

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT

155

**BUS USE OF HIGHWAYS
PLANNING AND DESIGN GUIDELINES**

TRANSPORTATION RESEARCH BOARD 1975

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT **155**

**BUS USE OF HIGHWAYS
PLANNING AND DESIGN GUIDELINES**

HERBERT S. LEVINSON, CROSBY L. ADAMS,
AND WILLIAM F. HOEY
WILBUR SMITH AND ASSOCIATES
NEW HAVEN, CONNECTICUT

RESEARCH SPONSORED BY THE AMERICAN
ASSOCIATION OF STATE HIGHWAY AND
TRANSPORTATION OFFICIALS IN COOPERATION
WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:

HIGHWAY DESIGN
TRAFFIC CONTROL AND OPERATIONS
URBAN TRANSPORTATION SYSTEMS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1975

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP Report 155

Project 8-10 FY '72
ISBN 0-309-02308-4
L. C. Catalog Card No. 75-13908

Price: \$7.60

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

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Printed in the United States of America.

FOREWORD

By Staff
Transportation
Research Board

This report will be of particular interest to public officials responsible for transportation policy, planning, design, and engineering. It contains guidelines for planning and designing preferential bus facilities relating to freeways, arterials, and terminals. Transportation engineers and planners will find the report of special value in helping to identify appropriate bus priority treatments for specific urban situations. In addition, the report will help the designer to incorporate the essential characteristics required for each type of treatment. It constitutes a single reference source on bus priority measures.

Highways are capable of moving large numbers of people on buses through the design of special facilities and control measures that produce a high level of service for peak commuter loads in heavy-volume corridors. Fundamental to this objective, however, is the employment of bus priority measures that include preferential bus lanes and ramps; traffic controls for smooth, uncongested flow; loading points and shelters; and park-ride lots. Although transportation planners and traffic engineers strive for rapid, convenient, reliable bus service, their ability to implement advanced concepts for bus utilization is hindered by the lack of planning experience and design guidelines.

The study reported herein was conducted by Wilbur Smith and Associates and constitutes the second phase of the research. The first phase, published as *NCHRP Report 143*, "Bus Use of Highways—State of the Art," contained a literature search and a survey of transportation agencies involved with bus priority measures; it identified more than 200 bus priority treatments throughout the world. The second phase developed planning and design guidelines for the efficient use of highway facilities based on the experience gained from the literature search and state-of-the-art survey.

The report identifies significant policy implications, contains relevant planning criteria, suggests measures of effectiveness, presents bus design parameters, and sets forth detailed planning and design guidelines for each type of bus priority treatment.

Implicit in providing bus priority treatments is the recognition of public transport as an essential community service. Bus priority treatments should be complemented by appropriate policies that encourage and reinforce transit use, such as low bus fares, downtown commuter parking supply and rate adjustments, and strict enforcement of bus priority treatments. Within this policy framework, various types of bus preferential treatments can be applied to select the measure most appropriate to the problem at hand.

The report then details basic planning parameters and warrants for various bus priority measures. Various measures of effectiveness are suggested to evaluate the actual performance of a bus system. In this context, it is essential to consider both

the mean and variance of bus and car times because the time variance is an important descriptor of service reliability.

To aid the designer, vehicle design and performance characteristics are given, together with bus capacity considerations. These include queue behavior parameters, bus unloading and loading times, and bus capacity ranges.

Finally, the guidelines present the important planning and design considerations associated with preferential bus treatments relating to freeways, arterials, and terminals. They provide a valuable supplement to the AASHTO design policies for urban roads and streets.

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ACKNOWLEDGMENTS

The research reported herein was conducted by Wilbur Smith and Associates as part of NCHRP Project 8-10, with Herbert S. Levinson, Senior Vice President, as principal investigator. Major supportive assistance was provided by Crosby L. Adams and William F. Hoey, Associates in the firm.

Sincere appreciation is expressed for the information obtained from the Federal Highway Administration, the Urban Mass Transportation Administration, the American Public Transit Association, the International Union of Public Transport, and the (British) Transport and Road Research Laboratory; from various transit companies; from various city, regional, and state highway and planning agencies; and from the several bridge-tunnel authorities.

BUS USE OF HIGHWAYS

PLANNING AND DESIGN GUIDELINES

SUMMARY

This report presents planning and design guidelines for efficient bus utilization of urban highway facilities. The guidelines, reflecting a thorough review of more than 200 bus priority treatments in the United States and abroad, and providing a single reference source of information on bus priority treatments, complement an interim report that presents the state of the art on bus use of highways (*NCHRP Report 143*).

Buses are the dominant form of public transport in the cities of the United States, carrying more than 70 percent of all transit riders. Operating over streets, highways, and in some cases special rights-of-way, they provide local and express bus services that complement or constitute an alternative to rail transit. They significantly increase the person-carrying capacity of urban highways.

Dimensions of Bus Use.—Passenger use of buses on radial freeways, on downtown streets, and in major bus terminals reaffirms the importance of bus priority treatments, as follows:

1. Buses carry more than 85 percent of all peak-hour person-trips through the Lincoln Tunnel in New York; account for about one-half of all peak-hour travelers on the San Francisco-Oakland Bay Bridge in California, the Shirley Highway in Northern Virginia, the Ben Franklin Bridge in Philadelphia, and the Long Island Expressway in New York; and for more than one-fourth of all passengers on radial freeways in other large cities.

2. Buses carry an even higher proportion of peak-hour travelers on city streets. More than 85 percent of all peak-hour travelers on Hillside Avenue, New York City; State Street, Chicago; Market Streets in Philadelphia and San Francisco, and Pennsylvania Avenue in Washington use buses. In many cities, buses accommodate more than one-half of all peak-hour person flow on downtown streets.

3. Urban bus terminals also serve heavy peak-hour movements. During a typical peak hour, New York's 184-berth Midtown Terminal serves 33,000 entrants; San Francisco's 37-berth Transbay Terminal, 13,000; Chicago's 22-berth 95th-Dan Ryan Terminal, 5,000; Toronto's 13-berth Eglinton Terminal, 15,000. Free transfer from bus to rail and a small number of low-headway bus routes account for the remarkably high flows accommodated in Toronto.

Types of Priority Treatments.—Bus priority treatments have been increasingly implemented throughout the world. The types of treatment, the numbers of people they serve, and the design details they utilize vary widely. Treatments can be grouped into three broad categories: those relating to freeways, arterials, and terminals, respectively.

Successful bus priority treatments, particularly those related to freeways, serve real, demonstrated needs. Their implementation and operating costs were low relative to actual and perceived problems. They are well patronized and produce peak-hour travel time savings of 5 to 30 min. These savings compare favorably with time savings resulting from rail transit improvements and extensions.

The successful treatments are usually characterized by: (1) an intensively

developed downtown area with limited street capacity and high all-day parking costs; (2) a long-term reliance on public transport; (3) highway capacity limitations on approaches to downtown; (4) major water barriers that limit road access to the CBD and channel bus flows; (5) fast nonstop bus runs for considerable distances; (6) bus priorities on approaches to or across water barriers; (7) special bus distribution within the CBD—often off-street terminals; and (8) active traffic management and operations programs.

Policy Perspective

Applied in isolation, individual bus priority treatments have slight impact relative to random variations in traffic flow or speeds. Yet the cumulative effect of a large number of small-scale treatments may radically alter system performance and utilization. Bus priority measures should be viewed as an integral part of over-all transportation management strategies that deal with streets, parking, and public transport. Combined with innovations in vehicle design, fare structure, and service patterns, treatments can improve the quality of bus transit and bring rapid public transportation to many communities.

Implicit in providing bus priority treatments is the recognition of public transport as an essential community service. There is little value in providing bus priority measures where service is poor, expensive, or nonexistent, and where the community does not want to improve service. Consequently, bus priority treatments should be complemented by appropriate policies that encourage and reinforce transit use. These include public support of low bus fares; downtown commuter parking supply and rate adjustments; and strict enforcement of bus priority treatments. Institutional changes that permit greater driver productivity will be increasingly essential.

Planning Parameters and Guides

Planning of new bus priority facilities calls for realistic assessment of demands, costs, and impacts. *The basic objective is to select and apply the appropriate types of treatment for specific urban situations.* Implicit in the selection process are: (1) the intensity and growth prospects of the city center; (2) the historic and potential future reliance on public transport; (3) the suitability of existing streets and expressways for bus service; (4) the extent of present and future overloads on the expressway system, including the ability to meet these demands by new road construction; and (5) public attitudes toward streets, parking, and bus transit.

Planning should (1) balance investments with demands, (2) identify the extent of capital-intensive bus priority facilities either in their own right or as an alternative to rail lines, (3) distinguish between building new facilities and more effectively managing existing facilities, (4) establish bus routing concepts that achieve operating economies through better scheduling and simplified station designs, (5) apply warrants that are realistic in terms of present and future needs, and (6) adopt design standards that reflect bus operating requirements and avoid over-design.

Bus Priority Objectives.—Efficient use of urban highways calls for maximum person flow with minimum net person delay over the long run. This can be achieved by (a) optimizing total person flow and, in some cases, (b) optimizing bus flow. The latter may be desirable in anticipation of a long-term shift to bus transit, or in response to CBD development or environmental policies. Both objectives may contrast with the goal of maximizing vehicle flow. Both call for a system of bus priority improvements.

Bus priority treatments may involve (1) developing a new facility through a high-travel-intensity corridor or (2) developing bypasses of specific bottleneck areas. They may involve adding a lane to existing road capacity in the flow direction of travel (the contra-flow freeway lane case) or preempting a highway lane in the heavy direction for bus use.

Measures that achieve “shared operations” and maximize joint person-flow efficiency by bus and car can have widespread application—i.e., metering of freeway ramps; effective enforcement of curb parking regulations; and traffic engineering improvements along bus routes. Treatments that optimize bus flow, *per se*, will be limited to larger urban areas—and will closely relate to downtown employment intensities. The existing and potential proportions of CBD travel by bus in specific corridors will influence the extent to which buses should be given priority over cars.

In most urban areas in the United States, justification of capital-intensive bus priority improvements depends on aggregating a sufficient volume of transit passengers to sustain the investments required in a particular corridor. It is usually an issue of identifying sufficient transit potentials rather than one of overcoming capacity deficiencies. This suggests major emphasis on operational treatments rather than physical construction wherever conditions permit. The general sequence of bus priority treatments, in order of ascending travel demands, is as follows:

1. Existing highway use should be optimized through traffic operations improvements, including construction. Where highway capacity and downtown parking are constrained, emphasis should be placed on bus priority improvements in conjunction with improved bus services. Arterial street bus lanes, for example, have widespread application.

2. Freeway ramps should be metered, with bypass lanes provided for buses. Car pool and bus parking lots should be provided at strategic locations.

3. Contra-flow bus lanes should be installed on freeways (and normal or contra-flow bus lanes on arterials) where sufficient bus volumes are aggregated, roadway conditions permit, and traffic volume imbalances exist.

4. Short busways that serve as “queue-jumpers” should be developed to link contra-flow lanes with terminals or to bypass freeway queues.

5. Busways should be constructed where location and design conditions preclude contra-flow operations on freeways or freeway development—e.g., where stations are required to serve adjacent areas, or where freeways bypass tributary traffic areas. Busways can be developed in stages, with interim operations on freeways or arterial streets.

The tradeoff between bus and rail systems depends primarily on the relationships between operating and capital costs for the two modes. The precise levels of demand of the break-even maximum load point volumes will vary among cities. Break-even points show wide ranges reflecting various assumptions of bus capacities, peak-to-base service ratios, and operating and construction costs. They generally lie in the 4,000- to 6,000-persons-per-hour range in the United States, although in special cases (i.e., use of articulated buses and minimum underground construction) higher break-even points have been cited. Below 2,000 to 4,000 passengers per hour (which can be accommodated in 40 to 80 standard buses at an average of 50 passengers per bus) buses clearly dominate, even on a mile-for-mile basis. The 6,000-persons-per-hour value represents the approximate capacity of a bus lane with on-line stations, 20-sec average station stops, and 30-sec headways between buses. This volume, of course, is considerably below the 20,000 to 30,000

passengers per hour that buses can (and actually do) accommodate where special downtown terminals are provided.

Buses, however, may provide equivalent service to rail with a lower mileage of special grade-separated facilities, because they can also operate on freeways and arterial streets. Where most system mileage is in mixed-traffic or special bus lanes, and only short sections of special busways are needed, express bus systems may prove the more economical option.

Establishing Warrants.—The underlying principle in formulating warrants for priority treatments is whether an exclusive bus lane or busway will carry more people than if the same lane is used by cars during the peak travel periods. The number of bus riders in the exclusive lane should at least equal the number of auto occupants in the adjoining lane. In the case of freeway and arterial bus lanes the warrant should apply during the hours that the lanes are in effect. For busways, the lanes should be based on peak-period travel.

This principle should be modified to meet air quality and energy conservation requirements, and to reflect downtown parking, transport, and development policy objectives. The ability of other streets to carry potentially displaced traffic should be considered.

With this principle as a guide, tentative warrants were established. Some of these, expressed in buses per peak hour, are given in Table S-1. A bivariate approach (1) recognizes future design-year corridor demands and (2) simultaneously considers base-year conditions. This allows flexibility for the future, and also safeguards against unrealistic demand forecasts. To accomplish this, (a) the warrants should apply to design-year conditions, and (b) 75 percent of the warrants should apply to current conditions (i.e., existing and divertible buses).

The range in warrants is realistic when compared to peak-hour bus volumes across the downtown cordon. In most cities, less than 400 buses cross the cordon in peak hours—an average of 100 per quadrant. If arterial and freeway bus lanes are to have widespread application, the basic warrants must be based on values less than these.

Multi-dimensional warrants are suggested for specific treatments. In the case of busways, downtown intensity parameters are significant. Busway installation generally should be contingent on a minimum CBD employment of 50,000 and a metropolitan population of at least 750,000. Similarly, contra-flow freeway bus lanes depend on a high peak-hour directional imbalance in traffic volumes.

Downtown transportation terminals and outlying modal interchange facilities are most appropriate where large numbers of passengers board or transfer daily. They generally should be provided in conjunction with express transit services. Patron reliance on bus or car access to express stations is a desirable precondition. Outlying change-of-mode parking facilities have greatest potentials where car travel to the city center is inhibited, CBD daily parking costs exceed \$2.00, and the multimodal trip is cheaper and faster than driving to the city center. (Ideally, multimodal trips should save at least 5 min.)

Measuring Effectiveness and Impacts.—The effectiveness and impacts associated with bus priority treatment can be measured in many ways. In comparing before and after conditions, it is essential to consider both the mean and the variance of bus and car travel times. The quantity of annual person-minutes saved per dollar of investment (including facility maintenance) provides an important quantifiable benchmark. In addition, the passengers carried per minute per mile of facility—the passenger-mile rate—provides a useful road-efficiency index. Cordon count

TABLE S-1
SUGGESTED RANGES IN PEAK-HOUR (ONE-WAY)
BUS VOLUMES FOR BUS PRIORITY FACILITIES

TYPE OF TREATMENT	NO. OF DESIGN-YEAR BUSES ^a
Freeway-Related:	
Busway	40-60 ^b
Contra-flow bus lane	40-60 ^c
Bus bypass lane at metered ramp	10-15
Arterial-Related: ^d	
Bus streets ^e	20-30
CBD curb lanes, main street ^e	20-30
Curb lanes	30-40
Median bus lanes	60-90
Contra-flow bus lanes, extended	40-60
Contra-flow bus lanes, short segments	20-30

^a Existing conditions should meet 75 percent of these volumes.

^b Busway installation should generally be contingent on a CBD employment of at least 50,000, 20 million square feet of floor space downtown, and a metropolitan population of at least 750,000.

^c Contra-flow bus lanes are contingent on directional imbalances in traffic volumes.

^d Where arterial bus volumes are less than 60 per hour, taxis may use bus lanes.

^e Environmental considerations may influence bus lane and bus street installation.

information on peak-hour travel to the city center should be an integral part of bus priority proposals.

Design Guidelines

Bus system planning should carefully reflect existing and potential demands. Therefore, service should be concentrated in heavy travel corridors. Express buses should operate mainly to the city center, and in a way that complements rather than erodes local bus service. Route structure should be clear and simple, and excess varieties of service should be avoided.

Freeway-Related Guidelines.—Selected freeway planning guidelines include the following:

1. The identification of major overload points on existing freeways and anticipated overloads on proposed freeways provide important guides as to where special bus priority facilities should be built. This approach is valid to the extent that the future road network has been committed and estimated future highway loads are realistic.

2. It is not generally feasible to remove existing freeway lanes from auto use in the heavy (flow) direction and give these lanes to buses. If the freeway is already congested, reducing the lanes available to cars will further increase delay. The overall loss in person-time to motorists will exceed the time savings achieved by bus patrons. The principal exceptions are where auto travel to the city center must be reduced to meet environmental, energy conservation, or air-quality requirements. When a bus lane is added in the existing flow direction, it is reasonable to expect a gain in peak-hour auto flows equal to the auto "equivalents" of the buses removed.

3. Right-hand freeway lanes are not usually desirable for exclusive bus use because of frequent weaving conflicts with entering and exiting traffic.

4. Standardization of freeway entrance and exit ramps to the right of the through traffic lanes will permit use of median lanes by buses either in normal or

contra (reverse) flows. Special bus entry and exit to and from the median lanes can be provided without interfering with normal auto traffic on the right-hand ramps.

5. Metering of freeway ramps with bus bypass lanes should be introduced where the techniques will improve mainline through-flow and reduce bus congestion. Other high-occupancy vehicles and trucks could also use the bus bypass lanes. Metering may not alleviate congestion resulting from lane-use imbalances at freeway-to-freeway interchanges. Metering usually requires available alternate routes.

6. Street-level bus stops, where buses leave the freeway for passenger pickup and delivery, are generally preferable to turnouts from freeway lanes. They can provide added convenience to patrons at minimum cost and bus bypass lanes on metered on-ramps can minimize delay to buses.

7. Effective downtown passenger distribution facilities are essential complements to regional bus rapid transit services. Downtown distribution should maintain service dependability, and minimize time losses resulting from general traffic delays. Distribution may take place in bus streets (or lanes), in bus tunnel, and/or in special terminals.

8. Busways should be of economical design. They should be built for lower per-mile capital costs than rail transit lines. This not only will offset the higher operating costs normally associated with bus service but it also is a realistic approach to providing bus facilities that may serve interim functions. The need for shoulders along busways should be assessed in terms of low bus volumes, infrequent bus breakdowns, and the low probability of delays to opposing traffic when stalled buses are passed.

9. Busways should be designed to allow for possible future conversion to rail or other fixed-guideway transit, with provisions that maintain service during the transition period. A 50- to 60-ft right-of-way would generally provide sufficient width for stations, with space for continuity of service during the conversion period.

10. Busways may provide service levels consistent with either freeway or arterial street standards. They may operate *normal flow* (with shoulders provided in unrestricted areas), *special flow* (with a central-shoulder or passing lane), or *contra-flow* (with a central-shoulder passing lane). The contra-flow configuration permits common island station platforms, which minimize station stairways, supervision, and maintenance requirements.

11. Busways should extend beyond the normal queuing distances from freeway convergence points, and park-and-ride facilities should be provided for convenient auto/bus transfer.

12. Ideally, busways should penetrate high-density residential areas, traverse the city center, and provide convenient distribution to major downtown activities. They should minimize branching to simplify route structure and station berthing. Station spacing should be inverse to population and employment density.

13. Downtown off-street busway distribution preferably should provide at least three stops at $\frac{1}{4}$ - to $\frac{1}{2}$ -mile intervals (in practice only the Runcorn Busway follows this concept). Linear rather than horizontal station expansion should be encouraged in an attempt to keep total cross sections under 60 to 80 ft and within street rights-of-way. Separate areas for loading and unloading would minimize station dwell times.

14. There may be merit in redirecting "busway emphasis" to developing facilities within the CBD, and on the close-in miles of radial corridors adjacent to it. Major bus priority treatments in the United States have focused mainly on the suburb-to-CBD trip component and provide little benefit to the majority of bus riders, who generally live within 4 to 5 miles of downtown. Arterial street bus lanes,

bus streets, and grade-separated busways in or on approaches to the CBD would benefit these travelers. The two types of bus service are complementary, thereby permitting bus lanes on freeways and arterials in the same corridor where traffic density warrants.

15. The segregation of bus and auto traffic should be actively pursued in new town development, as well as in existing urban areas. The Runcorn (England) New Town Busway is an important first step toward this objective.

16. Radial freeways in urban areas that exceed 1,000,000 population should provide reservations for future express transit (or special-purpose vehicle use) development, either within the median or alongside the facility.

Arterial-Related Guidelines.—Bus priorities along arterial streets form a logical component of traffic management strategies that specialize street use and give priorities to special classes of vehicles. The following factors are especially significant in achieving efficient bus utilization of city streets:

1. General traffic improvements and road construction should be coordinated with bus service to improve the over-all efficiency of street use. Buses usually benefit from street and traffic improvements that reduce over-all delay. The range of transit-related traffic improvements includes: grade separations to bypass delay points; street extensions to improve traffic distribution or provide bus routing continuity; traffic signal improvements such as system coordination, modernization, and bus preemptions or overrides; intersection channelization improvements; turn controls that exempt buses; bus turnouts for loading and unloading; bus stop lengthening or relocation; longer curb radii and corner rounding; effective enforcement and extension of curb parking regulations; improved spacing of bus stops; and bus shelters. One-way street routings can improve bus service except where (a) curb passenger loading requirements and, hence, curb bus lane capacity cannot be reduced or (b) one street of the one-way street couplet is eccentrically located in relation to principal passenger destination.

2. The prohibition of curb parking, at least during the peak hours, should be prerequisite to establishing bus lanes. This measure (a) makes an additional lane available to moving traffic, thereby substantially increasing capacity; (b) reduces delays and marginal frictions resulting from parking maneuvers; and (c) allows buses easier access to stops.

3. Bus routes should be restructured as necessary to make full use of priority lanes and streets. Buses may be shifted from other streets to build up patronage provided they do not exceed lane or street capacity or create passenger inconvenience. Peak hourly (one-way) bus volumes ranging from 60 to 90 will help "enforce" the bus lanes without creating excessive queuing.

4. Bus priority treatments should reduce both the mean and the variance of average journey times. Because the absolute time savings may be small in many situations, emphasis should be placed on increasing service reliability. A 10 to 15 percent decrease in bus running time in the bus priority areas is a desirable objective.

5. A wide application of bus lanes is necessary before schedule speeds can increase sufficiently to produce significant operating economies and/or encourage additional riding. Extended bus lanes on radial arterial streets could produce important benefits in service dependability. A saving of 1 min per mile (as by raising bus speeds from 10 to 12 miles per hour) could produce a 4-min saving if achieved over the entire length of a typical bus journey.

6. Bus lane and bus street installation should recognize the service needs of

adjacent land uses, which often result from long-established development patterns. Deliveries should be restricted during hours that priorities are in effect or be provided from the opposite side of the street, from side streets, or (ideally) off-street. Service requirements are especially significant where contra-flow bus lanes are provided.

7. Design of bus lanes should reflect available street widths and prevailing operating practices. Bus lanes should be provided wherever possible without reducing the lanes available to through traffic in the prevailing direction of flow. This may entail elimination of parking or reduction of lane width to provide additional lanes, elimination of left-turn lanes, and/or use of reversible-lane operations.

8. Effective enforcement of bus lanes is essential. Bus lane proposals should be accompanied by active enforcement programs.

9. Emergency vehicles—police cars, fire equipment, and ambulances—should be allowed to use bus lanes and/or bus streets. Taxis should be permitted wherever less than 60 buses use a lane in the peak hour. This will increase the utility and acceptance of bus lanes and bus streets.

