. This category might include costs for injuries and damages, marketing and promotion expenses, stations expenses, and taxes.

The costs associated with the routine operation of bus priority facilities such as reserved lanes or exclusive busways can be expected to be the same as the costs of operating diesel motor bus facilities, presented in Chapter II of this report.

Amortization Periods

Amortization periods for major components of an electric trolley bus system should be properly related to the expected service life. Amortization periods utilized for the systems planning of this mode are set forth in Table 85.

Table 85

TYPICAL AMORTIZATION PERIODS FOR ELECTRIC TROLLEY BUS SYSTEM COMPONENTS

System Component	Amortization Period in Years
Vehicles	20
Power Distribution System	30
Stations	30
Maintenance and Storage Facilities	30-40
Contingency and Agency Costs	30

Source: SEWRPC.

Energy Intensity of Electric Trolley Bus Transit

Energy requirements for transportation systems are frequently reported in terms of vehicle propulsion energy efficiency—that is, in terms of the number of vehicle miles per unit of energy used. However, vehicle energy efficiency is only one aspect of transit system total energy consumption. In addition to the energy required to propel vehicles, transit energy requirements that should be analyzed may include the energy needed to maintain vehicles and to operate stations and other system facilities, and the energy expended in the construction of the system and the manufacture of the vehicles. This more comprehensive consideration of energy requirements provides a basis for comparison of transit systems which may differ in vehicle and guideway types, in system configuration, in energy source, and in the length of useful life, as well as in vehicle propulsion energy consumption.

The separation of energy requirements into operation and construction energy permits consideration of potential future as well as current availability and cost of energy sources. Systems that require relatively small amounts of construction energy but relatively large amounts of operating energy may be less desirable in the future than systems which require less operating energy, or which use energy sources other than petroleum, but require more energy for construction. Data on construction energy intensity are not as readily available as are data concerning vehicle propulsion energy consumption.

For the purposes of this analysis, system operating energy is defined as the propulsion energy for the transit vehicles and the energy required to operate stations and maintain vehicles and system facilities. System construction energy is defined as the energy required for guideway construction and vehicle manufacture. Together, these elements constitute the total energy requirements, or energy intensity, of an electric trolley bus transit system.

Vehicle propulsion energy requirements constitute the majority of energy consumed and account for most of the variation in the overall energy utilization of bus transit systems. The propulsion energy requirements of electric trolley bus transit systems, based on the experience of transit operators in the United States, were discussed in an earlier section of this chapter. With respect to the second element of system operating energy—the energy used to maintain vehicles and to maintain and operate stations—relatively few data are available, since data on maintenance and station energy requirements are rarely segregated from overall energy consumption data by transit operators. Moreover, there has been relatively little research done to identify these requirements. Electric trolley bus maintenance energy, which principally includes the energy required for lubrication and for other service, parts, and repair, is estimated at 2,000 British Thermal Units (BTU's) per vehicle mile. No data are available on station operation and maintenance requirements specifically for electric trolley bus transit, but together with vehicle maintenance requirements, these requirements have been estimated to range between 10 and 20 percent of propulsion energy requirements. In general, the energy requirements for station operation and maintenance will vary from minimal for stations consisting of simple curbside stops with only small paved areas marked with appropriate signing to 4,000 BTU's per vehicle mile for larger station facilities consisting of specially constructed platforms, with lighting and support facilities such as telephone service, rest rooms, fare collection facilities, and a heated shelter building.

With respect to the energy requirements for system construction, no specific energy consumption estimates for the construction of an exclusive busway and its attendant station facilities are available. In order to estimate the energy required to construct a dual-lane guideway for electric trolley bus transit, it was assumed that the amount of energy required to construct such a guideway would approximate the amount of energy required to construct two lanes of freeway facility. Additionally, an estimate was made of the energy required to construct an overhead power distribution system. Recent studies have reported that such a facility requires about 60.2 billion BTU's per mile of two-lane at-grade roadway. Estimates of the amount of energy that can be expected to be expended in the construction of station facilities for electric trolley busways are not available. The energy required to manufacture an articulated electric trolley bus is estimated to approximate 1,530 million BTU's per vehicle.

SUMMARY

The electric trolley bus mode, as typically developed, is applicable only to the provision of strictly defined tertiary and secondary levels of service. This is because the maximum speed of electric trolley buses is, as a practical matter, limited by present vehicles and overhead power distribution systems to about 40 mph. The mode does, however, have the ability to provide high-quality line-haul service similar to that of light rail transit and very similar to that of diesel motor buses operated either over reserved lanes on surface arterials or over exclusive guideways, if special provision is made in the design of the vehicles and overhead power distribution system. This may be important because of the generally perceived local environmental advantages of the trolley bus over the diesel motor bus. As a consequence, the trolley bus may be considered further, following full development of the motor bus alternatives under this alternatives analysis, as a special alternative to the diesel motor bus, capable of achieving similar performance but differing in certain respects, including environmental impact, type of fuel used, support requirements, and costs.

The electric trolley bus mode consists of rubber-tired vehicles which operate on existing surface arterial streets and highways, generally in mixed traffic. The vehicles are propelled by electric motors which receive power through collection poles attached to the vehicle roof which slide along a pair of overhead contact wires. Because the vehicles require an overhead power distribution system, deviation from established transit routes cannot occur, although the mode does not require a special guideway as do rail transit modes. The boarding or alighting of passengers generally occurs at typical street corner bus stops, and fare collection procedures are generally the same as those used in the motor bus mode. Support requirements are also similar except for the need to construct and maintain the overhead power distribution system.

In the past, the electric trolley bus mode was seen as offering an intermediate capacity and level of service, or a level of service between that offered by the street railway mode and the motor bus mode. Most systems in the United States and Canada were installed during the 1930's and 1940's as a replacement for street railway facilities. The electric trolley buses of the period represented a substantial cost savings to the transit operators while offering a level of performance superior to that of most of the existing street railway and motor bus vehicles, while still permitting use of the existing electric power distribution facilities. From the late 1940's through the mid-1960's, the electric trolley bus systems in most cities were converted to diesel motor bus systems. Of the 63 systems that operated within the United States and Canada, 9 remain in operation as of 1979. These systems, plus two additional systems in Mexico, have been or are in the process of being upgraded in terms of fixed plant and vehicles.

The typical electric trolley bus vehicle has two basic body configurations: single-unit nonarticulated and two-unit articulated. Single-unit nonarticulated vehicles are used worldwide, while articulated electric trolley buses have not yet seen regular use within the United States or Canada. The typical nonarticulated vehicle consists of a single-unit body with a overall length of 40 feet, a width of 8.5 feet, and a height of about 10.3 feet. Articulated designs permit the operation of a single vehicle with a single operator and a large seating capacity and yet negotiate typical city streets without vehicle clearance and overhang problems. The typical articulated vehicle consists of two body units with an overall length of about 54.1 feet, a width of about 8.2 feet, and an average height of 10.3 feet. Unlike older electric trolley buses, currently available models have the same body designs that are used for urban diesel motor buses, the only difference between the two vehicles types being the propulsion and control systems.

Propulsion of electric trolley bus systems is in the form of relatively low voltage, generally 600 volts direct current (DC), which is transmitted from the power source to a traction motor via an overhead power distribution system. The traction motor is attached to the rear axle on nonarticulated vehicle designs, and to the second axle on articulated designs. The overhead contact wires restrict the lateral distance that a vehicle may move away from the wires to from 12 to 15 feet to either side. Vehicle speed is controlled by regulating the motor current and voltage with either a conventional rheostatic type of control, an electric solid-state control system, or a pulse width modulation system using alternating-current (AC) motors.

The typical rate of acceleration for standard nonarticulated North American designs is approximately 3.5 miles per hour per second, but rates vary between 2.5 miles per hour per second and 4.0 miles per hour per second for various European vehicle designs. Maximum vehicle speeds generally approximate 40 mph. Special work at intersections such as switches and crossings tends to limit speed and acceleration. Primary deceleration is achieved through the use of dynamic braking which utilizes the traction motors as generators, with a secondary mechanical braking system for low speeds.

It is generally held that the electric trolley bus is superior to the diesel or gas motor bus in terms of acceleration and overall operating performance. Although this was true during the period that this mode was widely used in the United States, during the early 1970's the performance of the diesel motor bus was greatly improved, making the overall performance of the two types of vehicles very similar. In fact, many transit operators who use both types of vehicles in local and some express service contend that the two have identical performance characteristics and thus can be treated interchangeably in daily operation.

Electric trolley bus vehicles can be equipped for off-wire operation for the purposes of bypassing route blockages, crossing wire gaps, or moving around garage or storage areas without overhead wire. This option, which is in evidence in certain European countries but not in North America, utilizes additional batteries, small gasoline engines, or diesel generators. Maximum speed and range are limited, as is the vehicle's grade-climbing ability. The use of vehicles with off-wire capabilities for traveling extended distances in daily revenue service is regarded as a fairly new concept, and such vehicles would require significant energy storage capacity.

Other important features of the physical design of electric trolley bus vehicles include passenger access, interior seating, suspension, interior climate control equipment, accessibility for the handicapped, and insulation from electrical shocks. If a self-service fare collection system is utilized, vehicles may have up to four doors in order to facilitate rapid boarding and disembarking of passengers. Interior seating designs in the United States are usually represented by a two-plus-two across seating arrangement. European vehicles generally provide large amounts of floor space for standing passengers.

The guideway requirements and station characteristics of the electric trolley bus mode are the same as those of the motor bus mode with the exception that electric trolley buses are unable to operate in mixed traffic over freeways because of their limited speed capabilities. These speed limitations result from the potential for dewirement and the necessity of restricted speeds through overhead wires, switches, and crossings. Nevertheless, it must be recognized that electric trolley buses are physically able to operate in mixed traffic on arterial streets, on reserved lanes, and on exclusive busways. The guideway requirements for the electric trolley bus mode and the diesel motor bus mode differ only in that ventilation needs to be provided in underground guideway facilities for diesel motor bus operation and additional vertical clearance is required for electric trolley bus operation to accommodate roof-mounted equipment and overhead wire construction.

The support requirements of electric trolley bus systems pertaining to guideway and structure maintenance, traffic control, and fare collection are quite similar to the requirements of motor bus transit systems. The support requirements related to vehicle storage and maintenance and power supply distribution, however, differ significantly. One of the most important considerations is that indoor storage is not necessary in low temperatures since electric trolley buses are propelled by electric motors rather than internal combustion engines. Also, electric trolley buses require less maintenance than do diesel motor buses, mainly because the propulsion system of the electric trolley bus mode has fewer moving parts and a longer life. The addition of an electric trolley bus fleet to an existing diesel motor bus fleet, however, would require the addition of specialized maintenance equipment, retraining of the staff, and an increased inventory because of the addition of a different propulsion system.

Electric trolley bus vehicle propulsion requires low-voltage direct current which is transmitted through an overhead contact wire system consisting of a pair of wires suspended over the roadway surface. Although this method of power distribution is somewhat similar to that employed with light rail transit, individual components for horizontal curve alignments, switches, and crossings are different. Additional overhead wiring and special work is required for turnaround loops, emergency routings, garage and storage area wiring, and routes with express service. Arterial express service can be accomplished in three ways, which differ in the configuration of the overhead wiring. These methods include the installation of passing sidings at certain intervals, the installation of a set of three wires down the middle of a street which would allow single-direction express service, or the installation of two additional complete sets of wire which would allow bidirectional express service. Electric power is purchased commercially and transformed into the operating voltage through a system of substations and primary feeders. The visual intrusion of the overhead power distribution system is frequently cited as a major disadvantage of electric trolley bus systems. Certain techniques, however, can be employed to mitigate these impacts.

The overhead contact wire systems currently available fall into one of two categories: rigid systems or elastic systems. Such classification relates to the method of suspension and the contact wire's ability to work with the current collector to avoid loss of contact at fixed suspension points. Rigid overhead wire contact systems generally allow operating speeds of up to 35 or 40 mph, with speeds through the overhead special work limited to about 25 mph. Rigid systems exclusively are used within the United States and Canada. Elastic overhead contact wire systems, which are in common use throughout Europe, will generally permit speeds of up to 50 mph, with maximum speeds of 35 mph through overhead special work.

Electric trolley bus system performance may be defined in terms of three critical characteristics: speed, headway, and capacity. These factors are important determinants of the level of public acceptance and patronage of a new primary transit system. Most currently available vehicle designs have a maximum attainable speed of approximately 40 mph. Utilization of a lower gear ratio could produce higher maximum speeds, although acceleration and the maximum grade capability may be reduced and power consumption increased. Maximum speeds for articulated vehicles generally range from 35 to 40 mph.

Typical operating speeds for electric trolley buses will be dependent primarily upon speed limits, existing traffic volumes, and street geometry. Along arterial streets, such speeds will typically range from 30 to 35 mph, while in densely developed areas on narrow arterial streets in older portions of the city, posted speed limits can be expected to range from 25 to 30 mph. Maximum attainable speeds can be permitted only on reserved lanes or exclusive guideways. Overhead special work at intersections will limit both the speed and acceleration of vehicles. For both types of overhead systems, increased vehicle speeds will also increase the possibility of dewirement.

Average speeds over an entire route of an electric trolley bus system are dependent upon surrounding traffic volumes, turning movements, and traffic signals—factors which can be expected to affect all traffic. Several cities which operate this mode have found the vehicles to be interchangeable with diesel motor buses over arterial street routes. Therefore, only if electric trolley bus operation is extensively employed on reserved lanes or on exclusive guideways will average speeds differ, being a function of the speed restrictions imposed by current vehicle design and the overhead wire system.

Vehicle headways are dependent upon the desired level of service and the manner in which schedules are designed by the local transit operator. Because the power distribution systems of electric trolley bus routes represent a significant investment, the mode is utilized only on trunkline routes where nonpeak as well as peak headways can be expected to be short. The shortest peak-hour headway reported for an existing electric trolley bus system in the United States is about 40 seconds.

The maximum passenger-carrying capacity of any electric trolley bus system is dependent upon vehicle capacity, vehicle configuration, and headway. Because vehicle body designs of currently available electric trolley buses are identical to those of currently available diesel motor buses, and because headway characteristics are very similar for the two types of buses, the capacity of each of the modes can also be expected to be similar. The electric trolley bus mode, which predominantly utilizes arterial street rights-of-way, can generally be expected to meet peak demands ranging from 2,000 to 10,000 passengers per hour. A consideration applicable only to the electric trolley bus mode is the constraint on capacity imposed by the inability of the vehicles to pass each other when operating on a single pair of wires. Similarly, capacity may be restricted when either electric trolley buses or diesel motor buses are operated through single-lane streets or other facilities where there is insufficient lane width for passing.

Capital costs are those investments associated with the design, construction, and acquisition of facilities required for the operation and maintenance of an electric trolley bus system. The major capital costs for electric trolley bus systems include the costs of acquiring vehicles and of constructing stations, the power distribution system, and maintenance and storage facilities; agency costs; and contingencies. Based upon the recent experience of selected United States operators, overhead power distribution systems can be expected to cost $500,000 per two-way mile, while vehicles can be expected to cost $164,000 each. Construction costs for the expansion or improvement of stations and maintenance and storage facilities depend upon the site-specific needs of the individual system. Costs for guideway segments such as exclusive busways, reserved lanes, or other traffic engineering measures designed to provide preferential treatment for transit vehicles would be the same as those for such segments utilized for diesel motor bus operation.

Operating costs for an electric trolley bus system consist of the daily costs associated with the operation of the vehicle fleet, regardless of the type of guideway utilized, and the costs associated with the routine operation of any priority facilities along exclusive guideways. Daily costs will include transportation expenses, maintenance and garage expenses, power expenses, administrative expenses, operating taxes and licenses, and miscellaneous expenses, and will total approximately 7 percent less per vehicle mile than diesel motor bus operation costs. The costs of the routine operation of priority facilities can be assumed to be the same as the costs of operating diesel motor bus priority facilities.

The energy requirements of electric trolley bus technology include not only the energy needed to propel vehicles, but also the energy needed to operate stations and maintain vehicles and system facilities, and the energy needed to construct the system and manufacture the vehicles.

Vehicle propulsion energy requirements constitute the majority of energy consumed and account for most of the variation in overall energy utilization of electric trolley bus transit systems. The propulsion energy requirements of electric trolley bus systems, based on the experience of transit operators in the United States, were estimated to range from 35,500 to 64,100 BTU's per vehicle mile. It has been estimated that electric trolley coach operation in the Milwaukee area could attain a propulsion energy efficiency approaching 35,500 BTU's per vehicle mile using standard trolley coaches. Articulated trolley coaches, although not presently operated in the United States, represent a potentially attractive high-capacity vehicle, and would permit operation with about 43 percent more seats than a standard coach while consuming only about 15 percent more energy.

Energy used to maintain vehicles and stations typically constitutes from 10 to 20 percent of the propulsion energy used per vehicle mile. Electric trolley bus maintenance needs are estimated at 2,000 BTU's per vehicle mile. Station energy needs vary from minimal for stations consisting of simple curbside stops with only small paved areas marked with appropriate signing to 4,000 BTU's per vehicle mile for larger station facilities. The energy used to construct an electric trolley bus guideway is estimated at 60 billion BTU's per dual-guideway mile for at-grade sections and 268 billion BTU's per guideway mile for elevated sections. Finally, the energy required to manufacture a single-unit articulated electric trolley bus is estimated to be 1,530 million BTU's per vehicle.

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Chapter V

OTHER TRANSIT TECHNOLOGY

INTRODUCTION

Previous chapters of this technical report have presented information on the "state-of-the-art" of those urban passenger transportation technologies that are potentially applicable to the provision of primary transit service in the Milwaukee area. All of these primary transit technologies—described to a degree of detail sufficient for systems planning purposes—possess technical and performance characteristics that would permit application in the Milwaukee area during the next 15 to 20 years. Those modes identified as having such potential applicability were classified into three broad categories: motor bus technology, rail transit technology, and electric trolley bus technology. Motor bus technology was further divided into four priority measures: operation of buses in mixed traffic on freeways, operation of buses over reserved lanes on freeways, operation of buses over exclusive busways, and preferential operation of buses on surface arterial streets. Rail transit technology was further divided into three modes applicable to primary transit service: light rail transit, heavy rail rapid transit, and commuter rail.

The popular perception of contemporary primary transit technologies frequently includes exotic modes which have a "futuristic" appearance, but which are either still in an experimental stage or, while in limited special service, unproven for day-to-day operation in regular urban primary transit service. Such technologies, while newsworthy because of their intriguing, radically different character, have, as a practical matter, limited applicability in the context of this study. Indeed, it is the stated policy of the federal Urban Mass Transportation Administration not to fund the application of such new or exotic technologies until they have been fully tested and proven practicable. These technologies, which will not be further considered in this study, are briefly described in this chapter, along with the principal reasons for eliminating each technology from further evaluation.

This chapter discusses three categories of transit technologies which have been identified as being inappropriate for further consideration as primary transit system alternatives for the Milwaukee area within the time frame of this study: modes that have become obsolete, modes still under development, and modes that have not been proven to be suitable for use in primary transit service.

OBSOLETE TECHNOLOGY

For the purposes of this inventory, obsolete technology is represented by certain modes, or components of certain modes, which are no longer considered suitable for application to proposed systems. Generally, a mode becomes obsolete when some other mode is able to provide superior performance at a lower cost and with less environmental impact for the same range of travel demand. Although there are a number of urban passenger transit modes that are now considered obsolete, it is not the purpose of this technical report to describe all these. Three such obsolete transit modes, however, warrant brief mention: street railways, electric interurban railways, and historic forms of heavy rail rapid transit.

Street Railways

The street railway mode is a form of urban transit provided by single- or double-unit vehicles operating in mixed traffic on standard arterial streets. The street railway mode cannot provide the high-speed and reliable-scheduled, high-capacity service required for a modern primary transit system. In fact, its use is limited to local service and some "skip-stop" express service. Because it offers greater flexibility and maneuverability and curbside loading and doesn't require fixed guideway facilities, the motor bus has almost entirely replaced the street railway in urban transit operations even for local service.

Nevertheless, the light rail transit mode has essentially evolved from the street railway. Most of the vehicle, trackage, and power supply characteristics of light rail represent only improvements and extensions of street railway technology. The most significant difference is the extent to which light rail modes use alignments designed for preferential treatment of transit vehicles. Such alignments give light rail transit performance capabilities superior to those of the street railway, and permit light rail to be used in primary transit service. No new street railway systems have been developed in recent years within the United States or Europe, although in some cities in the United States and Europe existing street railway facilities are being upgraded to light rail transit status. In the United States and Canada, the street railway mode is still utilized in the Cities of New Orleans, Philadelphia, and Toronto.

Electric Interurban Railways

Light rail transit technology has also evolved from the electric interurban railway mode, which may be considered to be virtually nonexistent in the United States today. The electric interurban railway mode typically consisted of one- to three-car trains propelled by electric power supplied through an overhead contact wire. The electric interurban railway generally served intraregional travel needs, connecting an important regional center to communities within 50 to 100 miles of that center. Track alignment was principally located on private rights-of-way adjacent to existing highways or railway main lines, but within larger cities and even within most smaller communities, the interurban railway alignment was almost always located over streets requiring operation in mixed traffic. Passenger service and package express and freight services were provided by the interurban railways. In addition, most electric interurban railway routes carried some daily work trips into the larger cities.

While electric interurban railway systems proliferated in certain parts of the United States during the late nineteenth and early twentieth centuries, the mode has today completely disappeared, its regional transportation function now accommodated largely by the private automobile, the intercity motor coach, and intercity trucking firms. The electric interurban railway mode is no longer considered appropriate for urban transportation applications because such applications can be better provided by the light rail transit mode, the motor bus mode, and, in some cases, the commuter rail mode.

Early Heavy Rail Rapid Transit

The third obsolete rail transit technology is the heavy rail rapid transit system of the type developed in the United States during the late nineteenth and early twentieth centuries. Such heavy rail rapid transit systems are still in operation in the Cities of Chicago, New York, and Philadelphia, and consist of elevated railways and subways generally built with sharp curvatures and limited clearances. Such systems have serious operating and environmental problems, including relatively low speeds and excessive noise. These problems have been mitigated by the improved vehicle and guideway design of modern heavy rail rapid transit systems constructed in the United States since the 1960's. The earlier type of heavy rail rapid transit system is considered inappropriate for future application because the more modern type of heavy rail rapid transit offers a better level of service without many of the undesirable operational and environmental problems attendant to the older technology.

TECHNOLOGY STILL UNDER DEVELOPMENT

During the last two decades, many new passenger transportation modes have been proposed, often in attempts to apply aerospace technology to ground transportation. These modes range from high-speed intercity systems using vehicles moving through vacuum tunnels to innovative rail technologies. Most of these modes have not, however, proceeded beyond the conceptual phase in terms of practical application in urban primary transit service. Some, however, have been operated on test tracks or on limited-purpose tracks, such as a shuttle service at a recreational "theme," or amusement, park or in a major activity center. Although prototype lines for some of these modes have been constructed and have successfully been operated in test or limited-purpose situations, it is unlikely that further technical development will occur rapidly enough to make these modes operational in a cost-effective manner for primary transit application within the 15- to 20-year time frame established for this study. Such technologies under development with potential future primary transit application include: automated guideway transit, intermediate-capacity transit systems, dual-mode transit, and various forms of alternative propulsion systems for transit vehicles.

Automated Guideway Transit

Predominant among the new urban passenger transportation system modes are various types of automatically controlled transit systems which utilize vehicles that proceed from origin to destination without a driver. The locations of vehicles on the guideway are continuously monitored and, in some applications, trip origin and destination information is obtained from passengers and the vehicles are automatically scheduled to serve the indicated trips. Such systems are referred to as automated guideway transit (AGT) systems. All AGT systems employ self-powered vehicles and have two distinguishing features: the use of exclusive guideways and the use of completely automated vehicles. AGT systems vary in vehicle size and speed, guideway type, and vehicle propulsion. The AGT mode includes both personal rapid transit (PRT) and light guideway transit (LGT).

Personal Rapid Transit: PRT is a transit mode in which small vehicles—each with a capacity of between two to six seated passengers—operate under total automatic control over an exclusive, fully grade-separated guideway. All stations are off-line and service is demand-activated. Individual persons or groups request exclusive use of a vehicle for a nonstop trip from the origin station to the destination station, thus the term "personal" rapid transit. Other terms used to identify this mode include taxi transit, capsule transit, advanced PRT, and high-capacity PRT.

The PRT mode theoretically incorporates many of the desirable features of the private automobile, such as high overall speeds and direct, immediate service from origin to destination with no intermediate stopping for other passengers. This mode also theoretically incorporates the high-capacity features of transit, even with the use of limited-capacity automobile-like individual vehicles, as the automatic control system theoretically permits very short headways. There have been, however, major difficulties in the development of control systems for PRT systems because of the complexity inherent in maintaining system safety and reliability at short headways. To achieve a capacity of 5,000 passengers per hour—equal to that available during the peak hour on Edmonton's new light rail transit system—a PRT system would need to carry 3,500 vehicles per hour, assuming an average of 1.4 passengers per vehicle. This would require an average vehicle headway of 0.99 seconds. The minimum vehicle headway would have to be significantly shorter to provide the unoccupied spaces required to accommodate the merging of different traffic streams.

If headways are increased to simplify the control system technology, the capacity of the overall system is substantially reduced and it does not perform a transit function, particularly with respect to primary service. So far, only PRT systems capable of headways of six seconds or more have been demonstrated, although fractional second headways are currently under development, with full-scale testing underway in some foreign countries. Furthermore, any further progress toward fractional second headways is dependent upon the commitment of substantial public funding of research, development, and installation. Research and development of PRT technology in the United States in recent years has been almost nonexistent, with development continuing, however, on AGT systems which utilize larger vehicles and much longer headways between vehicles. There are presently no known PRT systems providing service to the public. Two systems were demonstrated in the United States at the "Transpo '72" exposition during 1972, and one system was demonstrated near Tokyo in the late 1960's. These three facilities have since been dismantled.

Light Guideway Transit: LGT is a transit mode which utilizes vehicles operated singly or, in some cases, in small trains over an exclusive guideway generally under automatic control. Stations can be either on-line or off-line. The vehicles are usually the size of a small bus, with approximately the same passenger capacity, and permit standees. In the off-peak hours, some systems may offer personal demand-activated service. Other terms used to identify this mode include people mover systems and group rapid transit (GRT).

Group rapid transit systems have evolved as an extension of the personal rapid transit concept, moving groups of passengers instead of individuals and thus reducing guideway and vehicle control requirements. These systems include the technology of many modes at various stages of development, and are intended to provide an intermediate-capacity transit system with lighter vehicles and guideways than are required for full-scale rail rapid transit. A wide range of operational and performance characteristics and physical configurations are presently proposed in group rapid transit system technology. The vehicles can operate as single units, in tandem, or in small trains suspended below the guideway, riding over the top of the guideway, or, in some cases, along the side of the guideway. Because GRT systems group passengers in a single vehicle or train, the vehicle size tends to be larger than for a PRT and, hence, the guideway is wider and heavier. System construction costs have been estimated to be one-third to one-half of heavy rail rapid transit system costs, although actual development experience to date is very limited.

Group rapid transit systems are regarded as still being in the experimental and demonstration phase. Other than facilities constructed specifically for demonstration purposes, existing GRT technology in the United States has been employed to a very limited extent for circulation within major activity centers such as airports, universities, theme parks, exposition centers, and central business districts.

Probably the most well-known GRT system is the Morgantown Personal Rapid Transit System located in the State of West Virginia. This form of technology is also in use at other activity centers within the United States, including the Fairlane Town Center complex in Dearborn, Michigan, the Seattle-Tacoma International Airport in Washington, and the Dallas-Fort Worth Airport in Texas. Based on the operational systems that have been constructed, there is a high degree of uncertainty concerning costs because of the difficulties which have arisen in developing a complex new technology. The openings of a number of these systems were plagued with cost overruns and delays, making it necessary to view cost estimates with considerable caution.

The GRT systems implemented thus far have special-purpose and limited applications (see Figure 155). The high costs and technological problems involved have created uncertainties about widespread use. However, research and development are being continued by the U. S. Department of Transportation, Urban Mass Transportation Administration (UMTA), and some limited additional applications can be expected during the next decade (see Figure 156). Applications are most likely where large numbers of people need to travel short distances within a major activity center. A number of cities have been selected by the UMTA for the testing of people mover systems in downtown areas. The objective of these demonstration projects is to determine the feasibility of moving large numbers of people in densely developed downtown areas with a distribution system that serves existing or planned primary transit systems. Therefore, several operational people mover systems may be expected during the next decade, with wider application depending upon the success of these projects. The group rapid transit mode is therefore not seen as a feasible option for meeting primary transit needs in the Milwaukee area within the time frame of this study.

Intermediate-Capacity Transit Systems

The Urban Transportation Development Corporation, Ltd., (UTDC)—located in Kingston, Ontario, Canada—has built an intermediate-capacity transit system (ICTS) test vehicle to test advanced concepts, including steerable axle rail trucks and a linear induction motor propulsion unit (see Figure 157). Tests are being conducted on a 2,500-meter oval track at the UTDC transit development center. Unlike conventional rail trucks which have fixed axles that create wheel squeal and wear in curves, the steerable axle truck permits the wheels to follow rails through the curves. Tests to date have verified that the ICTS vehicle will negotiate tight curves with no wheel squeal or other excessive noise. Tests conducted in the winter prove the all-weather capabilities of the truck, which operated well under conditions of extreme cold, snow, and ice. Except for its linear induction motor propulsion system and steerable axle trucks, the ICTS mode is, in fact, very similar to the light rail transit mode. Vehicle size and training are similar between the two modes, as is performance. The ICTS mode, however,,has a significant disadvantage in that its linear induction motor propulsion system necessitates complete grade separation for the guideway, as is required for heavy rail rapid transit.[1] Yet heavy rail rapid transit is superior to the ICTS mode in terms of performance, including capacity and speed. The only purported advantage of the ICTS mode over heavy rail is that it may have the potential to be constructed at less cost than required for a heavy rail rapid transit system because it is intended for placement on aerial alignments rather than in subways in developed areas as a result of its smaller size and reduced noise impacts. However, because the propulsion and guidance features of the ICTS mode are still considered to be in the experimental stage, the mode must also be considered as such and, therefore, not presently capable of meeting the primary transit needs of the Milwaukee area.

Dual-Mode Transit

The concept of a dual-mode transportation system has received attention for many years, yet dual-mode transit remains one of the most complex and technologically uncertain forms of transportation. In a dual-mode system, vehicles are capable of operating on conventional roadways in a manual mode and on specially constructed guideways in a completely automated mode.

As envisioned, a dual-mode transportation system would consist of passenger vehicles resembling automobiles or small passenger buses that operate under automatic control on the guideway and manual control off the guideway. The automated guideways would be located in major travel corridors radiating from the central business district, where the movement of vehicles on the existing street network is normally severely hindered by peak-period congestion. The off-guideway collection and distribution functions would be performed under manual control on the existing roadway net-

[1] *Construction of intermediate-capacity transit systems has recently been proposed for the Canadian cities of Hamilton and Vancouver.*

Figure 155

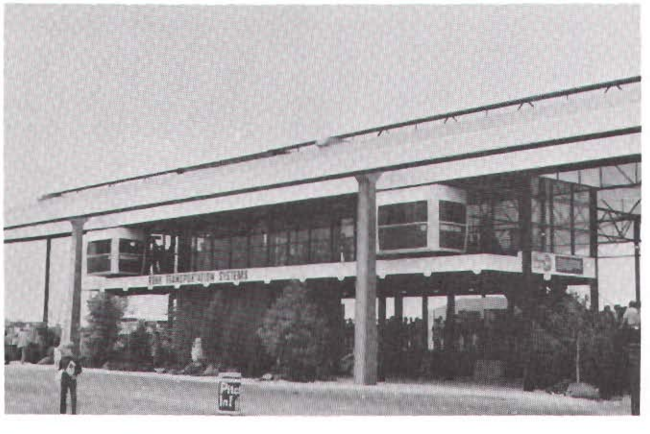
EXAMPLES OF EXISTING GROUP RAPID TRANSIT TECHNOLOGY

AUTOMATICALLY CONTROLLED TRANSPORTATION SYSTEM

The Ford Motor Company automatically controlled transportation (ACT) system is presently in operation at the Fairlane Shopping Center in Dearborn, Michigan. This system consists of a two-vehicle installation with a 2,600-foot guideway connecting the shopping mall with a nearby hotel. The two vehicles in this system carry 24 passengers each and can operate at speeds of up to 30 miles per hour, with headways of approximately two and one-half minutes.

Photo by Otto P. Dobnick.

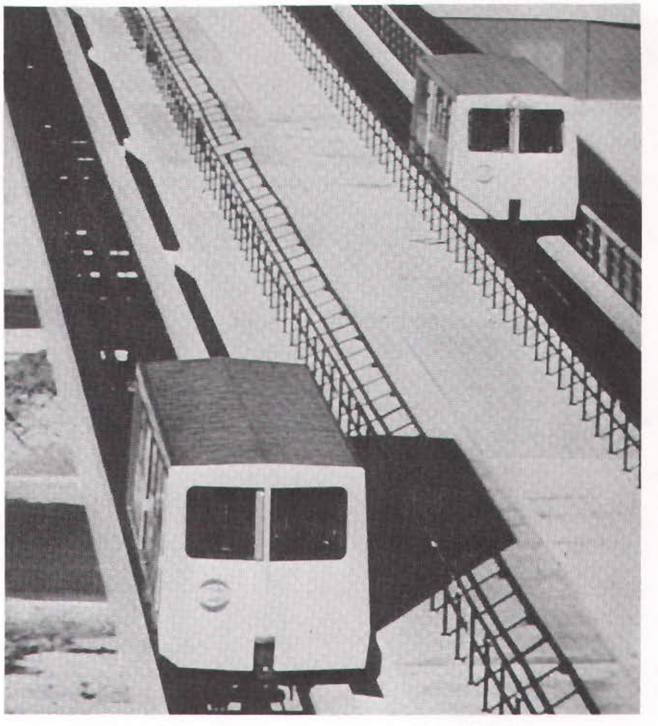
ROHR MONOCAB SYSTEM



During the 1970's, several companies designed automated guideway transit systems which incorporate the operation of a single vehicle suspended from elevated guideways and propelled by a variety of means, including linear induction motors. One such system is the Rohr Monocab which, as shown here, was demonstrated at the "Transpo '72" exposition held near Washington, D. C., during 1972.

Photo by Edward A. Beimborn.

TAMPA INTERNATIONAL AIRPORT SHUTTLE SYSTEM



The terminal complex at the Tampa International Airport consists of four satellite facilities connected to a central terminal building by an elevated structure containing two shuttle guideways as well as a pedestrian walkway for emergency use. Each shuttle guideway has a length ranging from 800 to 1,000 feet for the operation of one vehicle which has no seats, and which carries up to 125 standing passengers. Shuttle systems such as this, termed "horizontal elevators," are also in service at the Seattle-Tacoma Airport. This type of system is manufactured by Westinghouse Electric Corporation.

Photo courtesy of U. S. Department of Transportation.

work. At access stations, the vehicle driver would place the dual-mode vehicle under automatic control. If a bus-type vehicle were used, the driver could leave it for the guideway portion of the trip. If an automobile-type vehicle were used, the driver would remain with it. The potential use of demand-responsive manual operation would give dual-mode systems a unique capability to provide the system user with on-call, no transfer, door-to-door service on a transit system using automated operation.

Figure 156

MORGANTOWN PERSONAL RAPID TRANSIT SYSTEM

The Morgantown People Mover System, constructed by the Boeing Company, connects various campuses of the University of West Virginia at Morgantown by 2.2 miles of dual guideway over which a total of 45 vehicles operate. The Morgantown system operates as a scheduled system during peak hours, when each vehicle follows a predetermined path. At other times the system operates on demand, with the passengers indicating desired destinations. The system was planned as a research and demonstration project with the intention that it would continue in revenue service. Such a system is similar to that envisioned in the Urban Mass Transportation Administration downtown people mover project, which is to demonstrate the benefits of fully automated people mover systems in selected urban downtown areas.

Photos courtesy of University of West Virginia.

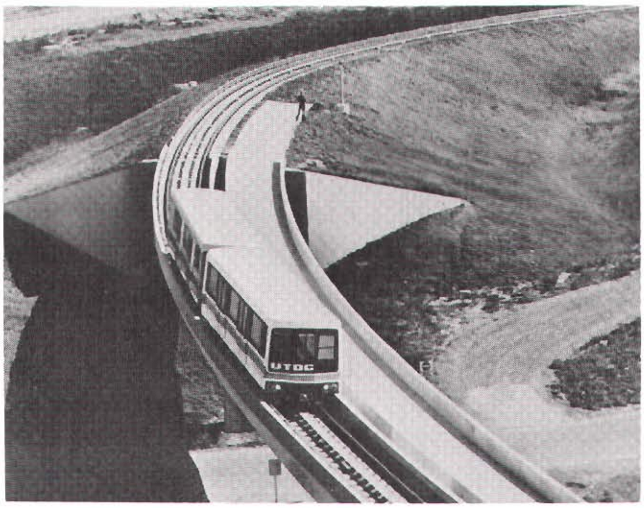
Several propulsion concepts have been considered for dual-mode systems. Electric versions would use electric energy from a battery during the off-guideway portion of the trip, and electric power from a wayside collection rail while on the guideway. It would also be possible to utilize internal combustion engine propulsion both on and off the guideway, or a hybrid version using electric power on the guideway and internal combustion engine power off the guideway. One concept that has been researched employs a pallet guideway system, where the vehicles or individual automobiles are transported on air-cushioned pallets propelled by linear induction motors.

During the 1970's, the U. S. Department of Transportation, Urban Mass Transportation Administration, awarded contracts for the conceptual design of a dual-mode transit system which included the development of a system prototype vehicle design. Because of waning interest on the part of the public sector in funding dual-mode research and development, further development of this concept has stagnated, with a demonstration facility yet to be constructed. Thus, the practical application of this concept for primary transit service in the Milwaukee area cannot be envisioned within the next 15 to 20 years.

A dual-mode transportation system—in concept—has been considered in the past for the Milwaukee area. In 1969, Representative Henry S. Reuss proposed that Milwaukee County, the Allis Chalmers Corporation, and the American Motors Corporation jointly apply for funding from the Urban Mass Transportation Administration for a dual-mode

Figure 157

INTERMEDIATE-CAPACITY TRANSIT SYSTEM TEST FACILITY



The intermediate-capacity transit system (ICTS) is an advanced technology rail transit system designed to have minimal environmental impact in developed urban settings. The technology has been developed by Urban Transportation Development Corporation, Ltd., of Canada and is being tested and demonstrated at that Corporation's test facility located near Kingston, Ontario. The test facility for the ICTS involves the replication of guideway characteristics expected to be encountered on such a proposed system for the City of Hamilton, Ontario.

Photo courtesy of Urban Transportation Development Corporation, Ltd.

demonstration project that would use abandoned railway rights-of-way. Following a suggestion by the UMTA in 1970 that a "preliminary study phase" be first undertaken, a systems analysis was funded. The Regional Planning Commission participated in the study by providing data and simulation modeling assistance and by serving on the advisory committee which directed the study. The consortium presented the findings and recommendations of the systems analysis in 1971. The findings reached indicated that no technological breakthroughs were necessary to demonstrate the dual-mode concept. Also, benefits would exceed costs, and uncertainties such as ridership attraction would be able to be resolved by an urban demonstration, not by theoretical studies or small test track experiments. The study recommended that the UMTA request $174 million from Congress for a 10-year development and demonstration project that would involve 200 to 300 vehicles and 15 to 25 miles of guideway.[2]

No action was, however, taken to fund the development and demonstration project. Nevertheless, the UMTA continues to consider dual-mode transportation worthy of further research and development, as well as study at a conceptual level to determine whether it is more cost-effective than proven transit technologies.

In 1977, the results of a study sponsored by the UMTA were released which analyzed the operation, economics, and impacts of two dual-mode concepts using the Milwaukee area and Orange County, California, as case study settings. The Commission again provided data and simulation modeling assistance. However, the study for the Milwaukee area, sponsored by the UMTA and performed independently by the consulting firm of Cambridge Systematics, Inc., was as concerned with developing and testing new planning techniques as with comparing various alternative dual-mode systems, and does not adequately address the cost-effectiveness of dual-mode transportation relative to proven technologies, nor does it address the availability of dual-mode transportation technologies.[3]

Of particular interest to the current alternatives analysis study are the dual-mode system test networks utilized in the latter study. As shown on Map 8, many of the automated guideway alignments are very similar to the corridors of major travel demand identified in the "design, test, and evaluation" portion of this study. Such corridors

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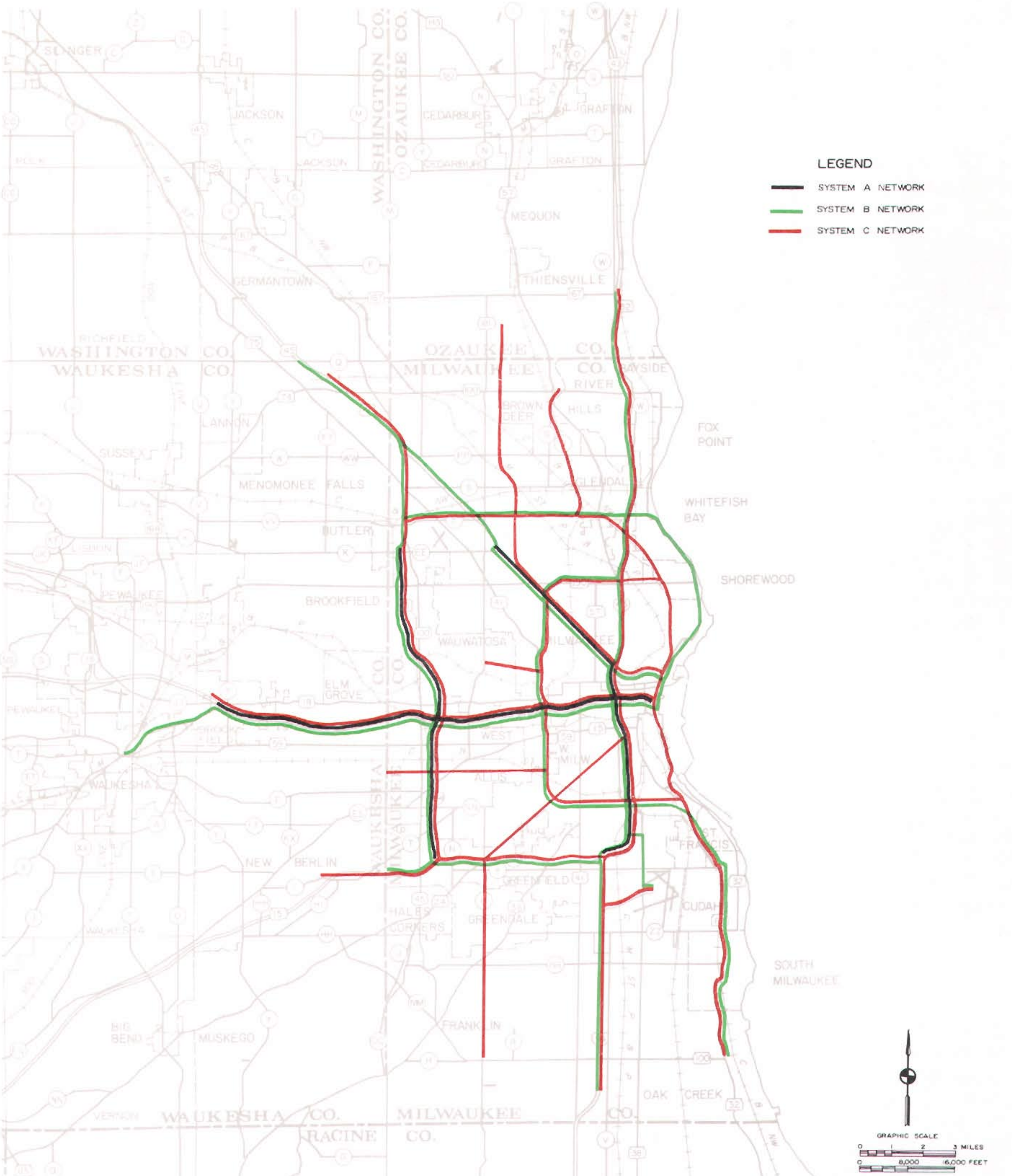
[2] *See Milwaukee County Dual-Mode Systems Study, Volume 1, Summary Report; Volume 2, Technical Evaluation; Volume 3, Socio-economic Evaluation; and Volume 4, Implementation Plan, prepared for the U. S. Department of Transportation, Urban Mass Transportation Administration by Allis Chalmers Corporation, Milwaukee, December 1971.*

[3] *See Dual Mode Planning Case Study—Milwaukee, Volume 1, Executive Summary and Planning Analysis; Volume 2, Technical Appendices; Volume 3, Transit Sketch Planning Manual, prepared for the U. S. Department of Transportation, Urban Mass Transportation Administration, by Cambridge Systematics, Inc., August 1977.*

Map 8

TEST NETWORKS UTILIZED IN DUAL-MODE PLANNING CASE STUDY FOR THE MILWAUKEE AREA



The dual-mode system—a public transit mode that requires further research and development—uses vehicles capable of operating both on conventional roadways and on automatically controlled guideways. The potential of this mode was investigated using the Milwaukee area as a case study, and the investigation resulted in the postulation of this test network. The network is of particular interest since it provides an independent identification of major travel corridors in the Milwaukee area that may warrant a high-capacity, fixed-guideway-type transit facility.

Source: Dual-Mode Planning Case Study—Milwaukee, Volume 1, Executive Summary and Planning Analysis, prepared for the U. S. Department of Transportation by Cambridge Systematics, Inc., August 1977.

include those radiating from the Milwaukee central business district in a northeasterly, northerly, northwesterly, westerly, southerly, and southeasterly direction. Similar crosstown corridors also exist north and west of the downtown area.

In what can be considered an offshoot of the dual-mode concept, a West German manufacturer of motor buses has devised a relatively simple automatic steering system to guide city buses along exclusive guideways. Known as the "O-Bahn," the proposed system has seven-inch-high steel guide rails mounted on either side of the guideway. Near the front wheels are single horizontal rubber rollers on brackets bolted to the steering arm of the vehicle. These rollers do the hands-off steering while in contact with the guide rails. Only one roller maintains contact with the rails at a time, the clearance on the free side being small enough to prevent vehicle weaving.

The guide rails are 8.5 feet apart—which is slightly wider than the typical dimension of a bus—compared with a minimum of 12 feet which is required for vehicle operation under manual control. Because the system is self-steering, the vehicle can operate through guideways with very narrow horizontal clearances, much like rail transit modes, resulting in a potential for decreased guideway construction costs. The manufacturer claims that the guidance system is reliable even under heavy snow conditions, and that the mechanical system is more accurate than electronic guidance with wires buried in the roadway because of the system's basic simplicity and lower failure risk. Except for a short test section, there are no known applications of this vehicle guidance system, making the concept unproven and therefore not applicable for implementation in the Milwaukee area within the 15- to 20-year time frame of this study.

Alternative Propulsion Systems

In addition to totally new passenger transportation systems, several propulsion and propulsion-related technologies are currently undergoing research and development. These technologies can be applied to more than one mode, and therefore should more appropriately be reviewed under the planning and preliminary engineering studies which would be conducted in the second phase of the Milwaukee area primary transit system alternatives analysis, should it be found desirable to proceed with such a phase. For the purpose of introduction, however, these technologies are briefly described herein.

The propulsion technologies discussed below include battery power, hybrid systems, flywheel technology, linear propulsion motors, and vehicle levitation systems. Developments in internal combustion engine technology such as improved diesel or gas turbine bus engines and regenerative electric braking have been excluded from this discussion since they would not affect the operational characteristics of the respective systems. Battery power, hybrid systems, and flywheel technology could all potentially be applied to the heavy rail rapid transit, light rail rapid transit, and electric trolley bus modes. Flywheel technology could also be applied to the motor bus mode. Linear propulsion motors used either with conventional flanged wheels or with vehicle levitation systems may lead to new types of heavy rail rapid transit systems or smaller light guideway systems.

Battery Power: Battery energy storage offers a wide range of performance and distance capabilities for bus vehicles. On several European properties battery power is used for limited operation of electric trolley buses to bypass route blockages or move around garage or storage areas without overhead wire. Vehicle speed and range are severely restricted, and the batteries must be charged by the regular auxiliary supply while the vehicle is operating under the trolley wires. Batteries to provide significant off-wire capabilities for daily revenue service present major difficulties for transit application. Although several high-technology batteries have been developed with impressive energy densities and power-to-weight ratios, only the conventional lead acid battery is expected to be commercially available in the near future. The battery weight and volume necessary to give reasonable performance cannot be accommodated in a North American transit vehicle without major redesign. To date, the only full-size transit vehicle with adequate performance is a West German design which carries a battery pack in a 10-foot-long trailer towed behind the coach. This provides sufficient energy for approximately 30 miles of urban stop-and-go operation. The batteries that propel this vehicle must be exchanged at a wayside station.

An alternative method of battery propulsion involves operating the electric trolley bus vehicles on batteries in suburban areas and even in central business districts if overhead wires are prohibited. The only constraint is that the vehicle must spend adequate time under wires during each cycle to recharge the battery. Equipping only transit trunk routes with wire is a fairly new concept for revenue transit service. There is no North American experience in this respect; however, West Germany is pursuing the concept with a demonstration project. In this project, vehicles are equipped with power collection poles and have approximately a six-mile off-wire range, with an equal distance required under wire for recharging. Known as the DUO-BUS, the operation in and around the City of Esslingen involves a 20-mile network, of which 5 miles are under wire. Based on the demonstration project, it appears that the DUO-BUS technology offers no economic advantage over ordinary diesel motor buses when considering only direct costs. However, if sufficient importance is placed on environmental and energy conservation concerns, the DUO-BUS may become appealing, especially in light of possible advancements in energy storage—battery or flywheel—technology.

Hybrid Systems: Any vehicle capable of operation using more than one source of propulsion energy is defined as a hybrid vehicle for the purposes of this report. Two types of hybrid transit vehicles are currently undergoing research and development: electric-internal combustion vehicles and electric-battery vehicles. Electric-internal combustion vehicles are capable of operating on electric traction motors using electricity drawn directly from an external source such as an overhead power distribution wire or a third rail, and are also capable of operating on the electric traction motors using electricity produced by an on-board generator powered by a gasoline or diesel engine. Electric-battery vehicles can also operate on electric traction motors using electricity drawn directly from an external source, but are also capable of operating on electricity drawn from on-board batteries. The above-described West German DUO-BUS is an electric-battery hybrid vehicle. Hybrid vehicle technology is still undergoing research and development. Since there are no known applications of hybrid vehicle utilization in regular service in the United States, further consideration within the planning horizon of this study is not considered to be warranted.

Flywheel Technology: Kinetic energy storage wheels—or flywheels—have long been used to store temporarily small amounts of kinetic energy, an example being the flywheel of an internal combustion engine. Recently, this technology has experimentally been applied to transit vehicles. A relatively lightweight flywheel spinning at a very high rate of speed in a partially evacuated capsule can store a considerable amount of kinetic energy and yet be contained within and transported by modern electrically propelled vehicles, such as electric trolley buses or rail transit vehicles.

The flywheel is attached to an electric motor generator. The motor produces kinetic energy and stores it in the flywheel when extra current is available from regenerative braking or from the vehicle's normal power supply. When more power is needed, such as during acceleration of rail transit vehicles, during off-wire operation of electric trolley buses, or during power failures, the energy stored in the spinning flywheel is used to generate electricity to power the vehicle. The Urban Mass Transportation Administration is in the process of testing flywheel energy source systems as a means of reducing the energy requirements of fixed-route, multiple-stop, urban transit vehicles. A recent demonstration of on-board flywheel energy storage on heavy rail rapid transit vehicles in actual service showed overall propulsion energy reductions of from 14 to 26 percent as compared with the requirements of conventional equipment. Other characteristics of flywheel energy storage were also evaluated, including tunnel heating effects and gyroscopic forces. Energy storage technology utilizing flywheels is still experimental, and several years will be required to determine its applicability for regular use in transit vehicles. Flywheel technology cannot be applied in regular service until it can be demonstrated that it offers an operating cost advantage sufficient to offset the installation costs. Consideration of such application is moot with respect to this alternatives analysis since it will not significantly affect system configuration or performance.

Flywheel technology may also have application to conventional motor buses. The U. S. Department of Transportation's Transportation Systems Center is currently engaged in a four-year project that will see testing of a full-size transit bus equipped with a flywheel-electric propulsion system. Each day prior to the first run, the flywheel—fabricated from 3,000 pounds of steel disks sealed in a low-pressure helium atmosphere—will be charged to its design speed of 10,000 revolutions per minute. This should provide sufficient energy to move the fully loaded vehicle a distance of 3.5 miles in city traffic. The flywheel must then be reenergized at a curbside charging station, this process expected to take 90 seconds. The flywheel is attached to a motor-alternator which drives a single direct current traction motor. According to flywheel technology proponents, this vehicle design offers the environmental and energy advantages of the electric trolley bus without the cost and maintenance associated with the overhead power distribution system. In addition, unlike battery-powered vehicles, flywheel-propelled buses can be recharged quickly and be operated around the clock. The purpose of applying flywheel technology to motor buses would be to conserve petroleum-based fuels and avoid noise and pollutant emissions when the bus is operating in particularly sensitive areas.

Linear Propulsion Motors: Linear motors, like conventional rotary electric motors, consist of a stator and a rotor which alternately attract and repel each other to produce motion. In the linear motor, both the stator—or the field magnet—and the rotor—or armature—are "unrolled," and instead of the rotor turning on a fixed axis as in a rotary electric motor, it travels along a guideway. In its application to transit vehicles, the rotor is carried aboard the vehicle and moves the vehicle along the linear armature located on the guideway.

There are two types of linear motors: inductive and synchronous. If the guideway is made of a conductor such as aluminum, the motor is called a linear induction motor because the vehicle is moved by eddy currents induced by the moving field produced in the stator. If, however, the guideway is composed of magnets, either temporary or permanent, the motor is called a linear synchronous motor.

Tests and demonstrations of relatively small linear inductive and linear synchronous motors have been conducted, these motors having been proven operational for limited functions at this time. However, neither motor has been demonstrated in actual primary transit operation, although the Urban Transportation Development Corporation of Canada is testing an intermediate-capacity transit system which uses such propulsion technology. Problems of power pickup, control of acceleration and deceleration, and costs are still to be overcome before linear motors can be considered applicable for regular service. Research on and development of linear motors is continuing, primarily in Germany and Japan, but breakthroughs in this propulsion technology appear to be occurring slowly. Therefore, linear propulsion motors cannot at this time be considered proven for primary transit system application.

Vehicle Levitation Systems: Raising the vehicle above the guideway to eliminate physical contact and thus minimize friction and provide a smooth ride can be accomplished through the use of magnetic levitation (Maglev). Two fundamental approaches can be used to produce magnetic levitation: repulsion or attraction. With the repulsion technique, the vehicle is levitated by on-board magnets chilled with liquid helium to a highly efficient, super-conducting state. The magnets then generate a force field so powerful that it pushes the vehicles up and away from metal coils located in the guideway under the vehicle. The other technique utilizes magnetic attraction between the metal guideway and vehicle-mounted electromagnets under the rails. The magnets are held under the rail by a projection from the vehicle body, and when the magnets are energized, they pull upward toward the rails lifting the vehicle. Once the vehicles are levitated, most systems are propelled by a linear induction motor.

The major benefit offered by magnetic levitation is that it allows operation at very high speeds—between 200 and 300 miles per hour—because of the reduction in friction and vibration. Because speeds for primary transit are limited by close station spacing, vehicle levitation appears to be potentially more applicable for long-distance intercity facilities than for urban transit systems. Problems of control have not yet been overcome for magnetic levitation, and a practical turnout to move vehicles from one guideway to another has not yet been developed. Development of this technology appears to have stagnated in the United States, but is continuing in Germany and Japan. This technology is far from proven, especially for application in primary transit service, and therefore is not considered applicable within the framework of this study.

TECHNOLOGIES INAPPROPRIATE FOR PRIMARY TRANSIT SYSTEMS

This category of transit technologies includes several modes which have been demonstrated to be operational in regular service but do not appear to be applicable for primary transit application in the Milwaukee area. These modes have been determined to be inappropriate because they either are more suitable for secondary or tertiary transit service or offer no advantages over other existing and proven primary transit modes. Such modes discussed herein include automated guideway transit, monorail, rubber-tired duorail, and moving way transit systems.

Automated Guideway Transit

Transit systems utilizing automatic vehicles designed to travel along their own separate guideways are called automated guideway transit (AGT) systems. A number of such systems are currently in operation at activity centers across the country, including airports, shopping centers, college campuses, and theme parks. This mode is described under the section of this chapter entitled "Technology Still Under Development." As explained in that section, AGT systems are considered unproven since operational systems are not yet available that can operate at short enough headways to meet primary transit service demands. The technology, however, is also included in this section since there are systems that have been successfully operated in recent years in and around major activity centers, albeit without fractional second headways. Existing systems of this nature have been implemented only for circulation in activity centers, making this mode unproven for other than tertiary transit service. In fact, through the downtown people mover (DPM) program, the Urban Mass Transportation Administration is attempting to show that fully automated, relatively simple, people mover systems operating in urban environments can provide an adequate level of reliable service at reasonable costs. The projects to be constructed, however, will be limited only to distribution systems in the central business districts of selected United States cities.

Monorails

Monorail systems incorporate a single rail which is utilized for vehicle support as well as lateral guidance. There are two basic variations of monorail technology: top supported systems, where the vehicles are suspended from an overhead rail; and bottom supported systems, where the vehicle straddles a single beam. The only operating examples of a top-supported or suspended monorail utilized in daily public transit service are in Yokohama, Japan and in Wuppertal, Germany. The later system opened to service in 1901 (see Figure 158). Bottom-supported monorail systems are operated in regular daily service in Seattle, Washington, and in Japan at Inuyama, Yomiuri, and Tokyo (see Figure 159). Numerous monorail facilities of both the suspended and bottom-supported type have been constructed for demonstration purposes around the world, including a number of locations within the United States.[4] These systems, however, are of an experimental and temporary nature and, for the most part, are of short length. Monorail technology has also found application in theme parks, zoos, expositions, and other activity centers, being either full size but limited complete systems or applications of the single rail concept to various people mover systems. Examples of these applications can be found at Disneyland, Walt Disney World, Kings Island (Cincinnati, Ohio), and the Minnesota Zoological Garden. Although popular opinion views monorails as a new and modern form of transportation, the mode has been in existence for almost 100 years.[5]

Aside from a relatively smooth and quiet ride, albeit at low speeds, monorails have comparatively few advantages over other proven primary transit modes. The primary disadvantages of monorails include a history of oscillation or sway of suspended monorails in high winds and at high speeds, which may cause riding quality, station clearance, and vehicle switching problems. The stability of suspended vehicles can be improved by dual rail construction, but such construction further complicates the switching mechanisms. Switches or turnouts for both the suspended and bottom-supported monorails are elaborate, cumbersome, and slow acting because of the large guideway assemblies that must be moved to change routes. In addition, monorails are not as readily adaptable to at-grade or underground alignments as are other primary transit modes because of their comparatively large vertical dimensions. And finally, monorails cannot provide the high-speed operation required for line-haul sections of primary transit routes. Most monorails that are now in operation or that have been demonstrated can attain speeds of only 20 to 30 mph. Therefore, their best application is as elevated alignments, which may produce aesthetic problems in urbanized areas—especially top-supported systems, which require an elaborate superstructure.