10. The high proportion of peak-hour urban travelers using buses in downtown areas suggests increased consideration of (a) bus streets and (b) bus priorities in “auto-free zones.” Bus streets can provide early-action, cost-effective downtown distribution for radial busways. They can also help improve the pedestrian amenity of major activity centers, particularly retail areas.

Terminal Planning Guidelines.—Terminal planning and design embodies basic traffic circulation, transit operation, and site planning principles. Design and operation should: (1) provide bus priority access directly to and from express roads or busways; (2) maximize berth capacity and turnover by keeping bus layover and recovery times to a minimum; (3) separate urban from intercity bus services, and loading from unloading operations; (4) minimize the number of differing bus routes utilizing each loading berth; (5) minimize walking distances for transferring passengers, especially to and from local bus lines; and (6) utilize outlying automobile parking as an alternative to excessive local bus mileage in low-density residential areas. Other guidelines are as follows:

1. Downtown terminals should be located at points of “optimum efficiency” where express modes have just lost their essential freedom of high-speed movement. They should (a) be located within a short walking distance of major office concentrations in the city center, (b) connect with secondary public transport distribution systems, and (c) minimize travel times to and from major approach roads or busways. They generally should serve intercity and express buses. Local bus service should remain on city streets.

2. Express-local transit transfer facilities should be developed at a smaller scale than downtown terminals. Designs should be simple, ancillary facilities should be kept to a minimum, and a relatively few bus bays should serve peak-hour loads. Direct pedestrian access should be provided to major nearby generators, such as office buildings, shops, and apartments. Facilities are most applicable in medium-density areas 4 to 10 miles from the city center. Loading berth capacities of 10 buses per hour are typical, but may be greater where free transfer is provided between modes.

3. Successful park-and-ride facilities require (1) free (or low-cost) parking, (2) bus service on peak headways of 10 min or less, (3) congestion on approaches to the city center, (4) high downtown parking costs, and (5) free-flowing express bus travel to the city center. Outlying parking appears more economical than local

feeder bus service where land costs are low and travel distances to line-haul bus service are long.

4. Park-and-ride facilities should be located as far from downtown as possible to remove the maximum number of vehicle-miles driven during the rush-hour traffic period. Rail-oriented facilities should not exceed 2,000 spaces; 1,000 spaces represents a desirable size; 400 to 700 spaces represent an optimum size range for bus-oriented lots, with 1,200 spaces a desirable maximum. A 400-car bus lot justifies direct 10-min peak-hour bus service to the city center—the minimum desirable bus service frequency.

5. Park-and-ride facilities should give priority to interchanging bus passengers, according to the following sequence: (a) bus loading-unloading; (b) taxi loading-unloading; (c) passenger car unloading (dropoff); (d) passenger car loading (pickup); (e) bicycles; (f) short-term parking; and (g) long-term parking.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

This final report on NCHRP Project 8-10, "Planning and Design Guidelines for Efficient Bus Utilization of Highway Facilities," describes bus service characteristics, identifies relevant planning parameters, establishes warrants for bus priority treatments, and contains planning and design guidelines. It also suggests measures of effectiveness and identifies significant policy implication.

RESEARCH PROBLEM STATEMENT

Buses provide important mobility within most urban areas. They carry more than 70 percent of the 7 million annual public transport passengers in the United States and serve 15 billion person-miles of travel annually. They are the dominant form of public transport, even in most cities served by rail transit facilities.

Buses serve a wide variety of transportation functions. They provide local and express service between downtown areas and residential neighborhoods. In larger cities, they provide for crosstown movements and serve as feeders to rapid transit lines. They operate on local streets, arterial streets, expressways, and, in some cases, special rights-of-way. They provide a high degree of service availability and flexibility, for a single vehicle often provides both line-haul and distribution services. They are an integral part of the modern multimodal urban transport system.

Most communities, because of their size, land-use patterns, and development densities, are not likely to warrant rail transit systems. Therefore, they must rely on buses for public transport. Buses also provide interim and feeder services in communities that are developing rail rapid trans-

it. Thus, the definition of practical ways to optimize urban bus movements has important national implications.

The Role of Buses

The widespread reliance on bus transport underlies current efforts to improve bus service, establish bus priorities on city streets, and achieve efficient bus utilization of highway facilities. These efforts reflect the national search for mobility options that minimize road construction in high-density areas, maintain air quality, and conserve energy.

Buses play an important role in reducing urban congestion. They effectively complement other modes in increasing the person-capacities in major travel corridors. In the long run, a high level of bus use can reduce highway requirements, impacts, and investments. Thus, how effectively buses are used has important bearing on the scale, investment, effectiveness, and impacts of the urban transportation system. A 50 percent increase in peak-hour bus use on the approaches to downtown in a city like Dallas or Milwaukee could reduce auto traffic about 20 percent and CBD parking demand by about 6,000 spaces.

Dimensions of Bus Use

Buses substantially increase the person-capacity in major travel corridors, as shown in the following:

1. Buses carry more than 85 percent of all peak-hour person-trips through the Lincoln Tunnel; account for about one-half of all peak-hour travelers on the San Francisco-Oakland Bay Bridge, the Shirley Highway (Virginia), the Ben Franklin Bridge (Philadelphia), and the Long Island

Expressway; and for more than one-quarter of all peak-hour passengers on radial freeways in other large cities.

2. Buses carry an even higher proportion of peak-hour travelers on city streets. More than 85 percent of all peak-hour travelers on Hillside Avenue, New York City; State Street, Chicago; Market Streets in Philadelphia and San Francisco; and Pennsylvania Avenue in Washington, D.C., use buses. Buses accommodate more than one-half of all peak-hour person flow on downtown streets in many other cities.

3. Urban bus terminals also serve heavy peak-hour movements. During a typical peak hour, New York's 184-berth Midtown Terminal serves 33,000 entrants; San Francisco's 37-berth Transbay Terminal, 13,000; Chicago's 22-berth 95-Dan Ryan Terminal, 5,000; Toronto's 13-berth Eglinton Terminal 15,000. Free transfer from bus to rail and a small number of low-headway bus routes account for the remarkably high flows accommodated in Toronto.

The heaviest transit riding, largest bus fleets, and greatest opportunities for major bus priority treatments are found in the traditionally transit-oriented cities. These cities have the highest downtown employment concentrations and highest proportionate transit travel to the city center. Many have or are planning rail transit systems.

New York City accounts for about one-fifth of all urban bus passengers in the United States; its total bus fleet exceeds 4,000. Approximately 40 percent of the Nation's bus riding takes place in New York, Chicago, Philadelphia, Boston, and San Francisco—cities with extensive rail transit. Fleets of more than 2,000 buses are found only in Chicago and New York. Fleets of 1,000 to 2,000 buses operate in St. Louis, Detroit, Washington, D.C., Philadelphia, San Francisco, Los Angeles, and Montreal. Most cities in the United States and Canada have bus fleets comprising less than 1,000 buses, and fleets of less than 500 buses are common (Fig. 1).

Optimizing Bus Use

A high degree of bus use requires service levels that compare favorably with automobile travel in terms of trip times, costs, and service dependability. This can be accomplished by (1) providing adequate route coverage and service frequency to most of the metropolitan area; (2) operating express bus service on selected routes; (3) effectively coordinating bus and highway operations, planning, and construction; (4) adjusting street routing patterns and traffic controls to more effectively meet bus needs; and (5) providing bus priority facilities, such as busways, bus streets, bus lanes, and bus ramps. These opportunities exist in most cities.

Applied in isolation, individual bus priority treatments have slight impact relative to random variations in traffic flow or speeds. Yet the cumulative effect of a large number of small-scale treatments may radically alter system performance and utilization. Combined with innovations in vehicle design, fare structure, fare collection techniques, and bus service patterns, bus priority treatments can improve the quality of bus transit, bringing rapid public transportation to many communities. They can provide "rapid transit" in communities without the employment and popu-

lation concentrations to support grade-separated rail transit systems. And, in the larger urban areas, bus rapid transit may provide useful interim service in future rail corridors during the long periods of system planning, financing, engineering, and construction.

RESEARCH OBJECTIVES

Efficient bus service and efficient traffic flow are highly interdependent; both benefit from street and traffic improvements. Accordingly, urban streets and highways have been increasingly adapted to bus service priorities. Within the past decade more than 200 bus priority treatments have been implemented or are under active consideration, and the number is increasing daily.

The research program was undertaken in response to the need for a systematic approach to optimizing bus use of urban highways. It was designed to produce a single reference source of information on bus-use applications that increase the person carrying capacity of existing highways. It documents existing and proposed preferential bus facilities and recommends needed research. It identifies economic and social benefits and costs.

Specific project objectives were to: (1) describe physical and operational characteristics of existing preferential bus facilities and controls for buses on urban highways, including costs and benefits where available; (2) describe major current proposals for preferential bus facilities and bus guidance systems; (3) describe research applicable to preferential bus facilities and bus guidance systems; (4) determine the extent to which research and empirical information is lacking, thereby limiting the preparation of definitive planning criteria for preferential bus facilities; (5) develop planning criteria for preferential bus facilities (similar to warrants for traffic control devices); (6) prepare design guidelines for roadway geometrics, traffic controls, and bus operation components for preferential bus facilities, that could supplement the *AASHO Policy on Arterial Highways in Urban Areas*, the *Manual on Uniform Traffic Control Devices for Streets and Highways*, and standard transportation engineering reference texts, cross-referencing these sources, as appropriate; and (7) suggest measures of effectiveness for highway transportation systems, with particular reference to preferential bus facilities.

RESEARCH PLAN

The over-all research program included 10 basic study tasks (Fig. 2). These were segregated into four principal phases: orientation; review and analysis of current treatments, experiments, and proposals; concept and guideline formulation; and final report preparation.

Orientation and Research Approach

At the outset of the study, contacts were made with key agencies concerned with bus priority treatments. These included: (1) the Highway Research Board (now the Transportation Research Board); (2) the Federal Highway Administration; (3) the American Association of State Highway and Transportation Officials; (4) the Urban Mass Transportation Administration; (5) the American Transit

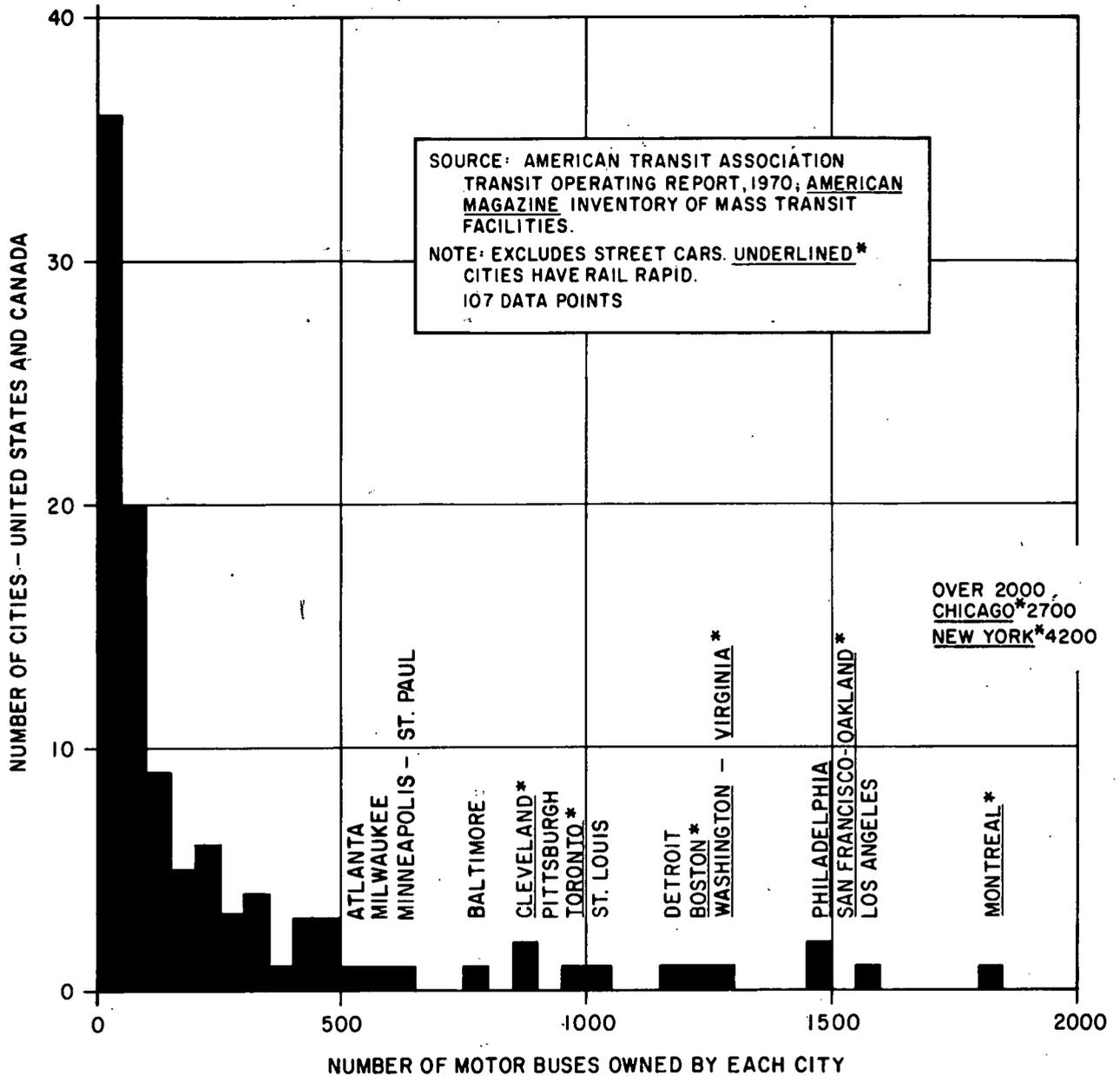


Figure 1. Bus fleet sizes, 1972.

Association; (6) the Transport and Road Research Laboratory (England); and (7) the International Union of Public Transport. City and state highway and transit agencies operating or planning bus priority treatments were interviewed. These agencies furnished valuable materials, insights, and observations. Major treatments were reviewed in the field. A detailed literature search provided additional information on bus priority treatments and on-going research. The materials and information were assembled and summarized for use in subsequent phases of the research.

The Interim Report

The interim report (1) contains the principal findings of the first five research tasks. It represents a selective overview

of the state of the art of contemporary bus priority practice. It analyzes existing and proposed bus priority treatments, reviews on-going research, identifies significant data gaps, and highlights research needs. It systematically classifies and assesses bus priority treatments in relation to (1) type, location, and status; (2) control methods and design standards; (3) daily and peak-hour use; (4) capital and operating costs; and (5) user and nonuser benefits. Experiences both in the United States and elsewhere are analyzed.

The Final Report

This report contains planning and design guidelines for bus priority treatments, presents the principal findings of the last four study tasks, and contains (1) significant bus design

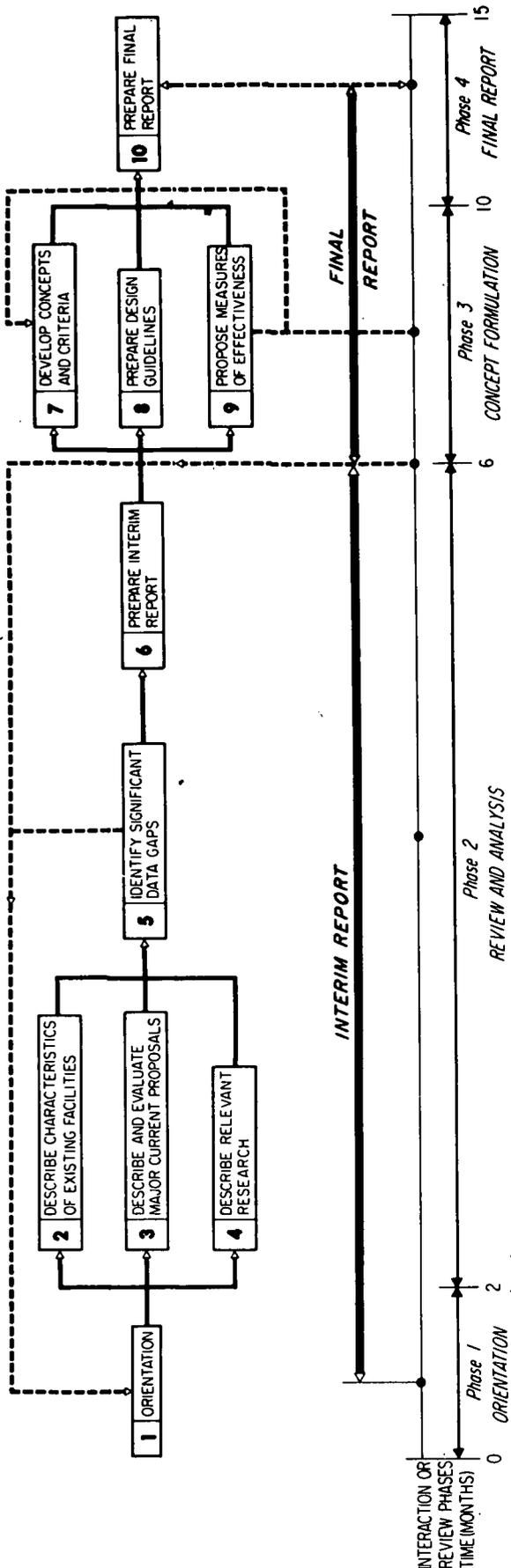


Figure 2. Project work program phases.

parameters, (2) concept and criteria, (3) planning and design guidelines for principal bus priority measures, and (4) measures of effectiveness associated with bus and highway facilities. The report is organized as follows:

Chapter One describes the context and the research plan.

Chapter Two discusses bus service planning; planning concepts, criteria, and warrants associated with bus priority facilities, including significant measures of effectiveness; and basic bus design considerations and parameters.

Chapter Three presents significant planning and policy implications.

Chapter Four sets forth detailed planning and design guidelines for freeway, arterial, and terminal-related bus priority treatments.

Appendices contain supporting materials.

The report, therefore, represents a manual on bus planning in relation to urban highways. It is designed to identify (1) when bus priority facilities are warranted, (2) how these treatments should be planned and designed, (3) how their effectiveness can be evaluated, and (4) what associated transport policies are essential.

The planning and design guidelines recognize that bus priority facilities become important when (1) economic or environmental conditions make it infeasible to provide additional highway capacity, and (2) there is an expressed desire to encourage public transport use. These factors should be recognized in application of the guidelines.

SUMMARY FINDINGS—STATE OF THE ART

The following summary of the state-of-the-art findings, condensed from the interim report (1) previously referred to, is given here to refresh the reader's memory concerning current practice in this field.

Bus priority treatments vary by type of treatment, number of people served, and design details utilized. Significant examples of bus priority treatments relating to freeways, arterials, and terminals are given in Table 1.

Existing freeway-related treatments include the San Bernardino (Calif.), Shirley Highway (Virginia), and Runcorn (England) Busways; contra-flow bus lanes on the Long Island Expressway (New York City), I-495 (New Jersey), Southeast Expressway (Boston), and U.S. 101 (Marin County, Calif.); a special bus ramp for Seattle's Blue Streak express bus service; and the bus-car pool bypass lanes at the San Francisco-Oakland Bay Bridge toll plaza.

Existing arterial street treatments include bus streets in Chicago, Minneapolis, and Paris; contra-flow bus lanes in San Juan, Louisville, San Antonio, and London; median bus lanes in New Orleans and Chicago; and curb bus lanes in most major cities.

Significant bus terminals include New York's Midtown and George Washington Bridge terminals, Chicago's 69th and 95th Street "bus bridges" over the Dan Ryan Expressway, Toronto's Eglinton Terminal, and Cleveland's extensive bus-rail-car interchange facilities.

Most bus priority treatments consist of reserved bus lanes on downtown city streets. Busways and other freeway-related treatments are relatively few in number. They are mainly found or proposed in large American cities, often

TABLE 1
SUMMARY OF THE STATE OF THE ART OF BUS PRIORITY TREATMENTS, 1974

TYPE OF TREATMENT	SIGNIFICANT EXAMPLES OF EXISTING TREATMENTS
1. <i>Freeway-Related:</i>	
A. Busways:	
1. Busway on special right-of-way	Runcorn, England, Busway
2. Busway on freeway, median or right-of-way	Shirley Busway, Washington, D.C., area San Bernardino Busway, Los Angeles
3. Busway in railroad right-of-way	None
B. Reserved lanes and ramps:	
1. Bus lanes on freeways, normal flow	9th Street Expressway, Washington, D.C.
2. Bus lanes on freeways, contra-flow	Southeast Expressway, Boston; I-495, New Jersey; Long Island Expressway, New York; US 101, Marin County, Calif.
3. Bus lane bypass of toll plaza	San Francisco-Oakland Bay Bridge
4. Exclusive bus access to non-reserved freeway (or arterial) lanes	Seattle Blue Streak express bus service and bus ramp.
5. Metered freeway ramps with bus bypass lanes	Harbor Freeway, Los Angeles
6. Bus stops along freeways	Hollywood Freeway, Los Angeles
2. <i>Arterial-Related:</i>	
A. Reserved lanes and streets:	
1. Bus streets	Nicollet Mall, Minneapolis; 63rd and Halsted Sts., Chicago
2. CBD curb bus lanes, normal flow	Washington, D.C.; Baltimore, Maryland
3. Arterial curb bus lanes, normal flow	Hillside Avenue, Queens, New York City; Connecticut Ave., Washington, D.C.
4. CBD median bus lanes, normal flow	Canal Street Neutral Ground, New Orleans; Washington Street, Chicago; 14th Street, Washington, D.C.
5. Arterial median bus lanes, normal flow	None
6. CBD curb bus lanes, contra-flow	Alamo Plaza, San Antonio
7. Arterial curb bus lanes, contra-flow	Ponce de Leon, Fernandez Juncos, San Juan
B. Miscellaneous:	
1. Bus signal preemption	Kent, Ohio
2. Special signalization	Cermak Road, Chicago
3. Special turn permission	"No Left Turn, Buses Excepted," Los Angeles
3. <i>Terminals:</i>	
A. Central-area bus terminals	Midtown Terminal, New York City
B. Outlying transfer terminals	Dan Ryan—69th Street bus bridge, Chicago; Dan Ryan—95th Street bus bridge, Chicago; Eglinton Terminal, Toronto
C. Outlying park-and-ride terminals	Lincoln Tunnel approach at I-495 contra-flow bus lane

with rail transit systems, large downtown employment, and heavy peak-hour transit use. These specialized treatments, however, are of greatest concern to public officials, for they involve larger expenditures and produce the most significant benefits.

An overview of contemporary practice discloses many significant factors. These include: ability to schedule busways for construction by stages, allowing service improvements to be inaugurated while parts of the facility are still being built; the value of clearly identifiable busways (the transit "image"); the development of busways at costs that are less than those for rail transit; the importance of parking at fringe transit stations; the suitability (or unsuitability) of specific freeways for bus service; the limited number of existing arterial bus lanes, although the number is increas-

ing; the need for (and enforcement problems associated with) curb bus lanes; the relatively small number of bus priority treatments that have been discontinued; and the problems of operating costs associated with providing peak-hour bus services.

Planning and Design Considerations

Bus priority treatments vary widely in planning philosophies; design concepts; operating policies; and their documentation of costs, patronage, and impacts. The most striking variabilities are found when busways and contra-flow lanes are compared. Standards for starting anew are viewed differently from those that optimize existing facilities. (For example, the I-495 contra-flow bus lane is 11 ft wide, whereas each San Bernardino Busway lane is 17 ft wide.)

Downtown Distribution

Distribution of buses in central areas remains an important challenge. Downtown and its approaches are among the few areas where buses can afford time advantages over automobiles. However, most current busway proposals (as well as existing treatments) provide good access to the CBD perimeter but do not substantially improve service within the downtown core. Many treatments rely on terminals or on-street distribution systems that in large measure duplicate service patterns and inefficiencies of former interurban railway lines.