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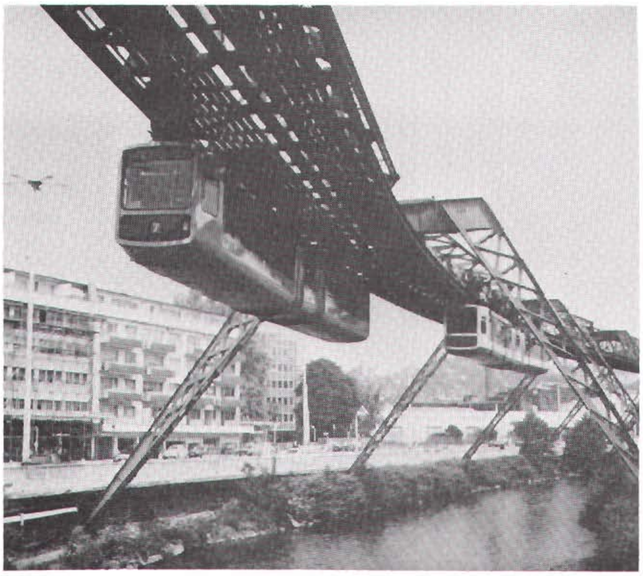
[4] *In addition to being operated in Seattle, such facilities within the United States have been constructed and operated at the 1964-1965 New York World's Fair, at the Houston Airport, at Pelham Bay, New York, and in South St. Paul, Minnesota.*

[5] *One of the first monorails in the United States was a top-supported system partially opened in 1888. Operated as the South St. Paul Rapid Transit Company, only 0.75 mile of double guideway was constructed of the line that was intended to terminate in downtown St. Paul, Minnesota.*

Figure 158

TOP-SUPPORTED (SUSPENDED) MONORAIL IN WUPPERTAL, GERMANY



One of only two operating examples of top-supported, or suspended, monorails utilized in daily public transit service is in Wuppertal, Germany, where an 8.3-mile-long system has been in service since 1901. As shown in this photograph, much of the guideway is suspended from large structural steel supports over the Wupper River. In the 1970's, the aged vehicles were replaced with modern equipment, and the system remains as a basic part of the area's public transit network.

Photo by Edward A. Beimborn.

Figure 159

BOTTOM-SUPPORTED MONORAIL IN SEATTLE, WASHINGTON

A number of bottom-supported monorail systems have been constructed for either demonstration purposes, or, in a limited number of cases, daily revenue service. The vehicles on such systems are propelled by electric traction motors which drive rubber tires riding on a concrete beam supported on an aerial structure. The system shown here was constructed for demonstration purposes for the Seattle World's Fair held during 1962, but was retained as an operating part of the Seattle's metropolitan transit system upon the fair's closing. Although several proposals have been made for the system's expansion, the total length of each of the two guideways remains at 1.2 miles.

Photo by Thomas A. Matola.

A comparison of monorail systems with more conventional rail transit systems such as heavy rail rapid transit and light rail transit systems indicates a high degree of similarity in most characteristics including vehicles, terminals, and operating procedures, the major difference essentially being the number of rails used for the guideway. The utilization of a single rail instead of two rails does not appear to provide any substantial advantage, but does present some disadvantages, these being chiefly the difficulty in switching and the more complex and aesthetically unpleasing structural requirements, as well as the difficulty of maintaining the guideway. It is sometimes claimed that the monorail's single rail permits much less surface area to be required. Modern aerial guideway engineering and construction techniques, however, negate any such slight advantage formerly attributed to monorail facilities. It is generally agreed that these disadvantages outweigh any advantages of single-rail operation, therefore limiting the application of monorail technology to special-purpose systems such as short distance shuttles. For these reasons, the use of monorail technology is considered unacceptable as a primary transit mode for the Milwaukee area.

Rubber-Tired Duorail Systems

A variation of the modern heavy rail rapid transit mode is the use of pneumatic rubber tires on the vehicles. Systems using the rubber-tired "duorail" concept are in service in Paris, Montreal, and Mexico City. The vehicle bodies and propulsion are generally identical to those of typical heavy

Figure 160

RUBBER-TIRED DUORAIL MODE IN MONTREAL, CANADA

A variation of the modern heavy rail rapid transit mode is the use of pneumatic rubber tires instead of steel wheels on vehicles, allowing the vehicles to negotiate steeper grades than attainable with steel-wheeled vehicles. In addition to 16 rubber tires, each vehicle requires eight vertical steel wheels mounted inside the rubber tires to provide guidance at switches. Disadvantages include the requirement of a more complex guideway, pneumatic tire failure, and the large amount of heat caused by friction from up to 144 rubber tires per train. This technology is in service in the Cities of Paris, Montreal, and Mexico City. Following experimentation with the rubber-tired duorail concept, Paris has elected to continue modernizing its heavy rail rapid transit system with more conventional steel-wheeled technology.

Photos by Otto P. Dobnick.

rail rapid transit vehicles, with power transmitted through a shoe that slides along a third rail. In addition to the eight rubber-tired running wheels per coach normally used, there are eight vertical steel wheels per car mounted just inboard the rubber-tired wheels (see Figure 160). These wheels provide guidance at switches, and in case of pneumatic tire failure the steel wheel comes in contact with a steel rail, thus allowing the vehicle to continue to function. Guidance, except through switches, is provided by eight smaller rubber-tired wheels mounted horizontally and running against the sides of the guide rails.

The guideway consists of two concrete tire tracks, two conventional steel rails, and two guide rails. Grades are limited to a maximum of 6 percent, and horizontal curvature to a minimum of a 700-foot radius for speeds of 50 miles per hour. The principal advantages of the rubber-tired duorail system include somewhat quieter operation, and the fact that the greater traction of the rubber tires enables the vehicles to negotiate steeper grades than attainable with conventional modern heavy rail rapid transit vehicles. This advantage may permit more economical subway construction. The disadvantages include the high capital cost for construction, operation, and maintenance of the more complex guideway plus the high cost of purchasing and maintaining each vehicle. It should be noted that with this system, conventional steel rails are still required in addition to the concrete guideway. In addition, a large amount of heat is generated in the subway by friction and braking, the guidance system is not mechanically attractive, and a fully grade-separated right-of-way is required. Since converting two of its regular subway lines to rubber-tired vehicle operation, the Paris rapid transit system has apparently lost enthusiasm for such additional conversions and plans to extend other lines with the more typical heavy rail rapid transit mode, using flanged steel wheels on steel rails.

In a variation on the duorail concept, standard full-size diesel motor buses have been equipped with retractable steel wheels for operation on existing railway tracks. Such apparatus is common on railway company maintenance and inspection motor vehicles, enabling travel on both highway and railway. While operating on public streets and highways, the steel wheel assemblies are carried within the underbody of the bus. In the lowered position, the front tires of the bus are lifted slightly to reduce the tire-bearing weight, while the two inner rear wheels bear the vehicle weight and provide traction for movement. Braking is accomplished by the regular rear wheel brakes plus disc brakes on the steel wheel assemblies.

This mode was once thought to have promising application in travel corridors containing abandoned or lightly utilized railway trackage. Tests during the 1960's, however, indicated several problems with this concept. First, the quality of ride was generally not acceptable—partly because of the condition of the trackage on which the tests were run. Smooth operation was found to require a roadbed and track structure in excellent condition, continuous welded rail being desirable. Even with these track qualities, however, the existing motor bus suspension system was found not to produce a smooth ride. Because of safety considerations, the motor bus vehicles would require exclusive use of the railway line during operating periods. Railway lines which experience only small amounts of freight traffic can be expected to be poorly maintained and in need of major rehabilitation for an acceptable level of comfort and safety. This implies a substantial guideway capital cost item.

Another problem encountered was the lack of adequate traction between the rubber tires and the steel rails—especially during wet or icy weather. This condition would result in poor acceleration and questionable reliability in emergency deceleration. Finally, noise levels were undesirably high, particularly where the railway trackage was in poor condition. Since the 1960's there has been no known testing of this concept, nor has there been any operation on either a limited demonstration or regular service basis.

In what may be a revival of the concept of diesel motor bus operation on existing railway track, a new rail passenger vehicle is to be tested by the Federal Railroad Administration during 1980 and 1981. Known as a "railbus," the vehicle, which is essentially a motor bus body mounted on a two-axle railway carriage underframe, was developed in Great Britain as an inexpensive replacement for older, self-propelled vehicles which provide railway passenger service to rural districts. An Americanized version of the Leyland Experimental Vehicle—LEV-2—will be tested in the United States as a possible low-cost way to provide railway passenger service in lightly populated areas or feeder service to more heavily traveled intercity and commuter services. The LEV-2 weighs only 20 tons, seats 56 passengers, has a single-powered axle propelled by a 220-horsepower diesel engine, and is estimated to cost between $400,000 and $500,000 per vehicle if placed into regular production.

The LEV-2 railbus is considered to be inappropriate for further consideration at this time for use in primary transit service in the Milwaukee area because the vehicle is, at present, unproven for any type of passenger service on North American railway lines and must, therefore, be considered to be still under development. The vehicle's light weight poses several as yet unanswered questions concerning protection to passengers in the event of a collision with standard railway equipment or with heavy motor vehicles in grade-crossing accidents, the vehicle's ability to operate over icy grade crossings in the wintertime, and the vehicle's ability to activate signal circuits reliably. A high level of track rehabilitation and maintenance will be necessary in order for this vehicle to provide a safe and smooth ride.

Furthermore, it must be recognized that the "railbus," even if proven, would not be suitable for primary transit service in heavily traveled corridors, because it cannot provide sufficient passenger-carrying capacity. Although it would have to maintain relatively long headways as do other commuter trains, its vehicles—unlike standard equipment—cannot be trained together to increase capacity. And, the railbus has a much lower seating capacity per individual vehicle. Because of this lower seating capacity compared with that offered by other commuter rail vehicles, use of the railbus may be expected to entail greater capital costs in terms of the number of vehicles required to serve a given passenger demand and greater potential operating costs in terms of the number of passengers which could be carried per train crew member.

Moving Way Transit Systems

Moving way transit (MWT) systems encompass two basic categories of modes: "continuous carriers" and "discrete carriers." Continuous carriers include that group of systems in which the device is a continuously available surface such as a belt or a disc upon which passengers may stand or walk. Such modes include conventional, constant-speed, moving walkways, escalators, and accelerating moving walkways. Accelerating walkways are pedestrian assist devices capable of transporting large numbers of people short distances. A typical accelerating walkway moves at speeds somewhat less than normal walking speed for boarding and unloading but increases to more than twice the normal walking speed for the main portion of the trip. Such systems hold promise of application in heavy rail rapid transit and comuter rail terminals for the purposes of improving access, shortening trip times, and reducing congestion. Several prototype systems have been developed but none provide service to the public, although the Urban Mass

Transportation Administration is anticipating the construction of a demonstration facility.

Discrete carriers are those systems in which passengers accommodation is provided by a cab, compartment, or some other container which travels along a guideway. Such modes include aerial passenger tramways which utilize conventional cableway technology, and rigid guideway conveyor systems. Rigid guideway systems are derived from aerial cableway and funicular railway concepts. Cars are mounted on articulated rubber-tired drive carriages and may be suspended from the guideway or ride on top of it. An electric power unit drives the traction cable—which is contained with other propulsion gear between the guideway beams—which tows the vehicles along the guideway. To keep vehicle and support structure weight lower than the weight of conventional self-propelled vehicles, the power unit is housed in one of the system's terminals.

Moving way transit systems are employed exclusively as short-distance shuttle systems or as activity center circulation systems. Continuous carriers, for example, are utilized in transportation terminals, shopping centers, and exhibition halls, as well as to connect buildings with large parking lots. Discrete carriers which encompass the automated cable-driven people mover systems have in the past been employed mainly in remote mountain areas. However, such carriers are currently considered feasible for providing shuttle-type transportation in activity centers located in urban areas. Such a system is presently in regular operation in New York City, with additional systems under construction in Las Vegas and Memphis. While these technologies are well proven, they have application only in and around major activity centers, thereby making them impractical for primary transit service in the Milwaukee area.

SUMMARY

A number of transit technologies were determined early in the inventory of the state-of-the-art of primary transit technology not to warrant further consideration for primary transit system development in the Milwaukee area over the next 15 to 20 years. These technologies principally included "futuristic" technologies still under development. These technologies were eliminated from further consideration under this study because they were determined to require extensive further research, experimentation, testing, and demonstration before their application as a primary transit system could be considered practical, as well as before their costs, levels of service, and other impacts could be considered competitive with proven technologies. It is the policy of the federal Urban Mass Transportation Administration not to fund the implementation of such new or exotic technologies until they have been fully tested and proven practicable. Transit technologies were also removed from further consideration under this study if they were considered inappropriate for primary transit use—that is, if their existing applications had not yet proven their ability to perform at the level of service required for primary transit, or if they were not found to be in any way superior to proven existing primary transit technologies. Transit technologies considered to be outdated or obsolete for future application in primary transit service in the Milwaukee area were also identified and removed from further consideration under this study.

Transit technologies considered to be obsolete include street railways, electric interurban railways, and early conventional heavy rail rapid transit systems. Light rail transit technology, a mode which will be considered under this study as a primary transit alternative for the Milwaukee area, represents an evolution of both the street railway and electric interurban railway technologies, and is superior to both in all respects for urban passenger transportation application. Similarly, modern heavy rail rapid transit has evolved from the conventional heavy rail rapid transit technology which was first developed in the United States during the 1890's. Modern heavy rail transit provides advantages over early heavy rail rapid transit in terms of both operating speeds and environmental impacts.

Futuristic technologies still under development and not to be considered further under this study include automated guideway transit and dual-mode transit. These technologies will require extensive further research, experimentation, testing, and demonstration prior to their application in primary transit service. Automated guideway transit is a public transit mode in which the transit vehicles are automatically controlled and proceed from origin to destination without drivers. One type of automated guideway transit—known as personal rapid transit (PRT)—provides exclusive use of an automatically controlled vehicle for nonstop travel from origin to destination. Personal rapid transit appears to be capable of providing a primary transit service function only if fractional second headways can be maintained between the automatically controlled vehicles. The necessarily complex automatic control system needed to provide such headways has not yet been developed. There are presently no known PRT systems providing service to the public.

Another type of automated guideway transit is known as light guideway transit or group rapid transit. Light guideway transit vehicles operate singly or in small trains under automatic control over an exclusive guideway. Light guideway transit technology has been implemented in the United States not only for demonstration purposes, but also for the provision of transportation within major activity centers, including airports such as Dallas-Fort Worth, universities such as at Morgantown, West Virginia, and theme parks such as Walt Disney World. These applications, however, have demonstrated the need for further development of the technology if it is to be used to provide a primary level of urban transit service, since cost overruns and delays have occurred in nearly every case. Applications of this technology have never approached the needs of a primary transit system. Moreover, as in the case of the personal rapid transit application of automated guideway transit, shorter headways and higher speeds than those which have currently been tested or demonstrated would be necessary to permit the application of any form of group rapid transit in primary transit service.

Another technology considered to be still under development is dual-mode transit. In a dual-mode transit system, vehicles operate manually on conventional roadways, and in the automated mode on specially constructed guideways. Automatic control would be used only in major travel corridors and in central business districts where transit vehicles on existing streets in mixed traffic would be subject to severe traffic congestion. The advantage of the mode is that it would allow large capacities to be obtained in the corridors, a reduction in operator needs, and a convenient no-transfer and yet high-speed ride. None of the automated guideway concepts for dual-mode transit have been tested or demonstrated to date, making the practical use of this concept for primary transit service in the Milwaukee area unrealistic within the next 15 to 20 years. However, a demonstration project for the mode was proposed for the Milwaukee area in 1970 by a consortium consisting of Milwaukee County, the Allis-Chalmers Corporation, and the American Motors Corporation. Although the Milwaukee County Dual-Mode Systems Study presented a positive recommendation for this concept, implementation has not occurred. Of particular interest is the similarity of the automated guideway alignments to the corridors of major travel demand identified in this alternatives analysis.

The third category of transit technologies removed from further consideration under this study consists of those transit modes determined to be inappropriate because they have not yet proven their ability to perform in primary transit service, or because they cannot be considered to be in any way superior to proven existing primary transit technologies. Such modes include the existing forms of automated guideway transit. Automated guideway transit systems are considered unproven since operational systems are not yet available that can operate at short enough headways to meet primary transit needs.

Other inappropriate transit technologies include monorail systems, rubber-tired duorail systems, the railbus, and moving way transit systems. Monorail systems utilize a single rail for vehicle support as well as lateral guidance. Nearly all monorail systems presently constructed and operated are of an experimental nature. Those few systems that are used in daily public transit service, such as in Seattle, Washington, Tokyo, Japan, and Wuppertal, West Germany, are, for the most part, of short length. Monorails will not be further considered under this study because their technology and performance characteristics would be, at best, only similar to developed and proven heavy rail rapid transit and light rail transit technology but with several disadvantages. The major disadvantage of monorail systems is the elaborate and cumbersome switching mechanisms that would be necessary.

Also considered to be inappropriate primary transit technologies are rubber-tired duorail systems, such as those that are in service in Paris, Montreal, and Mexico City. Rubber-tired duorail transit is generally identical to heavy rail rapid transit except that propulsion and guidance is provided by rubber tires on a concrete guideway, although steel wheels and rails typical of modern heavy rail systems are also used in such systems for switching and for use in case of rubber-tire failure. The principal advantage of the rubber-tired rail system is that it can negotiate steeper grades than can modern heavy rail rapid transit systems. The disadvantages of this mode include higher construction and maintenance costs for the more complex guideways and vehicles.

Another type of technology considered inappropriate for transit service in the Milwaukee area is a variation of the dual-mode concept in which standard diesel motor buses are equipped with retractable steel wheels for operation on existing railway tracks. This technology was tested during the 1960's: however, the disadvantages that were discovered during the testing have not since been addressed. These disadvantages include the poor quality of ride and the lack of traction of the modified bus on the railway tracks. In addition, other problems such as the excessive interior noise which resulted from attempting to merge two different modes into one were never addressed.

The railbus—a vehicle which is essentially a motor bus body mounted on a two-axle railway carriage underframe—is also considered to be currently inappropriate for application in primary transit service. An Americanized version of a British railbus will be tested in the United States during 1980 and 1981 in order to assess the vehicle's operational characteristics. Problems related to this technology include numerous safety considerations and the need for a high level of track maintenance for an adequate quality of ride. In addition, railbuses cannot be trained together, thus severely restricting their passenger-carrying capacity.

Another transit technology considered inappropriate for primary transit service is moving way transit. One type of moving way transit system is termed the continuous carrier because it provides a continuously available surface such as a belt or disc upon which passengers may stand or walk. Such systems are not appropriate for primary transit service because they have not yet been developed to move at speeds necessary for primary transit. Discrete carrier moving way systems accommodate passengers in a cab or compartment traveling along a guideway, which could consist of a conventional ropeway or cableway. Moving way transit technology is considered inappropriate for primary transit service in the Milwaukee area because it provides neither the capacity or speed essential for the provision of primary transit service.

Chapter VI

SUMMARY

INTRODUCTION

A wide range of urban transit technologies exist, not all of which have potential for application in the provision of primary transit service in the Milwaukee area within the next two decades. The purpose of this technical report has been to identify those transit technologies which are applicable to meeting the primary transit needs of the Milwaukee area within the time frame specified, and to describe those characteristics of the applicable technologies pertinent to the design, testing, and evaluation of alternative primary transit systems for the Milwaukee area.

This chapter provides a summary and comparison of the design, performance, and cost characteristics of those technologies identified as applicable to the provision of primary transit service in the Milwaukee area. Set forth are the values of these characteristics to be used in the design, testing, and evaluation of alternative primary transit system plans for the Milwaukee area. This chapter is divided into six sections. The first section identifies and defines each of the primary transit technologies which are considered to be applicable to the Milwaukee area. Also identified and described are those technologies considered to be inapplicable, given the state-of-the-art of their development and the time horizon of the system plan. The second section discusses the physical characteristics of each applicable technology pertinent to systems planning, including such characteristics as the configuration and dimensions of the vehicles, the cross-sectional area and vertical and horizontal alignment requirements for associated guideways, and the spatial requirements of stations and support facilities. The third section discusses the performance characteristics of each applicable technology pertinent to systems planning, including speeds, headways, and capacities. The fourth section discusses pertinent economic characteristics, including capital and operating costs. Each section includes a concise comparison of the pertinent characteristics of each applicable technology, a comparison intended to help achieve a better understanding of the advantages and disadvantages of each technology. The fifth section of this chapter provides information on the energy efficiencies of the various primary transit modes. The sixth section consists of concluding remarks.

IDENTIFICATION AND DESCRIPTION OF APPLICABLE PRIMARY TRANSIT TECHNOLOGIES

Primary transit is defined as that component of the urban public transit system which provides relatively high-speed and high-capacity service in the most heavily traveled corridors of an urban area. The basic purpose of primary transit service is to facilitate intercommunity travel by providing a network of relatively high-speed and high-capacity facilities that link major regional activity centers to each other and to major concentrations of residential development. Primary transit, consequently, generally serves the longest transit trips of an urban region, and has the longest distances between stops of all of the various types of services provided by the entire public transit system.

Primary transit could be provided in the Milwaukee area by the proven and "readily available" technologies of commuter rail, heavy rail rapid transit, light rail transit, motor bus transit, and, with special design provisions, electric trolley bus transit. There are a number of additional transit technologies which, while conceptually having certain potential advantages over the proven and readily available technologies, cannot be expected to become practically available for the provision of primary transit service within the next two decades. These technologies, which must be termed futuristic, are in various stages of development and require extensive research, experimentation, testing, and demonstration prior to practical application in regular service. Included in this group are personal rapid transit and group rapid transit, referred to collectively as light guideway or automated guideway transit systems. Such systems would, in concept, provide for nonstop travel between trip origins and destinations for individuals or small groups of passengers over automatically controlled guideways at speeds and capacities required for primary transit service. Prior to practical application in primary transit service, significant advancement of this technology would be required in order to attain the requisite speeds and capacities. Automated guideway transit has been applied in the provision of special transit service in and around major activity centers; however, these applications have not proven the ability of such automated facilities to perform a primary transit function.

Another technology which still requires significant development is dual-mode transit. In a dual-mode transit system, vehicles operate under manual control in mixed traffic on conventional roadways, and as well as on specially constructed exclusive guideways in a completely automated mode. This highly sophisticated concept, although intensively studied for possible application on a demonstration and test basis in the Milwaukee area in 1970, has yet to be demonstrated and tested anywhere. A somewhat primitive variation of the dual-mode concept, but a technology which also must be considered as requiring further development, is the operation of standard motor buses with retractable steel wheels on existing railways. Performance and operational problems revealed in tests of this technology in the early 1960's have yet to be addressed.

Two other transit technologies—the intermediate-capacity transit system (ICTS) and the O-Bahn—which, while operational on test tracks, have yet to be demonstrated as practical in regular primary transit service. The ICTS is a modified form of light rail transit technology which, because of its smaller vehicle size and steerable wheel trucks, would purportedly not only reduce guideway development costs but permit the construction of less intrusive and disruptive elevated guideways than currently required for heavy rail systems. The O-Bahn would provide automatic steering for standard buses on exclusive guideways through the provision of steel guide rails on both sides of the guideway, and rubber rollers on guidance arms running along the guide rails and attached to the steering gear of the bus.

Other new and exotic forms of transit technology cannot reasonably be considered to be potential contenders for the provision of primary transit service in the Milwaukee area because demonstrations and application of these technologies to date have not established their superiority in any way over proven primary transit technologies. Such technologies include monorail technology and rubber-tired duorail technology. The performance of monorails must be considered inferior to that of proven heavy and light rail transit, while the performance of rubber-tired duorail systems must be considered, at best, similar to that of the proven rail systems. Both technologies, moreover, would require a higher cost than would proven rail technologies.

Moving way transit systems also cannot be considered as a primary transit technology alternative for the Milwaukee area, because these conveyor belt-type systems do not provide either the speed or capacity necessary for primary transit application. "Continuous carrier" moving way systems, or moving walkways, do not conceptually provide the necessary speed, while "discrete carrier" moving way systems, consisting of small cabs or compartments traveling on a beltway or cableway, do not conceptually provide the required capacity.

Table 86 indicates the potential for the future application in the Milwaukee area of the advanced technologies, should they, indeed, become operational in the distant future, by identifying those elements of the proven primary transit technologies which could accommodate or be adapted to the new technologies. Table 86 thus indicates which future technologies the application of a proven technology may be expected to foreclose, and thus provides a measure of the flexibility of a plan employing a particular proven technology.

Other transit technologies which cannot be considered to be reasonable alternatives for application in the Milwaukee area are those which are obsolete, including the street railway, the electric interurban railway, and the older forms of conventional heavy rail rapid transit technology. Light rail primary transit technology represents an evolution of street and electric interurban railway technology and is considered superior to both with respect to vehicle and guideway technology, and in terms of the degree of preferential treatment that can be provided in congested areas. Modern heavy rail rapid transit is similarly an evolutionary advancement of conventional heavy rail rapid transit in terms of vehicle and guideway technology and is considered superior to the older form in every way.

Motor Bus Primary Transit Technology

One of the three transit technologies considered suitable for primary transit application in the Milwaukee area over the next 15 to 20 years is the motor bus. However, to provide primary transit service it must be applied in one or more of the following four modes: in mixed traffic on freeways, over reserved lanes on freeways, over exclusive busways, or over reserved lanes on surface arterial streets. Motor buses are commonly used to

Table 86

DISTANT FUTURE APPLICABILITY OF NEW TRANSIT TECHNOLOGIES CONSIDERED TO BE PRESENTLY INAPPLICABLE FOR THE PROVISION OF PRIMARY TRANSIT SERVICE IN THE MILWAUKEE AREA

Presently Inapplicable Technology	Reason for Inapplicability	Element With Potential for Use in Application of Presently Inapplicable Technology										
		Motor Bus on Freeways	Motor Bus on Reserved Freeway Lanes	Exclusive Busways[a]		Arterial Express Lane Operation	Light Rail Transit[a]		Heavy Rail Rapid Transit	Commuter Rail	Electric Trolley Bus Technology[a]	
				Class A	Class B		Class A	Class B			Class A	Class B
Personal Rapid Transit . . .	1,2	E	E	A,B	E	E	A	E	A	E	A,B	E
Light Guideway Transit . .	1,3	E	E	A,B	E	E	A	E	A	E	A,B	E
Intermediate-Capacity Transit System.	2	E	E	A,B,C	E	E	A,B,D	E	A,B,C	E	A,B,C	E
Dual Mode	2	E	E	A,B,C	E	E	A,C	E	A	E	A,B,C	E
O-Bahn	2	D	D	A,B,C,D	D	D	A,C	E	A,C	E	A,B,C,D	D
Monorail	1,3,4	E	E	A,C	E	E	A,C	E	A,C	E	A,C	E
Rubber-Tired Duorail. . . .	4	E	E	A,B,C	E	E	A,C	E	A,C	E	A,C	E
Conventional Motor Bus With Railway Wheels . . .	2,3	D	D	A,B,C,D	A,B,C,D	D	A,B,C	A,B,C	A,B	A,B,C	A,B,D	A,B,C,D
Moving Way Transit.	1	E	E	A,C	E	E	A,C	E	A,C	E	A,C	E

Key to Reasons for Inapplicability

1. Present state of development provides insufficient capacity and/or speed for primary transit.
2. Not yet successfully demonstrated or applied as primary transit.
3. Technical problems determined in testing still exist and prevent application as primary transit.
4. Existing applications provide no evidence of any advantages over proven, existing primary transit technologies.

Key to Elements

A - Right-of-way
B - Guideway
C - Stations
D - Vehicles
E - None

[a] *For the purposes of this table, a Class A guideway has been defined to possess ideal horizontal and vertical alignment and full grade separation, while a Class B guideway has been defined to possess the minimum acceptable alignment which, in most cases, utilizes street rights-of-way and permits at-grade crossings.*

Source: SEWRPC.

provide primary transit service over existing freeways and arterial streets, and motor bus technology has important advantages over those rail transit technologies which require an exclusive guideway separated from all other traffic. Because they are capable of operating in mixed traffic over existing streets and highways, motor buses can be used in primary transit service to perform collection and distribution functions, thus offering the potential for a "one-seat, no-transfer" ride between a large number of trip origins and destinations.

Mixed Traffic Operation on Freeways: Bus operation in mixed traffic on freeways is defined as the operation of conventional, rubber-tired transit buses over freeway lanes that are open to other types of motor vehicle traffic. The collection and distribution portions of the trip may utilize surface streets and highways, and the transit vehicles may be provided with preferential access to the freeway network by the use of exclusive freeway entrance ramps. The freeway itself may be operationally controlled. Such operational control will constrain automobile access to the freeway system during peak traffic hours, ensuring high rates of traffic flow and reasonably high operating speeds. A typical operational control system may consist of interconnected demand-responsive ramp meters, priority access lanes for high-occupancy vehicles—including motor buses—at freeway entrance ramps, and improved driver information and incident management procedures. Without such a control system, operating speeds for transit vehicles will be limited by the traffic conditions on the freeway.

Of all of the bus transit modes of primary transit, operation in mixed traffic on freeways is the most widely used, becoming popular during the 1960's with the expansion of major freeway, expressway, and parkway systems. Application of this mode is almost entirely limited to direct nonstop peak-transit-period service between park-ride lots located adjacent to a freeway in and near outlying residential areas and the central business district. Because there is no need for major fixed facility construction, the implementation period for this type of service can be relatively short. Systems that provide preferential access for buses at freeway entrance ramp locations, however, are operated in only a small number of urban areas within the United States. Similarly, the application of metered freeway entrance ramps and the use of exclusive freeway ramps for transit vehicles is currently limited to a small number of urban areas.

This type of primary transit service is exemplified by the current "Freeway Flyer" service in the Milwaukee area. In 1980, the Milwaukee County Transit System operated 10 Freeway Flyer routes from 12 outlying park-ride lots to the Milwaukee central business district. In addition, four specialized express bus routes—known as UBUS routes—were operated along freeways to the University of Wisconsin-Milwaukee from various areas of Milwaukee County. There were also two locations at which special bypass lanes for buses were provided at metered freeway entrance ramps and two locations at which exclusive bus ramps leading onto the freeway system from park-ride lots were provided in the Milwaukee area.

Reserved Lane Operation on Freeways: On reserved lane bus systems, conventional motor buses are operated over normal flow or contraflow lanes reserved within the freeway rights-of-way for the exclusive operation of motor buses. This type of operation is utilized for the line-haul portion of the trip, while collection and distribution service is provided over surface streets. Vehicle operation on reserved lanes is generally nonstop, and is usually provided only during peak travel periods. Reserved bus lanes on freeways are a relatively recent development, being first implemented during the 1970's. Therefore, such facilities exist in only a few of the largest urban areas of the United States. Since existing facilities are utilized with little or no physical modification, initial capital costs and implementation time can be kept to a minimum with this mode.