Terminals are not always located near major employment concentrations, and may (as in Midtown New York) rely on secondary distribution systems; curb bus lanes do not appear to provide desired service levels; and the use of contra-flow downtown bus lanes remains to be tried. Elevated busways where proposed (i.e., Memphis, St. Louis) have not been accepted; and underground busways have not been provided because of construction complexity and costs.

Buses using the Shirley Busway, for example, experience their greatest delays in downtown Washington. The bus travel times required to leave downtown Washington to reach the Shirley Busway equal the travel times (15 min) from downtown to outer limits of rail transit lines in Boston, Chicago, and Cleveland.

The Runcorn New Town Busway (England) is a significant exception. The busway is elevated through the downtown area and is on surface, often with signal-controlled intersections, in outlying areas.

Conducive Factors

Successful freeway-related treatments implemented to date have served real, demonstrated needs. Implementation and operating costs were low relative to actual and perceived problems. They have attracted considerable use and have produced peak-hour travel time savings of 5 to 30 min. Savings compare favorably with those resulting from rail transit improvements and extensions.

These treatments are usually characterized by: (1) an intensively developed downtown area with limited street capacity and high all-day parking costs; (2) a long-term reliance on public transport; (3) highway capacity limitations on approaches to downtown; (4) major water barriers that limit road access to the CBD and channel bus flows; (5) fast nonstop bus runs for considerable distances; (6) bus priorities on approaches to or across water barriers; (7) special bus distribution within the CBD (often off-street terminals); and (8) active traffic management and operational programs. Major factors contributing to the success of the New York and San Francisco treatments have been (a) avoidance of downtown on-street bus operations and (b) coordination of several bus priority measures.

Most arterial bus priority treatments represent bus lanes in the CBD. They are too localized in extent and too sensitive to enforcement practices to produce major identifiable benefits to users and achieve substantial economies for bus companies. Moreover, most systematic measures of bus lane effectiveness are found in Europe; before-and-after studies in the United States have had limited statistical significance.

Data and Research Needs

There is a significant need for detailed information on downtown employment and peak-hour cordon crossing changes in many cities as they relate to bus priority proposals. Consistent peak-hour bus and passenger volume data for proposals are lacking. There is little correspondence in many cities between existing and proposed corridor volumes as they relate to downtown development trends and intensities. Simultaneously, there is need for greater clarity in downtown distribution proposals, because these will have an important bearing on costs, operational viability, and community acceptance.

Additional research is needed on (1) cost-effectiveness of existing measures; (2) operating and service consequences of new technologies; (3) underground bus operations; and (4) bus driver response to alternative design concepts.

CHAPTER TWO

FINDINGS

BUS SERVICE PLANNING

Planning for bus priority treatments should reflect the nature of bus service demands in relation to the capabilities of the vehicles themselves. Accordingly, this section highlights relevant bus service factors that have major bearing on the planning, design, and implementation of bus priority

treatments. These include demands, coverage, speed, and service coordination.

The Bus Transit Market

The reliance on and use of bus (and rail) transit varies widely among cities. Concentrations of population, land use, and employment—particularly in the city center and

the radial corridors leading to it—have major influence on transit patronage. Bus routes generally converge on the city center, where approximately 25 to 40 percent of all trips have their origins or destinations. Trips are typically 3 to 5 miles long and require 15 to 30 min travel time.

The downtown-oriented transit market has two major components, as follows:

1. The traditional transit market lies mainly within the central city. It involves trips between the CBD and older, intensively developed areas that surround the core. In most symmetrically developed metropolitan areas this market encompasses one-half or more of the urbanized area population within a 3- to 5-mile radius of the city center. These trips are largely oriented to arterial street local and express bus service. The high per capita CBD trip attraction and

the high transit use reflect (a) the relative attractiveness of the city center to close-in neighborhoods; (b) the high incidence of non-car-owning households in the central city; and (c) the higher population densities that permit greater bus service frequency.

2. The trips between the CBD and suburban communities are potential to express bus operations along freeways or special bus roadways. Many of these trips are made by residents of car-owning households. These suburb-to-CBD travelers represent an excellent market potential.

These patterns of decreasing CBD trip generation with increasing time-distance to the city center—generalized by Figure 3—are found in most cities. They are modified by the preference of CBD office employees to live in suburban areas and by the ease of access to the city center; they pre-

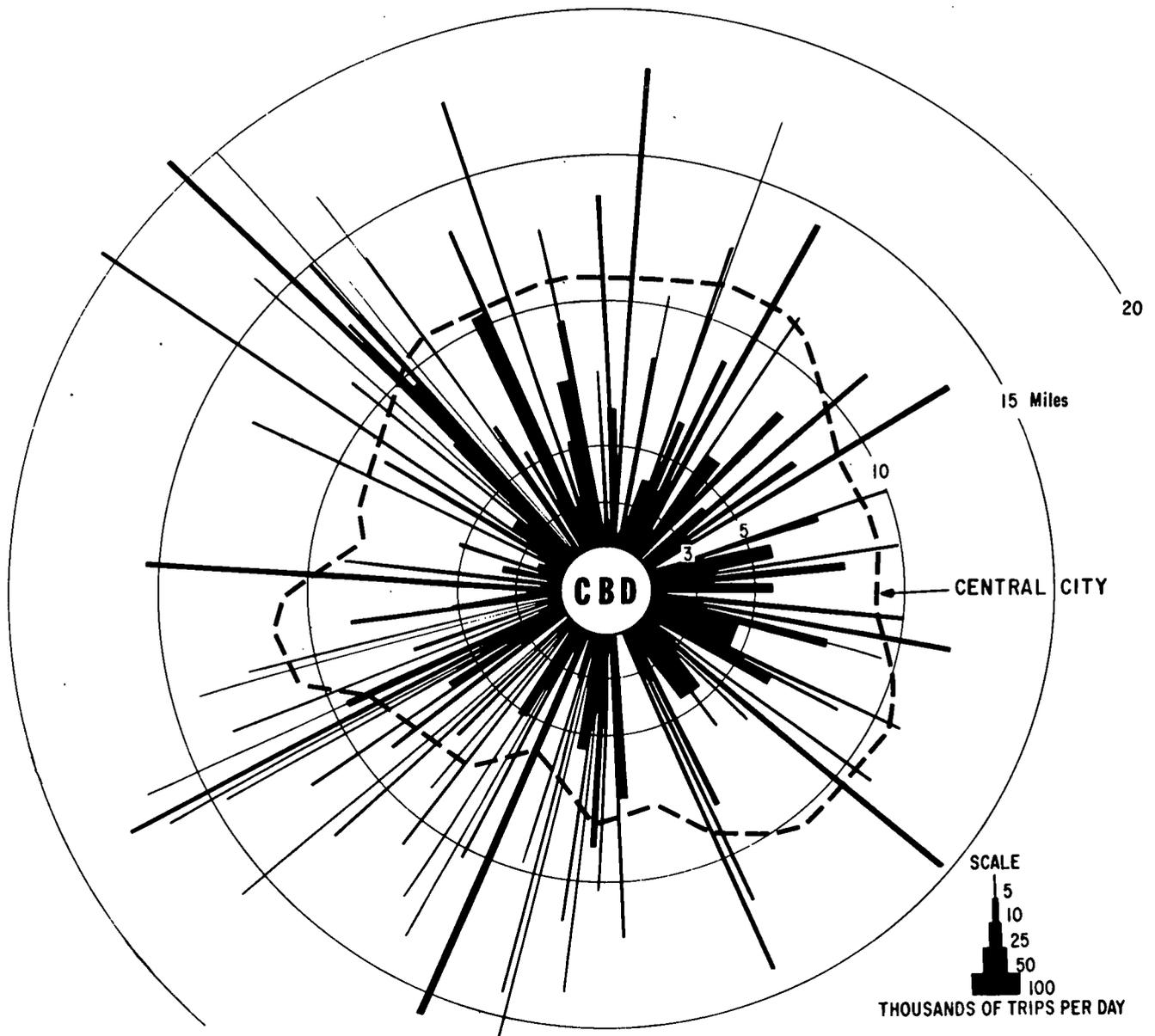


Figure 3. Projected person-trips to and from CBD by all modes of transportation in typical city of 3 million. (Source: Ref. 2).

vail even in the largest cities. Outlying areas are characterized by high automobile ownership, high income, and a CBD travel orientation that declines quickly as distance increases. This attraction is further reduced by land-use policies that encourage shopping centers, industrial parks, and office space in suburban locations.

Much of the reliance on bus transport by inner city residents relates to their economic and car availability status. Bus travel (10 to 12 mph) is usually twice as slow as car trips. Consequently, about three-fourths of all bus trips are made by "mode-dependent" (captive) travelers who have no driver's license and presumably no car (Table 2). The need to attract optional (or "choice") riders underlies the need for faster and more reliable bus service.

Bus Service Criteria

Planning guidelines for local and express bus service are presented in Table 3. Most cities of more than 25,000 can sustain some local bus service whereas express service generally requires an urban population of more than 250,000. Express service has greatest potentials in metropolitan areas of more than 1 million, where it may account for 25 to 30 percent of the total system mileage.

Routes and Coverage

Bus system planning should carefully relate service to existing and potential demands. Service should be concentrated in heavy-travel corridors; this implies greatest route coverage and service frequency on the approaches to the city center, with a thinning of service in suburban areas. Principal services generally should be radial, with crosstown (or circumferential) lines limited to larger cities. Express bus service should be provided mainly to the city center in a way that complements local bus routes and other public transport services. Route structure should be clear and simple, it should avoid excess varieties of service on a single street.

TABLE 2
OPTIONAL AND DEPENDENT TRANSIT TRIPS
IN SELECTED URBAN AREAS

AREA	YEAR	POPULATION	BUS TRIPS BY LICENSED DRIVERS (%)
Pittsburgh	1958	1,472,100	30 ^b
Chicago	1956	5,169,700	27 ^c
S.E. Wisconsin ^a	1963	1,644,000	30
Baltimore	1962	1,600,800	15
Springfield, Mass.	1965	531,000	17
Richmond, Va.	1964	417,600	20
Lehigh Valley, Pa.	1964	345,100	19
Columbia, S.C.	1964	196,000	13

^a Milwaukee.

^b Bus and street car.

^c 48 and 66 percent for rail rapid transit and suburban railroads, respectively.

Source: Origin-destination studies in each urban area.

Economic Constraints.—The best possible service should be provided the greatest number of people within the governing economic constraints: A standard 50-passenger air-conditioned bus costs about \$40,000 to \$50,000 at 1974 price levels, and operating costs range from about \$0.70 to \$1.30 per bus-mile, depending on system speed and wage rates. Labor usually represents about 65 to 75 percent of all operating costs. Consequently, costs are more sensitive to driver and equipment utilization than to vehicle size.

Viewed in this context, bus services require careful balancing of economics, costs, demands, schedule frequencies, route lengths, and garage locations. Community willingness to support marginal routes is an important element in establishing operating policies. Wage rates of \$4 to \$5 per hour cannot sustain average loadings of two or three passengers per bus-mile, except with high fare structures and/or operating subsidies.

Service Coverage.—Residential areas of more than four dwelling units per acre generally should be located within one-quarter mile walking distance of bus stops, and more sparsely populated areas within one-half mile. This results in a one-half mile spacing of bus routes in the more populated parts of the urban region. This desired spacing is not always possible because of the configuration of the street system, the interposition of physical barriers to continuous movement, and the occasional need to reach closer points of particularly heavy passenger travel demand.

Downtown Route Patterns.—Downtown bus routing should recognize factors such as the street pattern, major entry points, terrain, employment locations, and service frequency. Routes generally should be concentrated on key streets to provide a sense of "transit identity," although in large cities dispersed routing patterns may be necessary.

Through bus routing should be encouraged wherever operating conditions permit. Bus loops should be avoided because they tend to reduce service coverage, increase turning movements and conflicts, artificially overlap routes, and increase annual bus mileage and traffic conflicts. Routes that are linked together should be balanced in terms of lengths and service frequencies. They should also consider bus garaging requirements. Priority should be given to interconnecting short routes; through-routing of longer routes could complicate scheduling and operations.

Major downtown employment and shopping concentrations should be within 600 to 800 ft of a bus stop. The maximum waiting times along downtown streets served by a number of bus routes connecting major activity centers should not usually exceed 5 min during normal operating hours; average waiting times, 3 min. Headways on individual routes may be longer, depending on the number of routes combined.

Bus Rerouting Potentials.—Bus routes should be restructured in conjunction with bus priority treatments. Service should be concentrated in busways and bus lanes without excessively increasing walking distances. The maximum tolerable walking distance to local buses averages 1,300 to 1,500 ft (a 5- to 6-min walk). Thus, any bus that is rerouted more than 1,500 ft away from its original path will lose most of its walk-in patronage, although it may generate new trips on its new route.

TABLE 3
PLANNING GUIDELINES FOR URBAN BUS SERVICE

ITEM	LOCAL BUS SERVICE	EXPRESS BUS SERVICE
1. Minimum urban area population	25,000–50,000	250,000–300,000
2. Minimum CBD employment	Approximately 10,000	20,000–30,000
3. Minimum peak-hour peak-direction passengers per route-mile	15–20	30–50 for local service on surface street segment
4. User characteristics	Mostly mode-dependent, blue collar, low-income, senior citizens, students	Choice and mode-dependent, white collar, CBD employees, some professionals
5. Service objectives	Access within entire urban area with CBD focus	Rapid peak-period access to CBD, with emphasis on home-to-work trips
6. Route length, typical	Generally under 5 miles, minimum 1 mile	Five to 10 miles; express service for 3 or more miles
7. Route coverage	¼ mile of bus route, where residential densities exceed 4 dwellings per acre	¼ to ½ mile in local service areas
8. Access to bus stop	Pedestrian	Pedestrian, feeder bus, auto
9. Stop frequency	600–1,200 ft	¼ to 1 mile for intervals where stops are made in express zone
10. Maximum desired headways:		
Peak	10 to 15 min	20 min or less
Off-peak	10 to 30 min	May not operate
11. Over-all running speed:	10 to 12 mph	15 to 30 mph
Express only, on freeways	—	35 to 40 mph
Express only, on arterials	—	15 to 25 mph
12. Maximum door-to-door travel time, including transfers	45 min	45 min
13. Maximum accountable time difference by which bus can exceed car for door-to-door journey to attract choice trips	10 min	10 min
14. Minimum time advantage over local bus, excluding waiting and transfers	—	5 min

Source: Developed from information contained in Refs. (2) and (4).

Express Service Criteria

Express buses can utilize busways, freeways, or arterial streets. They can operate in mixed traffic on freeways where facilities are available, properly located, and relatively uncongested. They can utilize special reserved freeway lanes or bus roadways in congested areas. Arterial streets, especially with priority lanes, provide excellent potentials for express bus service. Express service on arterial streets is often more extensive than that provided over freeways (Fig. 4). However, service patterns vary widely among cities, depending on the availability and location of radial freeways.

Planning Guidelines.—Express bus service planning should reflect the following guidelines:

1. The CBD generally represents the primary area that can be served successfully with express buses. CBD employment should exceed 30,000. Occasionally an airport or outlying commercial center can be served, as well as special events at stadiums or sports arenas.

2. The journey to and from work usually represents the greatest proportion of express trips, and the system should be designed to meet this demand.

3. It is usually easier to draw patronage for a new express bus service from local buses than to get people to shift from automobiles. However, where service is competitive

with automobile travel, some diversion of motorists can be expected.

4. Express bus service on freeways should be offered in peak periods only, except in very large cities or under unusual circumstances. Express bus service on arterials can be provided during both base and peak periods.

5. Buses should operate at or near free-flow traffic conditions for all or most of their trips. The best routes are along busways, freeways, or other high-speed roadways where buses can travel quickly without congestion, once satisfactory passenger loads are achieved. Express bus service along arterial streets may be desirable where employment and population are clustered about major intersections and there is no freeway in the corridor.

6. Residential population densities should be high enough to generate a full or nearly full bus load with as few local service stops as possible. Unless there is a strong CBD orientation, fostered by express bus (or rail) service used in promoting an area's development, a gross density of about 7,000 to 10,000 persons per square mile is usually necessary to support direct express bus service. This density is common in older small-lot single-family developments, and is found in recent garden apartment and townhouse developments. At least 30 potential peak-hour CBD passengers per mile of route appear necessary for direct express bus service to a residential area.

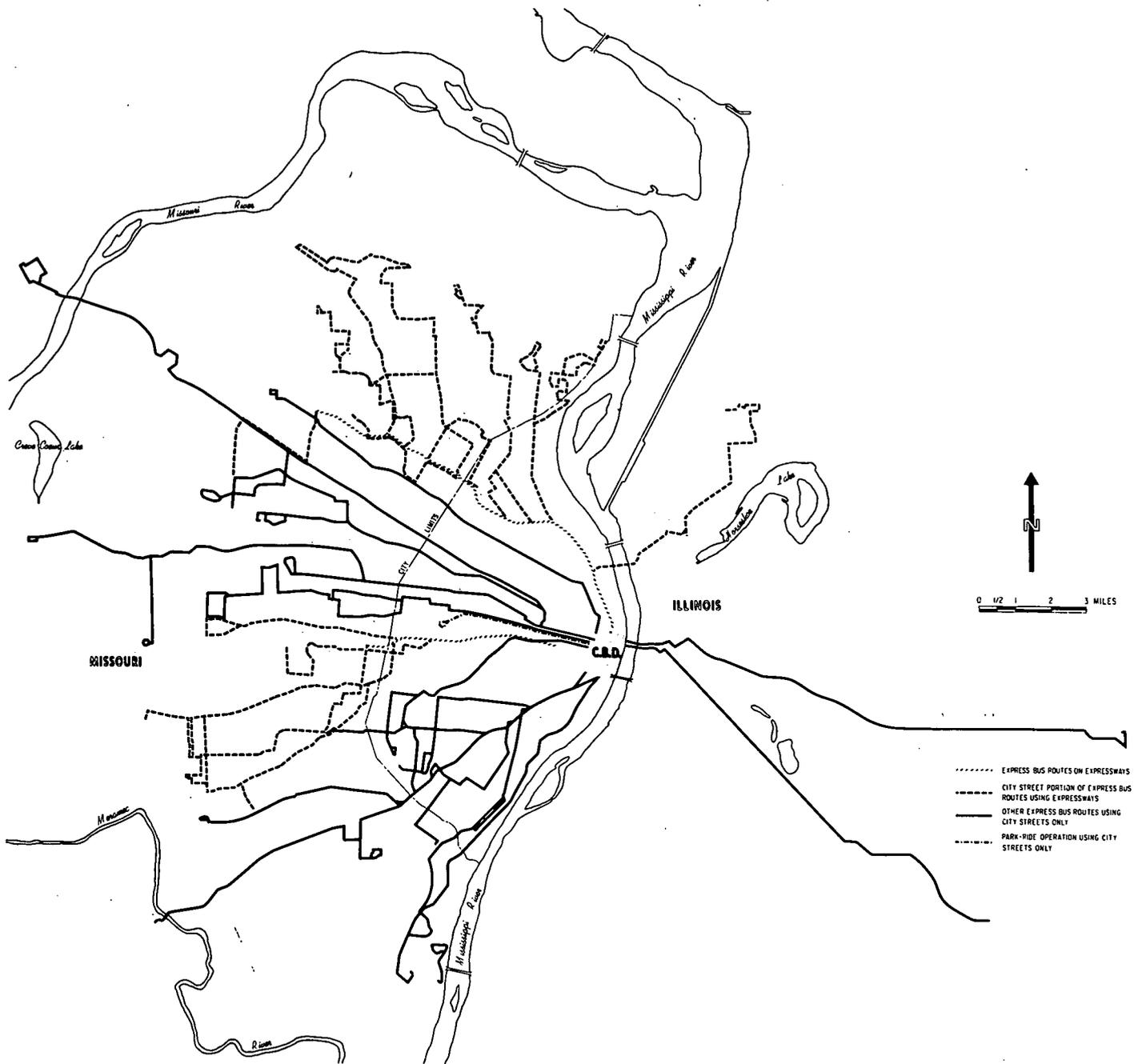


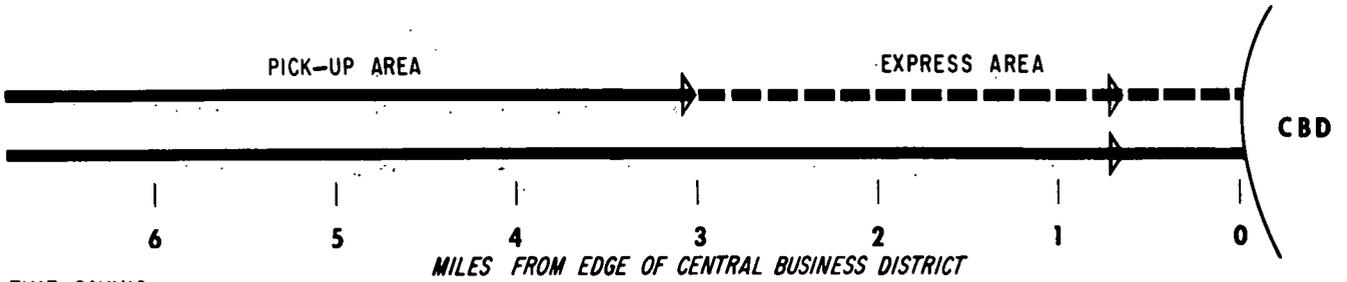
Figure 4. Bi-state express bus routes, St. Louis, 1972.

7. Express buses should save at least 5 min over local bus travel. This calls for a minimum 3-mile express bus run from the CBD. The time saved by express buses over locals operating on the same street is usually 1 to 2 min per mile (see Fig. 5). Where buses enter the downtown area, every effort should be made to give them preferential treatment to reduce delays and improve service dependability.

The extent to which 3- or 4-mile express runs can draw substantial patronage depends on: (1) the size and compactness of the group of transit patrons or potential transit patrons with CBD destinations to be served; (2) the avail-

ability of a busway, freeway, other type of limited-access highway, or multilane arterial street; (3) the assurance of reasonably free flow on that highway during weekday rush hours; (4) extensive congestion in the area to be bypassed (which makes it rewarding to avoid the surface streets); and (5) the practicality of bypassing a 3-mile annular ring around the CBD without creating demand for uneconomical duplication of bus services and without eroding existing local bus patronage.

Operating Concepts.—Operating concepts are shown in Figure 6. Express bus services on busways, freeways, and



TIME SAVING

LOCAL BUS (————) 3 MILES @ 10 MILES PER HOUR = 18 MINUTES
 EXPRESS BUS (-----) 3 MILES @ 15 MILES PER HOUR = 12 MINUTES
 SAVING 6 MINUTES

Figure 5. Potential express bus time savings. (Source: Ref. 2).