The provision of a reserved lane for buses on an existing freeway can have significant negative impacts, since reserved lanes are logically implemented only on congested freeways, there being no operational advantage to reserving bus lanes on uncongested freeways. Reserving a freeway lane for exclusive bus use in the peak travel direction on a congested freeway—a normal flow reserved lane—can severely disrupt travel in the freeway corridor unless a significant proportion of the automobile traffic can be diverted to the improved bus service. Reserving a freeway lane for exclusive bus use in the nonpeak direction on a congested freeway—a contraflow reserved lane—may cause little disruption if peak-period traffic volumes are directionally unbalanced. However, this is not the case on any freeway in the Milwaukee area, and thus disruption of traffic may be expected. Any disruption caused by the provision of a contraflow lane is particularly critical because the affected automobile traffic is in the opposite direction of, and therefore is not served by, the improved bus service.

Designation of a reserved, normal flow freeway lane is usually accomplished by appropriate pavement markings or by the use of traffic cones, traffic posts, and traffic barriers positioned to separate one of the existing traffic lanes from the remaining freeway lanes open to all traffic. These reserved lanes are typically installed on the inside of the roadway, adjacent to the median area, so that conflicts with traffic movements to and from ramps are avoided.

Reserved contraflow freeway lanes are applicable where a relatively large directional imbalance exists between opposing traffic movements during peak travel periods. Because of the safety factor involved in the operation of opposing flows of traffic within the same roadway, more positive means of lane separation than signs and pavement markings must be employed, such as traffic cones or posts and barricades.

Operation on Exclusive Busways: Busways are special-purpose roadways designed for the exclusive use of motor buses for the purpose of improving vehicle movement and travel times. The facility may be constructed at, above, or below grade and may be located on a separate right-of-way or within an existing freeway or railway right-of-way. This method of separating motor bus traffic from other traffic is the most positive, permitting this mode to provide the highest quality primary transit service of all of the motor bus modes. In fact, very high operating speeds are attainable, equaling or exceeding those of rail systems. The implementation of exclusive busways involves major facility construction and, therefore, a longer time period for implementation compared with that required for implementation of the other bus transit modes, as well as community disruption. In addition, capital costs are high relative to those of the other bus modes, and may approach those of light rail transit. As in other modes of motor bus primary transit operation, the motor buses may leave the exclusive busway to provide collection and distribution service. Existing busways in the United States are generally oriented toward providing high-quality, peak-period service to or from central business districts. Busways may be constructed either with or without intermediate station facilities and access locations.

Although no exclusive busways currently exist in the Milwaukee area, the construction of a busway paralleling the East-West Freeway was recommended in the initial regional transportation system plan, adopted in 1966. Following completion of a preliminary engineering study, the Milwaukee County

Board of Supervisors refused to proceed with construction of the proposed busway, acting in 1973 to adopt the Milwaukee Area Transit Plan exclusive of the busway proposal.

Arterial Express Operation: On arterial express bus systems, conventional, rubber-tired transit buses are operated over arterial streets, and some form of preferential treatment over other traffic is provided the buses. Although a strict definition of the term "primary transit" would preclude consideration of arterial express bus systems as a form of primary service, a level of service and performance approaching that of primary transit can be provided by arterial express bus operation if a sufficient degree of preferential treatment is provided.

Priority treatment for buses operating in the arterial express bus mode can be provided by operation over reserved lanes on existing surface arterial streets; by preferential treatment at selected traffic signals; or, preferably, by both if service approaching primary transit service levels is to be provided. Reserved lanes on arterial streets can be operated either normal flow or contraflow, and can be located over curb or median lanes. An extension of the arterial reserved lane concept is the transit mall, or exclusive transit street. Transit malls are typically implemented only in major business and shopping areas and include the provision of ancillary pedestrian amenities.

Preferential treatment for motor buses at selected intersection locations is intended to reduce overall vehicle travel time. Methods of accomplishing preferential treatment include the provision of special traffic signal phases for transit movements, the phasing of traffic signal cycles to facilitate bus movements through a series of signalized intersections, and the modification of the green phase time, actuated by the presence of a bus at the intersection approach. Because extensive use is made of existing facilities, only minor capital outlays are required for the initiation of arterial express bus service. Also, implementation time as well as community disruption are minimal. Like reserved lanes on freeways, reserved lanes on arterial streets are typically in service only during weekday peak travel periods.

Rail Primary Transit Technology

The rail transit modes capable of primary transit application and performance include light rail transit, heavy rail rapid transit, and commuter rail. Because of the requirements for, and characteristics of, the rail transit guideway, each of the rail transit modes can be considered to be an individual "self-contained" system that basically performs only a line-haul and not a collector-distributor function. This fact, combined with the need to limit station stops to provide an efficient line-haul function, requires that "park-ride" as well as "feeder bus" opportunities be exploited for efficient access to rail transit modes.

Light Rail Transit: Light rail transit is the most flexible and adaptable of the rail transit modes. Its electric power supply is provided by an overhead wire system and its electrically propelled dual-rail vehicles can be operated singly or in trains. Because of its overhead power supply system, light rail transit does not need to be provided with a fully grade-separated right-of-way, but can be operated over reserved lanes on surface streets, in transit malls, and over surface streets in mixed traffic. Fare collection can be on board the vehicle or at a station. Access to vehicles may be from ground-level or high-level platforms. The mode is considered to be capable of providing a wide range of passenger capacities and performance characteristics at relatively moderate costs.

The light rail mode can serve a variety of public transit functions, but the most common is that of primary transit service in medium-sized metropolitan areas. Because light rail vehicles can operate over reserved lanes of surface streets as well as over fully grade-separated rights-of-way, a light rail transit system does not require the high capital costs entailed in providing a fully grade-separated guideway, such as that required for heavy rail rapid transit. Moreover, the criteria for horizontal and vertical alignment of the facilities are less restrictive than those for heavy rail transit.

Light rail transit systems can be readily developed on an incremental basis to meet the changing needs of an urban area as those needs develop and are recognized, or as resources become available. An idea popular in certain Western European countries, especially West Germany, is to ultimately develop a heavy rail rapid transit system by utilizing light rail transit in an incremental, evolutionary manner to minimize the immediate acquisition of right-of-way and construction of costly subway or elevated segments, and staging future upgrading and development as the need develops.

Initially developed during the 1960's, light rail evolved into a separate mode as many street railway systems in Western Europe were upgraded to light rail standards and methods of operation.

During the 1970's, active interest in the mode gained momentum as urban areas outside Europe—including in the United States—started projects to either upgrade remaining street railway systems or construct new light rail systems. It is important to recognize that although some light rail components resemble those of street railways, the level of service provided more closely approximates that of heavy rail rapid transit because of the high degree of priority movement provided over other traffic in congested areas. Accordingly, light rail's inherent performance characteristics distinguish it as a unique and separate rail transit mode.

Heavy Rail Rapid Transit: Heavy rail rapid transit consists of dual-rail vehicles propelled by electricity transmitted through a side-running third rail. Heavy rail vehicles can thus operate only over an exclusive, fully grade-separated right-of-way. Heavy rail vehicles are generally coupled into trains and require high-level loading, with fare collection generally performed only at stations. Semi-automated train operation is commonplace in modern heavy rail systems.

The principal function of this mode is to provide high-capacity primary transit service in the most heavily traveled corridors. Because of its exclusive, fully grade-separated right-of-way, heavy rail rapid transit is capable of high operating and average speeds. Heavy rail rapid transit systems normally exist only in the largest urban areas, and are generally radial in configuration. Conventional heavy rail transit systems were constructed in the United States from the 1890's through the 1920's. After a two-decade suspension in construction, interest in such facilities increased sharply during the 1970's. Contemporary system start-ups exhibit an advanced level of automated train control and follow standard mainline railway practices far less than do older, conventional systems. Heavy rail transit is generally the most capital-intensive primary transit mode, requiring a major investment to produce a usable segment. The development of heavy rail rapid transit systems requires a lengthy implementation period. This is particularly true of systems with significant subway segments. Normally related to heavy rail construction are severe community disruption and long periods of negative impacts.

Commuter Rail: Commuter rail is characterized by relatively large peak-hour volumes, long average trip lengths, and long distances between stations. Commuter trains share mainline railway trackage with freight and interregional passenger train traffic, the common practice in the United States being the use of diesel-electric locomotives and coaches as opposed to electrified multiple-unit equipment. Rolling stock is manufactured to mainline railway standards with respect to suspension, size and strength, and seating arrangements. This, together with relatively long station spacings, characterizes the mode as providing a very high level of riding comfort.

This mode is the oldest of all the rail transit modes, but presently exists only where there are substantial concentrations of passenger trip origins in outlying suburban areas having destinations in the central business district. Because of this basic traffic requirement, commuter rail systems are found only in 10 cities within the United States and Canada. Only one of these systems has been instituted in recent years, and that was built as a replacement for an existing commuter rail service.

Commuter rail utilizes standard railway rights-of-way and track. Because the track is shared with interregional railway freight and passenger traffic, the mode does not require the construction of a new guideway system, resulting in capital and operating cost savings. Implementation of new routes or extensions of existing routes is generally confined to existing railway roadbeds, structures, and rights-of-ways, although rehabilitation of such fixed way facilities may be required prior to initiation of service. Thus, much of the potentially expensive right-of-way and fixed plant required to provide commuter rail service is in place.

Electric Trolley Bus Primary Transit Technology
In order to be considered as providing a primary level of transit, electric trolley buses must operate in an arterial express mode with substantial preferential treatment, or over an exclusive busway. The electric trolley bus today generally operates in mixed traffic over existing surface arterial streets and highways, providing a tertiary level of service. The vehicles are propelled by electric motors which receive power through power collection poles attached to the vehicle roof which slide along a pair of overhead contact wires. Because the vehicles require an overhead power distribution system, deviation from established transit routes cannot occur unless specially designed vehicles are used, although the mode does not require a special guideway as do the rail transit modes. Generally passengers board and alight at typical street corner bus stops, and the fare collection procedures are the

same as those used in most motor bus modes. Support requirements are also similar except for the need for the overhead power distribution system.

By a strict definition of the term "primary transit" the electric trolley bus mode is not suitable to the provision of a primary level of service. The typical electric trolley bus system has significant performance limitations imposed by its overhead power system. However, with special design provisions for the vehicles and overhead power system, this mode has the potential to provide a high-quality, line-haul service approaching that provided by light rail transit systems and equaling that provided by motor bus systems.

Summary of Applicable Primary Transit Technologies

Table 87 provides a summary of the requirements and typical characteristics of the primary transit technologies and modes identified as applicable in the Milwaukee area over the next two decades. The data provided on each of the technologies and modes are necessarily limited to the present "state-of-the-art"—that is, to the characteristics of recently constructed, improved, or expanded primary transit systems in the Milwaukee area or in other urban areas. Excluded are the characteristics of systems constructed to obsolete or outmoded standards as well as the characteristics of unproven technologies still in experimental stages of development. It is apparent that the applicable urban primary transit technologies provide a wide range of physical, operational, and economic options for the provision of primary transit service in the Milwaukee area.

PHYSICAL CHARACTERISTICS

Definitive information on the physical characteristics of the primary transit technologies is essential to an understanding of the developmental requirements of the technologies and of their potential performance and costs. This information must include pertinent data on the physical characteristics of the vehicles, guideways, stations, and support facilities. Pertinent physical characteristics of the vehicles include dimensions, weight, capacity, maximum speed, acceleration and deceleration rates, energy requirements, and means of passenger access. Pertinent physical characteristics of the guideways include dimensions, vertical and horizontal alignment and clearance requirements, signalization and other traffic control requirements, means of interface with other modes, and route flexibility. Pertinent physical characteristics of stations include dimensions, spacing, capacity, fare collection, and interface with other modes. Pertinent physical characteristics of support facilities include vehicle storage and maintenance requirements, guideway and station maintenance requirements, and power supply requirements.

Vehicle Technology

Motor Bus Primary Transit: Motor buses may be classified into three general categories: compact vehicles, conventional vehicles, and high-capacity vehicles. Only conventional and high-capacity vehicles are suitable for use in primary transit service. The need to minimize operating costs per passenger and to serve highly concentrated travel demands precludes the potential use of the low-capacity, compact buses in primary transit service in large urban areas.

The conventional, urban transit motor bus is by far the most common vehicle configuration utilized for primary transit service within the United States and Canada. The conventional bus has a single-unit body with an overall length of 35 to 40 feet. Recently, however, interest in the use of high-capacity buses has increased in North America. Such buses have been widely used in Europe because of their potential, especially in heavily used primary transit service, to reduce operating costs per passenger.

High-capacity vehicles are available in one of two configurations: articulated vehicles or double-deck vehicles. Articulated buses are extra-length vehicles—typically 55 to 60 feet in length—that "bend" in the middle in order to negotiate curves. This allows the articulated bus to have a minimum horizontal turning radius equal to that of a standard bus. Many of the characteristics of articulated buses are similar to those of conventional buses, although the range in seating capacity on the articulated bus of 67 to 77 passengers is 25 to 50 percent greater than that on the conventional bus. The top speed of the articulated bus is about 55 miles per hour (mph), which is similar to that of conventional buses. Its acceleration rate is 2.0 miles per hour per second, only 20 percent less than that of a standard bus, and its deceleration rate of 2.5 miles per hour per second is the same as that of a standard bus. Both conventional and high-capacity motor buses incorporate low-level loading of passengers, generally at curbside. Also, both types of vehicles utilize propulsion systems which employ a diesel prime mover with petroleum-based fuel.

Table 87

CHARACTERISTICS OF PRIMARY TRANSIT MODES

Element	Motor Bus on Freeways	Motor Bus on Reserved Freeway Lanes	Busways	Arterial Express Lane Operation	Light Rail Transit	Heavy Rail Rapid Transit	Commuter Rail	Electric Trolley Bus
Guideways								
New or Existing	Existing	Existing	New	Existing	New	New	Existing	Existing or new
Right-of-Way	Shared	Reserved	Reserved or exclusive	Reserved	Reserved or exclusive (may even be shared in uncongested areas)	Exclusive	Exclusive (however, shared with freight and intercity passenger traffic)	Reserved or exclusive
Surface Alignment	Depends upon existing freeway facilities	Depends upon existing freeway facilities	Most common	Depends upon existing arterial street facilities	Most common	Common	Depends upon existing railway facilities	Common
Aerial Alignment			Possible		Possible	Common		Possible
Subway Alignment			Possible		Possible	Common		Possible
Grade Crossings	None	None	May be accommodated	Frequent	May be accommodated	None	Common	May be accommodated
Construction Disruption . .	Minor	Minor	Major	Minor	Minor-Major	Major	Minor	Minor
Vehicles								
Configuration	Conventional, articulated, or double deck				Single unit to double articulated	Permanently coupled pairs	Single- or double-level coaches	Conventional or articulated
Length (feet)	35-60	35-60	35-60	35-60	44-91	65-75	85	40-55
Train Length	Single unit	Single unit	Single unit	Single unit	1 to 4 vehicles	1 to 10 vehicles	Locomotive plus 1 to 6 coaches (typical)	Single unit
Propulsion	Diesel	Diesel	Diesel	Diesel	Electricity	Electricity	Diesel or electricity	Electricity
Weight (tons)	10-18	10-18	10-18	10-18	16-43	26-40	37-54	11-17
Seating Capacity	47-84	47-84	47-84	47-84	42-84	58-80	88-162	29-73
Total Capacity	72-107	72-107	72-107	72-107	100-251	170-273	172-438	75-184
Stations								
Extent of Facility	Minimal	Minimal	Simple or elaborate	Minimal	Simple or elaborate	Elaborate	Simple	Minimal
Platform Height	Low level	Low level	Low level	Low level	Low or high level	High level	Low or high level	Low level
Actual Spacing	0.5-3.7 miles, or nonstop			0.2-0.5 mile or nonstop	0.2-0.5 mile	0.3-1.2 miles	0.7-2.8 miles	0.2-0.5 mile
Attendants	Not required	Not required	Optional	Not required	Optional	Necessary	Optional	Not required
Support Facilities								
Vehicle Storage	Inside	Inside	Inside	Inside	Outside	Outside	Outside	Outside
Vehicle Maintenance	Addition necessary to existing bus facilities				Separate facilities required		Contract with railway	Separate facilities required
Guideway Maintenance . . .	Minimal	Minimal	Significant	Minimal	Extensive	Extensive	Significant	Minimal
Traffic Control	Minimal	Simple	Minimal	Simple	Simple	Sophisticated	Standard	Minimal
Fare Collection	On board	On board	On board or at station	On board	On board or at station	At station	Through ticket sales	On board
Power Distribution	On board	On board	On board	On board	Overhead wire	Third rail	Locomotive hauled	Overhead dual wires

Source: SEWRPC.

The other high-capacity bus configuration, the double-deck motor bus, has been popular in Great Britain and in countries with historic British links since its inception. This type of configuration has recently been demonstrated in New York City and Los Angeles on a limited basis. Double-deck motor buses have a smaller total capacity than do current production articulated vehicles. Other disadvantages of double-deck buses in comparison with articulated vehicles are that they have more limited interior clearances; they require a stairway location near the doorway, which poses potential internal traffic flow problems; and there are no production models currently being manufactured within the United States. Therefore, the double-deck bus configuration will not be considered further within this study.

During the late 1960's, the federal Urban Mass Transportation Administration (UMTA) began development of a new urban transit bus which was intended to serve as an eventual replacement for the buses then in service within the United States—buses which had had no major design changes since 1959. This new bus, the Transbus, was to incorporate improvements to permit improved passenger comfort and quality of ride, reduced maintenance costs, and better accessibility for the elderly and handicapped. Manufacturers claimed difficulty in designing and building such a bus within the requirements set forth by the UMTA which, in turn, prevented bids for such vehicles from being procured. Subsequently, the U. S. Department of Transportation in August 1979 announced a temporary delay in the effective date of its requirements for procurement of the Transbus. In the interim, currently available buses may be purchased provided they meet established federal requirements, including the installation of wheelchair lifts. The applicability of the Transbus specifications to contemporary and future motor bus design is uncertain at this time. It therefore appears that the current conventional and articulated models equipped with wheelchair lifts offered by manufacturers may be acquired with federal support for use in primary transit service for at least the near-term future.

Rail Primary Transit: The vehicles for rail transit technology are specially designed and constructed for each rail mode—light rail transit, heavy rail rapid transit, and commuter rail.

Contemporary light rail vehicles are typically designed in either nonarticulated, single-articulated, or double-articulated configurations. Articulation allows extra-length vehicles to "bend" on joints supported by a two-axle truck when traversing curved trackage. Such design provides increased passenger capacity, yet retention of a narrow vehicle profile on curves. The seating capacity of articulated vehicles ranges between 46 and 84 passengers, or 10 to 100 percent more seats than can be accommodated by nonarticulated vehicles. The total capacity of articulated vehicles, which includes standees, ranges between 160 and 250 passengers, or 20 to 150 percent more capacity than that offered by nonarticulated vehicles. Vehicle propulsion for all types of light rail vehicles is typically provided by 600- to 650-volt direct-current electric motors, the power being collected by a panograph on the vehicle roof from an overhead wire system.

Light rail vehicles are generally the smallest as well as the lightest weight of all rail transit vehicles, varying from 50 to 53 feet in length for nonarticulated vehicles to 71 to 88 feet in length for single-articulated vehicles. In addition, light rail vehicles have the highest acceleration and deceleration rates. There is little difference in the acceleration and deceleration rates of articulated and nonarticulated light rail vehicles, nor is there much difference in the top speeds of such vehicles. These high rates of acceleration and deceleration are important because, of all the rail modes, light rail transit has the shortest station spacings and, because it permits operation in mixed traffic on surface streets, requires short stopping distances for safety. Advantages of light rail vehicles include a bidirectional operational capability, important to operational flexibility, and a multiple-unit operational capability, which allows trains of up to four vehicles to be assembled and controlled by one operator. The flexibility of light rail transit also allows for either low-level or high-level boarding at stations.

The most popular vehicle configuration for new light rail systems either recently opened or under construction in North America appears to be the single-articulated vehicle supported by three two-axle trucks. This configuration allows greater passenger capacity, yet retains the ability to negotiate sharp curves while not significantly reducing acceleration and deceleration rates and maximum speed. Within North America, nonarticulated vehicles appear to be purchased chiefly as replacements for nonarticulated streetcars on transit routes which are operated almost completely in mixed traffic. Double-articulated light rail vehicles have less impressive performance characteristics than do single-articulated vehicles because of their additional body weight and unpowered trucks. Thus, double-articulated vehicles are generally used only in Europe where light rail systems have been developed from existing street railways with narrow side clearances and narrow-gauge track.

The typical heavy rail rapid transit vehicle is a single, nonarticulated vehicle supported by two, two-axle trucks. The vehicle is usually capable only of single-direction operation with a control cab at one end. On most heavy rail systems, two vehicles are semi-permanently coupled into "married" pairs. Trains of up to 10 cars, or five married pairs, can be operated. Modern heavy rail rapid transit vehicles are typically propelled by 600- to 1,000-volt direct-current electric motors. The current is transmitted to the electric traction motors in the vehicles via an energized, side-mounted third rail, which necessitates complete grade separation of heavy rail rapid transit systems. High-level platforms are employed for loading and unloading at stations.

Existing commuter rail rolling stock can be classified into two physical configurations based upon the form of propulsion: electrified multiple-unit equipment and unpowered passenger coaches generally pulled by diesel-electric powered locomotives. The construction of a new electrified commuter operation entails a very high initial investment because of the electric power distribution system required. As a consequence, corridors of very high travel demand are required to support electrified commuter rail service. Moreover, the characteristics of the power distribution system are such as to preclude a gradual, economical phasing in of the service, as would be possible with a diesel operation. For this reason, electrified commuter rail will not be considered further within this study.

Contemporary diesel-powered commuter train operations are characterized by the use of bidirectional trains of locomotive-hauled coaches. Where vertical clearances permit, coaches are designed with two levels to significantly increase vehicle capacity. Since commuter rail operates on common-carrier freight and interregional passenger railway trackage, the rolling stock is constructed to mainline railway standards, thus making commuter rail vehicles the largest and heaviest of all rail transit vehicles. Typical trains may be up to six coaches in length, and loading is from a low- or high-level platform.

In circumstances where the required capacity is low and necessary train lengths accordingly short, self-propelled coaches have proven to be popular. Self-propelled vehicles have a seating capacity similar to that of typical, single-level intercity railway passenger coaches but also have control cabs at each end and diesel engine propulsion equipment mounted below the floor. Commuter rail operators maintain that self-propelled coaches are best applied only in the lightest traffic operations—operations in which only short trains are required. The training of more than two or three such units is generally not considered to be as cost-effective as the use of locomotive-hauled trains in situations where appreciable ridership is anticipated. For this reason, commuter rail rolling stock will be assumed for the purposes of this analysis to be provided using trains of bi-level coaches propelled by diesel-electric locomotives. This assumption would not preclude the use of self-propelled equipment in initial operations should the use of such equipment be found to be advantageous.

Electric Trolley Bus Primary Transit: There are two basic types of electric trolley bus vehicles: non-articulated vehicles and articulated vehicles. Non-articulated vehicles are typically 40 feet in length and are the only configuration presently used within the United States. Articulated electric trolley buses would offer the same capacity and economic advantages of diesel-powered articulated motor buses. Vehicle propulsion is provided by 600- to 650-volt direct-current electric motors, the power being collected by two roof-mounted trolley poles from a dual-wire overhead power distribution system. The loading of the vehicles is low level, generally at curbside. While it is generally held that the acceleration characteristics of electric trolley bus vehicles are superior to those of diesel- or gasoline-powered buses, improved diesel bus performance achieved during the 1970's makes the overall performance of the two types of vehicles quite similar. In fact, many transit operators who use both types of vehicles in local and express service contend that they have identical performance characteristics and can be used interchangeably in daily operation.

Generally, the electric trolley bus mode is applicable only in the provision of tertiary and secondary levels of service. The mode can, however, provide high-quality, line-haul service—similar to that of diesel motor buses—over either reserved lanes on surface arterial streets or exclusive guideways if special provision is made in the design of the vehicles and overhead power distribution system. Therefore, the electric trolley bus mode will be considered as may be necessary following full development of the motor bus alternatives, and as a special alternative to the diesel motor bus.

Summary: A wide variety of transit vehicles applicable to each of the various primary transit modes are available from domestic and foreign manufacturers. Table 88 presents those characteristics of the vehicles that are available for each mode that are considered to be particularly important to the primary transit alternatives analysis. It is evident from Table 88 that rail transit vehicles can offer the highest level of performance in primary transit service, as evidenced by the large vehicle capacities and greater acceleration and deceleration rates over those of motor buses. Whether these characteristics will be necessary to provide an adequate level of primary transit service in the Milwaukee area can be determined only through the design and testing of alternative system plans within the context of probable future as well as existing area travel needs. Of all the modes, light rail transit offers the widest variety of vehicle characteristics because of its

Table 88

CHARACTERISTICS OF PRIMARY TRANSIT VEHICLES

Characteristic	Conventional Motor Bus	Articulated Motor Bus	Nonarticulated Light Rail Vehicle	Single Articulated Light Rail Vehicle	Heavy Rail Rapid Transit Vehicle	Commuter Rail Coach	Self-Propelled Commuter Rail Coach	Conventional Electric Trolley Bus	Articulated Electric Trolley Bus
Length (feet)	36-40	55-60	50-53	71-88	65-75	85	85	36-40	54-59
Width	96-102 inches	98-102 inches	8.5 feet	7-9 feet	9.2-10.5 feet	9.8-10.6 feet	10.5 feet	98-102 inches	98 inches
Height	118-122 inches	119-124 inches	10.8-11.0 feet	9.75-11.5 feet	10.5-12.3 feet	12.7-15.9 feet	14.3 feet	115-136 inches	115-136 inches
Net Weight (tons)	10-12	13-18	26	22-43	26-40	37-54	64	11-13	13-17
Minimum Horizontal Turning Radius (feet)	44	40-44	36-60	42-100	120-400	N/A	N/A	34-42	34
Propulsion	6 or 8 cylinder diesel	6 or 8 cylinder diesel	600-650 volts D.C.	600-650 volts D.C.	600-1,000 volts D.C.	Diesel locomotive	Diesel locomotive	600 volts D.C.	600 volts D.C.
Acceleration Rate (miles per hour per second)	2.5	2.0	1.8-4.3	1.8-3.6	2.5-3.0	Depends on locomotive	0.5	3.5-4.0	3.5-4.0
Deceleration Rate (miles per hour per second)	2.5	2.5	1.8-4.3	2.2-3.8	2.7-3.0	Depends on locomotive	3.0	3.5	3.5
Maximum Speed (mph)	44-70	55	50	50-60	65-80	Depends on locomotive	80	37-51	37-44
Maximum Grade (percent)	N/A	N/A	8	4-9	3-4	N/A	N/A	N/A	N/A
Passenger Access (number of doors)	2-3 one side	2-4 one side	2 one side	3-4 each side	2-4 each side	1-2 each side	2 each side	2-3 one side	2-4 one side
Seating Capacity	47-53	67-72	42-50	58-84	58-80	104-162	88	29-53	31-67
Total Capacity	72-82	107-180	100-130	147-270	170-300	187-438	172	69-107	107-180

NOTE: N/A indicates data not available.

Source: Manufacturers, Operators, and SEWRPC.

flexibility. The electric trolley bus characteristics are very similar to those of motor buses, which is to be expected since the same vehicle bodies are generally used for both types of vehicles.

With such a large variety of primary transit vehicles available and in use, it is important for the systems analysis to select specific vehicles applicable for use in each of the primary transit modes—vehicles which best typify the state-of-the-art for each vehicle type. The specific characteristics of these selected vehicles can then be utilized in the testing and evaluation of alternative primary transit system plans. The individual vehicles that have been selected, along with the characteristics considered pertinent to systems planning, are shown in Table 89. The selection of specific vehicles is based upon how well each represents the characteristics of the state-of-the-art for each transit mode; the passenger-carrying capacity of the various vehicles, from which the operating costs per passenger mile can be determined; and whether or not the vehicles are presently manufactured within the United States.

Guideway Technology

Primary transit modes which incorporate motor bus technology employ the basic guidance principle of rubber-tired vehicles operating over roadway pavements, while primary transit modes which incorporate rail transit technology employ the principle of flanged steel-wheel vehicles operating on a track structure consisting of steel rails attached to a roadbed surface. Insofar as guideways are concerned, the electric trolley bus mode utilizes the same type of guideways utilized by the motor bus modes. The basic difference between the guideway technologies employed by the various modes to be considered within this alternatives analysis is important because it determines the nature of fixed facilities, as well as the magnitude of the capital costs required to implement one or more of the modes. Three of the four motor bus modes identified in this study, along with the electric trolley bus mode, are able to operate on existing public street and highway facilities, thus precluding the need for a large capital investment in fixed guideways. The motor bus-on-busway mode requires fixed guideway for operation in the line-haul service, although

Table 89

CHARACTERISTICS OF PRIMARY TRANSIT VEHICLES SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Characteristic	Conventional Motor Bus	High-Capacity Motor Bus	Light Rail Vehicle	Heavy Rail Rapid Transit Vehicle	Diesel Locomotive	Commuter Rail Coach	Electric Trolley Bus
Configuration	Single unit	Articulated	Articulated	Married pairs	Single locomotive	Bi-level gallery coach	Articulated
Length (feet)	40.0	59.8	71.0	75.0	56.2	85.0	55.0
Width	102 inches	102 inches	8.8 feet	10.2 feet	10.7 feet	10.6 feet	98 inches
Height	120 inches	119 inches	11.5 feet	11.8 feet	15.4 feet	15.9 feet	125 inches
Net Weight (tons)	12	18	33	36	130	52	14
Number of Axles	2	3	6	4	4	4	3
Acceleration Rate (miles per hour per second)	2.5	2.0	2.8	3.0	N/A	Not applicable	3.5
Deceleration Rate (miles per hour per second)	2.5	2.5	3.5	3.0	N/A	Not applicable	3.5
Maximum Speed (mph)	55	55	50	70	65	Not applicable	37
Passenger Access (number of doors)	2 one side	2 one side	3 each side	3 each side	Not applicable	1 each side	2 one side
Seating Capacity	48	67	68	74	Not applicable	157	67
Total Design Capacity	72	107	147	222	Not applicable	187	107

NOTE: N/A indicates data not available.