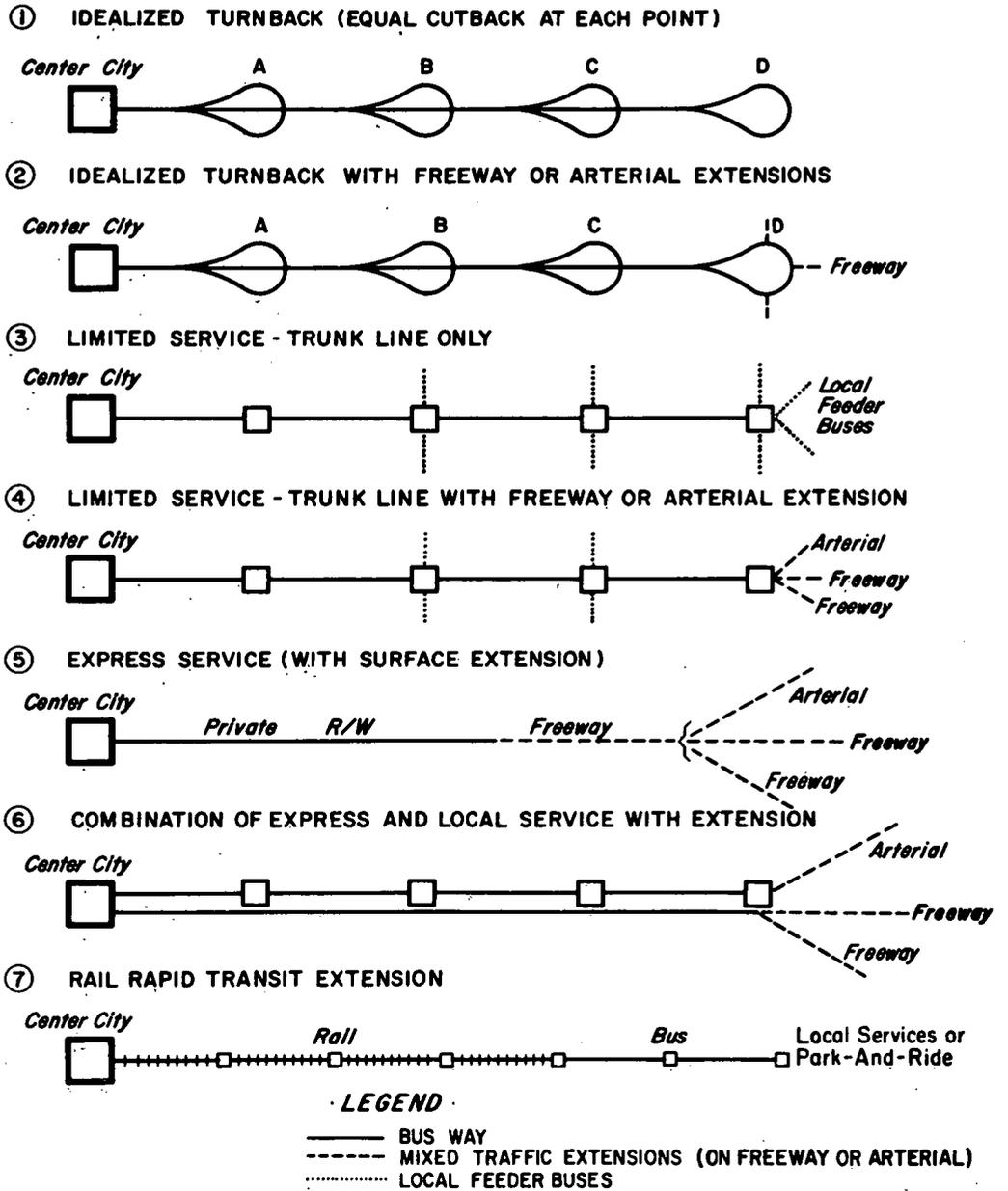


Figure 6. Bus rapid transit operating concepts.

arterial streets can use (1) a single vehicle that provides combined line-haul and distribution functions or (2) separate vehicles for express (line-haul) and local (collection-distribution services). Buses may operate nonstop or with limited stops; they may operate directly to the city center or serve as extensions of rail rapid transit lines. The choice of operating pattern will depend on passenger demand levels, operating economics, facility design, and service area characteristics.

- Local distribution should be as pedestrians in high-density areas, by bus in medium density areas, and by car in low-density areas.

- Local feeder buses are viable where (1) line-haul conditions require a simplified route structure, (2) operating characteristics in collection-distribution areas limit service dependability, and (3) transit patterns have been well established.

- Neighborhood collection and distribution by express buses involves a balancing of three operational objectives: (1) providing an acceptable headway (no more than 15 to 20 min in the peak hour, preferably under 10 min); (2) filling buses with passengers before the point of express operations is reached, and (3) minimizing the time spent in local street operations.

Operating Speeds.—Express bus service on city streets and urban freeways is essentially faster than the typical local bus speeds of 10 to 12 mph (Table 4). Terminal-to-terminal speeds of many express bus routes range up to 40 mph and compare favorably with rail transit speeds.

Illustrative time differences for typical door-to-door trips by local bus, express bus, and rail rapid transit are summarized in Table 5, which clearly identifies the effects of stop spacing and transfers on total journey items. Compu-

tations assume 12 mph for local bus service, 15 to 18 mph for express bus service, and 24 mph for rail rapid transit. Local bus service is faster than either express bus or rail transit operations for trips of less than 2 miles. As distances increase, there is a corresponding time savings in express transit travel. In the 2-to-5-mile trip length range, express bus and rail transit can achieve comparable time savings over local bus operations.

High express bus speeds are essential to attract patrons and to achieve operating economies. Doubling bus speeds from 10 to 20 mph would reduce operating costs about one-third, because both labor and equipment costs would be reduced in proportion to the increases in speed.

PLANNING CONCEPTS AND CRITERIA

This section sets forth the basic concepts, criteria, and principles that underlie bus priority measures and bus service improvements. It shows how the demands for bus service, highway service deficiencies, and bus priority potentials interrelate. It presents warrants for preferential bus facilities, contains illustrative planning examples, and suggests measures of effectiveness.

Basic Planning Principles

Planning for new bus priority facilities calls for realistic assessment of demands, costs, and impacts. The basic objective is to select and apply the appropriate types of treatment for specific urban situations. Implicit in the selection process are: (1) the intensity and growth prospects of the city center; (2) the present and potential future reliance on public transport; (3) the suitability of existing streets and expressways for bus service; (4) the extent of present and future overloads on the expressway system, including the ability to meet these demands by new road construction; and (5) public attitudes toward streets, parking, and bus transit.

Planning should (1) balance investments with demands; (2) identify the extent of capital-intensive bus priority facilities either in their own right or as an alternative to rail lines; (3) distinguish between building new facilities and more effectively managing existing facilities; (4) establish bus routing concepts that achieve operating economies through better scheduling and simplified station designs; (5) apply warrants that are realistic in terms of present and future needs; (6) develop basic road design standards that are conducive to bus use; and (7) adopt busway design standards that are scaled to the nature and requirements of bus operations.

The following principles are basic:

1. Bus priority treatments should maximize person flow with minimum net person delay over the long run. In some cases, environmental or land-use considerations may make it desirable to optimize bus flows.

2. The extent of capital investment and the amount of bus service provided should bear a reasonable relationship to existing and potential demands.

3. Warrants for the installation of various bus priority treatments should allow widespread, yet meaningful, application. They should reflect the preceding objectives and

TABLE 4
EXPRESS BUS SPEEDS ON URBAN FREEWAYS

CITY	NUMBER OF ROUTES WITH RUSH-HOUR SPEED DATA	RANGE IN TERMINAL- TO- TERMINAL RUSH-HOUR SPEED (MPH)
Atlanta	11	15-19
Baltimore	1	26
Chicago	2	13-23
Cleveland	6	17-26
Dallas	14	13-21
Detroit	6	12-24
Houston	11	14-24
Los Angeles	19	13-28
Milwaukee	6	28-42
Minneapolis-St. Paul	6	18-29
New York-New Jersey	59	11-34
Philadelphia	7	17-24
St. Louis	15	14-20
San Francisco-Oakland	11	21-32
Seattle	7	16-25

Source: Adapted from Tables A-1 and A-2 of Ref. (1).

TABLE 5
COMPARATIVE TOTAL JOURNEY TIMES FOR VARIOUS TRANSIT MODES

ITEM	JOURNEY TIME (MIN) FOR DISTANCE OF					
	1 MILE	2 MILES	3 MILES	4 MILES	5 MILES	10 MILES
Local bus:						
Walk to bus stop ^a	1.5	1.5	1.5	1.5	1.5	1.5
Wait for bus ^b	2.5	2.5	2.5	2.5	2.5	2.5
Ride bus (12 mph)	5.0	10.0	15.0	20.0	25.0	50.0
Walk to destination	2.0	2.0	2.0	2.0	2.0	2.0
Total time	11.0	16.0	21.0	26.0	31.0	56.0
Express bus (nonstop):						
Walk to bus stop ^c	3.0	3.0	3.0	3.0	3.0	3.0
Wait for bus ^b	2.5	2.5	2.5	2.5	2.5	2.5
Ride bus (15 mph)	4.0	8.0	12.0	16.0	16.5 ^d	33.0 ^d
Walk to destination	2.0	2.0	2.0	2.0	2.0	2.0
Total time	12.5	15.5	19.5	23.5	24.0	40.5
Rail rapid transit:						
Walk to shuttle bus stop ^a	1.5	1.5	1.5	1.5	1.5	1.5
Wait for shuttle bus ^e	5.0	5.0	5.0	5.0	5.0	5.0
Ride shuttle bus ^f	0.8	0.8	0.8	0.8	0.8	0.8
Wait for rapid transit ^g	1.0	1.0	1.0	1.0	1.0	1.0
Ride rapid transit (24 mph)	2.5	5.0	7.5	10.0	12.5	25.0
Walk to destination	3.0	3.0	3.0	3.0	3.0	3.0
Total time	13.8	16.3	18.8	21.3	23.8	36.3
Time savings:						
Express/local bus	-1.5	+0.5	+1.5	+2.5	+7.0	+14.5
Rapid transit/local bus	-2.8	-0.3	+2.2	+4.7	+7.2	+19.7

^a Assumes walk of 200 ft, or one-fourth of 800-ft stop spacing.

^b Assumes headway of 5 min.

^c Assumes walk of 400 ft.

^d Assumes 18 mph for 5- and 10-mile trips.

^e Assumes headway of 10 min.

^f Assumes ride of 950 ft, or one-fourth the 3,800-ft distance between stations.

^g Assumes headway of 2 min.

Source: Adapted from Ref. (8).

should not be unduly restrictive in relation to actual urban needs.

4. Bus priority treatments should be viewed as a system of measures that is designed to improve the speed and schedule dependability of bus flow. Express and local bus services should be carefully coordinated with proposed treatments.

Minimizing Person Delay

Efficient use of urban highways calls for maximum person flow with minimum net person delay over the long run. This can be achieved by (a) optimizing total person flow and, in some cases, (b) optimizing bus flow. The latter may be desirable in anticipation of a long-term shift to bus transit, or in response to CBD development or environmental policies. Both objectives may contrast with the goal of maximizing vehicle flow. Both call for a system of bus priority improvements.

A bus priority treatment generally reflects one of the two basic strategies shown in Figure 7, as follows:

1. Treatments involving new facilities through a high travel intensity corridor generally produce a strong sense of transit identity and can help achieve desired land-use

impacts. They usually involve substantial capital investments. Most busways fall into this category (for example, the Runcorn and Shirley Busways, and Pittsburgh's proposed PATways). Arterial street bus lanes, such as proposed for Houston, St. Louis, and Washington, also reflect this objective, but do not involve major costs.

2. Treatments involving development of bus priorities upstream and/or through bottleneck areas usually produce a high level of service efficiency with relatively small investments. They are designed to improve operations through major delay areas and are generally provided upstream of the bottleneck area. Most reserved bus lanes and special bus bypass ramps on freeways reflect this concept (for example, the contra-flow bus lanes on approaches to New York's Midtown and Lincoln Tunnels; Seattle's Blue Streak bus operations; and the bus bypass lane on the San Francisco-Oakland Bay Bridge approach).

Bus priority planning should clearly differentiate between facilities that (1) add a bus lane to existing highway capacity in the flow direction of travel and (2) preempt a highway lane in the heavy direction of travel for bus use (Fig. 8). Freeway bus priority treatments mainly apply the former; arterial treatments, the latter. The exclusive use of existing peak-direction freeway lanes by buses should be

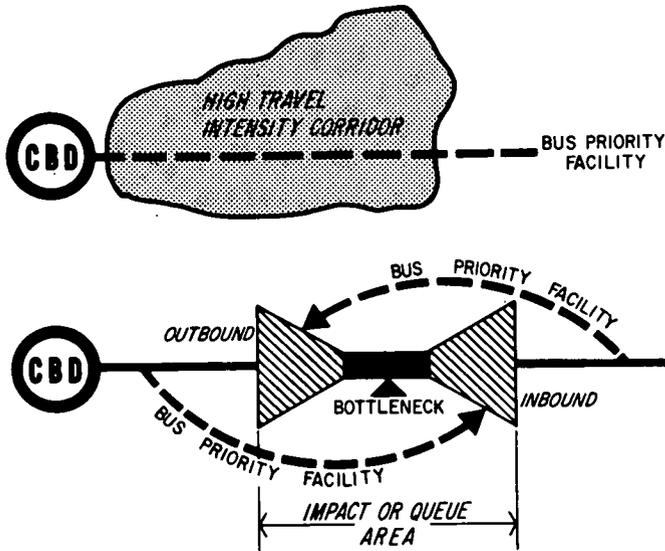


Figure 7. Bus priority concepts.

limited to conditions where environmental policy calls for reducing CBD auto travel.

Inbound bus priority treatments are relatively the most important, because travelers make their choice of mode primarily on the basis of the relative time and cost of the home-to-work trip. The return trip home may be secondary; time constraints are usually less severe than at the work arrival point. Moreover, a car not driven to work cannot contribute to congestion on the homeward journey.

Relating Improvements to Demands

Measures that achieve shared operations and maximize person-flow efficiency by bus and car have widespread application (i.e., metering of freeway ramps, effective enforcement of curb parking regulations, and traffic engineering improvements along bus routes). Treatments that optimize bus flow, per se, will be limited to larger urban areas—and will closely relate to downtown employment intensities. The existing and potential proportions of CBD travel by bus in specific corridors will influence the extent to which buses should be given priority over cars.

Extensive capital investments in public transport traditionally have been limited to the heaviest travel corridors in the largest urban areas. The traditional demand-investment hierarchy for public transit includes, in order of ascending demand: (1) dial-a-bus, (2) fixed-route local bus, (3) fixed-route express and local bus services, (4) busway development, (5) light rail rapid transit (or “personal rapid transit”), and (6) rail rapid transit.

This basic principle also applies to bus priority treatments (Fig. 9). Capital-intensive bus priority facilities in most American cities depend on aggregating sufficient volumes of transit passengers to sustain the investments required in a particular corridor. It is usually more an issue of identifying sufficient transit potentials than one of overcoming capacity deficiencies. This suggests major emphasis on operational treatments rather than physical construction wherever conditions permit.

Bus Priority Sequence.—The general sequence of bus priority treatments, in order of ascending travel demands, is as follows:

1. Existing highway use should be optimized through

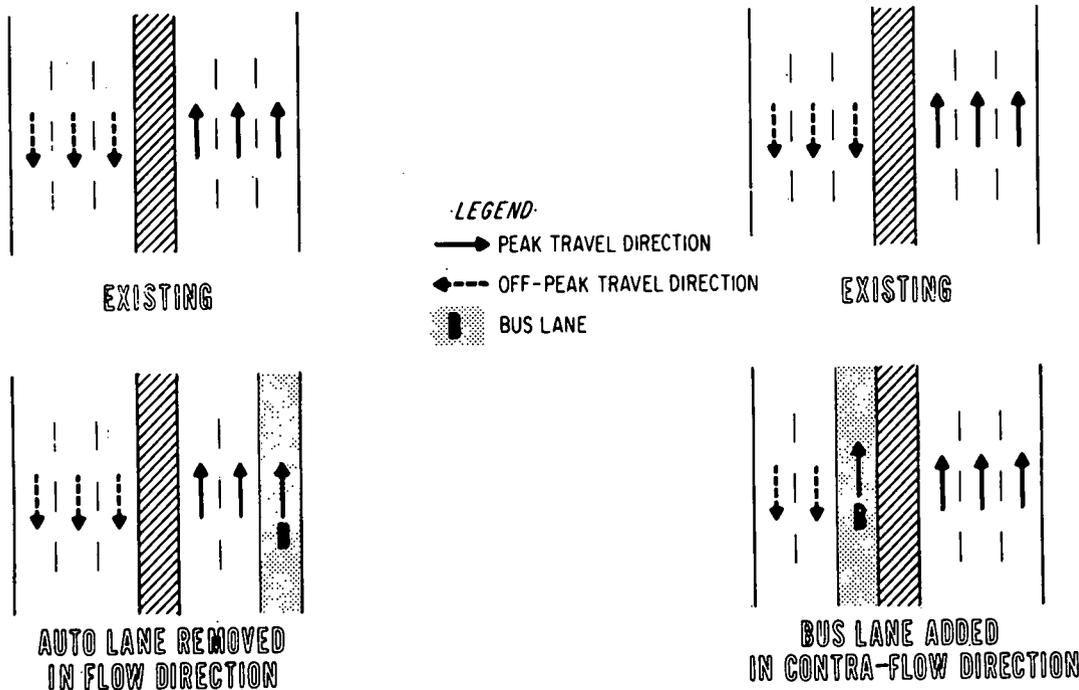


Figure 8. Bus lane options.

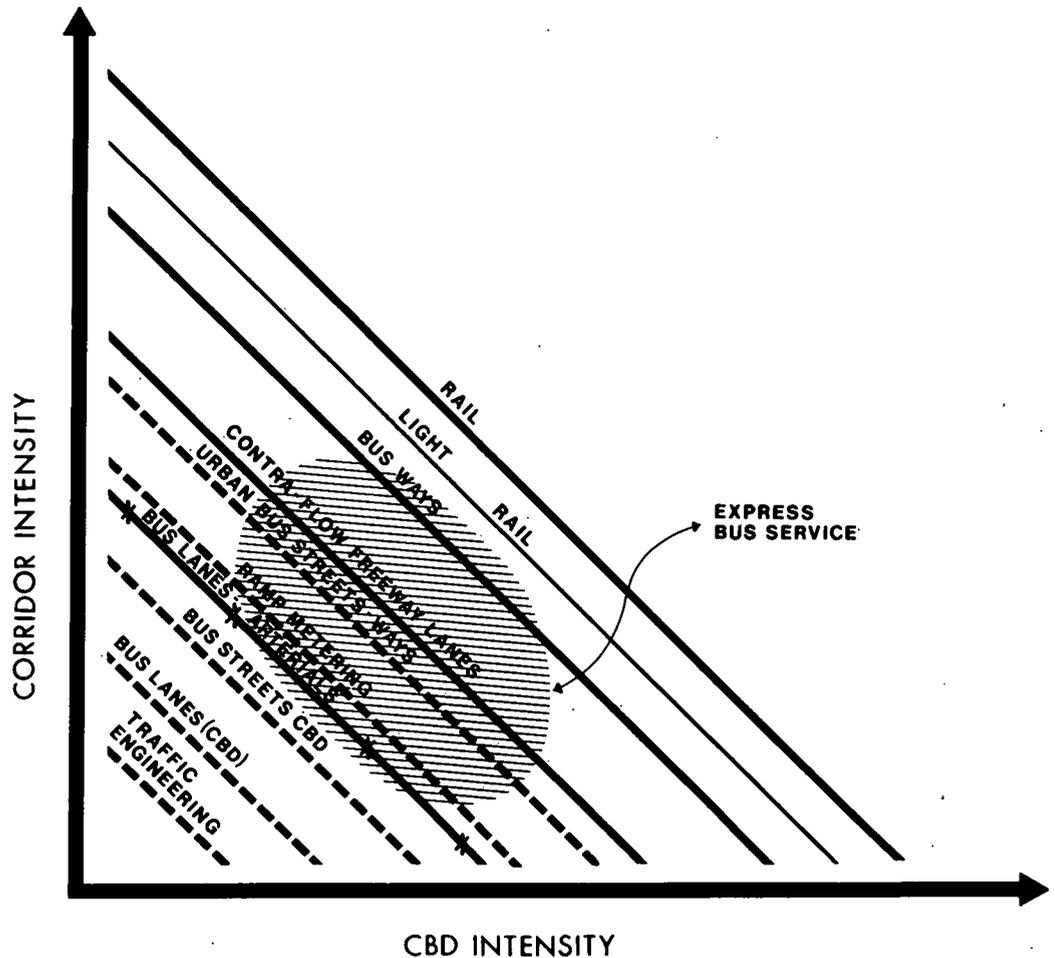


Figure 9. Bus priority topology.

traffic operations improvements, including construction. Where highway capacity and downtown parking capacity are not feasible for economic, environmental, or other reasons, emphasis should be placed on bus priority improvements in conjunction with improved bus services. (Arterial street bus lanes, for example, have widespread application.)

2. Freeway ramps should be metered, with bypass lanes provided for buses. Bus and car pool parking lots should be provided at strategic locations.

3. Contra-flow bus lanes should be installed on freeways where sufficient bus volumes are aggregated, roadway conditions permit, and traffic volume imbalances exist. Similarly, bus lanes could be installed along arterial and downtown streets.

4. Short busways that serve as "queue-jumpers" should be developed to link contra-flow lanes with terminals or to bypass congested areas.

5. Busways should be constructed where location and design conditions preclude contra-flow operations on freeways or freeway development (for example, where stations are required to serve adjacent areas, or where freeways bypass tributary traffic areas). Busways can be developed in stages, with interim operations on freeways and arterial streets.

Downtown Intensity Factors.—The heaviest travel concentrations are, and will continue to be, in the corridors that serve the central business district. Bus and rail services mainly operate to the city center, and there are strong interrelationships between service frequency and downtown land-use intensity (3).

Accordingly, land use, employment, and travel intensities in major American central business districts have been summarized in Tables 6 and 7. These tables provide a broad-gauged guide in appraising the relative potentials of rail and bus transit, and serve as a benchmark against which demand forecasts for bus priority treatments should be assessed. The information contained in these tables should be an integral part of any bus or rail rapid transit proposal.

Depending on the number of CBD approaches that serve the urbanized area, principal travel corridors will develop varying intensities of traffic demand under different conditions of population growth and downtown employment. A relatively small population spread along a narrow river valley, or hemmed in between mountains and water, can generate corridor volumes that equal or exceed those in larger, symmetrically developed urban areas.

Based on the preceding travel characteristics in American cities, it has been possible to model peak-hour corridor travel. Generalized ranges in peak-hour peak-direction cor-

TABLE 6

SELECTED CHARACTERISTICS OF AMERICAN CENTRAL BUSINESS DISTRICTS

1970 CENSUS RANK	URBANIZED AREA	1970 POPULATION (MIL.)		1970 CENTRAL CITY POP. DENSITY (PERSONS/ SQ MI)		YEAR OF O-D SURVEY	CENTRAL BUSINESS DISTRICT						
		URBAN- IZED AREA	CENTRAL CITY	CBD AREA (SQ MI)	EMPLOY- MENT (1,000's)		FLOOR SPACE (MIL. SQ FT)	DAILY PERSON-TRIP DESTINATIONS		DESTINATIONS/ SQ MI			
								NO. (1,000's)	PERCENTAGE BY	ALL MODES	AUTOS ONLY		
1	New York—NE New Jersey	16.207	7.895	26,343	9.0 ^a	1963	1,777	800	1,300	5	95	1,300	66
					2.0 ^b	1963	1,000	241	—	—	—	—	—
					1.0 ^b	1963	500	—	—	—	—	—	—
2	Los Angeles—Long Beach, Calif.	8.351	2.816	6,073	0.6 ^c	1960	130	42	158	45	55	250	114
					2.0 ^d	1966	176 ^e	76	—	—	—	—	—
3	Chicago—NE Indiana	6.715	3.367	15,126	1.1	1956	300	92	466	29	71	439	128
4	Philadelphia—New Jersey	4.021	1.949	15,164	2.2	1960	225	124	389	41	59	177	73
5	Detroit, Mich.	3.971	1.511	10,953	1.1	1953	114	50	253	56	44	234	132
						1974	—	—	62	65	35	—	—
6	San Francisco—Oakland, Calif.	2.988	0.716	15,764	2.2	1965	282	88	423	63	37	192	71
7	Boston, Mass.	2.653	0.641	13,936	1.4	1963	246	—	400	50	50	290	145
						1972	263	96	—	—	—	—	—
8	Washington, D.C.—Maryland— Virginia	2.481	0.757	12,321	4.5 ^f	1955	315	—	442	57	43	98	43
					1.7 ^g	1955	212	—	266	55	45	156	86
9	Cleveland, Ohio	1.960	0.751	9,893	1.0	1963	117	47	123	59	41	123	73
10	St. Louis, Mo.—Illinois	1.883	0.622	10,167	0.8	1957	119	39	125	53	47	178	95
11	Pittsburgh, Pa.	1.846	0.520	9,422	0.5	1958	84	32	154	49	51	308	151
						1969	100	—	—	—	—	—	—
12	Minneapolis—St. Paul, Minn.	1.704	0.434	8,135	0.9	1958	90	—	188	73	27	209	153
13	Houston, Tex.	1.678	1.231	3,102	0.9	1953	—	—	141	69	31	157	109
						1960	120	—	113	80	20	125	100
14	Baltimore, Md.	1.580	0.906	11,568	0.8	1962	78	33	130	54	46	162	88
15	Dallas, Tex.	1.339	0.844	3,179	0.54 ^c	1964	—	—	—	—	—	—	—
					1.50 ^e	1964	135	31	164	86	14	109	94
16	Milwaukee, Wis.	1.252	0.717	7,548	0.9	1963	—	31	104	66	34	115	76
17	Seattle—Everett, Wash.	1.238	0.531	6,350	0.6	1961	60	27	126	71	29	210	167
18	Miami, Fla.	1.220	0.335	9,763	—	1964	28	12	35	73	27	—	—
20	Atlanta, Ga.	1.173	0.497	3,779	0.6	1961	75	30	94	72	28	156	112
21	Cincinnati, Ohio—Kentucky	1.111	0.452	5,794	0.5	1965	—	35	113	71	29	220	156
22	Kansas City, Mo.—Kansas	1.111	0.502	2,101	0.9	1957	65	—	107	70	30	118	82
23	Buffalo, N.Y.	1.087	0.463	11,205	0.9	1962	48	28	104	67	33	115	77
24	Denver, Colo.	1.047	0.515	5,406	0.5	1959	50	24	105	80	20	210	167
27	Phoenix, Ariz.	0.863	0.582	2,346	0.7	1957	21	—	65	89	11	93	83
53	Nashville—Davidson, Tenn.	0.448	0.436	1,305	0.6	1959	34	—	64	79	21	110	87

^a Manhattan. ^b Midtown. ^c Core. ^d Cordon area. ^e 1966. ^f Zero sector. ^g CBD.
Source: O-D studies in each urban area.

ridor travel in symmetrical cities with strong downtown areas are given in Table 8. Express bus service potentials are also identified.

The heaviest corridor is assumed to attract 25 to 35 percent of the total CBD approach volumes. Where cities have major physical barriers, or imbalances in trip orientation, the indicated values should be adjusted accordingly. Thus,

for "half a city" the express bus potentials would be double the values shown. Other factors include:

1. Corridor express bus volumes are relatively light until the urban population approaches 1 million. At this population range, peak-hour bus volumes in the heaviest corridor would range from 30 to 60.

TABLE 7

CENTRAL BUSINESS DISTRICT CORDON COUNTS, UNITED STATES

1970 CENSUS RANK	URBANIZED AREA	1970 URBANIZED AREA POPULATION	YEAR OF COUNT	PEAK-HOUR ONE-WAY PERSONS			PEAK ACCUMULATION ^a		
				(1,000's)	PERCENT BY		(1,000's)	PERCENT BY	
					AUTO	TRANSIT		AUTO	TRANSIT
1	New York, N.Y.	16,206,841	1971	805	8	92	2,056	NA	NA
2	Los Angeles, Calif.	8,351,266	1970	99	69	31	148	67	33
3	Chicago, Ill.—Ind.	6,714,578	1971	210	19	81	283	14	86
4	Philadelphia, Pa.-N.J.	4,021,066	1955	177	29	71	210	23	77
5	Detroit, Mich.	3,970,584	1974	39	68	32	62	65	35
6	San Francisco-Oakland, Calif.	2,987,850	1959	130 ^b	45 ^b	55 ^b	165	NA	NA
7	Boston, Mass.	2,652,575	1972	143	50	50	195	38	62
8	Washington, D.C.	2,481,489	1961-62	138	65	35	NA	NA	NA
9	Cleveland, Ohio	1,959,880	1970	50 ^b	56	44	92	41	59
10	St. Louis, Mo.	1,882,944	1957	62	58	42	89	50	50
11	Pittsburgh, Pa.	1,846,042	1963	56	54	56	94	40 ^b	60 ^b
13	Houston, Tex.	1,677,863	1965	57	80	20	60	88	12
14	Baltimore, Md.	1,579,781	1955	67	56	44	119	66	34
15	Dallas, Tex.	1,338,684	1964 ^c	62 ^c	81 ^c	19 ^c	86 ^c	84 ^c	16 ^c
			1971 ^d	50 ^d	72 ^d	28 ^d	64 ^d	72 ^d	28 ^d
20	Atlanta, Ga.	1,172,778	1962	31	55	45	NA	NA	NA
21	Cincinnati, Ohio	1,110,514	1962	35	70	30	NA	NA	NA
24	Denver, Col.	1,047,311	1962	31	76	24	38	57	43
26	New Orleans, La.	961,728	1966	36	56	40	55	54	46

^a NA = Not available.

^b Estimated.

^c Larger CBD area.

^d Cordon around core area.

Source: Cordon counts in each urban area.

TABLE 8

PEAK-HOUR TRAVEL DEMAND IN HEAVILY TRAVELED CORRIDORS ON APPROACH TO A STRONG CBD (Symmetrical City)^a

ITEM	VALUE FOR URBAN AREA POPULATION OF			
	250,000	500,000	1,000,000	2,000,000
CBD destinations/day (persons)	40,000	80,000	135,000	225,000
PM peak-hour outbound across cordon (persons)	16,000	32,000	54,000	100,000
Heaviest corridor, 25 to 35 percent (persons)	4,000-5,600	8,000-11,000	13,500-19,000	25,000-33,000
Percent transit	10-15	25-35	40-50	50-65
Number of transit passengers	400-800	2,000-3,300	5,400-8,500	12,500-21,300
Percent express bus transit of total transit	10-15	15-20	25-35	35-50
Express bus transit (persons)	40-120	300-660	1,350-2,900	4,400-10,600
Equivalent buses at 50 pass. per bus	1-3	6-12	27-58	88-212

^a For city with major barriers or imbalances in trip orientation multiply values by 360/x, where x = degrees in city. Thus, for one-half a city, the express bus transit potentials would be: 6, 24, 116, and 424 respectively. Source: Adapted from Table 1 of Ref. (3) and Table A-9 of Ref. (4).

2. When urban population approaches 2 million, heaviest-corridor peak-hour bus volumes would range from 90 to more than 200. The higher part of this range represents rail as well as bus transit potentials.

Bus-Rail Potentials and Tradeoffs.—By using the characteristics of American cities with rail transit as a guide, it is possible to postulate circumstances under which rapid transit is desirable. Broad-gauged “pre-conditions” for rail and bus rapid transit are given in Table 9. These threshold values should reflect specific local conditions, preferences, needs, and opportunities.

Factors of downtown intensity and corridor demands also influence the decision to construct busways as a complement to, or substitute for, rail transit lines, as follows:

1. Rail transit systems operate in cities where urban population exceeds 2 million, downtown employment exceeds 100,000, and PM peak-hour corridor movements usually exceed 75,000.

2. Busway development will generally require lesser threshold conditions—minimum design-year criteria of 750,000 urban population, 50,000 CBD employment, and 35,000 people leaving the CBD in the peak-hour are suggested. These correspond to Downtown Denver’s 1974 employment and cordon movements.

The choice of bus or rail rapid transit will be influenced by comparative cost and service factors. Both year-by-year operating expenses and capital (investment) cost factors must be carefully included in any analysis of system alternatives and, in turn, related to the operational practicability of the system.

Conditions under which busway development is preferable—i.e., is more economical than rail systems—will vary

among cities, and will reflect a wide range of assumptions. These “tradeoff” or “break-even” points between bus and rail systems depend primarily on the comparative operating and capital costs for specific conditions. They will be influenced by (1) the amount and types of physical construction (surface, subway, elevated), (2) peaking factors, (3) operating speeds, (4) wage rates, and (5) driver productivity.

Many “cost models” have been developed in an attempt to compare rail and bus rapid transit costs systematically. These models often have been theoretical and do not fully reflect the practical operating realities of a given transportation facility. Moreover, many cost comparisons usually show relatively small differences among modes—differences that can be inverted by modifying basic assumptions (see, for example, Refs. (6) and (7)).

In comparing options it is essential that each alternative (1) constitute an operationally viable system; (2) serve comparable peak-hour passenger loads; (3) provide comparable service in terms of route length, line-haul operating speeds, station stops, CBD distribution, and feeder service; and (4) utilize comparable types of construction (3).

Typical break-even points for bus and rail transit, based on recent studies, are summarized in Table 10. These break-even points show wide ranges reflecting various assumptions as to bus capabilities, peak-to-base service ratios, operating and construction costs, interest rates, and driver wages. The higher labor productivity (lower operating costs) of rail operations tends to counterbalance the high initial investments in rail systems where heavy peak-hour volumes are to be carried. The cost per car-mile in Chicago and Cleveland is about 10 to 15 percent less than the cost per bus-mile. The Lindenwold Line carries 171 daily pas-

TABLE 9
GENERAL CONDITIONS CONDUCIVE TO URBAN RAPID TRANSIT DEVELOPMENT
—DESIGN YEAR

PRIMARY DETERMINANT	DESIRED CONDITION FOR SYSTEM DEVELOPMENT		
	RAIL	RAIL OR BUS	BUSWAY ^a
1. Urban area population	2,000,000	1,000,000	750,000
2. Central city ^b population	700,000	500,000	400,000
3. Central city ^b population density (people/sq mi)	14,000	10,000	5,000
4. High-density corridor development	Extensive and clearly defined ^c	Limited but defined	Limited but defined
5. CBD function	Regional	Regional or sub-regional	Regional or sub-regional
6. CBD floor space (sq ft)	50,000,000	25,000,000	20,000,000
7. CBD employment	100,000	70,000	50,000
8. Daily CBD destinations per square mile	300,000	150,000	100,000
9. Daily CBD destinations per corridor	70,000	40,000	30,000
10. Peak-hour cordon person movements leaving the CBD (four quadrants)	75,000–100,000	50,000–70,000	35,000

^a Minimum requirement.

^b “Effective central city,” including the central city and contiguously developed areas of comparable population density.

^c Depends on land-use assumption.

Source: Adapted from Ref. (5).

sengers per employee; Shirley Highway (Va.) express buses carry 52 daily passengers per employee (10).

Below 2,000 to 4,000 passengers per hour (which can be accommodated in 40 to 80 standard buses at an average of 50 passengers per bus) buses clearly dominate on a mile-for-mile basis. The 6,000-persons-per-hour value represents the approximate capacity of a bus lane with on-line stations, 20-sec average station stops, and 30-sec headways between buses. This volume, of course, is considerably below the 20,000 to 30,000 passengers per hour that buses can (and do) accommodate where special downtown terminals are provided.

Both these analyses and current operating experience suggest break-even points in the 4,000- to 6,000-persons-per-hour range in the United States. According to Parkinson (11), surface bus service is inefficient in its use of labor and road space above 8,000 persons per peak hour in the peak direction. However, in special cases—where minimum underground construction is involved—higher break-even points (up to 12,000 persons per hour) have been cited. Deen and James (7) indicate that “rail systems can demonstrate cost superiority where peak-hour passenger volumes exceeding 12,000 must be carried and/or where more than 20 percent of the system requires subways. At volumes of 4,000 peak-hour passengers, and where no subways are required, buses show cost superiority.”

Cost comparisons should compare specific systems in specific cities and should relate to the services afforded and the benefits derived. Busway development has cost and service advantages when:

1. A relatively small amount of special construction is required to achieve regional express transit.
2. Contra-flow bus lanes, bus streets, or existing bus terminals can provide effective downtown distribution, thereby obviating the costs of below-ground construction.
3. Utilization of buses for light-volume conditions reduces the need for special power distribution, train control, and rail yard facilities.
4. Busways can be effectively utilized by trucks or high-occupancy vehicles during selected periods of the day.
5. Busways can form the first-stage development of an eventual rail system.

It should be clearly recognized that buses may provide equivalent service to rail with a lower mileage of special grade-separated facilities (buses can also operate on freeways and arterial streets, in mixed-traffic and/or specially reserved lanes). Where most system mileage is in mixed-traffic or special bus lanes, and only short sections of special busways are needed, express bus systems may prove to be the more economical option.

Establishing Warrants

Warrants for bus priority treatments should clearly identify (1) when and where capital investments for various types of bus priority treatments are justified and (2) conditions under which auto traffic lanes should be preempted for bus service. The objective is to identify a realistic range for bus priority facilities that can complement, rather than compete with, other transportation investments.

TABLE 10

SOME REPORTED TRADE-OFF POINTS BETWEEN BUS AND RAIL RAPID TRANSIT

SOURCE	PEAK-HOUR ONE-WAY PASSENGER VOLUME	REMARKS AND ASSUMPTIONS
Ref. (9)	2,000 to 5,000	Mile-for-mile comparison. Busway uses 36-ft roadway on 48-ft right-of-way. One station per mile on both facilities. Relatively high operating costs (based on New York City Transit and San Francisco data).
	3,000 to 6,000	Same except that 28-ft busway roadway and 32-ft right-of-way are assumed.
Ref. (4)	About 7,500	Depends on unit construction costs below 7,500 passengers per hour. Unless construction costs are substantially higher for rail, rail is less expensive above 7,500 (assumed capacity of bus lane).
Ref. (7)	4,000 to 12,000 ^a	Maximum headways of 5 min, both rail and bus. Various percentages of subway assumed. Rail preferred when subway percent exceeded 20 at volume as low as 4,000 per hour. Compared on equal mileage basis. Articulated 60-ft buses assumed.

^a With no subway.

The underlying principle in formulating warrants for bus priority treatments is whether an exclusive bus lane or busway will carry more people than the same lane when used by cars during the peak travel periods. The number of bus riders in this lane should at least equal the number of auto occupants in the adjoining lane. In the case of freeway and arterial bus lanes the warrant should apply during the hours the lanes are in effect. For busways, the lanes should be based on peak-period travel. This principle should be modified to reflect desired downtown parking, transport, and development policy objectives; air quality standard objectives; and the ability of other streets to carry potentially displaced traffic. Modification of existing warrants is necessary to allow more widespread application of bus priority treatments.

Tentative warrants were established for various bus priority treatments using this principle as a guide. These warrants are summarized in Table 11. They are also discussed in greater detail as they relate to specific bus priority facilities.

The warrants attempt to achieve (1) simplicity, (2) uniformity, (3) applicability, (4) measurability, (5) replicability, and (6) flexibility. They are multidimensional in nature. They are expressed in terms of peak-hour buses and passengers; however, other relevant factors are also noted. For example, in the case of busways, downtown intensity parameters (as presently cited) are significant.

TABLE 11
GENERALIZED APPLICABILITY OF BUS PRIORITY TREATMENTS

TYPE OF TREATMENT	GENERAL APPLICABILITY TO:			DESIGN-YEAR CONDITIONS		RELATED LAND-USE AND TRANSPORTATION FACTORS
	LOCAL BUS SERVICE	LIMITED-EXPRESS BUS SERVICE	PLANNING PERIOD (YEARS)	RANGE IN ONE-WAY PEAK-HOUR BUS VOLUMES	RANGE IN ONE-WAY PEAK-HOUR PASSENGER BUS VOLUMES	
<i>Freeway Related:</i>						
Busways on special right-of-way	x	x	10-20	40-60	1,600-2,400	Urban population, 750,000; CBD employment, 50,000; 20 million sq ft of floor space.
Busways within freeway right-of-way		x	10-20	40-60	1,600-2,400	Freeways in corridor congested in peak hour.
Busways on railroad right-of-way	x	x	5-10	40-60	1,600-2,400	Not well located in relation to service area. Stations required.
Freeway bus lanes, normal flow		x	5	60-90	2,400-3,600	Applicable upstream from lane-drop. Bus passenger time saving should exceed other road-user delays.
Freeway bus lanes, contra-flow		x	5	40-60	1,600-2,400	Freeways 6 or more lanes; where imbalance in traffic volumes permits level of service D in off-peak travel directions.
Bus lane bypass at toll plaza		x	5	20-30	800-1,200	Adequate reservoir on approach to toll station.
Exclusive bus access ramp to nonreserved freeway or arterial lane	x	x	5	10-15	400-600	
Bus bypass lane at metered freeway ramp		x	5	10-15	400-600	Alternate surface street route available for metered traffic. Express buses leave freeways to make intermediate stops.
Bus stops along freeways		x	5	5-10	50-100 ^a	Generally provide at surface street level in conjunction with metered ramp.
<i>Arterial Related:</i>						
Bus streets	x	x	5-10	20-30	800-1,200	Commercially oriented frontage.
CBD curb bus lanes, main street	x		5	20-30	800-1,200	Commercially oriented frontage.
Curb bus lanes	x		5	30-40	1,200-1,600	At least 2 lanes available for other traffic in same direction.
Median bus lanes	x	x	5	60-90	2,400-3,600	At least 2 lanes available for other traffic in same direction; ability to separate vehicular turn conflicts from buses.
Contra-flow bus lanes, short segments	x		5	20-30	800-1,200	
Contra-flow bus lanes, extended	x	x	5	40-60	1,000-2,400	At least 2 lanes available for other traffic in opposite direction. Signal spacing greater than 500-ft intervals.
Bus turnouts	x		5	10-15	400-600	Points of major passenger loadings on streets with more than 500 peak-hour autos using curb lane.
Bus preemption of traffic signals	x		1-5	10-15	400-600	Wherever not constrained by pedestrian clearance or signal network constraints.
Special bus signals and signal phases, bus-actuated	x		1-5	5-10	200-400	At access points to bus lanes, busways, or terminals; or where special bus turning movements must be accommodated.
Special bus turn provisions	x		1-5	5-10	200-900	Wherever vehicular turn prohibitions are located along bus routes.

^a Boarding or alighting passengers in peak hour.

A bivariate approach is suggested in applying warrants. The warrants should be based on future design-year corridor demands, and at the same time they should consider base-year conditions. This allows flexibility for the future, and simultaneously safeguards against unrealistic demand forecasts. That is,

1. The warrants should apply to design-year conditions. Design years (planning horizons) should range from 5 years for operational treatments to 20 years for busways.
2. Seventy-five percent of the warrants should apply to current conditions—i.e., existing and divertible buses.

Use of design-year as well as base-year data recognizes the ability of bus priority treatments to attract bus patronage. This is readily apparent from the growth in ridership in the Shirley Busway south of Shirlington Circle from 1,900 morning peak-period riders in 39 buses in September 1969 to 8,600 riders in 177 buses in November 1972 (Table 12). This growth clearly indicates that existing ridership alone is not necessarily a sufficient criterion for determining the feasibility of bus priority treatments.

Off-street bus facilities in the city center should be considered wherever it is not possible to provide effective on-street distribution. They will generally be applicable for peak-hour volumes of 60 or more buses, in CBD's where bus speeds are less than 6 mph, and where the intensively congested area extends for more than a mile.

The warrants allow busways to be developed for conditions considerably below those specified for rail transit. The range in warrants is realistic when compared to peak-hour bus volumes across downtown cordons (Fig. 10). In most cities, fewer than 400 buses cross the CBD cordon in peak hours—an average of 100 per quadrant. If arterial and freeway bus priority measures are to have widespread application, the basic warrants must be below these values.

TABLE 12

GROWTH IN SHIRLEY BUSWAY PATRONAGE:
RIDERSHIP SOUTH OF SHIRLINGTON CIRCLE

DATE	MORNING PEAK-PERIOD	
	RIDERSHIP ^a	BUS TRIPS ^a
Sept. 1969	1,900	39
Apr. 1971	3,403	66
Dec. 1971	5,967	112
July 1972	7,045	148
Nov. 1972	8,630	177

^a On that portion of the roadway opened since September 1969.
Sources: Northern Virginia Transportation Commission, Urban Mass Transportation Administration, Virginia Department of Highways.

System Planning Examples

Bus priority treatments should be developed as a system of improvements that permit fast, continuous bus travel at minimum capital cost. This system will involve a combination of treatments designed to meet specific urban needs—a system that fully recognizes the ubiquity of bus transport. Parts of the system may involve special bus rights-of-way; other parts may call for preferential use of city streets, or for operation in mixed traffic. Within this context, priority treatments should be concentrated (1) in the central business district, (2) on principal approaches to the downtown area, and (3) at other points of major congestion. The location, planning, and design of new express highways should make provisions for bus service, particularly in urban areas of more than 1 million population.

No single bus priority should be pursued to the exclusion of others over all bus routes. A workable strategy must clearly take into account the varying applicability of com-

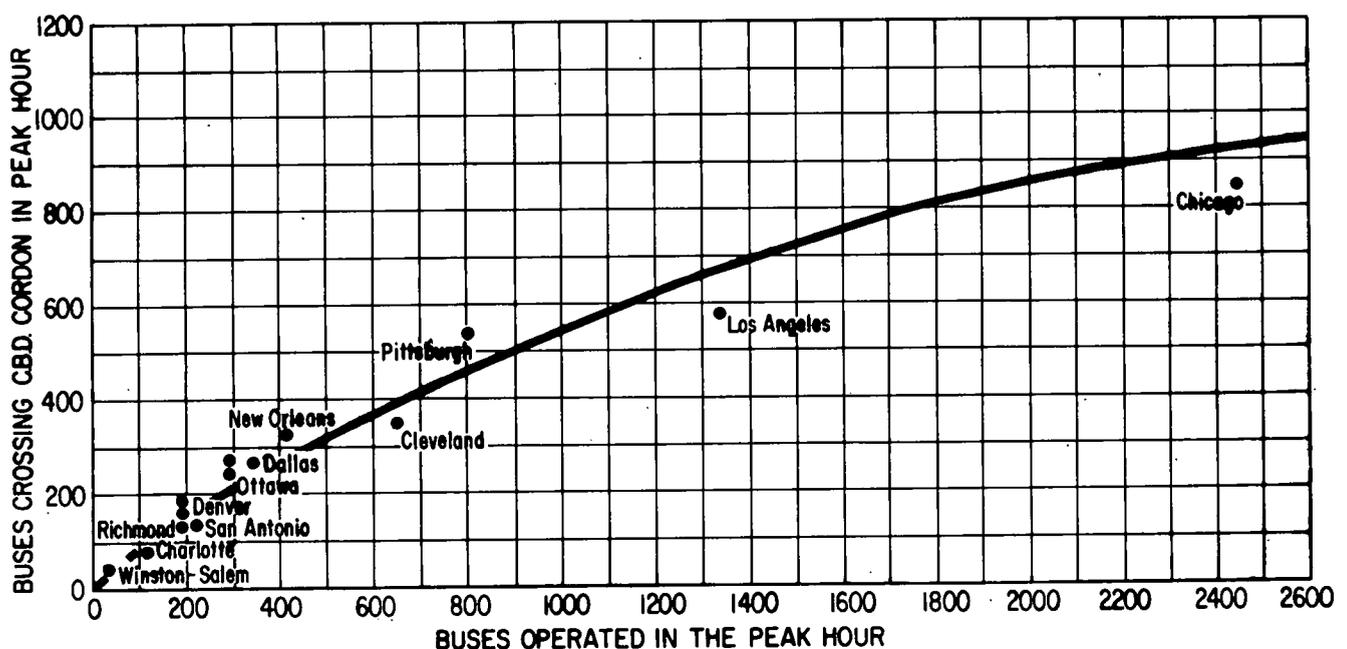


Figure 10. Number of buses entering CBD in peak hour.

ponents to the different parts of a highly complex, and often intensively used, road network. It must be flexible and continually monitored, leaving open the opportunity to modify goals and methods in the light of experience (12). Improvements to a single bus route might include:

- A new traffic signal to permit buses to enter an arterial road from a local street.
- A special turning lane and advance signal phase to permit the buses to turn left.
- A special ramp to gain entry to a freeway.
- A reserved bus lane on a portion of a freeway.
- Bus-actuated signal preemption to enter a downtown CBD street.
- Bus lanes on downtown streets.
- Lengthened bus-stop zones in the city center.