Source: Manufacturers, Operators, and SEWRPC.

the transit buses used can also operate on public streets and highways. Two of the three rail transit modes require extensive fixed guideway construction prior to system start-up. Commuter rail is the one rail transit mode which would not require extensive guideway construction since existing railway rights-of-way and trackage are utilized. It must be recognized, however, that primary transit modes which do employ fixed guideways generally are able to provide a higher level of service and to transport larger numbers of people per hour than can primary transit modes which operate without the benefit of fixed guideways.

Motor Bus Primary Transit: Primary transit bus operation over freeways in mixed traffic, over reserved freeway lanes, and over reserved arterial street lanes all usually utilize roadway facilities that are already in place, the design and construction of which generally conform to the widely accepted engineering standards prescribed by the American Association of State Highway and Transportation Officials (AASHTO). Engineering standards for service segments of primary transit motor bus systems that do require new guideway construction are identical to those for normal heavy-duty highways designed for heavy volumes of high-speed mixed traffic. It is not the intent of this report to describe the geometric or structural design characteristics of arterial streets and highways that may be used for primary transit service, but rather to point out important considerations concerning the use of such facilities as well as modifications of such facilities that may be necessary to provide the different modes of motor bus primary transit service.

Motor Bus on Freeways: The operation of motor buses in mixed traffic over freeways usually requires few or no guideway-related additions or modifications to the existing freeway facilities. The one type of guideway component that may be necessary, however, is bypass lanes for transit vehicles at metered freeway entrance ramps or entrance ramps for the exclusive use of buses. Such exclusive bus lanes should be a minimum of 12 feet wide with appropriate shoulders, while the design of any new entrance ramps should comply with accepted freeway ramp design standards.

The implementation of reserved freeway lanes for motor bus operation also involves a minimum amount of physical construction or reconstruction. The separation of normal flow reserved lanes is usually accomplished by the temporary placement of traffic cones and barricades or flexible traffic posts between the reserved and mixed traffic lanes, or by delineation with pavement markings and striping. The separation of a contraflow lane from the remaining mixed traffic lanes is usually accomplished in the same manner except that some sort of physical separation such as posts or cones is considered essential because of the opposing directions of the adjacent traffic streams. While the daily installation and removal of cones, barricades, posts, and signs may represent a significant operating cost attendant to a particular reserved lane facility, these devices permit entrance through the lane at only one point and are thus self-enforcing. Contraflow lane operations also require a special transitional lane to allow the motor buses to cross the median area and enter the reserved lane.

The only bus-on-freeway technology to be considered further in this study for the provision of primary transit service is the bus-on-operationally controlled or ramp-metered freeway mode. Motor bus operation on freeways in mixed traffic was eliminated from further consideration principally because a freeway operational control system is already partially in place and working in the Milwaukee area. To plan further for the operation of buses in mixed traffic without operational control would require an assumption that the existing freeway operational control system would be dismantled. The installation of additional ramp meters and the interconnection of all of the meters through a central operational control unit are also recommended in the adopted regional transportation system plan, and these recommendations are programmed for implementation in the near future.[1] Moreover, it must be recognized that one of the purposes of considering the bus-on-freeway transit alternative in this study is to use that alternative as a basis for the comparative evaluation of more capital-intensive primary transit alternatives such as exclusive busways and light and heavy rail rapid transit. Motor buses operating over operationally controlled freeways should present a more attractive low-capital investment alternative for this purpose than buses operating on potentially congested freeways in mixed traffic, and thus this mode provides a better basis for the comparative evaluation.

For the same basic reasons, bus operation over reserved freeway lanes was eliminated from further consideration. Motor buses operating over operationally controlled freeways can provide the benefits of reserved lane freeway systems, including preferential vehicle access and higher operating speeds for buses, at relatively low cost. Four additional considerations support the superiority of the bus-on-operationally controlled freeway mode over the bus on reserved freeway lane mode. First, the benefits of preferential treatment and higher

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[1] *The adopted 1978 transportation systems management plan for the Milwaukee area, as documented in SEWRPC Community Assistance Planning Report No. 21, A Transportation Systems Management Plan for the Kenosha, Milwaukee, and Racine Urbanized Areas in Southeastern Wisconsin: 1978, recommended that, as a condition of the inclusion in the annual transportation improvement program for the Milwaukee area of additional freeway ramp meters, a prospectus for a preliminary engineering study of an areawide freeway traffic management system be prepared. The study itself was to provide recommendations concerning the extent of a freeway ramp-meter system and related preferential treatments for motor buses at freeway entrance ramps in the greater Milwaukee area; the speeds and volumes to which the area freeway system should be controlled; and, importantly, the degree of metering which should be achieved at each on-ramp to achieve those freeway speeds and volumes. The study was to address the potential costs and benefits of freeway traffic management, including resultant freeway and surface arterial street congestion and travel speeds, freeway entrance ramp queues and impacts of such queues on connecting surface arterial streets, and the costs and equity of freeway traffic management. On March 26, 1979, the requested prospectus was unanimously approved by a steering committee created by the Commission to assist the Commission staff in the preparation of the prospectus, and by the Commission itself on June 7, 1979. The necessary funds to conduct the study could not, however, be obtained. As a consequence, the Intergovernmental Coordinating and Advisory Committee on Transportation System Planning and Programming for the Milwaukee Urbanized Area decided to continue the incremental implementation of a freeway traffic management system in the Milwaukee area through its consideration of individual freeway traffic management projects in its annual review of the transportation improvement program for the Milwaukee area.*

speeds for buses can be achieved without restricting freeway capacity for automobile travel as would be required with reserved freeway lanes. Second, the restriction on freeway access imposed by the freeway operational control system would affect travel in the same direction in which the improved bus service is provided, therefore helping to divert trips to the primary motor bus service. Third, while the freeway operational control system can be applied at low cost over the entire area freeway system, reserved bus lanes cannot be applied systemwide because of the design of the freeway-to-freeway interchanges and left-hand entrance and exit ramps of the Milwaukee area freeway system. Overcoming these limitations would entail significant capital construction costs. The segments of the Milwaukee area freeway system which do not permit the low-cost development of reserved lanes include much of the East-West Freeway in Milwaukee County, portions of the Zoo and Airport Freeways, and that portion of the North-South Freeway near its interchange with the East-West Freeway in Milwaukee County. These segments of freeway, however, may be expected to be the most heavily congested freeways in the future and are, therefore, also the most needed for the location of a reserved lane operation. Fourth, a freeway operational control system has a distinct safety advantage over contraflow reserved lanes in that it does not require vehicles to operate in opposing directions at high speeds with little or no physical separation between the traffic streams.

Motor Bus on Busways: Motor bus on busway is the only motor bus mode which requires a fixed guideway to be constructed prior to initiation of service. Busways may be classified as Class A or Class B busways, depending upon the anticipated overall level of service desired. Class A busways provide for high-speed, high-capacity, rapid transit service similar to that provided by the heavy rail rapid transit mode. Being fully grade-separated, Class A busways are generally applicable in major travel corridors of large urbanized areas where primary transit vehicles must operate nonstop over relatively long distances. Class B busways provide for a somewhat lower quality of service, similar to that provided by the light rail transit mode. Class B busways serve somewhat shorter distance trips and operate at lower overall speeds than do Class A busways. Station frequency is usually greater along Class B busways, and at-grade crossings with arterial streets may be incorporated to assist in minimizing capital costs. Considerations in the design of busways include appropriate transitional lanes for any necessary connections to freeways and appropriate intersections for connection to surface arterial streets. In some instances, ridership forecasts may indicate the potential for future conversion of a busway into a rail transit guideway. In such cases, the right-of-way cross-section and alignment should be designed so that minimal changes are required for conversion to the selected rail transit mode.

Special consideration is required for exclusive busway segments that are to be located in tunnels or subways of greater length than about 1,500 feet. Because of the need for adequate ventilation to control vehicle exhaust fumes, construction costs for underground busways can be expected to be 20 to 30 percent greater for diesel bus operation than for comparable electric vehicle operation. Underground stations along busways will also require special design consideration in order to minimize air pollution in passenger waiting areas. For these reasons, and because the motor bus can operate in mixed traffic over surface streets in congested areas or can utilize a Class B busway design—therefore, not absolutely requiring an exclusive, grade-separated right-of-way—motor bus subways will not be further considered within this study.

Motor Bus on Reserved Street Lanes: Primary transit arterial express bus systems utilize existing street facilities but require preferential treatment over other traffic. If a primary transit function is to be provided, necessary preferential treatment takes the form of reserved lanes, which can be implemented in a variety of ways. Normal flow lanes located adjacent to curbs should be at least 10 feet wide, while contraflow curve lanes should be at least 12 feet wide. Reserved lanes located adjacent to the centerline or in the center of the roadway should be at least 10 feet wide for one-way operation, and 20 to 22 feet wide for two-way operation. Reserved lanes on arterial streets may, in effect, constitute a Class B busway. Appropriate transition lanes to and from the reserved transit lanes are necessary and should include proper lane channelization, pavement markings, striping, and appropriate signing.

A Class B busway, or an arterial express bus operation on reserved surface street lanes, would provide a level of service similar to that of light rail transit operating over reserved lanes or in the median area of a surface arterial street. Because of these inherent similarities, arterial express bus systems could be expected to have the same route configuration and alignments as will any Class B busways to be tested under the study. It seems reasonable, therefore, to combine these two modes for system planning purposes and to consider them together under the motor bus-on-busway alternative.

Rail Primary Transit: The individual rail transit modes utilize somewhat different types of guideway technology. Nevertheless, all three rail technologies utilize the basic guidance principle of the flanged steel wheel on the steel rail, and have common track structure and roadbed requirements. There are three basic types of track structure and roadbed: open track, fixed track, and paved track. Open track consists of steel T-rails attached to either creosoted hardwood or concrete cross ties which are anchored to the roadbed by crushed stone ballast. Fixed track consists of steel T-rails fixed directly to a concrete slab base with special elastomeric tie pads for noise control. Paved track is required wherever a rail transit mode shares the roadway with rubber-tired vehicles or pedestrians, such as in mixed traffic operation or over transit and pedestrian malls. To date, North American practice involves the placing of pavement over open track construction, the result being that the track is rigidly attached to the pavement, thereby transmitting noise and vibration. Contemporary European paved-track construction differs in that the rail is laid directly on the ballast without cross ties, the gauge being maintained by tie bars. The rail is bordered and surrounded by a jacket of mastic asphalt which deadens noise and vibration. The remainder of the track zone is paved with one of several materials, such as concrete blocks. In both types of paved-track construction, girder rail, which incorporates a built-in flangeway, is used. The most common track gauge utilized for rail transit systems in the United States and Canada, regardless of which type of track structure and roadbed is used, is standard gauge of 4 feet 8½ inches between the running rails.

Light Rail Transit: Of the rail transit modes discussed in this report, light rail transit has the greatest variety of alignment options and track structure options available, and thus is considered to be the most versatile primary transit mode. Light rail transit can be applied over reserved lanes and medians of public streets, over pedestrian and transit malls, along freeway and active railway rights-of-way, in subways, and over other open areas in urbanized areas. Light rail transit could also be operated over public streets in mixed traffic; however, unless the streets are not congested, such operation may not be able to meet the primary transit requirements of high speed and capacity. Typically, paved track is used where light rail vehicles must share the right-of-way with rubber-tired vehicles, such as in transit and pedestrian malls. Fixed track is used where location over or through structures is necessary, such as on elevated segments or in subways. Open track is used in most other types of locations.

Like busways, light rail transit guideways may be classified into Class A and Class B alignments. Class A light rail transit alignments make more extensive use of exclusive rights-of-way with relatively gentle horizontal curves and gradients and with grade separations at arterial street crossings. Class B light rail alignments provide little or no grade separation, involving extensive use of public street rights-of-way with the trackage situated in reserved lanes or in median strips. Class B light rail transit alignments may also utilize sharper, railway-like horizontal curves and steeper gradients than do Class A alignments. Class A alignments provide a level of service approaching that of heavy rail rapid transit, with higher operating speeds than provided by Class B alignments. An advantage of light rail transit and buses on busways is that Class A and Class B alignments can be used alternately on segments of a transit corridor, as the constraints of a given corridor may dictate, in order to maximize operating speed at a reasonable guideway construction cost.

Heavy Rail Rapid Transit: The alignment options for heavy rail rapid transit guideways are much less flexible than those for light rail guideways, since the guideway must be totally grade-separated. Modern heavy rail alignments generally utilize subways through major activity centers such as a central business district, and either elevated or depressed alignments in other areas. Because of the cost and disruption attendant to the location of heavy rail rights-of-way through built-up areas, new systems tend to utilize either expressway medians or active railway rights-of-way for guideway location through such areas.

Commuter Rail: Commuter rail operations are normally limited to the existing mainline common carrier railway network radiating out of the central business district. Therefore, the completed guideway is normally in place, although improvement of the trackage to be utilized may be required to permit desirable operating speed. To adequately provide for commuter rail operation, trackage should meet at least the Class 3 requirements of the Federal Railroad Administration track safety standards, which allow passenger train speeds of up to 60 mph. Under all but the most unusual conditions, the trackage need not meet better than Class 4 requirements, which allow passenger train speeds of up to 80 mph.

Summary and Conclusions: Actual guideway locations and dimensions for all the modes discussed herein are highly dependent upon site-specific conditions. Overall, right-of-way width requirements, distances between track or lane centers, side clearances, and vertical clearances are the least for light rail transit and the greatest for commuter rail. This is because light rail transit guideways must frequently be designed to fit into an already existing urban infrastructure, while commuter rail systems are located over existing mainline common-carrier railway trackage. Clearances and other cross-sectional requirements for heavy rail rapid transit systems fall somewhere in between those of these two modes. A light rail transit system may require more vertical clearance than do busways, heavy rail rapid transit systems, or commuter rail systems to accommodate the overhead electric power distribution system. While there is great variation among the longitudinal cross-sectional characteristics of each of the modes, certain ranges of values typify each rail transit mode. These values are presented in Table 90 for both the motor bus modes and the rail primary transit modes.

Station Characteristics

Station design and operation vary considerably among the various primary transit modes. They may also vary within each mode, particularly within the light rail and busway modes. These differences in station design and operation are due, in part, to the requirements of each mode. For example, the design and operation of stations on heavy rail rapid transit systems are significantly influenced by the need for grade separation on such systems. Similarly, the potential of commuter rail to use existing facilities, including downtown intercity rail terminals, influences its station needs. The station design and operation required by a particular mode is also partly a function of the level of passenger use of the station, and the manner of access to the station—walking, collector-distributor bus, or automobile. Finally, station design and operation are dependent upon the level of primary transit service provided to the station, and the interface provided for connection with local transit facilities serving as collection-distribution facilities. Consequently, station facilities can only be described generally in a state-of-the-art report.

Stations for the motor bus and light rail primary transit modes may vary widely in complexity. Three general categories of stations can be defined for these two modes: minor stations, major stations, and central business district passenger collection and distribution areas. Minor stations can vary from facilities resembling a typical urban bus stop, consisting only of a small paved area marked with appropriate signing, to specially constructed platforms, attendant signing, lighting, and support facilities such as telephone service, rest rooms, and fare collection facilities, and a heated shelter building. For the motor bus technologies, such facilities may require turnout bays for buses so that stopped vehicles can be easily passed by other buses. Minor stations would generally be utilized on all motor bus-on-freeway, motor bus-on-reserved arterial lane, and electric trolley bus systems. Minor stations would also be used on busway and light rail transit systems at locations with light to moderate patronage.

Major station facilities for motor bus and light rail transit technologies have application at transit centers or other major transfer points, and at line-haul locations where large passenger volumes are anticipated. Design and capital and operating costs for such major stations may approach those of heavy rail rapid transit stations, especially if fare collection is incorporated into the facility design.

On light rail and motor bus primary transit systems, passenger collection and distribution in the central business district is usually facilitated by the operation of the vehicles in mixed traffic over surface streets, or over reserved lanes or transit malls, the latter typically incorporating pedestrian amenities. As of 1980, 11 major American cities had developed transit malls in their downtown areas. Specialized terminal buildings for primary transit are only found in New York City and in the City of San Francisco, both of which have intensive central area transportation demands.

Two important considerations have an important bearing on the design and overall configuration of light rail and motor bus primary transit stations: the method of fare collection and the loading platform height. Fare collection in the station facility as opposed to on-vehicle or self-service fare collection requires substantially more station area as well as a more complex station design. Boarding platform height is also an important design consideration, although this should not significantly affect the spatial requirements of light rail transit stations. The advantage of low-level boarding is that it permits use of a minimum design for a light rail

Table 90

CHARACTERISTICS OF DUAL GUIDEWAYS FOR PRIMARY TRANSIT MODES SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Characteristic	Motor Bus on Freeways	Motor Bus on Reserved Freeway Lanes	Busways		Arterial Express Lanes	Light Rail Transit		Heavy Rail Rapid Transit	Commuter Rail	Electric Trolley Bus Technology
			Class A	Class B		Class A	Class B			
New Guideway Construction	Not required	Not required	Necessary	Necessary	Not required	Necessary	Necessary	Necessary	Not required	Not required
Right-of-Way Width	Existing	Existing	32-foot minimum	32-foot minimum	Existing	30-foot minimum	30-foot minimum	32-foot minimum	Existing	Existing
Minimum Desirable Guideway Width[a] (feet)										
Surface	12-	12-	32	32	10- to 12-	32	32	38	34	10- to 12-
Aerial	foot	foot	36	36	foot	30	30	32	34	foot
Subway	lanes	lanes	34	34	lanes	34	34	34	34	lanes
Maximum Mainline Gradient (percent)	--[d]	--[d]	5	6	--[d]	4	8	3	1	--[d]
Minimum Horizontal Mainline Curvature[b] (degrees)	--[d]	--[d]	7½	23	--[d]	8	50-foot radius	7	2	--[d]
Minimum Vertical Clearance[c]	14'-9"	14'-9"	14'-9"	14'-9"	12'-6"	17'-0"	17'-0"	17'-0"	22'-0"[e]	13'-6"
Grade Separation	Complete	Complete	Complete	Optional	Minimal	Partial	Optional	Complete	Existing	Minimal
Extent of New Construction	Ramps	Ramps and transition lanes	Entire guideway	Entire guideway	Lane separation	Entire guideway	Entire guideway	Entire guideway	Possible rehabilitation	Minimal

[a] *Applicable only for level, tangent guideway segments. Guideway segments that are curved either horizontally or vertically may require greater clearances, depending upon site-specific design. Such variations for cross-sectional requirements are set forth in Chapter II and Chapter III of this report.*

[b] *Does not apply to station and storage areas, junctions, intersections, or crossovers. Curvature is measured from centerline of guideway.*

[c] *Measured from either top of roadway surface or top of rail.*

[d] *Determined by existing freeway or surface arterial facilities.*

[e] *For new bridge structures. Existing bridges may not meet the recommended minimum vertical clearances.*

Source: SEWRPC.

transit station since such a facility can be nothing more than a typical urban bus stop location. High-level boarding offers the advantages of more rapid passenger flow on and off the vehicles and thus shorter dwell times at stations, and improved accessibility for elderly and handicapped riders. In addition, if high-level boarding is used throughout a system, a simpler vehicle design may be used because stepwells or movable steps would not be required, and thus operating and maintenance expenses would be reduced.

Both heavy rail rapid transit and commuter rail technologies have unique station characteristics. Heavy rail rapid transit stations are the most elaborate and costly of those of all the primary transit modes. Its station facilities generally have two levels, a characteristic dictated by the need for full grade separation. Typically, one level is equipped with the platforms for boarding the trains, and the other level provides for fare collection and interface with other modes. Where unconstrained by surrounding intensive urban development, heavy rail rapid transit stations usually include large park-ride lots. When located in downtown areas, heavy rail stations can be very costly, but can offer the opportunity to provide direct sheltered access to shopping areas and other major trip generators. Commuter rail stations are generally simple adaptations of existing railway stations. The principal downtown station is generally the existing intercity passenger train terminal, while suburban stations consist of either existing railway depot structures and platforms or, in some cases, newly constructed platforms with minimal amounts of lighting and shelter.

An additional item critical to station design is automobile parking lot space, since primary transit systems—especially those utilizing fixed guideways—may, in outlying areas, depend in part upon automobile access to stations. Such park-ride facilities are considered to be necessary for exclusive busway, heavy rail rapid transit, and commuter rail technologies, and desirable for light rail transit and bus transit technologies. The parking lots are usually located at or very near stations in medium-density and suburban areas.

Table 91

SELECTED STATION CHARACTERISTICS FOR PRIMARY TRANSIT MODES

	Motor Bus on Freeways	Motor Bus on Reserved Freeway Lanes	Motor or Electric Trolley Bus on Busways	Motor or Trolley Bus on Arterial Express Lanes	Light Rail Transit	Heavy Rail Rapid Transit	Commuter Rail
Station Type							
Medium-Density Areas	Minor[a]	None	Minor	Bus stops	Minor	Major	Platforms
High-Density Areas	Minor[a]	None	Minor[b]	Bus stops	Minor[b]	Major	Platforms
Downtown	Transit mall	Transit mall	Transit mall	Transit mall	Transit mall	Major	Intercity rail terminal
Typical Station Spacing							
Medium-Density Areas	1-2 miles	- -	1-2 miles	1 mile	1-2 miles	2 miles	3 miles
High-Density Areas	½-1 mile	- -	½-1 mile	½ mile	½-1 mile	1 mile	2½ miles
Downtown	¼ mile	¼ mile	¼ mile	¼ mile	¼ mile	½ mile	Intercity rail terminal
Platform Height	Low level	Low level	Low level	Low level	Low or high level	High level	Low or high level
Typical Platform Length (feet)	140	140	140	140	200	500	400
Vehicle Capacity at Platform	2 vehicles	2 vehicles	2 vehicles	2 vehicles	2-car train	6-car train	4-car train
Typical Station or Stop Dwell Time (seconds)	30	30	30	30	30	20	30-60

[a] *Stations are assumed to be located off the freeway travel lanes.*

[b] *Stations at major interchange points between routes and/or modes may be expected to be more elaborate.*

Source: SEWRPC.

Precise station characteristics for any primary transit mode can be determined only as a part of detailed system design which includes a projection of passenger volumes at individual stations, a determination of the need for feeder bus service, a determination of the need for and capacity of park-ride lots, and site-specific location information. In a systems level analysis of alternative transit systems, station spacing and general design criteria may be assumed. Such information is set forth in Table 91.

Support Requirements

Support requirements for primary transit technologies consist of five elements: vehicle storage and maintenance, guideway and structure maintenance, power supply, traffic control, and fare collection. Vehicle storage facilities for bus transit modes typically consist of garages and attendant paved lots, while storage facilities for light rail transit and heavy rail rapid transit consist of specially constructed railway yards. The climate of the Milwaukee area requires that storage facilities for the motor bus transit modes consist of heated garages so that the diesel engines may be easily started during the winter season. Electrically propelled vehicles may be stored outside. Commuter rail storage tracks are generally located outdoors, and thus during winter months the locomotive engines may be required to idle overnight, possibly causing noise and air pollution problems.

Light rail and heavy rail transit systems require specially designed maintenance and repair facilities, while motor bus systems normally require only an expansion of existing facilities. The addition of an electrified primary transit mode—such as the trolley bus—to an existing diesel motor bus system would require the addition of specialized maintenance equipment, the retraining of the staff, and increased parts inventories because of the addition of a different propulsion system. Improvements to existing railway yard facilities or some new construction would be required to accommodate commuter rail equipment storage and servicing areas. Heavy maintenance and repair could be contracted out to the participating railway company.

The maintenance of guideways, structures, rights-of-way, stations, and other fixed facilities can be expected to be the least complicated for the motor bus transit modes and the most complicated for the rail transit modes. Except in situations where extensive exclusive busway facilities are utilized, such maintenance activities can be expected to be minimal for motor bus transit and electric trolley bus systems. For the small amount of guideway and grounds maintenance that may be required, agreements may be negotiated with local authorities or private contractors. Newly constructed light rail transit and heavy rail rapid transit systems would require specialized equipment, crews, and material inventories for the regular roadbed and track structure maintenance and repairs. For commuter rail, these tasks are generally the responsibility of the operating railway, the costs being prorated according to predetermined agreements.

Power supply and distribution requirements are attendant to the light rail transit, heavy rail rapid transit, and electric trolley bus modes. Power plants for diesel motor bus technologies as well as dieselized commuter rail service are contained on-board the vehicle or train, requiring no attendant guideway-related apparatus. Power for the electrified primary transit technologies is purchased commercially and transformed into an operating voltage through a system of primary and secondary substations. Primary substations are normally located at 10-mile intervals, and secondary substations at 1- to 2-mile intervals. It should be recognized that the extent and complexity of the power supply and distribution system are dependent upon peak-period power requirements, the determination of which requires detailed systems analysis and facility design.

The light rail transit mode requires an overhead wire power distribution system consisting of either a simple contact wire or a catenary system. A simple contact wire is practical where high speeds—generally above 45 mph—are not required or in areas where aesthetic considerations are particularly important. Simple contact wires require support columns at approximately 100-foot intervals. Catenary overhead is required for high-speed operation and requires support structures every 150 to 300 feet. Power distribution for heavy rail transit is normally effected by a side-mounted third rail. The larger cross-section of the third rail provides a greater current capacity which, in turn, permits longer trains than can be operated in a light rail transit system, while allowing for similar substation arrangements.

The electric trolley bus mode requires an overhead power distribution system consisting of a pair of wires suspended over the roadway surface. The overhead contact wire systems currently available fall into one of two categories: rigid systems which allow operating speeds of up to 35 or 40 mph, and elastic systems which permit speeds of up to 50 mph. The visual intrusion of the overhead power distribution system for both the electric trolley bus mode and the light rail transit mode is frequently cited as a major disadvantage to the construction of electrified transit systems. Proper design can mitigate these impacts, however.

Traffic control for the bus and rail transit modes differs substantially. For the bus modes, traffic control involves the use of signing, pavement markings, channelization, and traffic signal priority devices to improve vehicle movement through the existing traffic patterns. Such devices are especially important at transitional lanes and at other joint-use or mixed-traffic areas. These traffic control devices should follow the standards set forth in the latest revision of the Manual on Uniform Traffic Control Devices for Streets and Highways.[2] Priority at traffic signals may be provided for motor buses, electric trolley buses, and light rail transit vehicles operating over a Class B guideway, over reserved lanes, or in mixed traffic on arterial streets. Passive signal priority involves the retiming of signals for vehicle progression through a series of consecutive intersections or the reordering of signal phases to activate a special phase for transit vehicle movements. Active signal priority involves the detection of approaching transit vehicles in order to activate a special phase or to extend or advance the available green time at an intersection.

The principal functions of traffic control apparatus on rail transit systems are to control the speed and spacing of traffic along the guideway; to protect against conflicting movements, including the interface with other modes; and to control routings within the system. Modern heavy rail rapid transit systems in the United States employ automatic train control systems whereby most functions of train operation are automated. The majority of the

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[2] *U. S. Department of Transportation, Federal Highway Administration, Manual on Uniform Traffic Control Devices for Streets and Highways, (Washington, D. C., U. S. Government Printing Office, 1978).*

existing light rail systems rely on visual sight rules for operation, with some automatic train protection on segments with restricted visibility. Commuter rail service is governed by whatever general railway signal system is already in place, this normally being automatic block signals or centralized traffic control.

There are four basic fare collection procedures that have application for primary transit system operation. The most common procedure is the pay-as-you-enter system, which is normally used on motor bus and light rail transit systems within the United States. Recently, interest has been expressed in using self-service fare collection for these modes. Under a self-service ticketing system, passengers purchase tickets from vending machines and validate them at another machine mounted in the vehicle or at the station at the time of use. Compliance with this system is maintained by a staff of checkers who, in European practice, are legally empowered to fine offenders on the spot. Popular throughout Western Europe, self-service ticketing can reduce average travel time and operating expenses, although this system remains untried in the United States as of 1980. Controlled fare access collection is common on heavy rail rapid transit systems throughout the world. Under this system, fares are collected at stations before passengers are permitted access to the boarding platform. The fourth and last fare collection procedure is on-board ticket collection, which is typical of commuter rail service in North America.

PERFORMANCE CHARACTERISTICS

The critical system performance characteristics for the bus and rail primary transit technologies are speed, headway, and capacity. These factors are important determinants of the level of public acceptance and use of a new primary transit system. Consequently, these characteristics are particularly important in the testing and evaluation of alternative system plans.

Speed Characteristics

For use in primary transit system analysis, speed may be expressed in terms of absolute maximum vehicle speeds, typical maximum operating speeds, and average speeds over an entire route or route segment of a system. Absolute, or maximum, vehicle speeds are determined by the capabilities of the individual vehicle design. Although the maximum attainable speed of vehicles within the same mode will depend upon their particular design, this speed may be constrained by other system components such as signalization or guideway design. The electric trolley bus generally has the lowest maximum vehicle speed of the primary transit vehicles—approximately 40 to 45 mph. Motor buses and light rail transit vehicles typically have maximum speeds of between 50 and 55 mph. Heavy rail rapid transit vehicles have maximum speeds of up to 80 mph. Diesel-electric locomotives utilized in commuter rail service have maximum speeds ranging from 65 to 100 mph, depending upon the drive axle gear ratios.

Maximum operating speeds for primary transit technologies are the maximum speeds at which the transit vehicle can operate along a particular actual segment of guideway. This speed necessarily reflects the constraints of the guideway type and configuration and of adjacent land uses. Maximum operating speeds for motor bus operation in mixed traffic on freeways are limited to the posted speed limits of 50 to 55 mph. Traffic conditions on freeways may further limit the operating speeds. The operation of vehicles—motor buses, trolley buses, or light rail vehicles—over reserved lanes within public street rights-of-way is also limited to the posted speed limit. Such limits are determined primarily by safety considerations for adjacent and crossing vehicular and pedestrian traffic. In transit malls or in a downtown area, operating speeds may range from 20 to 25 mph. Over reserved median lanes, maximum operating speeds of up to 10 mph over the posted speed limits for adjacent mixed traffic lanes may be attained. The operation of motor buses and light rail vehicles over exclusive, fully grade-separated guideways will permit the attainment of maximum vehicle speeds, as will the operation of trolley buses using a specially designed overhead power distribution system.

Because they operate over a fully grade-separated right-of-way, heavy rail rapid transit systems have few speed constraints, and maximum operating speeds equal to maximum vehicle speeds can be achieved except when traversing some curves and passing through stations and junctions. Operating speeds for commuter rail trains are restricted by the condition of the track structure,[3] the number

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[3] *Because of the proposed level of railway track rehabilitation assumed in this study, the maximum operating speed for commuter trains within the Region would be limited to 60 mph. See Chapter VII of SEWRPC Technical Report No. 23, Transit-Related Socioeconomic, Land Use, and Transportation Conditions and Trends in the Milwaukee Area.*

of at-grade crossings with public streets, and the extent to which the surrounding area is developed and populated. Train operation through terminal areas and railway yard districts will severely limit the maximum attainable operating speeds because of the special trackwork and other train movements in the area.

Average system speeds for primary transit technologies reflect a variety of critical performance and operational criteria, including maximum vehicle speeds, maximum operating speeds, vehicle acceleration and deceleration characteristics, station spacing, and station dwell times. An additional consideration for primary transit technologies that utilize guideways located over reserved sections of public street rights-of-way is the extent to which preferential treatment is available at cross streets. If transit movements are required to stop at intersections for cross traffic, the effect on average speeds will be the same as that which would result from having station stops equal in number to those intersections without preferential treatment. Therefore, for the purpose of comparing various modes operating under the most favorable conditions, both Class B busways and light rail transitways are assumed to have preferential treatment provided at all intersections where motor vehicle traffic conflicts are possible.

Utilization of exclusive, fully grade-separated, fixed guideways—busways, light rail transitways, heavy rail rapid transitways, and commuter rail lines—provides for the highest average system speed. Light rail transitways can provide somewhat higher average speeds than busways can, since vehicle acceleration and deceleration rates are higher, allowing the maximum operating speed to be more frequently attained and, if attained, maintained for a longer period of time between stops. The average speeds of light rail transit and busway operations are dependent upon the type and configuration of the guideway—that is, the horizontal and vertical alignment and the degree of grade separation provided. The remaining motor bus primary transit modes—motor bus operation over freeways in mixed traffic, over reserved freeway lanes, and over reserved surface arterial street lanes—have a wide range of average speeds for similar reasons. For example, if a large proportion of the transit route is located over reserved freeway lanes or over operationally controlled freeways, then the average speed can be expected to be high. However, if much of the route is operated in mixed traffic, then the average speed will be reduced accordingly. Since the overall performance of electric trolley bus vehicles is very similar to that of diesel motor buses, average speeds may be expected to be similar, provided there is a specially designed overhead contact wire system for the trolley buses, which permits high operating speeds.

It should be recognized that a number of critical factors determine average system speeds, and that maximum vehicle speeds represent only one element, and not necessarily the most important, of these factors. Vehicle acceleration and deceleration rates are apt to be as important or more important than maximum vehicle speeds in attaining high average operating speeds. As evidenced by the data provided in Tables 88 and 89, electrically propelled vehicles possess significantly higher acceleration and deceleration rates than do diesel-powered vehicles. The most favorable acceleration and deceleration rates are attained by light rail vehicles, which have the combined advantage of electric propulsion with a relatively lightweight vehicle. Station dwell times are also an important determinant of average operating speed. Station dwell time is a function of how fast vehicles can be loaded and unloaded at each stop. Therefore, heavy rail rapid transit typically has the shortest station dwell times since heavy rail vehicles have several relatively large door openings along the side of the vehicle. Station spacing is another critical factor determining average system speed since each station stop requires time for vehicle deceleration, loading and unloading of passengers, and vehicle acceleration. Increasing the station spacing will significantly increase the average speed for all primary transit modes.[4]

The speed characteristics for various right-of-way types and station spacings selected for primary transit system design, testing, and evaluation are set forth in Table 92. For the purpose of comparing alternative alignments, optimal operating conditions are assumed, with the theoretical average speed calculated from the maximum vehicle speed, acceleration and deceleration rates, typical

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[4] *Within the context of this technical report, motor bus primary transit modes are generally considered to have station spacings similar to those of rail transit modes. It is, however, common practice to operate nonstop buses in a "freeway flyer" type of service in which the vehicle makes no stops along the line-haul portion of each trip. Consequently, the average speed may be very high and, possibly, equal to that of heavy rail rapid transit operation with its attendant station spacing.*

Table 92

SPEED CHARACTERISTICS FOR PRIMARY TRANSIT MODES SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Characteristic	Miles per Hour									
	Motor Bus on Freeways	Motor Bus on Reserved Freeway Lanes	Busways		Arterial Express Lanes	Light Rail Transit		Heavy Rail Rapid Transit	Commuter Rail	Electric Trolley Bus Technology
			Class A	Class B		Class A	Class B			
Maximum Vehicle Speed	55.0	55.0	55.0	55.0	55.0	50.0	50.0	70.0	65.0	40.0[f]
Typical Operating Speeds										
Transit Mall	20.0	20.0	20.0	20.0	20.0	20.0	20.0	--	--	20.0
Surface Arterial Reserved Right-of-Way	--	--	--	40.0	30.0	--	40.0	--	--	30.0
At-Grade Exclusive Right-of-Way	--	--	--	45.0	--	--	45.0	--	50.0	40.0[f]
Grade-Separated Exclusive Right-of-Way	45.0-55.0[b]	40.0[c]; 55.0[d]	55.0	--	--	50.0	--	70.0	60.0	40.0[f]
Average Speeds on Transit Malls and in Central Business District										
One-Quarter-Mile Station Spacing	10.7	10.7	10.7	10.7	10.7	11.3	11.3	--	--	11.1
Average Speeds on Surface Arterial Rights-of-Way[a]										
One-Half-Mile Station Spacing	--	--	--	19.4	17.4	--	21.5	--	--	18.2
One-Mile Station Spacing	--	--	--	26.1	22.0	--	28.0	--	--	22.7
Two-Mile Station Spacing	--	--	--	31.6	25.4	--	32.9	--	--	--
Average Speeds on At-Grade Exclusive Rights-of-Way										
One-Half-Mile Station Spacing	--	--	--	19.9	--	--	22.5	--	26.0 to 32.8[e]	20.8
One-Mile Station Spacing	--	--	--	27.6	--	--	30.0	--	26.0 to 32.8[e]	27.4
Two-Mile Station Spacing	--	--	--	34.2	--	--	36.0	--	26.0 to 32.8[e]	32.5
Average Speeds on Grade-Separated Exclusive Rights-of-Way										
One-Half-Mile Station Spacing	19.9-20.9[b]	19.4[c]; 20.9[d]	20.9	--	--	23.4	--	26.1	26.0 to 32.8[e]	20.8
One-Mile Station Spacing	27.6-30.0[b]	26.1[c]; 30.0[d]	30.0	--	--	31.9	--	38.0	26.0 to 32.8[d]	27.4
Two-Mile Station Spacing	34.2-38.8[b]	30.2[c]; 38.8[d]	38.8	--	--	38.9	--	49.3	26.0 to 32.8[e]	32.5

[a] *Assumes preferential treatment at all arterial cross streets.*

[b] *On operationally controlled freeway under mixed traffic conditions.*

[c] *On contraflow lane.*

[d] *On normal flow lane.*

[e] *Average speed is within this range, based upon route-specific station spacing.*

[f] *Assumes use of available technology.*

Source: SEWRPC.

station dwell times, and typical station spacing. It must be recognized that in later phases of this study in which individual alignments are examined in greater detail, such speeds must undergo refinement after the site-specific effects of station locations and extent of preferential treatment over conflicting traffic movements have been determined.

Headway Characteristics

Vehicle headways are dependent upon the desired level of service and the manner in which schedules are designed by the transit operator. Minimum possible headways for motor buses and trolley buses in revenue service operation range from one-third to one-half minute, although headways as short as 2.5 seconds have been actually achieved under test track conditions for the motor bus mode. Minimum possible headways for revenue service operation range from approximately 0.5 minute to 1.5 minutes for light rail transit, from 1.5 to 3.0 minutes for heavy rail rapid transit, and from 2.0 to 6.0 minutes for commuter rail. Actual headways are normally greater as they reflect the need to serve ridership demand at desired levels of service. However, in situations where two or more routes converge to use the same guideway or alignment, headways will necessarily be shorter. Table 93 sets forth the typical headways selected for use in the design, testing, and evaluation of alternative primary transit systems under this study.

Minimum headways will occur only under the highest travel demands, and then only for short periods of time. For motor bus transit operation, electric trolley bus operation, and most light rail transit operations, vehicle spacing is under the direct control of the driver of each vehicle, making headways a function of the capabilities of visual manual control. Automatic train protection systems regulate heavy rail rapid transit operations some light rail transit operations, and commuter rail operations. Such systems have built-in safety margins which prohibit excessively short headways from occurring.

Table 93

HEADWAYS FOR PRIMARY TRANSIT MODES SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Time of Operation	Headway (minutes)							
	Motor Bus on Freeways	Motor Bus on Reserved Freeway Lanes[a]	Busways	Arterial Express Lanes[a]	Light Rail Transit	Heavy Rail Rapid Transit	Commuter Rail	Electric Trolley Bus Technology
Weekday Peak Periods	5	5	5	5	5	5	30	5
Midday	10	- -	10	- -	10	10	60	10
Evening	15	- -	15	- -	15	15	60	15
Saturdays	10	- -	10	- -	10	10	120	10
Sundays and Holidays	15	- -	15	- -	15	15	180	15
Minimum Headway (seconds)	5[b]	5[b]	5	30	36	90	120	30

[a] *Operation assumed only during weekday peak periods.*

[b] *Assumes no on-line stops.*

Source: SEWRPC.

It should be recognized that headways are an important part of the level of service provided by any public transit system as they affect the wait times of the transit user for a transit vehicle. As such, proposed headways are particularly important in determining the utilization of alternative transit systems. Under this study, average wait times will be calculated as one-half of the headway, with a minimum average wait time of five minutes. This average wait time reflects the assumption that regular transit users will arrive at the initial transit station shortly before scheduled arrival times. This also assumes schedule coordination between transit collector-distribution routes and primary transit routes.

Capacity Characteristics

The maximum passenger-carrying capacity of any segment of primary transit system is dependent upon vehicle capacity, vehicle configuration, and headway. In general, rail transit modes are able to carry the highest passenger volumes because of the larger vehicle capacities and the ability to couple the vehicles into trains. Of the rail transit modes, heavy rail rapid transit is able to meet the highest peak-hour demands. While the passenger-carrying capacities attainable by the motor bus transit technologies somewhat overlap the lower range of capacities attainable by the rail transit technologies, capacities typically cited for the bus transit modes are applicable only in a nonstop, line-haul operation. Should station stops be required of most motor bus vehicles along a designated priority facility, station design may become a critical factor since queues could form outside station areas should an insufficient number of bus berths be available. The rail transit modes do not have this potential problem. The electric trolley bus mode can be expected to have capacities similar to those of motor bus transit modes.

Table 94 identifies the capacities selected for primary transit system design, testing, and evaluation under this alternatives analysis. Reflected in these capacities are headways that could be expected to be attained during peak travel periods, as well as the use of the specific primary transit vehicles identified earlier in this chapter as selected for consideration in this alternatives analysis. The capacities set forth in Table 94 are based upon characteristics—such as type of vehicle, train size, and headway—that can reasonably be expected for systems in the Milwaukee area. These assumed characteristics are only of a preliminary nature and will require refinement and modification in later phases of the study process.

A particularly important consideration in determining the maximum capacities of each of the primary transit modes is the load factor. The load

Table 94

MAXIMUM LINE-HAUL CAPACITIES FOR PRIMARY TRANSIT MODES SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Length of Headway	Passengers per Hour							
	Motor Bus on Freeways	Motor Bus on Reserved Freeway Lanes	Busways	Arterial Express Lanes	Light Rail Transit	Heavy Rail Rapid Transit	Commuter Rail	Electric Trolley Bus Technology
Maximum Peak-Hour Capacity								
One-Half-Minute Headway	8,040	8,040	12,840	12,840	- -	- -	- -	12,840
One-Minute Headway	4,020	4,020	6,420	6,420	17,640[a]	- -	- -	6,420
Two-Minute Headway.	2,010	2,010	3,210	3,210	8,820[a]	39,960[c]	- -	3,210
Five-Minute Headway.	804	804	1,284	1,284	3,528[a]	15,984[c]	7,536[d]	1,284
Midday Capacity (10-minute headway except commuter rail)	402	402	642	642	882[b]	2,664[a]	314[e]	642
Maximum Load Factor.	1.0	1.0	1.6	1.6	2.2	3.0	1.0	1.6

NOTE: Rail transit mode capacities are based upon the train length and headways shown in this table and possible vehicle seated capacities and load factors. Rail capacities can be increased as more cars per train are added—specifically, two cars per train for light rail transit, or a 100 percent increase; two to four cars per train for heavy rail rapid transit, or a 33 to 67 percent increase; and 12 cars per train for commuter rail, or a 300 percent increase.

[a] *Assumes two-car train.*

[b] *Assumes one-car train.*

[c] *Assumes six-car train.*

[d] *Assumes four-car train.*

[e] *Assumes two-car train operating on a 60-minute headway.*

Source: SEWRPC.

factor is defined as the ratio of the total number of passengers carried on a public transit vehicle to the seating capacity of that vehicle. A load factor of 1.00 would represent an ideal condition, since every seat would be filled—an economically desirable situation—and there would be no standees on the vehicle—a desirable situation for passenger comfort and safety. Maximum load factors vary for the different primary transit technologies. Heavy rail and light rail vehicles are typically designed to accommodate large numbers of standee passengers during peak periods. This is accomplished through interior vehicle designs that minimize the number of seats and provide greater floor space. Because standing passengers require less area than do seated passengers, a typical North American rail transit vehicle will provide a greater total capacity than will a standard North American motor bus.

Based upon the design characteristics of the specific vehicles identified in Table 89, maximum load factors to be used for each of the modes in the systems analysis are presented along with the attendant capacities in Table 94. Motor buses that operate either wholly or partially in mixed traffic on freeways may be subject to unexpected stops during periods of heavy traffic. This consideration, along with the stop-and-go operation that is possible on freeways during peak periods, creates a dangerous situation for standing passengers. For these reasons, motor bus operation on freeways both in mixed traffic and in reserved lanes has been assigned a maximum design load factor of 1.0. High-speed motor bus operation on busways would not normally be subject to the safety hazards of high-speed motor bus operation in mixed traffic, while arterial express operation does not involve high speeds. These two motor bus modes, therefore, have been assigned a maximum design load factor of 1.6.

As already noted, light rail and heavy rail vehicles are typically designed with interior seating arrangements conducive to accommodating large groups of standing passengers. Accordingly, a design load factor of 2.2 has been assigned to the light rail transit mode, while a design load factor of 3.0 is used for the heavy rail rapid transit mode. Commuter rail rolling stock, on the other hand, is assigned a design load factor of 1.0 because of the relatively long trip lengths involved compared with those of the other primary transit modes.

Since the electric trolley bus mode is not easily acceptable to operation on freeways, the technology would—in a primary level of service—be applied to busway and arterial express service. Like these applications of the motor bus modes, these applications of the electric trolley bus mode have been assigned a maximum load factor of 1.6.

ECONOMIC CHARACTERISTICS

Within the context of this technical report, the term "economic characteristics" pertains primarily to the capital and operating costs of each primary transit technology. The cost data presented represent generalized, nonsite-specific information assembled by the Regional Planning Commission staff for systems recently constructed and operated in other urban regions of the United States. The cost data are intended to be applicable at the systems planning level for comparatively evaluating alternative primary transit systems. All capital and operating costs are presented in 1979 dollars.

Capital Costs

Capital costs are those monetary investments required to construct the physical facilities and acquire the equipment necessary for the operation and maintenance of a primary transit system. The capital costs include the costs for the acquisition of right-of-way and vehicles; the construction of, or modification to, specific guideway segments; the construction of stations and boarding facilities; the installation of signals and communication equipment; and the provision of maintenance and storage facilities.

Right-of-way acquisition costs include all costs entailed in obtaining easements over, or fee simple title to, all real property required for the development of a primary transit system. Since land acquisition costs for primary transit technologies which utilize existing rights-of-way will be limited to the cost of acquiring the land required for support facilities and stations, right-of-way costs will be highest for those primary transit modes which require the construction of a special guideway. These modes include bus on busway, light rail transit, and heavy rail rapid transit. Local land values usually determine the cost of right-of-way acquisition. In addition to the property costs, substantial legal, brokerage, and relocation costs may be incurred in the acquisition of right-of-way. Although site-specific knowledge is required for any detailed analysis of right-of-way acquisition costs, some measure of such costs is provided in Table 95, which presents typical right-of-way acquisition costs based upon recent primary transit facility construction and extensions in the United States.

The cost of primary transit vehicles is a function of the basic vehicle configuration and options. The major factors influencing vehicle costs include the overall vehicle length and weight, configuration, passenger capacity, type of propulsion, and degree of sophistication of various vehicle subsystems such as train control and communications equipment. Over the last decade, rail transit vehicle costs have escalated at a more rapid rate than have the costs of other capital items. Vehicle acquisition costs for the primary transit vehicles selected for each of the technologies set forth earlier in this chapter are presented in Table 96 on a per-vehicle basis.

Guideway costs will generally constitute the largest proportion of the total capital costs of any primary transit system which requires extensive fixed guideway construction. The three primary transit modes identified in this study that require extensive guideway construction are operation of motor buses on exclusive busways, light rail transit, and heavy rail rapid transit. Fixed guideway development costs are greatly affected by the horizontal and vertical alignment. Therefore, specific unit costs stratified according to the vertical configuration of the guideway as well as according to its location in the urbanized area were developed for application to the various primary transit alternative alignments. The unit costs of the primary transit fixed guideways include the costs of earthwork, drainage, utilities, primary structures, other structures, fencing, trackage or roadways, electrification, signals and communications, grade-crossing protection, and incidentals. Table 97 sets forth typical construction costs in millions of dollars per mile based upon recent experience in other North American urban regions. The range in construction costs for specific alignments for each mode will ultimately be dependent upon the degree to which each of the above-mentioned item costs is applied.

It is apparent that there are large differences in the costs of the vertical alignments for each of the modes that require fixed guideways. Aerial seg-

Table 95

TYPICAL LAND COSTS FOR FIXED GUIDEWAY RIGHTS-OF-WAY FOR PRIMARY TRANSIT MODES

Location of Right-of-Way	Land Costs (in millions of 1979 dollars per mile)	
	Busway Transit[a]	Rail Transit[b]
Central Business District . . .	3.24	4.14
High-Density Area	2.92	2.68
Medium-Density Area	2.60	2.39

NOTE: Costs are applicable in Standard Metropolitan Statistical Areas with populations of more than one million people.

[a]Based upon land required for 41-foot-wide, dual-guideway right-of-way.

[b]Based upon land required for 36-foot-wide, dual-guideway right-of-way in open cut or on fill, and 30-foot-wide dual-guideway right-of-way on elevated segments or in subway segments.

Source: D. B. Sanders and T. A. Reynen et. al., Characteristics of Urban Transportation Systems—A Handbook for Transportation Planners, National Information Service, Springfield, Virginia, 1979.

Table 96

VEHICLE ACQUISITION COSTS FOR PRIMARY TRANSIT MODES SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Vehicle Type	Capital Cost (in 1979 dollars)
Conventional Motor Bus[a]	$140,000
Articulated Motor Bus[a]	240,000
Light Rail Vehicle[b]	800,000
Heavy Rail Rapid Transit Vehicle[c] . . .	750,000
Diesel-Electric Locomotive	930,000
Bi-Level Gallery Commuter Coach[c] . . .	565,000[e]
Self-Propelled Commuter Coach[c]	960,000
Conventional Electric Trolley Bus[d] . . .	164,000

[a] Includes air-conditioning equipment and wheelchair lift.

[b] Single-articulated vehicle with air-conditioning equipment but no wheelchair lift.

[c] Includes air-conditioning equipment.

[d] Does not include air-conditioning equipment or wheelchair lift. If limited off-wire capability is desired, add either $8,000 for battery package or $15,000 for generator package.

[e] Average cost of one control cab and three trailer coaches.

Source: SEWRPC.

ments may be expected to cost substantially more than surface segments, and subway segments can be expected to cost substantially more than aerial segments. The cost of guideway construction on the surface is also highly dependent upon whether the alignment is at-grade or grade-separated. A decision as to what vertical configuration is desirable for a new primary transit system is fundamental to any estimate of the ultimate system cost. It is also important to recognize that the availability and use of existing rights-of-way may significantly reduce total guideway construction costs, since the use of existing rights-of-way minimizes the cost of not only land acquisition, but earthwork and structures for the crossing of streets, highways, and roadways. The use of open rights-of-way for primary transit guideways does, however, entail an acquisition cost and a cost attendant to foregoing the use of the rights-of-way for other public or private purposes.

Of the three primary transit modes which would require new fixed guideway construction, busways require the least expensive guideways, and heavy rail rapid transit requires the most expensive guideways. Light rail transit cost advantages over heavy rail rapid transit can be exploited only when extensive use is made of nonexclusive surface alignments while minimizing investment in station facilities and sophisticated train control equipment. When light rail is designed with a predominantly grade-separated right-of-way, the distinction between the two modes may become blurred and the guideway construction costs may become quite similar.

Guideway costs for commuter rail operation represent primarily the cost of rehabilitating existing railway trackage. Although the necessary railway alignments are of an exclusive nature, by definition commuter rail uses mainline trackage which is already in place. Guideway development costs for commuter rail will, consequently, be far less than those for the other rail transit modes. In addition to the rehabilitation of existing trackage, the construction of some ancillary trackage may be necessary prior to service initiation. The rehabilitation cost is dependent upon the extent to which each

Table 97

TYPICAL CONSTRUCTION COSTS FOR PRIMARY TRANSIT FIXED GUIDEWAYS SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Type of Guideway	Construction Costs (in millions of 1979 dollars per mile)[a] Heavy Rail Rapid Transit	Light Rail Transit	Busways
Medium Density			
At-Grade	4.2- 6.1	3.8- 7.4	1.4- 2.9
Elevated on Fill or Structure	6.3-12.3	6.3-12.3	3.9-10.4
Retained Cut	8.5-16.1	8.5-16.1	6.1-14.2
High Density			
At-Grade[b]	--	4.0- 5.4	3.2- 6.8
Elevated on Fill	19.6-24.5	9.3-19.0	7.0-17.7
Aerial Structure	20.9-23.6	8.6-17.1	6.3-10.1
Retained Cut	25.3-30.6	11.9-23.5	9.5-22.2
Cut-and-Cover Subway	38.0-46.6	--	--
Central Business District			
At-Grade[c]	--	3.7- 4.3	1.9- 2.7
Aerial Structure	21.0-23.8	8.8-17.2	6.3-11.3
Cut-and-Cover Subway	38.1-46.7	38.1-46.7	--

[a] *Does not include agency and contingency costs.*

[b] *Exclusive right-of-way and in reserved median areas.*

[c] *Reserved median areas and transit malls.*

Source: SEWRPC.

individual commuter rail line must be upgraded, a situation which varies considerably for the different potential commuter rail routes in the Milwaukee area. The cost of track rehabilitation was estimated in the alternatives analysis on the basis of a segment-by-segment field inspection and was found to range from a low of $60,000 per track mile to a high of $700,000 per track mile.

Three of the motor bus transit modes—reserved lane operation on freeways, motor bus operation in mixed traffic on freeways, and arterial express lane service—utilize existing arterial street and highway facilities. Primary motor bus service employing these modes will have minimal capital costs for guideway construction. Implementation costs for reserved lane operation on freeways and arterial streets will depend primarily on the extent to which sophisticated lane control equipment is utilized. Reserved normal flow freeway lanes may be expected to cost between $12,000 and $35,000 per mile for basic lane separation and attendant signing. Contraflow freeway lanes may be expected to range in cost from $9,000 to $109,000 per mile. If the construction of an additional lane is required in order to accommodate a normal flow freeway lane, implementation costs may be expected to range between $0.5 million and $1 million per mile.

Arterial street reserved lane implementation costs will depend primarily on project location and adjacent land uses. Costs may be expected to range between $4,000 and $110,000 per mile for a normal flow reserved curb lane, between $5,000 and $140,000 per mile for a contraflow reserved curb lane, and between $20,000 and $210,000 per mile for a reserved median lane. The actual costs for such facilities will depend upon the method of lane separation—for example, painting, cones, or curb barriers—and the sophistication of lane control signing and signalization. Finally, exclusive bus malls, or bus streets, may be expected to cost between $0.7 million and $2.7 million per mile, the cost being contingent upon the extent of modification to the existing street facility.

It is possible that a new electric trolley bus system could include segments of exclusive busways, and reserved lanes or other traffic engineering measures, to grant preferential treatment for the transit vehicles. While these elements could represent a significant proportion of the capital investment required, their costs may be expected to be the same as those of similar facilities that would be utilized for a motor bus primary transit system.

The capital costs of station facilities will depend primarily on the particular requirements of a mode and the site-specific considerations of a particular lane. Generally, primary transit technologies which do not require the construction of new fixed guideways employ minor station facilities which require only minimal capital investment. Primary transit technologies which do require the construction of new fixed guideways generally require moderate to extensive stations which require a large capital investment. Three of the four primary motor bus transit applications require only minor stations, many of which may be nothing more than the normal curbside bus stops equipped with shelters and appropriate signing. The use of more elaborate stations may be expected at major transfer locations. For these motor bus transit technologies, curbside stops with shelters may be expected to

Table 98

TYPICAL CONSTRUCTION COSTS FOR PRIMARY TRANSIT FIXED GUIDEWAY STATIONS SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Type of Guideway	Construction Costs (in millions of 1979 dollars per facility)[a]			
	Light Rail Transit	Heavy Rail Rapid Transit	Busways	Commuter Rail
Medium Density				
Exclusive At-Grade Right-of-Way	0.02-3.4	0.5- 5.0	0.02-3.3	0.07-0.84
Elevated on Fill or Structure	0.2 -4.4	0.5- 5.5	0.3 -4.1	- -
Retained Cut	0.3 -4.4	0.9- 6.7	0.3 -4.1	- -
High Density				
Exclusive At-Grade Right-of-Way	0.2 -3.4	- -	0.02-3.30	0.03-0.64
Shared Street Right-of-Way.	0.02-0.09	- -	0.02-3.30	- -
Elevated on Fill or Structure	0.4 -4.4	1.0- 4.8	0.2 -4.2	- -
Retained Cut	0.4 -4.5	1.0- 4.8	0.2 -4.2	- -
Cut-and-Cover Subway	- -	6.2- 9.5	- -	- -
Central Business District				
At-Grade[b].	0.05-0.19	- -	0.02-0.19	0.12-1.14
Aerial Structure	1.6 -4.2	1.4- 5.6	1.5 -4.2	- -
Cut-and-Cover Subway	2.3 -7.5	6.0-14.5	- -	- -

[a] *Does not include agency and contingency costs.*

[b] *Reserved median areas and transit malls.*

Source: SEWRPC.

cost between \$3,000 and \$9,000, outlying terminal locations may be expected to cost between \$5,000 and \$22,000, and major at-grade transfer stations may be expected to cost between \$20,000 and \$110,000.

The primary transit technologies which require fixed guideways are exclusive busway operation, light rail transit, heavy rail rapid transit, and commuter rail. Station capital costs for these modes will depend upon platform length, the individual station facility design, parking facility requirements, access facility requirements, and passenger amenities. The capital cost of commuter rail stations will depend to a considerable extent upon the degree to which existing facilities can be utilized or rehabilitated. Light rail stations can range from simple trackside shelters and platforms to elaborate multi-level facilities generally associated with heavy rail rapid transit systems. Heavy rail rapid transit stations may be expected to be the most expensive of those for all the modes, a result of that mode's inherent requirement for total grade separation. Light rail transit stations located on either elevated or underground segments will tend to approach those of heavy rail rapid transit in design and cost. Typical construction costs for primary transit fixed guideway stations are given in Table 98 according to the type of guideway alignment and location within the urbanized area.

The power distribution system includes those facilities required to provide electrical power for vehicle propulsion and for operation of fixed facilities. This component consists of the necessary complement of electrical wires and apparatus for the propulsion of light rail vehicles, heavy rail rapid transit vehicles, and electric trolley buses. This cost component is not applicable to any other primary transit technology to be examined within this study. For the light rail transit and heavy rail rapid transit modes, the costs of electrical power distribution are included in the construction costs set forth for the primary transit fixed guideways; this portion of the total cost will range from approximately $900,000 to $1,300,000 per mile, respectively. For a new electric trolley bus system constructed in the same manner as those systems already in existence—for operation at relatively low speeds over arterial street systems—the power distribution element will represent the largest capital cost, ranging between $500,000 and $700,000 per two-way route mile. The costs will depend upon whether a conventional feeder system or feederless system is selected, plus the extent of overhead special work construction required.

The capital costs of signals and communication equipment vary considerably among the modes. Traffic control requirements and attendant systems are generally the most complex and elaborate for the rail transit modes, with heavy rail rapid transit requiring the most sophisticated apparatus because of the wide use of automated control. The cost of signal apparatus for light rail transit varies greatly with system design, but such apparatus may be expected to be limited to relatively simple wayside block signalization and preemptive traffic signals at at-grade intersections. If required for operation in heavily trafficked areas, signalization for commuter rail operation will normally already be in place. As applicable, the signal and communication component of the capital costs is included in the range of construction costs per mile for primary transit fixed guideways.

Motor bus transit modes do not normally require sophisticated signalization and communication equipment since traffic control is effected principally by wayside signs and pavement markings. A freeway operational control system working in conjunction with motor bus operation on freeways in mixed traffic will require a central control center, traffic detectors, ramp control signals, and appropriate interconnections of the system components. Based on the limited experience of such installations in the United States, the control center can be expected to range in cost from $2 million to $6 million, with ramp detection and control apparatus costing approximately $67,500 per freeway entrance ramp. Ramp bypass lanes and exclusive ramp construction would entail additional costs. Arterial express bus systems may require traffic signal preemption equipment, which may be expected to cost approximately $500 per vehicle for signal transmitters plus $3,000 per intersection for fixed signalization apparatus.

Initial costs incurred in the construction of vehicle storage yards, maintenance and servicing facilities, and repair shops relate directly to the mode, the size of the completed system, and the extent to which an existing vehicle fleet is being expanded. In the Milwaukee area, all primary rail transit modes except commuter rail would require the construction of completely new facilities. A commuter rail system would require only the expansion and upgrading of the facilities of the operating railway. A new primary transit system based upon the operation of express buses would be integrated with the existing motor bus services, whose basic storage and maintenance facilities are already in place. Costs for such improvements can be expected to approximate $25,000 per vehicle for motor bus primary transit systems, $218,000 per vehicle for light rail transit systems, $200,000 per vehicle for heavy rail rapid transit systems, and $75,000 per coach for maintenance facility improvements attributable to commuter rail service.