Typical examples show how combinations of bus priority measures can achieve the necessary continuity of bus flow:

- Figure 11 shows how contra-flow lanes, arterial street curb bus lanes, and bus preemption of traffic signals can improve linehaul services in urban areas within the 50,000- to 250,000-population range.
- Figure 12 shows how arterial street median bus lanes, special bus bypass lanes at metered ramps, and outlying park-ride facilities can improve express bus service in urban areas within the 250,000- to 1,000,000-population range.
- Figure 13 shows how bus bypass lanes at toll stations, combined with contra-flow expressway lanes and CBD bus lanes, can facilitate express bus service in medium-sized metropolitan areas with toll roads or toll bridges.
- Figure 14 shows how busway development can be coordinated with special bus ramps, contra-flow bus lanes, arterial street bus lanes, and outlying parking terminals.

Measuring Improvement Effectiveness

Bus priority measures should benefit (1) the general community, (2) the urban traveler, and (3) the transit operating agency. They should be designed to (a) produce additional capacity in high-density corridors, (b) reduce travel times and person-delay, and (c) increase patronage. Maintaining or increasing patronage can reduce road and parking costs. Certain bus priority treatments may also benefit land development.

The effects of bus priority measures—particularly those of an incremental nature—on commercial core vitality are difficult to isolate, although some benefits may be apparent in terms of environment or amenity. Similarly, it may be difficult to identify and assess the impacts on urban development patterns and land use because these impacts may be overshadowed by exogenous social and economic influences.

Suggested effectiveness measures for highway and bus transportation focus on costs, patronage, and travel times—all measurable parameters. Most other service goals (i.e., environmental quality, energy conservation, and land development) can be satisfied only if bus patronage is increased.

Statistical Analysis

In evaluating improvement effectiveness, it is essential to collect relevant data on bus and car travel times and occupancies, accident experiences, and observance of basic regulations. These observations provide a basis for systematically monitoring, assessing, modifying, and optimizing bus priority treatments.

Scientific and systematic measurements should be made of bus and vehicle performance before and after priority treatments are installed. "Before" and "after" measurements should utilize appropriate statistical techniques. Both means and variances of key parameters should be obtained. Standard significance tests should determine the significance of differences between means. Variance ratio (F) tests

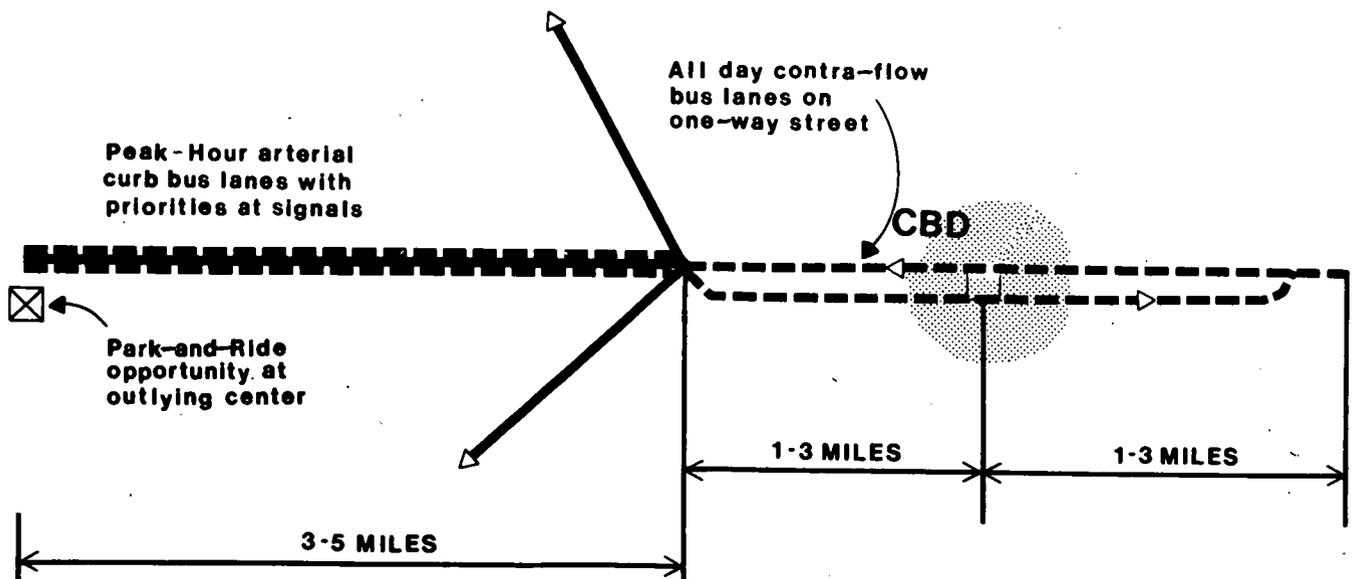


Figure 11. Bus priority treatments and system integration, small metropolitan area (50,000-250,000).

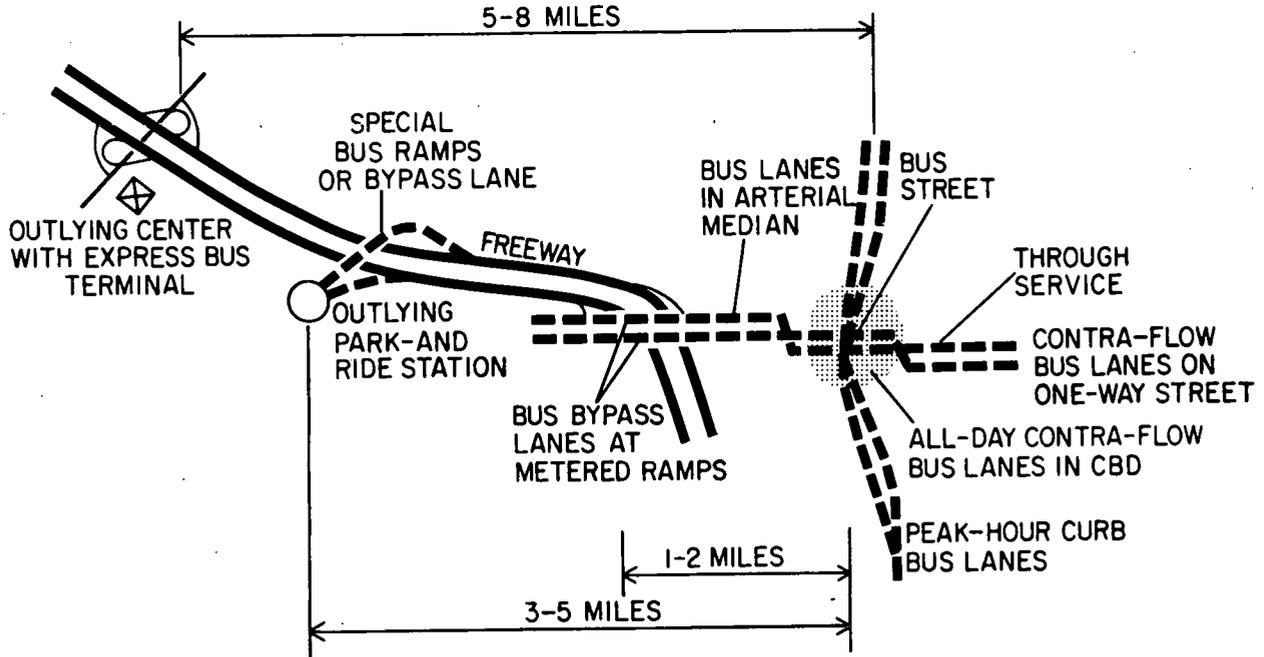


Figure 12. Bus priority treatments and system integration, medium-size metropolitan area (250,000-1,000,000).

should identify the significance of changes in variance, especially where measures of bus schedule adherence or travel times are concerned and service reliability is being assessed.

Suggested Effectiveness Measures

The nature and application of particular effectiveness measures should depend on the type of treatment being analyzed. Capital-intensive treatments, such as busways, should be analyzed in far greater detail than bus lanes along arterial streets. Cost and patronage factors, as well as travel time savings, for example, are necessary in assessing busway effectiveness. Similarly, reductions in the mean and variance of bus journey times should be analyzed for bus lane and bus street developments. The attendant reductions in bus fleet requirements and operating cost changes should be identified for both types of improvement.

The various effectiveness measures are designed to identify (1) the passenger volumes assumed by improved bus service, (2) the time saved by these passengers, and (3) the corresponding reductions in highway travel. These benefits, in turn, should be compared with the cost and community impact associated with the bus priority improvement. The benefits derived from any specific bus priority treatment should bear a reasonable relationship to the costs involved.

Minimizing Person-Delay.—The simplest effectiveness measure is to compare the aggregate person-minutes saved (or lost) by a given bus priority measure. These comparisons are especially valuable where freeway or arterial bus lanes are being assessed. An illustrative comparison is given in Table 13.

Investment Utilization.—Where capital-intensive bus priority treatments are involved, comparisons should be made of costs and use. The persons carried per dollar of invest-

ment should be computed on both a daily and a peak-hour basis.

$$U = \frac{P}{C_a K} F \quad (1)$$

in which:

- U = investment utilization index;
- P = number of passengers served;
- C_a = capital cost;
- K = capital recovery factor; and
- F = factor to convert costs and patronage to a daily or peak-hour basis.

The cost per passenger served represents a more effective criterion than the cost per unit of capacity, because realization of capacity is usually more significant than its availability.

Investment Effectiveness.—The effectiveness of bus (or highway) improvements is perceived differently by various interests. The transit company is concerned primarily with changes in operating costs, whereas the transit user is primarily concerned with the changes in travel time and service quality. The community is concerned with time, operating costs, and capital costs.

The annual person-minutes saved per dollar of investment provides a basic benchmark by which over-all improvement effectiveness can be assessed. It is defined as

$$I = \frac{P(t_1 - t_2)}{K C_a + (O_2 - O_1)} = \frac{P \Delta t}{K C_a + \Delta O} \quad (2)$$

in which:

- I = investment efficiency index;
- P = number of passengers served;

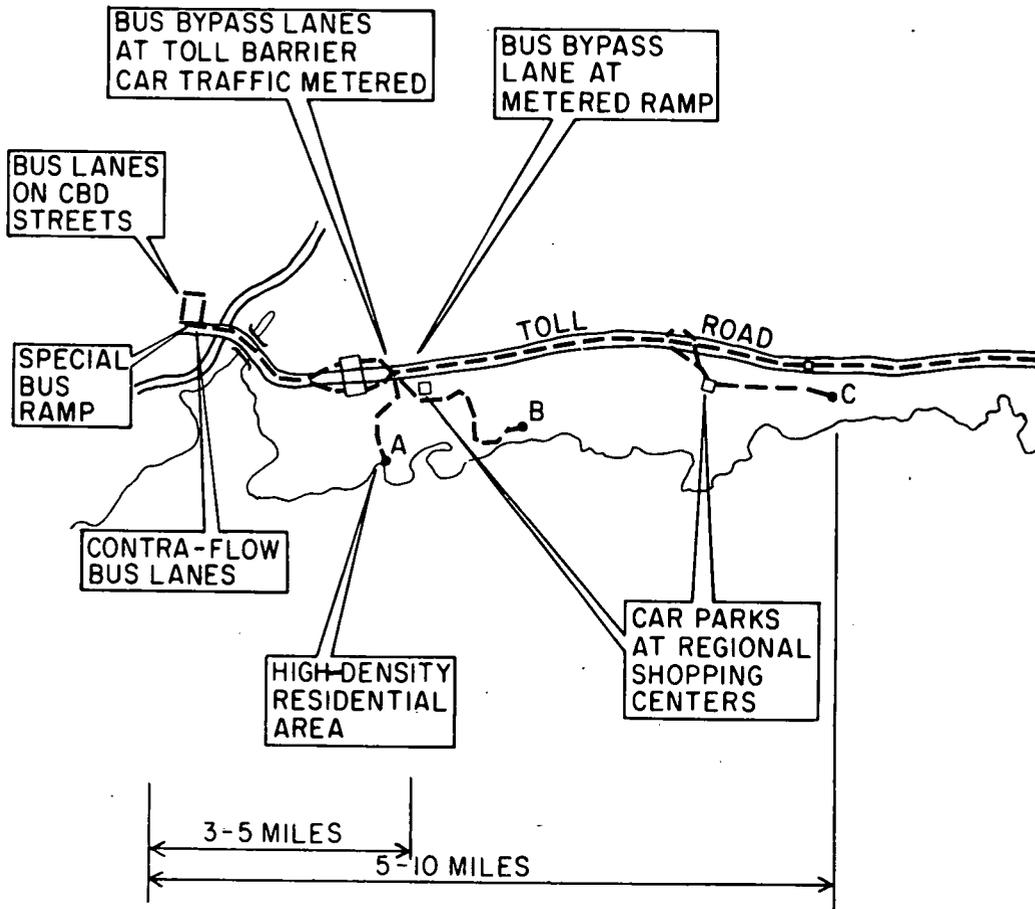


Figure 13. Bus priority treatments and system integration, medium-size metropolitan area (250,000-1,000,000) with toll road and direct freeway access to CBD.

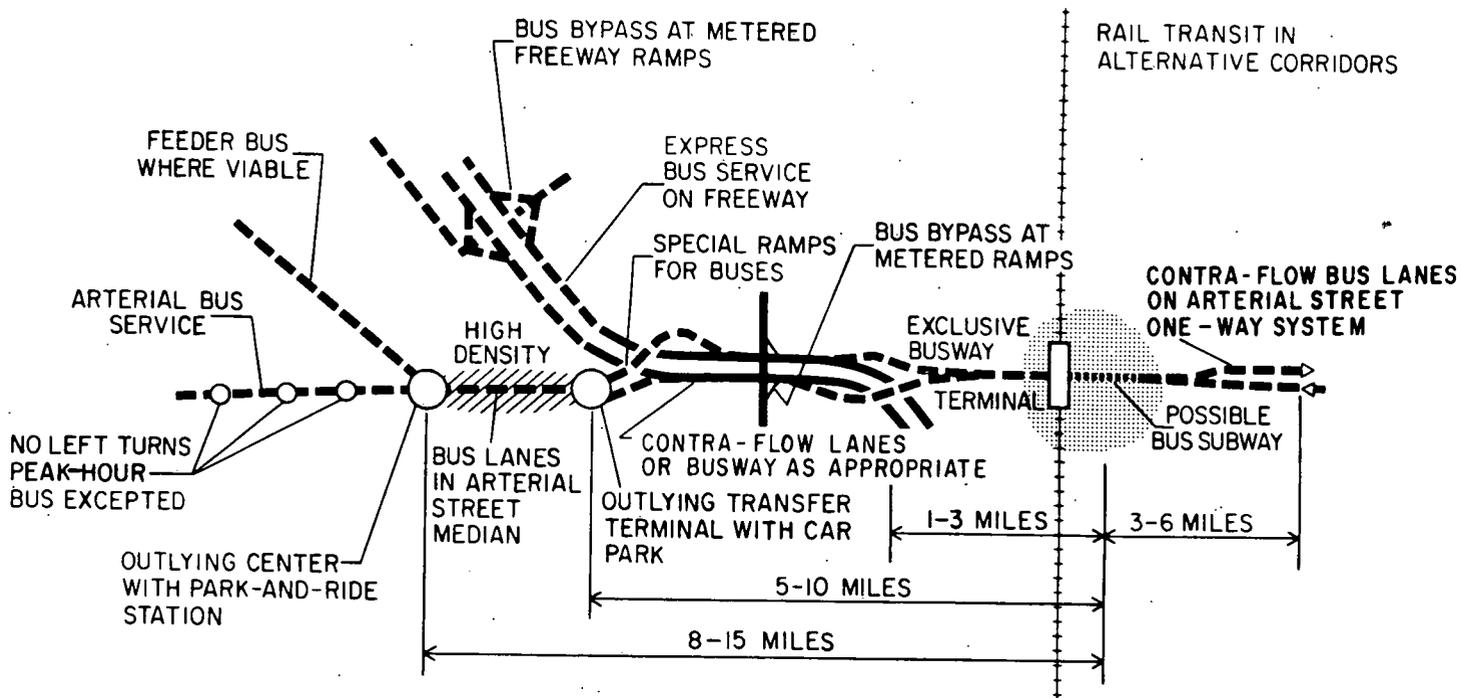


Figure 14. Bus priority treatments and system integration, major metropolitan area (1,000,000 or more).

TABLE 13
NET USER BENEFITS FROM CONTRA-FLOW BUS LANE,
SOUTHEAST EXPRESSWAY, BOSTON

ITEM	PEOPLE CARRIED (NO.)	TIME SAVINGS			MONEY VALUE ^b (\$)
		PER TRIP (MIN)	TOTAL DAILY (MIN)	TOTAL ANNUAL ^a (HR)	
AM Peak Hour					
Northbound buses	2,450	14	34,300	143,000	429,000
Northbound cars ^{c, d}	6,000	4.5	27,000	112,500	337,500
Southbound cars ^e	2,900	-25 ^e	-1,200	-5,000	-15,000
Total					751,500
PM Peak Hour					
Southbound buses	2,450	4	9,800	40,800	122,400
Southbound cars ^{c, d}	7,400	0	0	0	0
Northbound cars	4,400	-35 ^e	-2,600	-10,800	-32,400
Total					90,000

^a 250 days per year.
^b At \$3.00 per hour.
^c Occupancy 1.43 persons per vehicle.
^d At Boston.
^e Seconds lost.
Source: Ref. (13).

t_1 = initial travel time;
 t_2 = subsequent travel time;
 K = capital recovery factor;
 C_a = capital cost;
 O_1 = initial operating costs;
 O_2 = subsequent operating costs (may include consequences of impacting alternative bus lines);
 $\Delta t = t_1 - t_2$ = change in travel time; and
 $\Delta O = O_2 - O_1$ = change in operating costs.

Where changes in patronage are involved, the index can be expressed as

$$I = \frac{(P_1 t_1 - P_2 t_2) + (P_3 t_3 - P_4 t_4)}{K C_a + (O_2 - O_1)} \quad (3)$$

in which:

P_1 = number of initial bus riders;
 P_2 = number of subsequent bus riders;
 P_3 = number of initial highway travelers;
 P_4 = number of subsequent highway travelers;
 t_3 = initial highway time;
 t_4 = subsequent highway time;
 $P_1 - P_2$ = change in number of bus passengers (i.e., gain); and
 $P_3 - P_4$ = change in number of auto passengers (i.e., loss).

Street-Use Efficiency.—A desirable street utilization objective is to carry the maximum number of people at any given time at the highest possible speed. A street-use efficiency index can be obtained for each section of roadway by computing the product of passenger-miles and speed. For each section of road, indices can be computed separately by mode and then aggregated. They should be computed for both peak and off-peak conditions.

The street-use efficiency index is defined algebraically as

$$E = P_1 d_1 v_1 = (P_1 d_1^2) / t_1 \quad (4)$$

in which:

P_1 = number of passengers in section 1;
 d_1 = distance (miles) of section 1;
 v_1 = speed (mph) in section 1
 $= d_1 / t_1$.

On a per-mile basis, Eq. 4 reduces to

$$E_1 = P_1 / t_1 \quad (5)$$

Thus, peak-hour street-use efficiency increases with the number of persons transported and decreases proportionally with the time required to transport them.

A further cost-use-efficiency measure can be obtained by relating the efficiency index to the capital costs of proposed facilities, as follows:

$$M = E / (K C_a) \quad (6)$$

in which:

M = cost-use-efficiency index;
 E = street-use efficiency index;
 K = capital recovery factor; and
 C_a = capital cost (for improvement).

Cordon-Count Changes.—Detailed information on downtown employment and peak-hour-and-on crossings should accompany capital-intensive bus priority measures. Changes in peak-hour bus and passenger volumes and modal use across the CBD should be measured. Cordon-counts of people entering and leaving the city center should be recorded by 15-min intervals. These counts are essential for scaling urban transportation demands, particularly where busways are being considered. Changes in total demands and modal use in each peak 15-min period should be identified to assess modal changes within the peak. Similar analysis should be made across screen lines (Table 14).

Reduced Highway Travel.—Reductions in vehicle-miles of travel to the city center should be computed based on the

TABLE 14

COMPARISON OF BEFORE AND AFTER OBSERVED SCREENLINE PERSONS AND AUTOS ON SHIRLEY HIGHWAY BUSWAY IN AM PEAK PERIOD

ITEM	TOTAL SCREEN LINE BUSWAY		NON-SHIRLEY ROUTES BUSWAY		SHIRLEY HIGHWAY BUSWAY	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Total person trips ^a	64.8	59.2	48.2	43.9	16.6	15.4
Total auto vehicles ^a	35.8	31.3	26.8	25.9	9.0	5.4
Auto person trips ^a	50.9	42.9	38.3	35.7	12.6	7.3
Auto occupancy	1.42	1.37	1.43	1.38	1.40	1.36
Bus person trips ^a	13.9	16.3	9.9	8.2	4.0	8.1
Percent bus	21.5	27.5	20.6	18.6	24.0	52.4

^a In thousands.
Source: Ref. (14).

use of each outlying modal-interchange parking area and its distance from the city center. An approximation of the travel savings in each corridor is given by

$$Z = \sum_i^n V_i L_i \quad (7)$$

in which:

- Z = total vehicle-miles saved in the corridor;
- n = number of locations;
- V_i = volume of cars diverted at point i ; and
- L_i = distance of location i from downtown.

The total number of cars diverted in the corridor is adjusted by a factor of 0.4 to 0.5 to give the equivalent reduction in peak-hour road capacity. Thus, if 4,000 cars are diverted from a given corridor, 1,500 to 2,000 would be removed in peak periods—the equivalent of one freeway lane or four arterial street lanes.

Bus Service Indices.—Certain measures of bus service effectiveness relate to the over-all bus system and are appropriate in over-all system evaluation. The following measures for a specific system should be compared with the mean values and standard deviations for comparable systems: operating ratio (revenues/expense); average cost per bus-mile; average cost per bus-hour; average cost per revenue passenger; average bus-miles per man-year; annual miles operated per passenger; and average passengers per bus-mile.

BUS DESIGN PARAMETERS

Busway, bus lane, and bus terminal planning should reflect the capabilities of buses currently in operation or in advanced planning. This section describes basic vehicle design and performance characteristics and their planning implications.

Vehicle Design and Performance

Typical buses in urban transit service are shown in Figure 15. Most existing buses in the United States are 8.5 ft wide, 35 to 40 ft long, seat 40 to 50 passengers, and have an outside turning radius of 40 to 45 ft.

With these vehicles and on-going bus development ef-

forts as a guide, typical bus vehicle "designs" were developed. These designs, shown in Figure 16, include both conventional single-unit and articulated buses. Design vehicles are shown for both single- and double-door buses.

Two reasons underlie the development of design standards based on existing buses: (1) These buses are now in service and will continue to dominate most urban bus fleets; (2) Recent studies (15) have indicated that the controlling dimensions of buses are not likely to change significantly. Although bus appearance, passenger facilities, and some operating characteristics may change, these changes are not likely to affect basic design controls such as horizontal and vertical clearances and bus maneuverability.