Agency costs are an unallocated allowance for engineering and administration during project implementation. Specific tasks covered under this component include engineering and architectural design, construction management, cost estimation and control, construction supervision, inspection and testing, and system start-up. Fifteen percent of total capital construction costs is allocated to cover these needs. This cost component does not apply to vehicle acquisition.

Contingencies represent an unallocated allowance which is intended to cover unforeseen and unpredictable conditions that may arise during construction. Thirty percent of total capital construction costs is allocated for this component, which applies to all capital costs except vehicle acquisition.

Related to the capital costs of a new primary transit system is the amortization period for the major system components. The determination of suitable amortization periods for major components of motor bus, rail transit, and electric trolley bus systems should be properly related to the expected service life—"useful life"—of those components. The amortization periods selected for use use in this study are set forth in Table 99.

Operating Costs

Operating and maintenance costs for primary transit systems are normally expressed in monetary units per unit of service production, such units generally being vehicle miles or vehicle hours. Depending on the particular primary transit mode, operating costs are generally divided into up to five major categories which conform to accepted

Table 99

AMORTIZATION PERIODS FOR MAJOR PRIMARY TRANSIT SYSTEM COMPONENTS SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

System Component	Amortization Period in Years
Vehicles	
Motor Bus	12
Heavy Rail Rapid Transit	30
Light Rail Transit	30
Commuter Rail	30
Electric Trolley Bus	20
Right-of-Way	100
Guideways[a]	25
Structures	50
Stations, Including Parking	30
Power Distribution System	30
Control and Communication Equipment	30
Maintenance and Storage Facilities	35
Contingency and Agency Costs	30

[a] *Does not account for freight service utilization.*

Source: SEWRPC.

transit accounting practices within the United States. For motor bus transit modes these categories include transportation expenses, maintenance and garage expenses, administrative and general expenses, operating taxes and licenses, and miscellaneous expenses. For light rail transit and heavy rail rapid transit systems these categories are maintenance of way and structures, maintenance of vehicles, power, transportation, and general and administrative. For commuter rail systems the accounting format used is a uniform system of accounts for railroad companies as prescribed by the U. S. Interstate Commerce Commission, the categories of which are maintenance of roadways and structures, maintenance of equipment, transportation, traffic, and other costs. For any of the transit modes the transportation category can be expected to incur the largest expense since it is this category which includes the wages for the operating personnel. Table 100 sets forth the operating costs to be used within this study for alternative system plan evaluation and comparison.

Operating costs for rail transit systems include all costs incurred for operation of the system. Operating costs for primary transit motor bus systems consist of two components. The first components consists of those daily costs associated with operation of the vehicle fleet regardless of the type of guideway utilized. These costs are, as already noted, expressed in monetary units per unit of service production—dollars per vehicle mile. The second component consists of those costs associated with the route operation of the various bus priority treatments such as exclusive busways and reserved lanes. Such costs may or may not be shared with the local highway department or other local governmental agencies, depending upon the extent to which existing highway and street facilities are utilized. These costs will vary substantially with the design of the individual transit priority treatment and are therefore difficult to estimate in the absence of a specific plan. Overall, the annual operating costs for busways and reserved lanes may vary between $2,000 and $196,000 per lane mile, depending upon the sophistication of the priority treatment. The operating costs of a freeway operational control system are similarly system-specific, although such a control system for the Milwaukee area would cost approximately $800,000 a year to operate, based upon ramp meters located at about 50 freeway entrance ramps.

Price Indices

The assembly and refinement of capital costs and operating costs as set forth within this report are based on the cost experiences of primary transit systems presently operated in urban regions of the United States. These cost data have been assembled from various sources which document such information in a variety of base years. In order to provide uniformity in the dollar amounts, cost indices have been utilized to reduce all costs to the base year of 1979. The cost indices utilized are set forth in Table 101.

Three price indices have been used. Capital costs for all elements of new primary transit system construction or improvements, including vehicle acquisition, have been reduced to 1979 dollars using the Engineering News Record (ENR) building index. The ENR building index does not apply to commuter rail capital improvements. Operating costs for all primary transit technologies except commuter rail have been updated to 1979 dollars using the local transit wage rate index of union hourly wage rates for transit operating employees.

Table 100

PRIMARY TRANSIT SYSTEM OPERATING COSTS SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Primary Transit Technology	Range of Costs per Vehicle Mile Adjusted for Average Speed[b]	Cost per Vehicle Mile Adjusted for Average Speed	Cost per Vehicle Mile Adjusted for Average Speed and Energy Price[a]	
			Stable or Declining Growth Future	Moderate Growth Future
Motor Bus Transit (using conventional vehicles)	$1.13-$2.06[c]	$1.61[d]	$1.70	$1.84
Motor Bus Transit (using articulated vehicles)	- -	$1.87[e]	$2.00	$2.22
Light Rail Transit	$2.86-$4.04	$3.27[f]	$3.33	$3.41
Heavy Rail Rapid Transit	$3.27-$4.55	$4.27[g]	$4.34	$4.45
Commuter Rail	$2.99-$7.08	$5.40[h]	$5.67	$6.10
Electric Trolley Bus Techology (using articulated vehicles)	- -	$1.74[i]	$1.77	$1.81

NOTE: All costs are in 1979 dollars.

[a] *For the testing and evaluation of primary transit system alternatives for the Milwaukee area, an alternative futures approach was used in an attempt to deal with the high level of uncertainty that exists today concerning key future conditions which influence public transit needs. These conditions include the cost of energy, which is a key difference among the alternative futures. For further information, see SEWRPC Technical Report No. 25, Alternative Futures for Southeastern Wisconsin.*

[b] *The average operating costs in this table have been developed from Milwaukee County Transit System data where available, and otherwise from transit systems in North America having operations which would be similar to the operations envisioned in the primary transit alternatives to be considered for the Milwaukee area. Necessary adjustments have been made to assure that transit operator or driver costs for all modes, a significant proportion of total transit operating costs, reflect appropriate primary transit average overall speeds and wage rates for primary transit alternatives in the Milwaukee area. The costs have been developed to be applied to all modes on a per-vehicle-mile basis. For the rail transit modes, the costs reflect the average costs per vehicle mile based upon the average amount of multiple-unit or train operation of vehicles on the rail primary transit systems inventoried.*

The only factor not reflected in the adjustments is the potential for increases as a result of future real increase in energy costs. Generally, for all primary transit modes, power or fuel requirements were found to represent about 10 percent of total operating costs in 1979. No change in the future cost per vehicle mile of energy will result if it can be assumed that primary transit energy efficiency will increase at the same rate as will energy costs. However, if no change in energy efficiency can be assumed, and it is assumed that diesel fuel prices will increase at the same rate as will motor fuel prices, and that electrical power prices will only increase about one-sixth to one-half or, on the average one-third, as fast as will motor fuel prices as set forth in the most recent U. S. Department of Energy forecasts and supported by other long-range energy studies, then, for the stable and declining growth futures and the moderate growth futures, respectively, the cost of the conventional motor bus operation would be increased by 9 to 23 cents per vehicle mile, the cost of articulated motor bus operation would be increased by 14 to 35 cents per vehicle mile, the cost of light rail transit operation would be increased by 6 to 14 center per vehicle mile, the cost of heavy rail operation would be increased by 7 to 18 cents per vehicle mile, the cost of commuter rail would be increased by 27 to 70 cents per vehicle mile, and the cost of articulated electric trolley buses would be increased by 3 to 7 cents per vehicle mile.

[c] *Based on modification of systemwide average bus transit system operating costs per vehicle mile ($1.43 to $2.62 per vehicle mile). The modification was intended to reduce motor bus operator costs per vehicle mile by about 45 percent in order to reflect an expected 75 percent greater motor bus average speed in primary transit service than in local service. Based upon Milwaukee County Transit System 1979 financial and operations data, motor bus operator costs constitute about 50 percent of the total motor bus operating cost per vehicle mile.*

[d] *Based on modification of the Milwaukee County Transit System average motor bus operating cost per vehicle mile for the year 1979 ($2.05 per vehicle mile), as in footnote c.*

[e] *Based on the experience of other operators of articulated motor buses, the operating cost per vehicle mile in primary transit service for such a vehicle in the Milwaukee area may be expected to be about 16 percent greater than that for conventional nonarticulated motor buses. This assumes that nonlabor operating costs for articulated buses will be about 50 percent greater than those for conventional buses.*

[f] *Based on the 1976 operating costs per vehicle mile for light rail transit systems in Cleveland, Newark, and Philadelphia, updated to 1979. These operating costs assume some multiple-unit or train operation during peak periods of demand.*

[g] *Based on the 1976 operating costs per vehicle mile for modern heavy rail rapid transit systems in Philadelphia and San Francisco-Oakland as well as the 1979 operating cost per vehicle mile for the modern heavy rail rapid transit system in Washington, D.C.*

[h] *Based on the 1973 operating costs per car mile for commuter rail systems operated by the Chicago & North Western Railway; the Chicago, Rock Island & Pacific Railroad; and the Milwaukee Road in the Chicago area, updated to 1979.*

[i] *Based on analyses for Vancouver, British Columbia, which showed conventional electric trolley bus nonlabor costs to be approximately 84 percent of conventional diesel motor bus nonlabor costs, and on the assumption that the nonlabor cost differences between conventional motor buses and articulated motor buses will also hold for conventional and articulated electric trolley buses.*

Source: SEWRPC.

Table 101

PRICE INDICES SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Year	Engineering New Record Building Index[a]	Local Transit Wage Rate Index[b]	Association of American Railroads Combined Index[c]
1967	100.0	100.0	100.0
1968	107.3	106.6	105.7
1969	117.6	115.0	112.3
1970	124.4	125.2	123.0
1971	141.1	135.8	133.7
1972	156.0	144.9	145.6
1973	169.3	155.4	163.5
1974	179.2	173.3	186.8
1975	194.3	192.9	212.6
1976	212.1	205.2	235.4
1977	229.9	220.4	255.4
1978	249.1	232.5	277.4
1979	270.7	253.0	315.2
1980	Assumed 8.0 Percent Increase		

[a] *Used for updating all capital costs except commuter rail capital costs.*

[b] *Used for updating all operating costs except commuter rail operating costs.*

[c] *Used for updating commuter rail capital and operating costs only.*

Source: SEWRPC.

Finally, both capital and operating costs for commuter rail systems have been updated to 1979 dollars using the Association of American Railroads combined material price and wage rate index, which includes wage supplements.

It must be recognized that there may be a differential between capital and operating costs in the Milwaukee area and in other urban regions of the United States. Since such a differential will affect all costs which are derived in the study, any necessary adjustment can be most readily made to the final alternative plan costs. Based upon the construction cost indices for other selected major midwestern cities, such costs for the Milwaukee area can be expected to be between 1 and 5 percent lower than average national costs.

PRIMARY TRANSIT ENERGY CHARACTERISTICS

The energy requirements of primary transit technologies include not only the energy needed to propel vehicles, but also the energy needed to operate stations, maintain vehicles and system facilities, and construct the system and manufacture the vehicles. These energy needs can be classified into energy for operation—that is, for vehicle propulsion, station operation, and vehicle and facility maintenance—and energy for construction—that is, for guideway construction and vehicle manufacture. Table 102 sets forth the energy requirements for vehicle propulsion, station operation, vehicle and facility maintenance, guideway construction, and vehicle manufacture to be used in the testing and evaluation of alternative primary transit system plans for the Milwaukee area. These energy requirements are reported in British Thermal Units (BTU's), permitting the comparison of the energy consumption of systems using petroleum-based motor fuels and electrical power.

Energy for Operation

Vehicle propulsion energy constitutes the majority of the operating energy consumed by a primary transit system, and accounts for most of the variation in the overall energy use of each primary transit mode. The typical propulsion energy requirements for the primary transit modes provided herein are based on the recent actual experience of transit operators in the United States. It should be noted that the energy purchased comprises about one-third of the energy content of the fuel used to generate and distribute electricity to a user, such as light rail transit, heavy rail rapid transit, and electric trolley bus systems. Estimated to be about 30 percent of the total electricity used or purchased, transmission and distribution losses in the electric overhead wire system of light rail transit and the electric trolley coach, and in the third rail of heavy rail rapid transit, are also included.

In terms of propulsion energy per vehicle mile, the motor bus and electric trolley coach have the lowest energy requirements, ranging from 24,700 to 37,800 BTU's per vehicle mile. The rail modes require substantially more energy for vehicle propulsion, requiring from two to four times as much energy as do the motor bus and electric trolley bus modes. Of the rail technologies, heavy rail rapid transit and light rail transit require the least amount of propulsion energy, 74,000 and 84,400

Table 102

ENERGY REQUIREMENTS OF PRIMARY TRANSIT MODES SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Characteristic	Automobile	Motor Bus			Light Rail Transit	Heavy Rail Rapid Transit	Commuter Rail	Electric Trolley Bus
Vehicle Type	Five-passenger automobile	"New look" standard urban bus	Articulated urban bus	Advanced design bus	Single-articulated light rail vehicle	Modern heavy rail rapid transit vehicle	Bi-level gallery coaches propelled by diesel-electric locomotive	Articulated trolley bus
Energy Source	Gasoline	Diesel fuel	Diesel fuel	Diesel fuel	Electricity	Electricity	Diesel fuel	Electricity
System Operating Energy								
Vehicle Propulsion Energy[a]								
(BTU's per vehicle mile)	5,800-5,000	24,700	37,800	32,500	84,400	74,000	113,300	35,400
(BTU's per passenger mile)[b]								
Assuming Capacity Load	1,600-1,000	470[d]/300[e]	560[d]/350[e]	700[d]/430[e]	560	330	720	430
Assuming Average National Vehicle Occupancy	4,140-3,570	2,150	N/A	2,830	4,220	3,520	2,830	N/A
Station Operation and Maintenance Energy (BTU's per vehicle mile)	Negligible-2,000	Negligible-4,000	Negligible-4,000	Negligible-4,000	Negligible-5,100	12,200	Negligible-3,200	Negligible-4,000
Vehicle Maintenance Energy[c] (BTU's per vehicle mile)	1,600	900	1,300	900	2,000	2,100	3,800	2,000
System Construction Energy								
Guideway Construction (billion BTU's per dual-guideway mile)								
Surface Guideway	34.0	34.0	34.0	34.0	24.6	24.6	30.0	60.2
Elevated Guideway	153.2	153.2	153.2	153.2	111.0	111.0	Not applicable	268.4
Subway Guideway	N/A	Not applicable	Not applicable	Not applicable	234.0	234.0	Not applicable	Not applicable
Vehicle Manufacture[c] (million BTU's per vehicle)	125	1,020	1,530	1,020	5,500	4,100	6,800	1,530

NOTE: N/A indicates data not available.

[a] *Energy conversion losses associated with electricity production, which can be 200 to 250 percent of the amount of electricity used or purchased, have been included in the propulsion energy requirements for light rail transit, heavy rail rapid transit, and electric trolley coach technologies. Transmission and distribution losses in the electric overhead wire system of light rail transit and the electric trolley coach, and in the third rail of heavy rail rapid transit, are also included and have been estimated to be about 30 percent of the total electricity used or purchased.*

[b] *The propulsion energy requirements per passenger mile for each of the primary transit modes selected for use in this study reflect maximum design load factors of transit vehicles, and range from 1.0 for commuter rail and bus on freeway to 1.6 for light rail and bus or trolley bus on busway to 3.0 for heavy rail, thus providing an indication of the potential propulsion energy efficiency attainable under peak-travel-period conditions. Actual load factors during nonpeak periods can be expected to be significantly lower, and propulsion energy requirements can be expected to be significantly higher. Actual load factors over an entire average weekday will be a function of passenger demand—both peak and nonpeak—which is, in turn, a function of specific route configuration, level of service, and adjacent land use, and can only be determined through testing and evaluation of alternative plans. Average vehicle occupancies used in this table are based on national statistics, which are 1.4 passengers per automobile, 11.5 passengers per nonarticulated motor bus, 20.0 passengers per light rail vehicle, 20.0 passengers per modern heavy rail rapid transit vehicle, and 40.0 passengers per commuter rail coach.*

[c] *Estimates of vehicle maintenance and manufacture energy were reported for standard nonarticulated primary transit vehicles; these estimates were extrapolated on the basis of vehicle size and weight to obtain an estimate of the energy required to manufacture and maintain typical single-unit articulated motor bus, light rail transit, and electric trolley coach vehicles.*

[d] *Reflects motor bus operation on freeways.*

[e] *Reflects motor bus operation on busways.*

Source: Congressional Budget Office, U. S. Department of Transportation, and SEWRPC.

BTU's per vehicle mile, respectively. Commuter rail requires about 113,300 BTU's per vehicle mile.

Because vehicle propulsion energy tends to be greater for high-passenger-capacity vehicles than for lower-capacity vehicles, consideration of potential vehicle passenger loads is important to any comparison of modal energy efficiencies. The minimum potential energy used by each mode per passenger mile can be compared by assuming that each mode is carrying passengers at its maximum design load factor. Under this assumption, as shown in Table 102, vehicles with the lower design load factors have the higher energy requirements per passenger mile. Motor bus on freeway modes and commuter rail, which have a maximum load factor of 1.0, require between 560 and 720 BTU's per passenger mile. Motor bus on busway, light rail transit, and electric trolley bus, which have a design load factor of 1.6, require under this assumption between 350 to 560 BTU's per passenger mile. Because heavy rail vehicles are typically designed to accommodate large numbers of standee passengers, a design load factor of 3.0 is used, resulting in the lowest propulsion energy requirements of all the primary transit modes, about 330 BTU's per passenger mile. It should be noted that because these propulsion energy requirements assume maximum design load factors, they are an indication of the propulsion energy efficiency attainable under peak-period conditions only. Such high load factors can be expected to be achieved only during morning and afternoon peak-travel periods and over limited segments of the total transit system. Actual average weekday load factors, as opposed to theoretical maximum peak-period load factors, are a function of passenger demand, which is, in turn, a function of specific route configuration, level of service, and adjacent land use type and intensity within a particular corridor, and can only be determined through testing and evaluation of alternative primary transit system plans.

Energy used to maintain vehicles and stations typically constitutes from 10 to 20 percent of the propulsion energy required per vehicle mile. Maintenance energy needs for motor buses are about 1,300 BTU's per vehicle mile, and for heavy rail rapid transit, light rail transit, and electric trolley coach vehicles, about 2,000 BTU's per vehicle mile. Commuter rail maintenance energy requirements are estimated to be much higher—about 3,800 BTU's per vehicle mile.

The amount of energy required for station operation varies widely among the various modes, being particularly high only for heavy rail rapid transit, which normally has elaborate grade-separated stations with air conditioning and escalators. An average of 12,000 BTU's per vehicle mile is required to operate heavy rail rapid transit stations, about twice as much as is required for stations on other fixed guideway systems. Station energy requirements for the other primary transit modes vary from negligible for stations consisting of only small paved areas marked with appropriate signing to 5,100 BTU's per vehicle mile for larger station facilities consisting of specially constructed platforms, lighting and support facilities such as telephone service, rest rooms, and fare collection facilities, and a heated shelter building.

Construction Energy

Guideway construction and vehicle manufacture energy can constitute a significant portion of the energy requirements of primary transit. Construction energy requirements are similar for light rail and heavy rail rapid transit guideways. Somewhat more energy is consumed in the construction of commuter rail guideways. The energy used to rehabilitate commuter rail guideways can be expected to be some proportion of the energy that would be used if a new guideway were to be constructed, that proportion depending upon the extent of rehabilitation required. About 40 percent more energy is required to construct busways than to construct light rail and heavy rail rapid transit systems, and, because it requires an overhead power distribution system, an electric trolley busway has greater construction energy requirements than does a busway for diesel motor buses.

Motor bus and electric trolley bus manufacturing is estimated to require between 1,000 and 1,500 million BTU's per vehicle. Rail transit vehicles generally require two to four times as much energy to manufacture, with commuter rail vehicles requiring the largest amount of manufacturing energy—about 6,800 million BTU's per vehicle.

CONCLUSIONS

The inventory of the state-of-the-art of primary transit technology conducted as a part of the Milwaukee area primary transit system alternatives analysis has established that there are eight urban public transit modes which have the potential to provide high-speed and high-capacity primary transit service within the Milwaukee area. Of these eight modes, four are motor bus modes, three are rail transit modes, and one is an electric trolley bus mode. Of the four motor bus modes, three—motor bus operation on freeways in mixed traffic, motor bus operation on reserved freeway lanes, and motor bus operation on reserved surface arterial street lanes with other forms of preferential treatment—make use of existing freeways and surface arterial streets and highways. The fourth motor bus mode—motor bus operation on busway—as well as two of the three rail transit modes—light rail transit and heavy rail rapid transit—require the construction of guideways. However, the guideways for motor bus on busway and light rail transit may be located within existing surface street rights-of-way and need not be fully grade-separated. The commuter rail mode also makes use of existing facilities, specifically, mainline railway trackage, sharing the operation of such trackage with freight and inter-regional passenger train service. The eighth primary transit mode—the electric trolley bus—may operate over exclusive busways or over reserved lanes on surface arterial streets to provide, like the motor bus, primary transit service.

Motor Bus on Freeways—In Mixed Traffic and On Reserved Lanes

Motor buses may operate on freeways either in mixed traffic or on reserved lanes. Both modes use conventional single-unit or articulated high-capacity buses propelled by internal combustion engines powered by petroleum-based fuels. Motor bus operation in mixed traffic on freeways is defined as the operation of either conventional single-unit or articulated high-capacity buses over existing freeway lanes that are open to all forms of motor vehicle traffic. The freeway over which this mode operates may be operationally controlled. Operational control serves to constrain automobile and motor truck access to the freeway system during peak traffic periods, reducing the potential for freeway traffic breakdown and ensuring high rates of traffic flow and reasonably high operating speeds. A typical operational control system would consist of interconnected demand-responsive freeway ramp meters at freeway entrance ramps to constrain automobile and motor truck access, while providing unconstrained access lanes for motor buses. Without such a control system, operating speeds for motor buses will necessarily be limited to those imposed by existing traffic conditions on the freeways.

Motor bus operation on reserved freeway lanes involves the operation of either conventional or articulated high-capacity buses over existing freeway lanes reserved for the exclusive use of transit vehicles. The reserved lanes may be dedicated in either a normal flow direction—with the flow of other traffic—or a contraflow direction—against the flow of other traffic.

For both of these bus-on-freeway modes, vehicle boarding is effected from curb level and fare collection is on board. Stations can range from simple curbside bus stops to park-ride lots with passenger shelters to complex terminal facilities. Principally because of the need to maneuver buses within, into, and out of freeway traffic, stations for these modes are not usually located within the freeway rights-of-way. Thus, the motor buses normally travel nonstop over the line-haul portion of their trip. This nonstop operation generally results in longer service intervals at stations than found on other primary transit fixed guideway modes, although more direct nonstop service is provided by bus-on-freeway modes. However, stops to board or discharge passengers can be facilitated within this mode by the provision of either specialized stopping lanes within the freeway right-of-way separated from other traffic, or stations near exit or entrance ramps at diamond freeway-arterial street interchanges where a motor bus can more easily exit and re-enter the freeway. The use of such stations at a spacing typical of a bus-on-busway system, however, may be expected to reduce the average speeds of the bus-on-freeway mode to, and below, those of a bus-on-busway system. An increase in vehicle headways closer to those found on a bus-on-busway system to maintain primary transit performance levels would thus also be required along with the increased station stops, which would result in capacity characteristics similar to those of a bus-on-busway system.

The maximum vehicle speed for the urban transit-type motor bus is about 55 miles per hour (mph). Maximum operating speeds for motor buses in mixed traffic operation on freeways will vary from 45 to 55 mph along uncongested freeways, and will be below 35 mph on congested freeways, with potential traffic jams on occasion further reducing these speeds, making this mode somewhat unreliable. The provision of operational control on otherwise congested freeways will permit consistent operating speeds of from 35 to 45 mph. Maximum operating speeds for buses operating on reserved freeway lanes will be 55 mph and 40 mph for normal flow and contraflow reserved lanes, respectively. Headways for reserved freeway lane operation of buses can be as short as five seconds, although this extreme may be reached only under nonstop operation in line-haul service. The resultant capacity of such bus operation in a single lane would be 50,000 to 60,000 passengers per hour. The bus-on-freeway in mixed traffic mode could provide even greater capacity, as a multi-lane freeway would be available for its use.

Because existing freeway facilities are utilized for the operation of both the bus-on-freeway in mixed traffic and bus-on-reserved freeway lane modes, and because the local transit system in the Milwaukee area uses buses exclusively, the initial capital costs of these two bus-on-freeway modes would be limited primarily to vehicle acquisition, although additional capital costs for the expansion of existing, or provision of new, maintenance and storage facilities might be required. The cost in 1979 dollars of a typical urban bus varies from $140,000 for a conventional bus to $240,000 for an articulated bus. The articulated bus typically can carry about 50 percent more seated passengers and about 40 to 50 percent more standees. The articulated bus, however, has about a 20 percent lower acceleration rate, and the lowest acceleration rate of all primary transit vehicles except commuter rail vehicles. In freeway operation, an articulated bus requires more energy for propulsion per vehicle mile—37,800 BTU's, compared with 24,700 BTU's for a conventional "new look" bus—and per passenger mile—560 BTU's, compared with 470 BTU's for a conventional "new look" bus—at a maximum design load factor of 1.0. The operating cost of an articulated bus per vehicle mile in primary transit service would be about 16 percent greater, $1.87 compared with $1.61, but, per passenger mile at the maximum load factor for freeway operation, would be nearly 20 percent less, 2.8 cents compared with 3.4 cents. Principally for this reason, the articulated bus will be used in all bus primary transit alternative systems considered under this study.

The use of a freeway operational control system for the bus-on-freeway in mixed traffic mode would represent some additional cost, but the cost of ramp modification, necessary traffic control apparatus at ramps, and the provision of a central control center would represent a small fraction of the cost of a fixed guideway system of similar extent. The conversion of an existing freeway lane to an exclusive bus lane also costs a fraction of the provision of a new guideway. Another advantage of the bus-on-freeway modes is that their implementation period is relatively short and community disruption is minimal.

An important advantage of any motor bus mode, including the bus-on-busway mode, is that since motor buses can be operated over any public street or highway, they can offer a "one-seat, no-transfer" ride between a relatively large number of trip origins and destinations. The same motor bus can perform a passenger collection function, a high-speed line-haul function, and a distribution function. Also, a single motor bus primary transit route can be operated in combinations of the various bus modes.

Only one bus-on-freeway technology was determined on the basis of the inventory findings to merit further consideration for the provision of primary transit in the Milwaukee area: bus on operationally controlled, or ramp-metered, freeway. This is because a freeway operational control system is already partially in place in the Milwaukee area, and the adopted long-range transportation system plan for the area calls for its expansion and improvement. The provision of additional ramp meters and the interconnection of all such meters into a centrally controlled system are programmed for implementation in the near future. The existing ramp meters have already proven to be capable of significantly increasing operating speeds and improving traffic flow on some of the most congested segments of the freeway system in the Milwaukee area. Moreover, one of the purposes of considering the bus-on-freeway transit alternative in this study is to use that alternative as a basis for comparatively evaluating more capital-intensive exclusive guideway alternatives, as required by the federal Urban Mass Transportation Administration. Buses operating over operationally controlled freeways should present a more attractive low-capital investment alternative for this purpose, as well as a definitely more attractive public transit alternative for future implementation in the Milwaukee area, than buses operating on potentially congested freeways in mixed traffic.

Buses operating over operationally controlled freeways are also a more attractive alternative for the Milwaukee area than buses operating on a reserved lane freeway system. Both would provide preferential treatment of buses with higher operating speeds at relatively low cost. There are, however, additional advantages attendant to the bus-on-operationally controlled freeways alternative. First, preferential treatment and higher freeway speeds for buses can be achieved with operational control without restricting freeway capacity for automobile travel to the same extent as would a reserved lane freeway system, and therefore without engendering as much diversion of automobile traffic from the freeway to the surface street system. Second, under the operational control alternative, the restriction on freeway traffic occurs in the same direction in which the improved bus service is provided. Because of existing levels of traffic volume and congestion, extensive segments of reserved freeway lanes in the Milwaukee area would have to be provided in the contraflow direction, and, as a result, the freeway automobile traffic being restricted by the implementation of reserved lanes could not be diverted to the bus service. Third, and perhaps even more importantly, reserved bus lanes cannot be practically provided at low cost over the entire area freeway system, while freeway operational control can, and, in fact, works best when it is applied systemwide. One of the reasons that reserved lanes cannot be practically provided systemwide in the Milwaukee area is the frequent use of left-hand entrance and exit ramps. Developing freeway reserved lanes at these locations would entail significant reconstruction costs. Also, implementation of reserved lanes on some segments of freeway in the Milwaukee area, whether normal flow or contraflow, would cause significant volumes of freeway traffic to be diverted. Some segments of the Milwaukee area freeway system which would not permit the development of reserved lanes at low cost and within reasonable disruption of automobile traffic include the East-West Freeway in Milwaukee County, portions of the Zoo and Airport Freeways, and the North-South Freeway near its interchange with the East-West Freeway in Milwaukee County. These segments of freeway are presently, and may be expected to remain, the most heavily congested freeways in the area; will have the greatest affect on transit travel times over freeways; and may be expected to carry the most intense motor bus-on-freeway operations. Fourth, operational control has a distinct advantage over contraflow reserved lanes from a safety viewpoint in that it does not require buses to operate at high speeds with no physical separation between freeway traffic traveling in an opposite direction, as do contraflow reserved bus lanes.

Motor Bus On Busways

Busways are special-purpose roadways designed for the exclusive or predominant use of motor buses in order to improve vehicle movement and passenger travel times. These facilities can be constructed on an existing freeway right-of-way, other existing rights-of-way, or a newly acquired right-of-way. Busways may be classified as either Class A or Class B busways, depending upon the overall level of service provided. Class A busways provide for high-speed, high-capacity, fully grade-separated rapid transit service, very similar to that provided by the heavy rail rapid transit mode. Class B busways are intended to serve somewhat shorter trip lengths at lower overall speeds, and therefore provide a somewhat lower quality of service. Station or stop frequency is usually greater than that along Class A busways, and at-grade crossings with arterial streets are generally incorporated into the facility design.