Design Criteria

Design vehicle dimensions and performance characteristics are summarized in Table 15. Figure 17 shows typical turning radii for design vehicles. Among the noteworthy items are:

1. The design single-unit vehicle is 8.5 ft wide, 40 ft long, 9.8 ft high, and seats 50 persons.
2. The design articulated vehicle is 8.5 ft wide, 60 ft long, 9.8 to 10.5 ft high, and seats 60 to 70 passengers.
3. Width—A 9-ft width should be considered in facility planning and design. This will accommodate the slightly wider buses that are likely to result from new permissive legislation in many states.
4. Eye height—An eye height of 5.0 ft generally should be utilized in roadway design, although on most buses the driver's eye height approximates 7 ft. This will allow a factor of safety for potential new equipment and for possible use of bus priority roadways by other vehicles.
5. Acceleration and deceleration—Normal bus acceleration of 2.0 mph per second and normal deceleration of 1.5 mph per second should be used. Maximum deceleration in emergencies should not exceed 5 to 6 mph per second where standing passengers are involved. These rates reflect the performance capabilities of most buses in urban service (Table 16). They also permit buses to accelerate to 30 mph in 15 sec (Fig. 18).

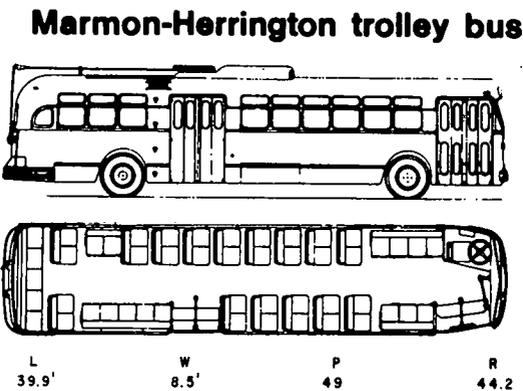
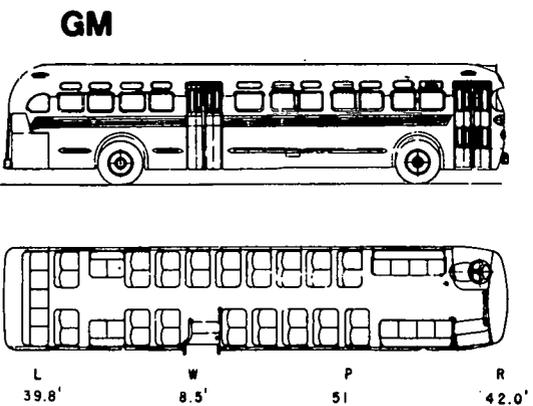
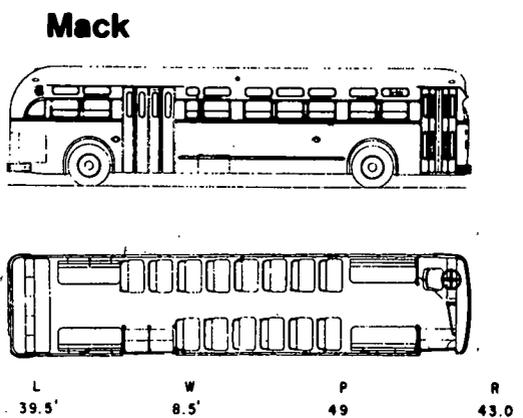
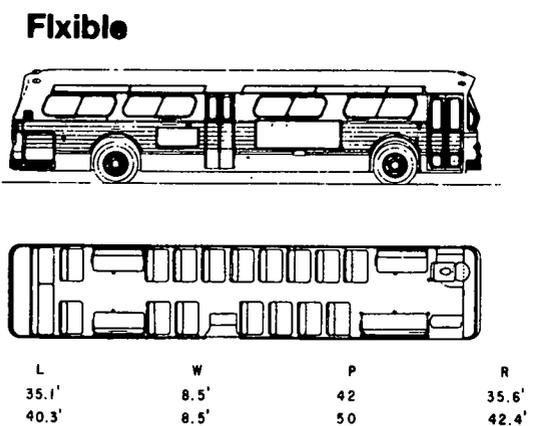
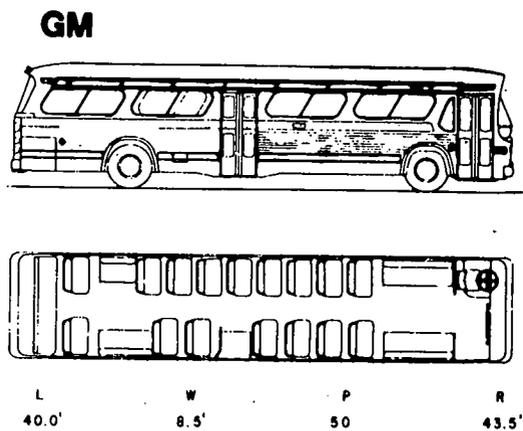
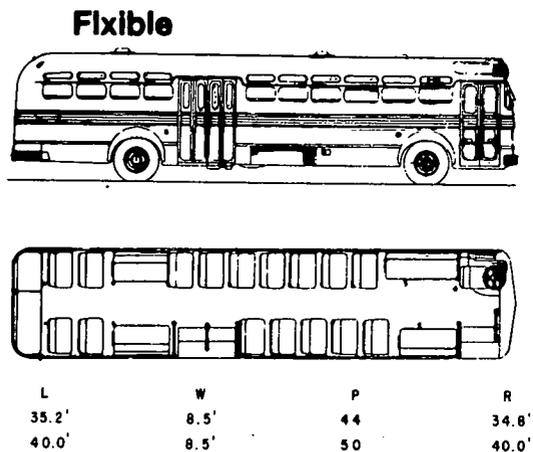


Figure 15. Examples of bus designs; L=length, W=width, P=seating capacity, R=turning radius of outside front corner.

Bus Berthing Requirements

Additional roadway width is required for swing-out maneuvers past other vehicles in close quarters. The roadway width and the amount of lineal space at a bus loading platform are directly related where designs allow departing buses to pull out from the platform around a standing bus. Figure 19 shows how a 40-ft bus, having a 16-ft clearance ahead, actually uses 22 ft of roadway width for its pull-out maneuver. This condition requires a roadway width of at least 24 ft, and a total minimum berth length of 56 ft for

each bus. Thus, five buses would require 264 ft of lineal distance. The shorter the berth length allowed, the wider the roadway must be, and conversely.

Considerable linear space is necessary to permit a bus to overtake and pull into a platform ahead of a standing bus. Illustrative platform requirements for 28- and 40-ft buses are shown in Figure 20. A 40-ft bus requires 92 ft to pull in, assuming the rear end of the bus is 1 ft out from the platform curb, 80 ft when the rear end of the bus is 2 ft from the outside of the curb, and 56 ft when a 5-ft "tail

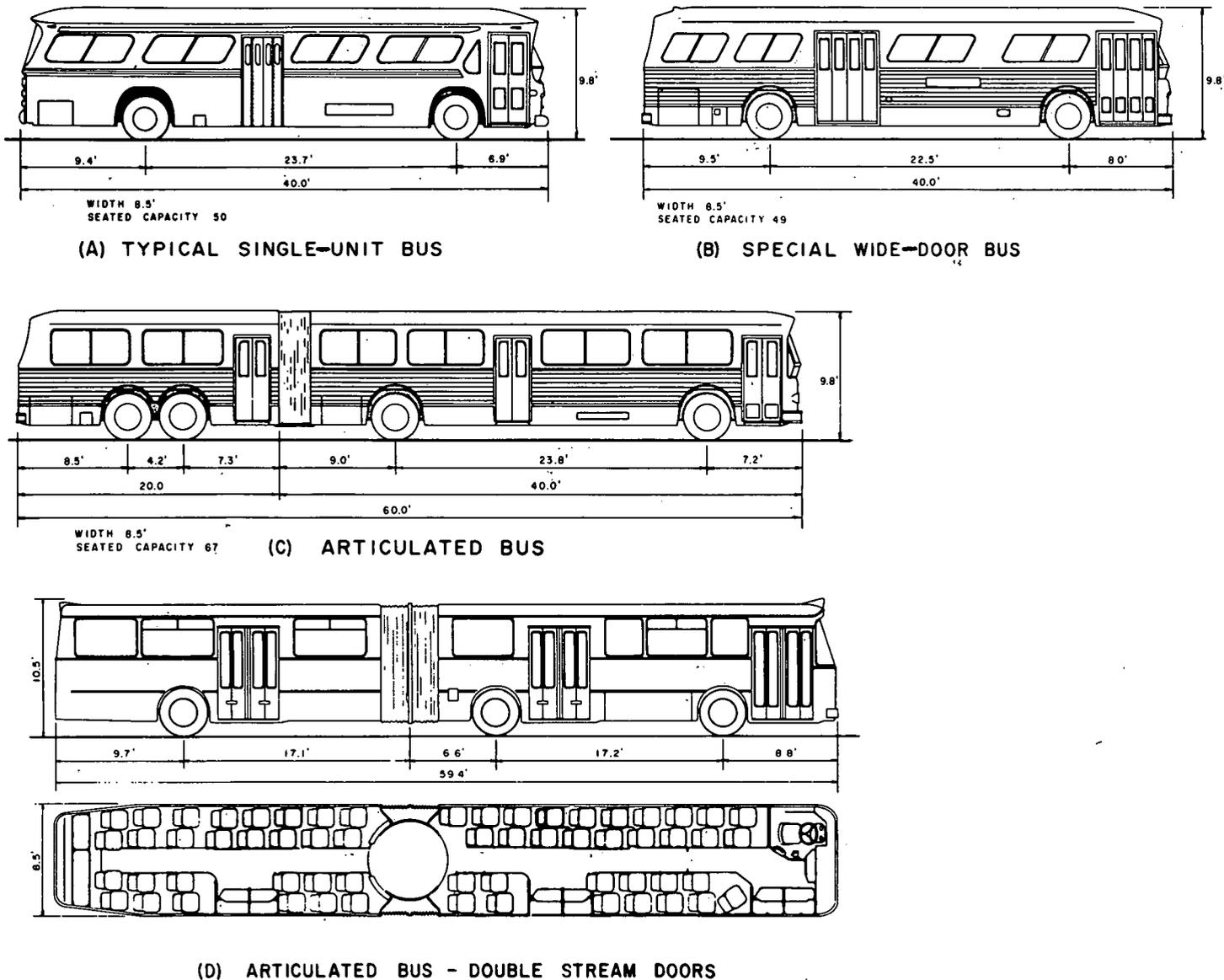


Figure 16. Projected bus vehicle designs.

out" is permitted. Thus, for any runway where such maneuvers are permitted, the road width should assure adequate safe clearance for vehicles in the outside or overtaking lane.

Illustrative "parallel" and "shallow-sawtooth" berth criteria are shown in Figure 21 for both single-unit and articulated buses. These criteria reflect bus dimension and maneuvering requirements. The in-line (parallel) normal berth and the shallow-sawtooth platform arrangements allow for passing of stalled buses. The minimum berth requirements for in-line platform would be used where physical, cost, or other conditions limit right-of-way (for example, a bus subway on a street with 50 ft between building setbacks).

Bus Breakdowns

Bus road failures—as measured by the frequency of road calls—range from 2,000 to 40,000 miles per call. The median road-call mileage approximates 5,000 miles; 75 percent of the properties report an average road-call mileage of 8,000 or less (18). A typical urban transit bus covers about 30,000 miles per year.

Daily road-call rates for transit companies generally range up to about 6 percent of the total bus fleet. Thus, a bus fleet of 500 would likely experience about 30 road calls per day. The probability of breakdown within a given area at any point in time would be very low. This low incidence of failure suggests that shoulders can be eliminated from conventional busway design, particularly in underground construction.

Bus Capacity Considerations

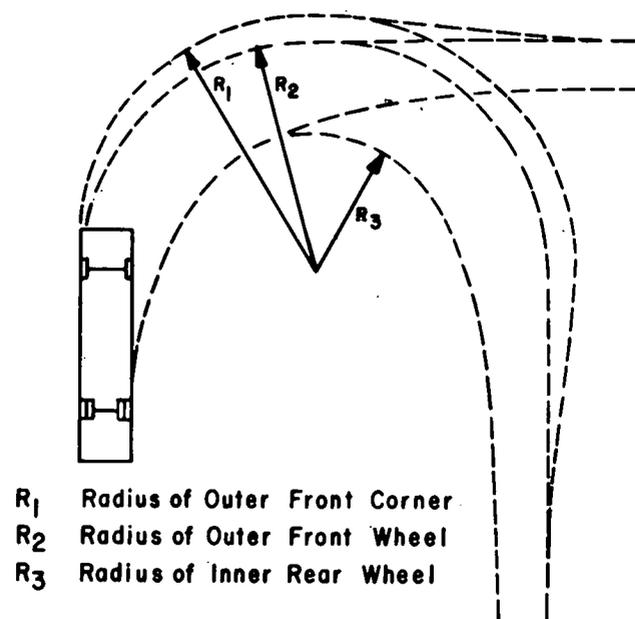
Extensive analyses were made of the capacities of busways, bus lanes, and bus terminals. These analyses update and extend the "Preliminary Progress Report" (1961) of the Transit Subcommittee of the Highway Research Board Committee on Highway Capacity (19) and the *Highway Capacity Manual, 1965* (20). They underscore the importance of viewing bus capacity in terms of people transported rather than buses moved per hour.

Bus Capacity Ranges

Ranges in bus capacity based on current operating experiences are summarized in Table 17, which includes both theoretical and actual figures. The number of buses per hour that can operate past a point in the same direction varies widely according to specific roadway and operating conditions, as follows:

1. The greatest number of buses per hour can be moved over a completely exclusive right-of-way when vehicles make no stops. Under these conditions, from 500 to nearly 1,500 buses per hour can be accommodated.

2. Where bus stops are involved, the number of buses



BUS MODEL	LENGTH	WIDTH	WHEEL BASE	R ₁	R ₂	R ₃
Single Unit (1)	35.0'	8.5'	19.6'	36.2'	31.3'	14.7'
Single Unit (2)	40.0'	8.5'	23.8'	42.2'	37.2'	17.6'
Single Unit (3)	40.0'	8.0'	26.5'	48.5'	45.0'	28.2'
Articulated Bus	60.0'	8.5'	23.8'	42.0'	36.5'	20.1'
Design Bus	40.0'	8.5'	24.0'	50.0'	47.0'	30.0'

(1) 45-Seat Urban Bus
 (2) 50-Seat Urban Bus
 (3) 49-Seat Intercity Bus

Figure 17. Bus turning radius data.

TABLE 15
CHARACTERISTICS OF DESIGN BUSES

ITEM	CONVENTIONAL TRANSIT BUS	ARTICULATED BUS
Vehicle dimensions:		
Width (ft)	8.0-8.5 ^a	8.0-8.5 ^a
Height (ft)	9.8	9.8-10.5
Length (ft)	40.0	60.0
Front overhang (ft)	6.9-8.0	7.2-8.8
Wheelbase (ft)	23.7	23.7
Driver eye height (ft)	7 ^b	7 ^b
Seat capacity	50	70
Weight (lb)	28,700	32,000
Maximum attainable speed (mph)	50-70	50-70
Acceleration (mph/sec)	2	1.5-2.0
Normal deceleration (mph/sec)	2.5	2.5
Maximum deceleration	6-12 ^c	6-12 ^c
Maximum operating grade (%)	10	10
Min. outside turning radius (ft)	42-50	42
Doors:		
Number	2	3
Width of each door (ft)	2.5-5.0	2.5-5.0

^a Design should provide for 9.0-ft bus width.

^b Use 5.0 ft for design purposes.

^c Use lower value where there are standees.

Source: Based on available bus specifications (obtained from Flexible and General Motors).

TABLE 16
PERFORMANCE CHARACTERISTICS OF URBAN BUSES

BUS TYPE OR CITY	ACCELERATION	DECELERATION (MPH/SEC)	
	AVERAGE (MPH/SEC)	AVERAGE	MAXIMUM
Conventional transit bus	2.0	2.5	12-13.4 ^a
RTX bus	2.5-3.0	2.5	12 ^b
Articulated bus	2.0	2.5	12 ^b
Copenhagen	1.8	NA	11.2
Dublin ^c	1.8	2.7	13.2
Tokyo	1.4	3.6	NA

^a Higher value is for Toronto; for standing passengers 0.30 g or 6 mph/sec is a desirable maximum.

^b Estimated.

^c Single- and double-decked.

Source: Adapted from Refs. (16) and (17).

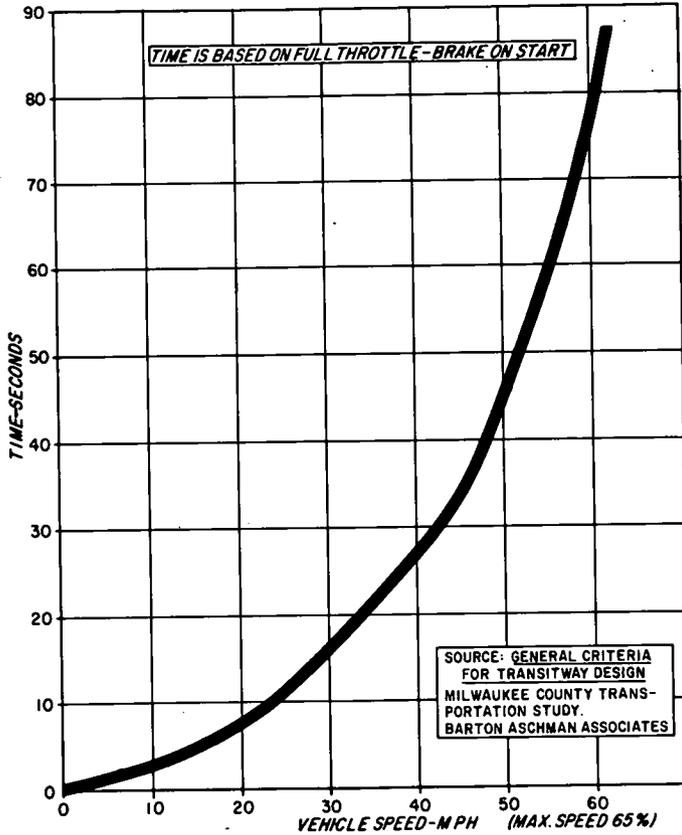


Figure 18. Conventional bus vehicle performance.

per hour reduces to about 120 to 180. Under these conditions, bus speeds are often under 15 mph.

3. Where buses can operate in platoons, substantially greater capacities can be attained (Table 18). However, specific arrival patterns at points of platoon formation would have to be maintained. Schedule reliability is an essential consideration in bus platoon operations.

Significant Variables

The number of buses per lane per hour and the number of people they carry depend on a variety of roadway and operating factors. These factors include:

1. Type of roadway. Mixed traffic versus special busways; expressways versus arterial lanes.
2. Mode of operation. Singly or in platoons; on-line versus off-line stations; consistent arrival versus random arrival at designated loading areas.
3. Clearance between buses. Queuing versus nonqueuing operations; low-speed versus high-speed operations.
4. Frequency and duration of stops. Dispersed versus concentrated loadings; joint, common or separated passenger boarding and alighting; prepayment versus on-vehicle fare collection; single-coin versus odd-penny fares.
5. Bus capacity and door configuration. Single versus articulated vehicles; standing versus seated loads; single versus multiple doors.

These variables can be expressed in analytical terms, as given in Table 19. The various formulas indicate that the number of persons per hour per bus channel, rather than the number of buses per hour, is the key variable to be maximized.

The number of bus berths required at the maximum load

TABLE 17
BUS CAPACITY RANGES

CONDITIONS	BUSES PER HOUR	HEADWAY (SEC)	AVERAGE BUS STOP SPACING (FT)	AVERAGE BUS SPEED (MPH)
1. G.M. proving grounds, uninterrupted flow	1,450	2.5	No stops	33
2. Highway Capacity Manual: Freeway, level of service D	940	3.8	No stops	33
Freeway, level of service C	690	5.2	No stops	40-60
3. Lincoln Tunnel, uninterrupted flow	735	49	No stops	30
4. I-495 exclusive bus lane, uninterrupted flow	485	74	No stops	30-40
5. Freeway with 20-sec on-line stops and 10-sec clearance between buses	120	30	Variable	30-40
6. Hillside Ave., N. Y. City, multiple lane use with lightly patronized stops	170	21	530	9
7. Downtown streets, single lane, with stops	90-120	30-40	500	5-10
8. Highway Capacity Manual: Arterial streets, 25-sec loading and 25-sec clearance	72	50	—	—
9. Toronto Transit Commission	60	60	500-600	10

Source: Compiled from various bus use studies summarized in Ref. (1).

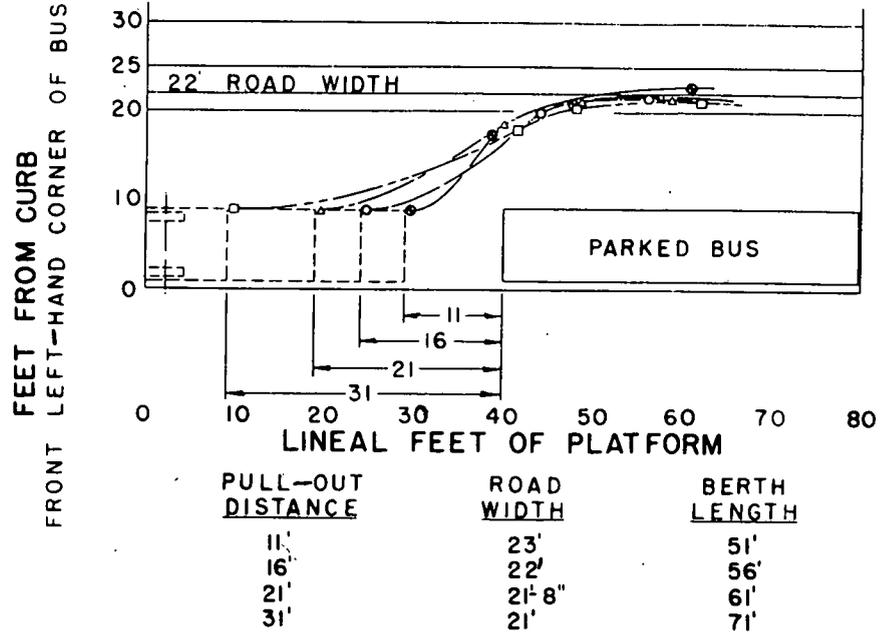


Figure 19. Required road widths and berth lengths at selected pullout distances, 40-ft GMC bus. (Source: Port Authority of New York and New Jersey).

point varies directly with the total passengers to be served at that point, the loading and unloading times required per passenger, and the clearance times between buses per boarding or alighting passenger. These formulas imply that loading requirements can be reduced by (1) increasing the number of downtown stations, thereby reducing the boarding and alighting passengers at the maximum load point; (2) reducing the loading and unloading times per passenger through multiple doors on buses, prepayment, and/or separation of loading-unloading; and (3) using larger buses to reduce the clearance interval time losses between

successive vehicles. Thus, the person-capacity per bus lane appears to be largely dependent on the number of doors per bus and the method of fare collection.

The following sections translate these broad analytical relationships into suggested design and planning values.

Queue Behavior Parameters

Typical bus queue behavior along downtown arterial streets is given in Table 20. These statistics suggest that when bus volumes exceed 100 per hour, queues of 2 to 4 buses are likely to develop approximately 20 percent of the time.