For the purpose of the Milwaukee area primary transit system alternatives analysis, the mode of arterial express bus operation, or operation of buses over reserved lanes on surface arterial streets, will be considered the equivalent of motor bus operation over a Class B busway. Preferably, such operation includes preferential treatment for the transit vehicles at selected traffic signals. Reserved lanes on arterial streets can be operated in either a normal flow or contraflow direction, and can be located adjacent to the curb or in the center of the roadway. An extension of the arterial reserved lane concept is the transit mall, or exclusive transit street, typically implemented only in major business and shopping areas. The level of service afforded by this mode, as well as by other types of motor bus on Class B busways in street rights-of-way, however, will still be affected to some degree by cross traffic at intersections and by parallel traffic on the same street. Arterial street capacity will also be constrained, both on the streets where the reserved lane is implemented and on cross streets, if transit vehicles receive priority at signalized intersections.

As with the other bus transit modes, boarding for the bus-on-busway mode is at curb level. Station design typically ranges from simple curbside stops with passenger shelters to more elaborate facilities at transit centers or major transfer locations. Major station facilities similar to those employed by Class A light rail transit and heavy rail rapid transit modes are yet another possibility. Fares are usually collected on board, but can be collected at stations.

The motor bus-on-busway mode involves the operation of either conventional or articulated rubber-tired buses at maximum vehicle speeds of 55 mph. Typical maximum operating speeds are 20 mph along transit malls, and between 40 and 55 mph on line-haul segments, depending upon whether the alignment is reserved or exclusive, as well as upon the degree of grade separation provided. Assuming typical station spacings, overall average speeds may be expected to vary between 11 and 34 mph for Class B busways, and between 21 and 39 mph for Class A busways. Motor bus headways can be as short as five seconds, although this extreme may be reached only under special operating conditions—that is, in nonstop, line-haul service. Based on the use of an articulated motor bus with a maximum design load factor of 1.6, a maximum peak-hour capacity for exclusive busway operation with a minimum 30-second headway will be about 12,840 passengers per hour. This capacity could be increased several times through the platooning of several buses at absolute minimum headways, by maintaining reasonable minimum headways between platoons, and by providing sufficient berthing areas for the boarding and deboarding of passengers at station facilities.

The implementation of busways involves major facility construction, and therefore may take relatively long periods of time compared with the implementation periods of other motor bus primary transit modes. The capital costs of a Class A busway may approach those of some rail transit modes, and the potential for community disruption during the implementation phase may be high. The average construction cost, not including the cost of right-of-way or stations, of a two-lane busway varies from under $2 million per mile to about $7 million per mile when at-grade, and from under $4 million per mile to nearly $20 million per mile when elevated, expressed in 1979 dollars. Specialized design considerations are required for exclusive bus subways because of the need for adequate ventilation, especially in underground station areas. For this reason, plus the fact that there are few such facilities in actual service, underground busway segments will receive no further consideration within this study.

If reserved lanes on existing arterial streets and highways are utilized for Class B busways, initial capital costs may be quite low—from $5,000 to $200,000 per lane mile—depending upon the sophistication of traffic control equipment modification and the complexity entailed in reserving surface arterial street lanes for the exclusive use of transit vehicles. The implementation period, as well as community disruption, may also be minimal.

The provision of motor bus-on-busway primary transit service may be expected to entail capital costs similar to those entailed by the bus-on-freeway modes for the provision or expansion of maintenance and storage facilities, and for vehicle acquisition. Operating costs, however, will be different. Because the maximum design load factor for the bus-on-busway mode is 1.6 passengers per seat, or 60 percent higher than that for the bus-on-freeway mode, an articulated bus on busway at its maximum design load factor will have an operating cost of about 1.7 cents per passenger mile, about 40 percent lower than the same cost for an articulated bus on freeway in primary transit service. A conventional bus on busway at its maximum design load factor will have an operating cost of about 2.2 cents per passenger mile, about 35 percent less than the operating cost of a conventional bus on freeway operating in a primary level of transit service.

The propulsion energy per passenger mile for an articulated bus on busway at its maximum design load factor, 350 BTU's, is about 38 percent lower than for an articulated bus on freeway. The propulsion energy per passenger mile for a conventional bus of this busway mode is about 300 BTU's, about 36 percent less than that for the same bus on freeway.

Light Rail Transit

One of the three rail transit modes—light rail transit—involves the operation of electrically propelled, dual-rail vehicles over predominantly reserved, but not necessarily grade-separated, rights-of-way. The principal feature distinguishing light rail transit from the other rail transit modes is that light rail vehicles, like motor buses, have the flexibility to operate safely and effectively at-grade over existing public street rights-of-way as well as along exclusive, grade-separated rights-of-way. As a consequence, costly and disruptive elevated and underground facilities need not be used in high-density areas or in central business districts where no exclusive grade-separated right-of-way may be readily available.

Light rail vehicles can be of a nonarticulated, single-articulated, or double-articulated configuration and can be coupled into trains of up to four vehicles. Access to the vehicles may be from curb-level or high-level platforms. Power is supplied from an overhead power distribution system. Fares can be collected on board the vehicles, or self-service ticketing fare collection procedures may be used; however, fares can be collected at stations. Station design can range from simple stops with passenger shelters to a complex station of the type required for heavy rail rapid transit. The large variety of design options available to light rail transit permits it, like motor bus transit, to provide a wide range of passenger capacities and performance capabilities at a relatively moderate cost.

Like busways, light rail transit guideways may be developed as Class A or Class B guideways. Class A guideways for light rail transit make extensive use of exclusive rights-of-way with relatively gentle horizontal curves and gradients and with grade separations at arterial street crossings. Class A guideways provide a level of service incorporating high speeds approaching those of heavy rail rapid transit. Class B light rail guideways provide little or no grade separation and involve extensive use of public street rights-of-way, with trackage situated in reserved lanes or within street medians. In addition, a Class B alignment may utilize sharper, street railwaylike, horizontal curves and steeper gradients than do Class A alignments.

The maximum vehicle speed for current state-of-the-art light rail transit vehicles is about 50 mph, the lowest of all primary transit modes except the electric trolley bus. However, because vehicle propulsion is provided by electric traction motors, light rail vehicles have high acceleration and deceleration rates, up to twice those of an articulated bus, and up to 50 percent greater than those of heavy rail vehicles. Typical light rail transit maximum operating speeds are 20 mph along transit malls, 40 mph along reserved arterial street rights-of-way, and 45 to 50 mph on exclusive rights-of-way, this range depending upon whether or not the guideway is grade-separated. At typical station spacing, overall average speeds for this mode will range between 11 and 36 mph for Class B alignments and between 23 and 39 mph for Class A alignments.

Headways for light rail can be as short as 36 seconds. The passenger capacity of a light rail facility, however, can be readily increased by simply coupling additional cars together into a train. Based on the use of a train of two single-articulated light rail vehicles with a maximum load factor of 2.2, the maximum peak-hour capacity of a light rail transit facility operating at a minimum 60-second headway will be 17,640 passengers per hour.

Light rail transit entails capital costs for new vehicles, stations, guideways, maintenance facilities and equipment, and the expansion of existing, or the construction of new, storage facilities. However, new storage facilities may consist simply of outside yards. The average construction cost of a light rail dual guideway in 1979 dollars is between $4 and $8 million when at-grade, $6 and $19 million when elevated, and $38 and $50 million when in cut-and-cover subway. The cost in 1979 dollars of a single-articulated light rail vehicle, the type of light rail vehicle which maximizes passenger capacity without a loss of performance or maneuverability, is $800,000.

The operating cost of light rail vehicles is about $3.27 per vehicle mile, expressed in 1979 dollars, or about 2.2 cents per passenger mile at its maximum design load factor of 2.2 passengers per seat. The propulsion energy requirements of a light rail vehicle are 84,400 BTU's per vehicle mile, or 560 BTU's per passenger mile at its maximum design load factor.

<u>Heavy Rail Rapid Transit</u>

Heavy rail rapid transit consists of dual-rail vehicles propelled by electricity distributed through a side-running third rail. Because of its use of a third rail, plus the characteristic high operating speeds and use of semi-automated train control, this mode can operate only over exclusive, fully grade-separated rights-of-way.

Heavy rail vehicles are typically semi-permanently coupled into pairs which can be made up into trains of up to 10 vehicles. Station facilities are the most elaborate of those of any of the primary transit modes and are designed with separate levels for fare collection areas and for passenger loading, which is effected from high-level platforms. The principal function of this mode is to provide high-speed, high-capacity primary transit service in the most heavily traveled corridors of an urban area.

The maximum vehicle speed for heavy rail rapid transit vehicles is 80 mph, the highest of all the primary transit modes. In the absence of constraints such as sharp curves, steep gradients, stations, and junctions, typical maximum operating speeds will approach 80 mph. Depending upon the station spacing, overall average speeds for this mode will range between 26 and 49 mph. Headways can be as short as 90 seconds. Based on the use of a six-car train and a maximum design load factor of 3.0, the maximum peak-hour capacity for the heavy rail rapid transit mode with a minimum 120-second headway will be 39,960 passengers per hour. Operation at the maximum train length of 10 vehicles can increase this capacity by 67 percent.

Because of its ability to train many vehicles together and its use of semi-automated operational control, the heavy rail rapid transit mode has a capacity generally exceeding that of all other primary transit modes. In addition, because of its exclusive, fully grade-separated right-of-way, the mode is capable of high speeds and a high level of reliability. However, heavy rail rapid transit is normally the most capital-intensive primary transit technology, requiring a major investment to produce a usable segment. The development of this mode requires a lengthy implementation period, along with significant community disruption. These aspects are particularly true of systems requiring the construction of lengthy subway segments. Heavy capital costs for new vehicles, stations, guideways, maintenance facilities and equipment, and the expansion of existing, or the provision of new, storage facilities. Storage facilities may simply consist of outside yards. The average construction cost of a heavy rail rapid transit dual guideway in 1979 dollars is between $4 and $6 million when at-grade, $6 and $25 million when elevated, and $38 and $50 million when in cut-and-cover subway. The cost of a heavy rail rapid transit vehicle, which is one-half of the typical married pair of vehicles, is about $750,000, also based on 1979 dollars.

The operating cost of a heavy rail vehicle averages $4.27 per vehicle mile, expressed in 1979 dollars, or 1.9 cents per passenger mile at its maximum design load factor of 3.0 passengers per seat.

The propulsion energy requirements of a heavy rail vehicle are 74,000 BTU's per vehicle mile, or 330 BTU's per passenger at its maximum design load factor.

Commuter Rail

The last of the three rail transit modes—commuter rail—involves the operation of large mainline railroad-sized rolling stock moving over trackage and right-of-way shared with freight and interregional passenger train service. This technology is intended to serve the longest trips in metropolitan areas at high speeds with relatively few station stops. Various vehicle configurations are available for use in commuter rail service. The rolling stock configuration considered under this study consists of a bidirectional train of bi-level gallery coaches propelled by a diesel-electric locomotive which uses petroleum-based fuels. Such trains typically are up to six coaches in length, and boarding may be from either low- or high-level platforms. This assumption does not preclude the examination and comparison of electrified, or self-propelled, coaches in later, more detailed phases of this study.

Fare collection for commuter rail is usually by means of tickets which are sold at stations or by mail and then collected on board the trains. Stations for the commuter rail mode typically consist of the intercity passenger terminal in the central business district, and of newly constructed platforms in suburban areas where there are no existing facilities.

The maximum practical speed for the diesel-electric locomotives used in commuter rail service is 65 mph. With optional gear ratios, higher speeds of up to 101 mph can be reached. Typical maximum operating speeds are 25 to 40 mph in high- and medium-density urban areas, and 50 to 60 mph in low-density and suburban areas. Depending on typical station spacing, the overall average speeds for the commuter rail mode as tested under this study range between 26 and 33 mph. Headways can be as short as two minutes, although this extreme can be reached only under special operating conditions. Coupling additional coaches to existing scheduled trains is a more practical means of increasing the passenger-carrying capacity. Based on the use of a four-car train of bi-level gallery coaches with a maximum load factor of 1.0, a maximum peak-hour capacity for this mode with a five-minute headway is 7,536 passengers per hour. Operation of trains of up to 12 coaches in length can increase this capacity by 300 percent.

Commuter rail rolling stock is manufactured to mainline railway standards with respect to suspension, size and strength, ad seating arrangement. This, together with relatively long station spacings, characterizes the mode as providing a very high level of riding comfort. In addition, commuter rail utilizes standard railroad right-of-way and trackwork, and therefore does not require the construction of a new exclusive guideway system, resulting in capital cost savings. The implementation of new commuter rail routes or extension of existing routes is confined primarily to existing railway trackage and rights-of-way, although rehabilitation and additional grade-crossing protection along fixed way facilities may be required prior to the initiation of service. Between $118,000 and $484,000 per mile in 1979 dollars would be required for such rehabilitation and grade-crossing protection on the six potential commuter rail routes in the Milwaukee area.

Commuter rail would, however, entail capital costs for vehicles, stations, and maintenance and storage facilities. At the end of each commuter line, servicing and overnight storage facilities would be required at an estimated cost of $200,000 each. Other maintenance and storage facilities could be provided by the railroad providing the service. These facility needs could be accommodated through the expansion of existing facilities or the provision of new facilities. A typical diesel-electric locomotive costs approximately $930,000 in 1979 dollars, and a bi-level gallery coach, $565,000. The operating cost of a commuter train is about $5.40 per car mile, or 3.4 cents per passenger mile at its maximum design load factor of one passenger per seat. The propulsion energy requirements of commuter rail are about 113,300 BTU's per coach mile, or 720 BTU's per passenger mile at its maximum design load factor.

Electric Trolley Bus Technology

The electric trolley bus mode may be defined as the operation of electrically propelled rubber-tired transit buses over paved roadways. The electrical power is distributed to the vehicles via a system of twin overhead contact wires. Except for the type of vehicle propulsion, the electric trolley bus would differ little from the motor bus in primary transit operation over reserved lanes on surface arterials or over exclusive busways. Both have similar roadway requirements and similar performance characteristics, including speed, headway, and capacity. Generally, electric trolley buses are operated in mixed traffic over existing arterial streets and highways, providing a tertiary level of service. In order for the electric trolley bus mode to be considered a primary transit mode, the trolley bus must operate in an arterial express service with substantial preferential treatment, or over an exclusive busway. Electric trolley bus vehicles are available in either a standard nonarticulated version or high-capacity articulated version. Loading and unloading is typically at curbside and fares are collected on board.

Maximum vehicle speeds for most trolley bus vehicles are about 40 mph, owing to the conventional rigid overhead power distribution system of this mode. However, use of elastic overhead power distribution systems and lower gear ratios on the trolley buses should permit maximum speeds of 55 mph, the maximum speed attainable by diesel motor buses. Typical maximum operating speeds for trolley buses vary between 20 and 40 mph, depending upon the type of alignment. With typical station spacing, overall average speeds for the electric trolley bus vary between 11 and 39 mph, depending upon the degree to which an exclusive guideway is provided. Based upon the experience of existing electric trolley bus systems in North America, it can be concluded that the overall performance of the diesel motor bus and the electric trolley bus in local and express service are quite similar, and the two modes can be considered to be basically interchangeable in daily operation. Headways can be as short as 30 seconds for this technology. Based on the use of an articulated electric trolley bus with a maximum load factor of 1.6, the maximum peak-hour capacity for this mode with a 30-second headway is 12,840 passengers per hour. This capacity could be increased several times by the operational training of trolley buses, but this would require a significantly expanded power distribution system.

Electric trolley bus systems generally use existing paved roadways, making the construction of a new fixed guideway unnecessary—although the overhead power distribution system and attendant support facilities do represent a major capital investment. The overhead wire system does not permit immediate route changes or detours, nor does it permit vehicles to readily overtake and pass each other without either the removal of the power collection poles from the contact wires, or the provision of additional overhead wires and switches. Electric trolley bus vehicles can be equipped with batteries or small gasoline engines for limited off-wire operation for such purposes as bypassing route blockages or moving around garage areas not fully equipped with overhead wire.

Electric trolley bus transit entails capital costs for new vehicles, stations, guideways, maintenance facilities, and the expansion of existing, or the provision of new, storage facilities. New storage facilities may consist simply of outside yards since trolley buses are electrically powered. The average guideway construction cost for the trolley bus will be the same as that for the motor bus, with the addition, however, of the cost of the overhead power distribution system. The cost in 1979 dollars of a conventional trolley bus is estimated at $164,000.

The operating cost of an articulated trolley bus vehicle—operating in a primary level of service—in 1979 dollars averages $1.74 per vehicle mile, or about 1.6 cents per passenger mile at its maximum design load factor of 1.6 passengers per seat. The propulsion energy requirements of the trolley bus mode are 35,400 BTU's per vehicle mile, or 430 BTU's per passenger mile at its maximum design load factor.

The electric trolley bus mode is generally applicable only in the provision of secondary and tertiary levels of service because of the speed limitations imposed by current vehicle and overhead wire designs. The mode, however, has the potential to provide high-quality line-haul service equaling that offered by motor buses—in terms of speed and capacity—over reserved arterial street lanes and exclusive busways, but only if special provision is made in the design of the vehicles and power distribution system. As a consequence, it was determined that, following full development of the motor bus primary transit alternatives, the electric trolley mode should be considered further in this study only as a special alternative to the diesel motor bus, capable of achieving similar performance but differing in certain respects, including environmental impact, energy requirements, and costs.

Concluding Remarks

Five urban transit modes were determined on the basis of an inventory of the current state-of-the-art of primary transit technology to merit further consideration in the Milwaukee area for the provision of primary transit service: bus in mixed traffic on operationally controlled freeway, bus on busway, light rail transit, heavy rail rapid transit, and commuter rail. The inventory findings indicated that, of the motor bus modes, motor bus operation in mixed traffic on operationally controlled freeways is a definitely superior primary transit mode for the Milwaukee area, and thus the bus-on-freeway in mixed traffic and bus-on-reserved freeway lane modes were eliminated from further consideration under the Milwaukee area primary transit system alternatives analysis. The electric trolley bus mode was determined to be a special variation of the motor bus mode, as it could provide similar performance but only with special design provisions. Accordingly, it was determined to further consider that mode only as may be necessary following full development and evaluation of the motor bus and other primary transit alternatives.

These five primary transit modes provide the Milwaukee area with a broad range of possibilities for the provision of primary transit service with respect to travel speed, capital and operating costs, and energy requirements, as summarized in Table 103.

An important distinction between the five modes is that three require new exclusive guideway construction, while two can use existing facilities as guideways. The motor bus-on-freeway mode would use existing operationally controlled freeways. It would require only completion of the planned expansion of the present freeway operational control system in the Milwaukee area and the provision of preferential bus ramps at those metered ramps where park-ride lots would be located. The commuter rail mode, the other mode which would use existing facilities, would use existing mainline railways, and would require only some track rehabilitation and grade-crossing protection. The principal advantage of these modes is that they can use existing facilities, and therefore have lower capital costs than do the modes requiring new guideway construction. The disadvantage is that primary transit service cannot be provided by these modes in areas where the required facilities do not exist. In addition, these two modes must share existing facilities with other traffic: the motor bus mode with automobile and truck traffic, and the commuter rail mode with freight and interregional passenger train service. The use, however, of a freeway operational control system would limit the detrimental effects on buses of mixed traffic operation on freeways, as it would restrain automobile and truck traffic from entering the freeway during peak travel periods so as to ensure a reasonable travel speed on the freeway for the motor bus. Similarly, commuter rail could receive preferential use of the shared railway facilities during peak travel periods, through the coordination of train schedules.

There are important distinctions among the three guideway modes of motor bus on busway, light rail transit, and heavy rail rapid transit with respect to guideway needs. The motor bus-on-busway mode and the light rail transit mode can use either Class A guideways, which are exclusive and fully grade-separated, or Class B guideways, which may be only semi-exclusive and partially grade-separated. Class A guideways require elevated or subway sections in high-density and central business district areas, while Class B guideways can use reserved lanes on surface arterial streets or some other portion of the street right-of-way such as the median. Heavy rail rapid transit requires fully grade-separated, exclusive rights-of-way over the entire length of all guideways.

The typical average speeds for the five primary transit modes are quite similar, although the motor bus-on-freeway mode has slightly higher speeds than do the other modes because it usually provides nonstop, line-haul service. The addition of any reasonable amount of time for collection and distribution at the destination end of a motor bus-on-freeway route, such as a central business district, will lower the average speed, bringing it into the range of the other modes. The lower end of the speed range for the bus modes reflects operation in a transit mall and on reserved street lanes. Commuter rail and heavy rail rapid transit do not have such lower ranges in speeds because they cannot operate over transit malls or reserved lanes on existing streets. Heavy rail rapid transit requires elevated or subway alignments, which do not impose an operating speed restriction as do transit malls and reserved lanes. Some of the difference in average speeds among the modes is also attributable to differences in station spacings, particularly the larger spacings for the heavy rail rapid transit and commuter rail modes. Longer distances between stations increase travel speeds, but reduce accessibility to a system by the most convenient form of access, walking.

Light rail and motor bus operation over transit malls in a central business district have definite cost advantages. There is little difference in the unit costs of at-grade, elevated, and subway guideway segments for the three modes requiring new guideways. However, elevated guideway segments, regardless of the mode, may be expected to cost from two to four times as much as an at-grade guideway, and subway segments from five to 15 times as much as at-grade guideway segments. Because the heavy rail rapid transit mode requires a fully grade-separated guideway, its capital costs greatly exceed those of the motor bus-on-busway and light rail transit modes.

Table 103

SUMMARY OF PRIMARY TRANSIT MODES SELECTED FOR USE IN THE MILWAUKEE AREA ALTERNATIVES ANALYSIS

Element	Motor Bus on Operationally Controlled Freeway (articulated bus)	Motor Bus on Busway (articulated bus)		Light Rail Transit (articulated vehicle)		Heavy Rail Rapid Transit (married pair of single-unit vehicle)	Commuter Rail (diesel-electric locomotive and bi-level coach)
Guideway Requirements	Existing freeway	Class A	Class B	Class A	Class B	Exclusive and fully grade-separated	Existing mainline double-track railway
Stations							
Typical Average Station Spacing							
Central Business District	¼ mile	¼ mile	¼ mile	¼ mile	¼ mile	½ mile	Intercity Rail Terminal
High Density	½-1 mile	1 mile	½ mile	1 mile	½ mile	1 mile	2 ½ miles
Medium Density	1-2 miles	2 miles	1 mile	2 miles	1 mile	2 miles	3 miles
Speeds							
Selected Vehicle Maximum Speed (mph)	55	55		50		70	65
Maximum Operating Speed (mph)		Class A	Class B	Class A	Class B		
Transit Mall	$20	--	20	--	20	--	--
Surface Arterial Reserved Lane	(Ranges from	--	30-40	--	40	--	--
Exclusive Nongrade-Separated	40 to speed	--	45	--	45	--	50
Exclusive Grade-Separated	limit)	55	--	50	--	70	60
Average Speed (mph)	36 to 47	21 to 39	11 to 34	23 to 39	11 to 36	26 to 49	26 to 33
Costs							
Selected Vehicle Capital Cost (1979 dollars)	$240,000	$240,000		$800,000		$750,000	$930,000 for locomotive; $565,000 for coach
Guideway Capital Cost (1979 dollars)							
At-Grade	Existing[a]	$1.4 to $ 6.8 million		$ 3.7 to $ 7.4 million		$ 4.2 to $ 6.1 million	$60,000-700,000[b]
Elevated	Existing[a]	$3.9 to $17.7 million		$ 6.3 to $19.0 million		$ 6.3 to $24.5 million	--
Subway (cut and cover)	--	--		$38.1 to $46.7 million		$38.0 to $46.7 million	--
Operating Cost (1979 dollars)							
Per Vehicle Mile	$1.87[c]	$1.87[c]		$3.27		$4.27	$5.40
Per Passenger Mile at Maximum Design Load Factor (cents)	2.8	1.7		2.2		1.9	3.4
Energy							
Propulsion Source	Diesel fuel	Diesel fuel		Electricity		Electricity	Diesel fuel
Propulsion Energy per Vehicle Mile (BTU's)	37,800	37,800		84,400		74,000	113,300
Propulsion Energy per Passenger Mile at Maximum Design Load Factor (BTU's)	560	350		560		330	720
Guideway Construction Energy per Mile (billion BTU's)	--	34.0-153.2		24.6-234.0		24.6-234.0	30.0 (for new construction
Capacity							
Seats per Selected Vehicle	67	67		68		74	157
Capacity per Selected Vehicle at Maximum Design Load Factor	67	107		147		222	157
Selected Reasonable Maximum Train Length	1	1 (platooning possible)		2 (3 possible)		6 (10 possible)	4
Selected Reasonable Minimum Headway	5 seconds per freeway lane	30 seconds		60 seconds		120 seconds	5 minutes
Resultant Reasonable Maximum Hourly Capacity	Limited only by freeway capacity	12,840 (over 50,000 possible)		17,640 (over 25,000 possible)		39,960 (over 75,000 possible)	7,536 (over 30,000 possible)

[a] *Capital costs for guideway are limited to traffic control apparatus and ramp modifications.*

[b] *Costs reflect rehabilitation for existing trackage.*

[c] *Adjusted for average speed of vehicles in primary transit service.*

Source: SEWRPC.

Motor bus systems have the lowest operating costs per vehicle mile, followed by light rail transit systems, heavy rail rapid transit systems, and, lastly, commuter rail systems. In terms of costs per passenger mile at maximum design capacity, however, bus-on-busway systems have the lowest operating costs, followed by heavy rail rapid transit systems, light rail transit systems, motor bus-on-freeway systems, and commuter rail systems. No primary transit system will, of course, operate at maximum design load factors except for relatively short periods of peak travel demand. Consequently, only upon consideration of alternative system plans and determination of transit travel demand under those plans can the actual operating cost of each mode for the Milwaukee area be estimated.

Other important elements of the cost of the five primary transit modes are vehicles, stations, and maintenance and storage facilities. The vehicle cost for the motor bus mode is substantially less than that for the other modes. However, more motor buses would be necessary to carry equivalent numbers of passengers, and the bus has an estimated life of less than half that of the vehicles of the other modes. In the Milwaukee area the motor bus modes, and perhaps also the commuter rail mode, have a capital cost advantage over the light rail transit and heavy rail rapid transit modes in that existing maintenance facilities, equipment, and procedures could be used. The light rail transit and heavy rail rapid transit modes, however, have the advantage over the motor bus modes of not requiring indoor storage since they are electrically propelled and heated. Commuter rail rolling stock, although stored outside, requires special provisions in cold weather.

The costs of stations may be expected to be lowest for the motor bus-on-freeway and commuter rail modes. The motor bus-on-freeway mode would likely require only relatively simple park-ride lots in outlying areas. The commuter rail mode could use the existing intercity downtown passenger train terminal and existing outlying stations with simple low-level platforms. The unit costs for stations in subway segments or on elevated segments are quite similar for the motor bus-on-busway, light rail transit, and heavy rail rapid transit modes. The cost of stations for a system, however, is generally much higher for heavy rail rapid transit, since that mode requires greater use of elevated and subway segments.

With respect to energy use, perhaps the most significant consideration is that the light rail transit, heavy rail rapid transit, and trolley bus modes use electricity, while the bus modes use diesel fuel. Diesel fuel, like other petroleum-based motor fuels, has been subject to rapid increases in price over the recent past and to disruptions in supply. Long-term availability of such liquid fuels is in question, and short-term supply may be subject to further disruptions. It should be noted, however, that there are concerns as well about the provision of electricity, with current controversies focusing on the environmental impacts of coal and nuclear power utilization for the production of electrical power. Coal and nuclear power are the current sources of electrical power production for the Milwaukee area.

The motor bus modes are by far the most efficient primary transit modes in terms of the amount of energy used per vehicle mile. The determination of the amount of energy used per vehicle mile is based on the energy lost in the conversion of other sources of power to electrical power and the energy lost in the transmission and distribution of that electrical power. Heavy rail rapid transit and motor bus on busways are by far the most efficient modes in terms of the amount of energy used per passenger mile when loaded to maximum design capacity, followed by motor bus on freeways and light rail transit and, lastly, commuter rail. It should also be noted that a significant amount of energy is used in new guideway construction for transit service. This construction energy can differ by a factor of 10, depending on whether an at-grade guideway or a underground guideway is required. The energy used in the construction of even an at-grade guideway is significant in itself. The energy used in the construction of an average at-grade guideway is equivalent to the energy expended in an extensive operation of primary transit over that guideway for at least five years.

The passenger-carrying capacities of primary transit modes are a function of the size of vehicles used, the number of vehicles which can be trained together, and the necessary headways between vehicles. If used in nonstop operation over guideways, all five of the potential primary transit modes could provide capacities substantially greater than those necessary for the Milwaukee area, because they could then operate at absolute minimum headways. The motor bus on freeway and motor bus on busway, however, are the only modes having the potential to operate in a nonstop fashion, since only buses can pick up and discharge passengers at off-guideway stations, or park-ride lots, and can perform collection and distribution services on surface arterial streets. The highest capacities of the fixed guideway primary transit modes designed with station stops are provided by the heavy rail rapid transit mode because of its ability to train many vehicles together at smaller headways than allowable by the commuter rail mode. Light rail transit provides less capacity than do these two rail modes as it has a more limited potential to train vehicles together.

Presently, vehicles cannot physically be trained together under the motor bus-on-busway mode. However, the capacity of a busway could be increased to accommodate the capacity provided by any rail mode by platooning buses—operating small numbers of buses at short headways from station to station, which is essentially an operational train of vehicles—and designing stations to accept platoons of buses.

It should be recognized that the characteristics of the primary transit modes presented in Table 103 and discussed in this summary represent reasonable midpoints in the range of characteristics of each of the five modes. With special design provisions and operation, it may be possible to improve on some of these characteristics. However, the improvement of some characteristics may adversely affect other characteristics. The characteristics presented are considered sufficient for the preparation of alternative system plans and for a determination at a systems planning level of the best primary transit system for the Milwaukee area and, in particular, a determination of whether such a system should include major capital investment in fixed guideways for primary transit over the next two decades.