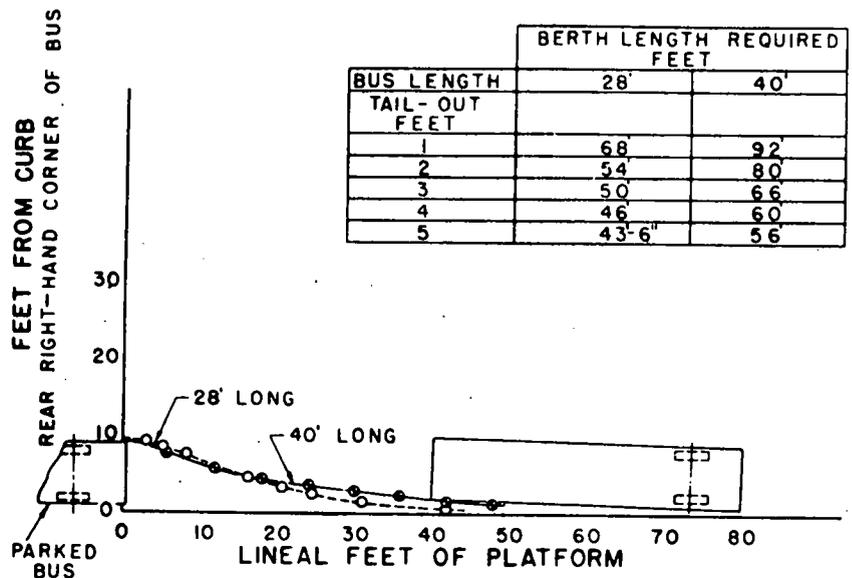
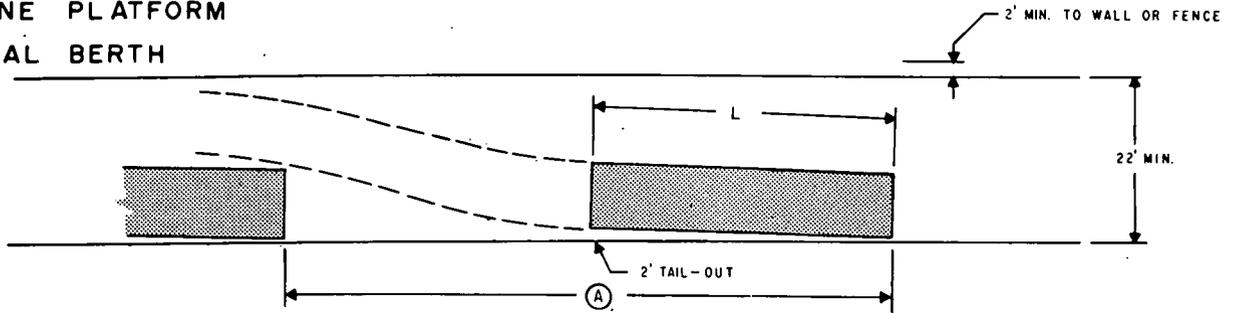
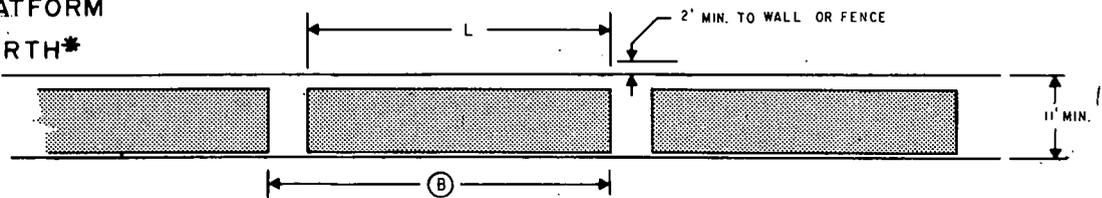


Figure 20. Required berth lengths as compared to bus tail-out, 28-ft and 40-ft GMC buses. (Source: Port Authority of New York and New Jersey).

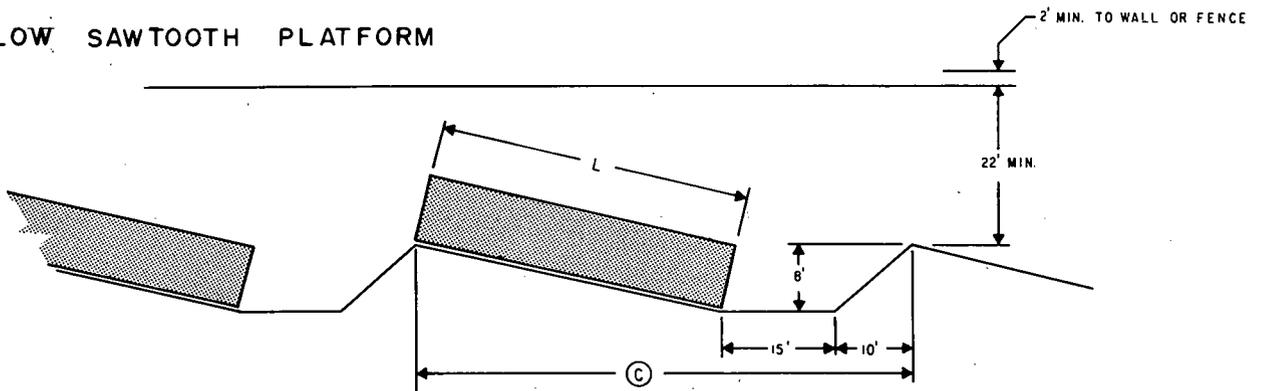
**IN-LINE PLATFORM
NORMAL BERTH**



**IN-LINE PLATFORM
MINIMUM BERTH***



SHALLOW SAWTOOTH PLATFORM



* BUS POSITIONS DEPENDENT ON ARRIVAL SEQUENCE. IF INDEPENDENT PULLOUTS DESIRED, INCREASE ROADWAY WIDTH TO 22 FT. MIN. AND ADD 11 FT. TO BERTH LENGTH.

	SINGLE UNIT Bus	ARTICULATED Bus
L	40'	60'
(A)	80'	100'
(B)	45'	65'
(C)	65'	85'

Figure 21. Bus berth criteria.

**TABLE 18
HOURLY BUS CAPACITY OF A LOADING PLATFORM
HANDLING SINGLE-LANE BUS PLATOONS**

NO. OF BUSES IN PLA- TOON	LOADING PLATFORM CAPACITY (BUSES PER HOUR) FOR PLATOON MAX. CRUISE SPEED OF								
	30 MPH			45 MPH			60 MPH		
	20 SEC	30 SEC	40 SEC	20 SEC	30 SEC	40 SEC	20 SEC	30 SEC	40 SEC
12	552	504	456	504	444	408	456	396	360
10	510	450	410	460	410	370	400	360	320
8	464	400	360	408	360	320	360	320	288
6	384	330	294	342	300	258	300	270	240
5	340	290	250	310	265	230	270	240	210
4	304	256	220	272	228	196	240	208	184

Source: Ref. (21).

Bus Loading and Unloading Times

Observed ranges in passenger service times for various bus operating and fare collection procedures are summarized in Tables 21 and 22 for both American and European experience.

Boarding times are usually greater than alighting times, although some dwell times reflect total passenger interchange. Differences among cities reflect door configurations, fare collections, practices, and one- versus two-man operation. The formulas given in Table 21 also reflect the time losses resulting from opening and closing doors.

American experience with single-door buses shows passenger boarding times ranging from 2 sec (single-coin) to more than 8 sec for multiple-zone fares collected by the driver (Table 22). Alighting times range from about 1½ to 2½ sec for typical urban conditions to 6 sec or more where baggage is involved.

Suggested ranges in bus service times in relation to door width, methods of operation, and fare collection practices are given in Table 23. These bus service times, based on current experiences, were used to derive bus and person-capacity ranges. They assume that prepayment before entering buses would reduce passenger headways.

Passenger service times decrease as the number of doors available to passengers increase. The decrease is less than proportional to the gain in capacity to allow for inefficiency in door utilization (i.e., a single passenger occupying a double door), and on-vehicle turbulence. This implies (1) separation of loading and unloading areas at heavy downtown stations to allow use of all doors for loading (or unloading) of passengers, (2) utilization of double-width doors on buses used for line-haul busway service, (3) utilization of multi-door articulated buses for heavy-channel express bus service.

Typical effects of bus door capacities and passenger loading intensities on bus dwell times at stations are shown in Figure 22. This chart (and the subsequent tabulations) assumes a 15-sec clearance time between buses to allow for door opening-closing and bus acceleration-deceleration. The clearance interval could be reduced where bus speeds are low or bus queuing is permitted (as along downtown streets).

Line-Haul Capacity Ranges

Line-haul bus berth capacities are given in Tables 24 and 25 for loading and unloading, respectively.

The tables give the approximate number of buses per hour that could be served by a typical line-haul bus stop for various passenger loading intensities and loading or unloading conditions. They also indicate the approximate maximum hourly person-capacities per berth for various loading and unloading conditions.

These values should be reduced in planning and design to allow for random variations in bus arrivals. A 20 percent reduction factor is suggested. The resulting line-haul bus stop capacities are given in Table 26. These values represent the maximum number of people that can board buses per berth, for various door configurations, bus sizes, and operating conditions.

Conventional bus loading through a single front door with a single-coin fare could accommodate 800 boarding passengers per hour; simultaneously, about 1,200 passengers could alight through the rear door. Prepayment of fares before boarding buses could increase loading capacities to 1,200 persons per hour.

As door capacities are increased, by use of wider doors and/or all doors for loading, up to 2,800 persons per hour could board regular buses per berth and up to 4,000 persons per hour could board articulated buses.

The number of bus berths that should be provided at any given location will depend on the mode of bus operation, the number of people boarding (or alighting) at the stop involved, and the design of the bus stop. The maximum 20-min flow rate, expressed in persons per hour, should be used in computing bus berth requirements.

Busway berth requirements at the heaviest CBD stop are related in Table 27 to the equivalent hourly bus passenger

TABLE 19

BUS SYSTEM CAPACITY EQUATIONS RELATING MAXIMUM LOAD POINT CONDITIONS TO BERTH CAPACITY^a

VARIABLE	EQUATION ^b
Minimum headway at stop	$h' = Bb + C$
Maximum buses per berth per hour	$f' = \frac{3,600}{h'} = \frac{3,600}{Bb + C}$
Max. passengers per berth per hour	$G = f' B = \frac{3,600 B}{Bb + C}$
Effective berths required to serve J passengers	$N = \frac{J}{G} = \frac{J(Bb + C)}{3,600 B}$
Bus frequency required to serve J passengers per hour	$f = f' N = \frac{J}{B}$
Bus frequency at maximum load point	$f = \frac{P}{S}$
Passengers per bus at heaviest station	$B = X S$
Minimum headway at heaviest stop	$h' = Bb + C = bXS + C$
Buses per hour at heaviest stop	$f' = \frac{3,600}{h'} = \frac{3,600}{bXS + C}$
Number of effective berths at heaviest stop ^c	$N = \frac{f}{f'} = \frac{P(bXS + C)}{3,600 S}$

^a Boarding conditions govern.

^b Nomenclature:

- A = Alighting passengers per bus in peak 10 to 15 min;
- a = Alighting service time, in sec per passenger;
- B = Boarding passengers per bus in peak 10 to 15 min;
- b = Boarding service time, in sec per passenger;
- C = Clearance time between successive buses (time between closing of doors on first bus and opening of doors on second bus), in sec;
- D = Bus dwell time at a stop (time when doors are open and bus is stopped), in sec per bus;
- f = Bus frequency, in buses per hour (all routes using a facility) at maximum load point. (If all buses stop at all stations, $= N f'$);
- h = Bus headway on facility at maximum load point, in sec ($= 3,600/f$);
- f' = Maximum peak bus frequency at a berth, in buses per hour;
- h' = Minimum bus headway at a berth, in sec ($= 3,600/f'$);
- G = Boarding passenger capacity per berth per hour;
- H = Alighting passenger capacity per berth per hour;
- J = Passengers boarding at heaviest stop (hourly rate);
- K = Passengers alighting at heaviest stop (hourly rate);
- L = Peak-hour load factor at the maximum load point, in passengers per bus seat per hour;
- N = Number of effective berths at a station or bus stop ($= N'u$);
- N' = Number of berth spaces provided in a multi-berth station;
- P = Line-haul capacity of bus facility past the maximum load point, in persons per hour (hourly flow rate based on maximum 10 to 15 min);
- S = Seating capacity of bus (varies with design);
- u = Berth utilization factor; an efficiency factor applied to total number of berths to estimate realistic capacity of a multi-berth station ($= N/N'$);
- X = Percentage of maximum load point passengers boarding at heaviest stop ($= J/P$);
- Y = Percentage of maximum load point passengers alighting at heaviest stop ($= K/P$).

^c Can be solved for P where N is given.

volumes approaching the CBD, the method of bus operation, and the proportion of bus passengers using the heaviest downtown stop.

The equivalent of 3,000 passengers per hour leaving the CBD in 50 passenger buses would require 4 berths (including a spare) at the heaviest load point, assuming that *all* passengers boarded at this stop and payment of a single-coin fare. With front and rear loading of double-width door buses and prepayment of fares, only 2 berths would

be needed. Articulated buses would require 1 or 2 berths. If only one-half of the 3,000 passengers used the stop, the berth requirements would be correspondingly reduced.

In estimating station requirements, it is important to con-

sider berth design. The values given in Table 27 assume that buses will be able to enter each berth with equal efficiency. This condition is not likely to exist in practice, as a result of variations in route demands and berth accessi-

TABLE 20
COMPARATIVE BUS FLOW AND QUEUE STATISTICS

(a) Actual Flow					
LOCATION	VOLUME (BUSES/ HR)	5-MIN FLOW RATE (BUSES/ HR)	HEADWAY (SEC)		MAX. QUEUE AT STOP (BUSES)
			AVER.	RANGE	
S. Michigan Ave., Chicago	174	228	21	16-33	4
N. Michigan Ave., Chicago	112	148	32	3-150	5
Washington St., Chicago	106	132	34	3-121	4

(b) Queue Behavior at Stop Locations ^a				
QUEUE LENGTH (NO. OF BUSES)	NO. OF OCCURRENCES	QUEUE DELAY (SEC)		
		RANGE	MEAN	MEDIAN
1	50-70	—	—	—
2	8	6-49	14	8
3	6	9-61	29	24
4	3	47-59	51	48

^a Data represent bus volumes of 100 to 120 vehicles per hour.
Source: Ref. (22).

TABLE 21
BUS BOARDING AND ALIGHTING TIMES, SELECTED URBAN AREAS

LOCATION	BUS TYPE	BOARDING AND ALIGHTING METHOD	FARE SCHEME	FARE COLLECTION	BOARDING AND ALIGHTING RELATIONSHIP ^a
Louisville, Ky.	One-man	Alighting only	Flat fare	Driver	$T = 1.8 + 1.1F$
	One-man	Boarding only	Flat fare	Driver	$T = -0.1 + 2.6N$
	One-man	Simultaneous	Flat fare	Driver	$T = 1.8 + 1.0F + 2.3N$ $- 0.02 FN$
London	Two-man	Consecutive	Graduated	Conductor	$T = 1.3 + 1.5(N + F)$
	One-man	Consecutive	Graduated	Driver	$T = 8 + 6.9N + 1.4F$
	One-man	Simultaneous	Flat fare	Mechanical	$T = 7 + 2.0N$
			Single coin		
			Two coin	Mechanical	$T = 5.7 + 3.3 N^b$
Toronto	One-man	Simultaneous	Zonal	Fare box	$T = 1.7N, T = 1.25F,$ $T = 1.4(N + F)$
Copenhagen	One-man	Simultaneous	Flat fare	Split entry ^c	$T = 2.2 N$
Dublin	Two-man	Consecutive	Graduated	Conductor	$T = 1.4(N + F)$
	One-man	Consecutive	Graduated	Driver	$T = 6.5N + 3.0 F$
France:					
Bordeaux	One-man	Simultaneous	Flat fare	Driver	$T = 15 + 3 N$
Toulouse	One-man	Simultaneous	Flat fare	Driver	$T = 11 + 4.6 N$
Paris	One-man	Simultaneous	Graduated	Driver	$T = 4 + 5N$
	Two-man	Simultaneous	Graduated	Conductor	$T = 2.3 N$

^a T = stop time, in sec; N = number of passengers boarding; F = number of passengers alighting.

^b In peak time; $T = 5.7 + 5.0N$ in off-peak time.

^c Driver and machine.

Sources: Refs. (23) and (16).

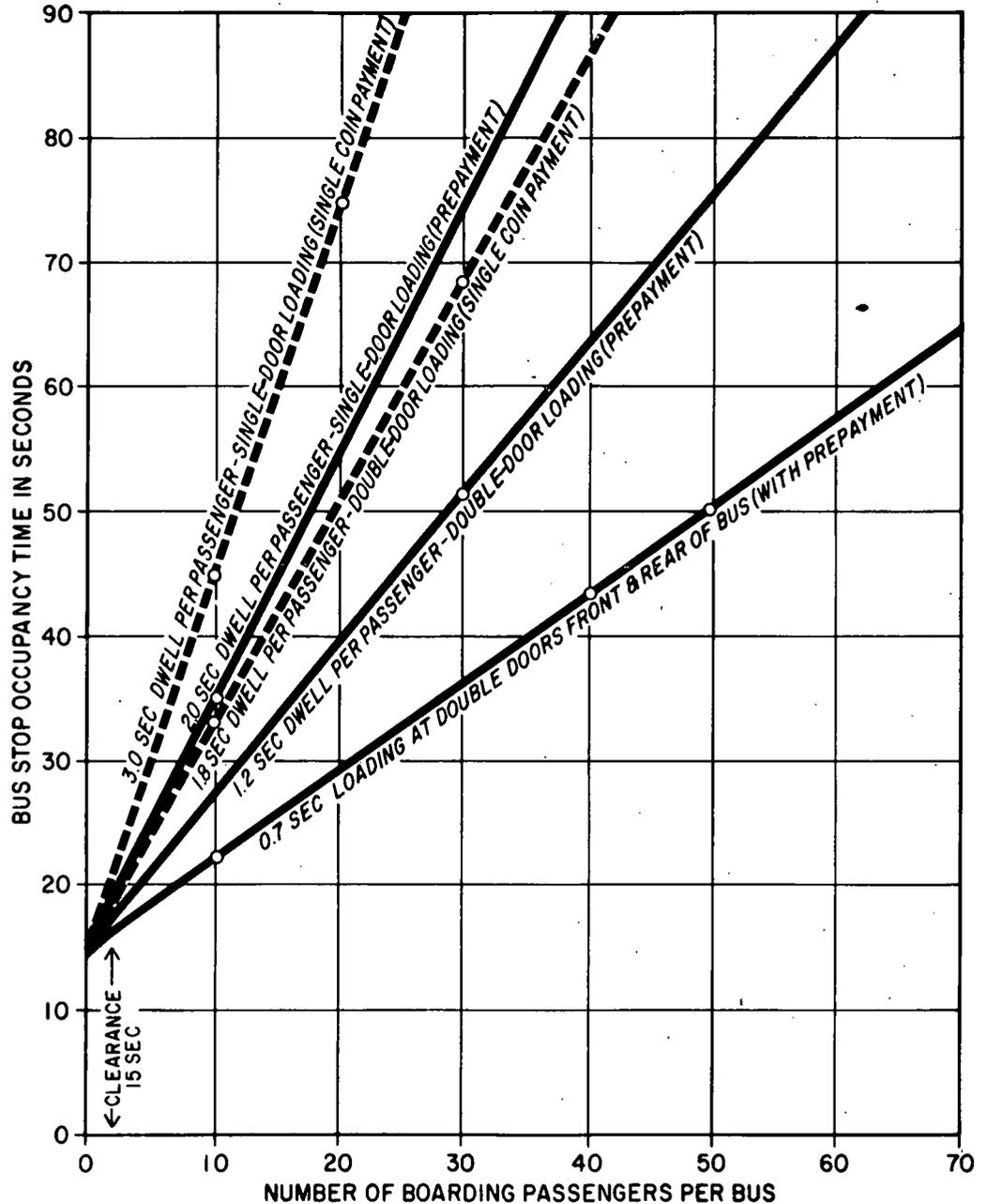


Figure 22. Boarding capacity and stop dwell time.

bility, especially with on-line stations. It is more realistic to assume that each berth will operate at reduced efficiency. The berth capacity factors suggested for on-line and off-line stations are given in Table 28.

Terminal Berth Requirements

Bus terminal berth requirements for local and commuter operations are given in Table 29. Passenger and bus headways and capacities reflect (1) door widths and bus size, (2) fare collection procedures, (3) amount of baggage, (4) driver layover-recovery times, and (5) bus and passenger queuing. Bus and passenger capacities assume (a) equal distribution of passengers throughout the hour, (b) 40 per-

cent of all passengers boarding in the peak 20 min, and (c) 50 percent of all passengers boarding in the peak 20 minutes.

Planning Implications

The capacity analyses and tables have several important bus planning implications, especially where capital investments are concerned, as follows:

1. Bus capacity should be expressed in terms of persons per hour, rather than vehicles per hour. The governing factor will be the peak boarding and alighting volumes at the heaviest downtown stop.
2. The number of bus berths required at the maximum

TABLE 22
APPROXIMATE PASSENGER SERVICE TIMES
ON AND OFF BUSES

OPERATION	CONDITIONS	TIME (SEC)
Unloading	Very little hand baggage and parcels; few transfers	1.5-2.5
	Moderate amount of hand baggage or many transfers	2.5-4
	Considerable baggage from racks (intercity runs)	4-6
Loading ^a	Single coin or token fare box	2-3
	Odd-penny cash fares; multiple-zone fares	3-4
	Pre-purchased tickets and registration on bus	4-6
	Multiple-zone fares; cash; including registrations on bus	6-8
	Prepayment before entering bus or pay when leaving bus	1.5-2.5

^a Add 1 sec where fare receipts are involved.
Source: Adapted from Refs. (20) and (24).

CBD stop largely depends on (1) the proportion of total busway passengers using the stop, and (2) the boarding time per passenger. The first factor relates to system layout; the second depends on operating patterns, door configurations, and bus capacities.

3. Busway planning should endeavor to provide at least three stops in the central area, with the maximum stop serving not more than 50 percent of the total entering or leaving peak-hour passenger volume.

4. Loading times, and hence berth requirements, further can be reduced by (1) using double-width door regular and articulated buses and (2) alternating peak-period loading and unloading stops in the downtown.

TABLE 23
BUS SERVICE TIMES IN RELATION TO DOOR CAPACITY ^a

CONDITIONS	DOORS FOR LOADING ^b	LOADING TIME ^b (SEC)		UNLOADING TIME ^b (SEC)	UNLOADING TIME WITH USE OF ONE OR MORE DOORS ^b (SEC)
		PRE-PAYMENT	SINGLE FARE ^c		
1. <i>Conventional buses:</i>					
A. Front door only:					
1. Single door	1	2.0	3.0	1.7	1.7
2. Double doors	1	1.2	1.8	1.0	1.0
B. Front and rear doors:					
1. Single door	2	1.2	NA	—	1.0
2. Double doors	2	0.7	NA	—	0.6
2. <i>Articulated buses:</i>					
A. Front and center					
single doors load; rear door unloads	2	1.2	NA	1.7	1.0
Front and center double doors load; rear door unloads	2	0.7	NA	1.0	0.6
B. Front, center, rear					
single doors load	3	0.9	NA	—	0.8
Front, center, rear double doors load	3	0.5	NA	—	0.4

^a Bus service times do not reflect minimum clearance between buses, usually 10 to 15 sec.

^b Assumed values.

^c NA = Not applicable.

TABLE 24

BUS BERTH CAPACITY FOR LINE-HAUL SERVICES UNDER VARIOUS LOADING CONDITIONS^a

LOADING CONDITION	LOADING TIME PER PASSEN- GER ^b (SEC)	PASSENGERS BOARDING PER BUS							APPROX. HOURLY PASSEN- GERS (MAX.) PER BERTH ^d
		10	20	30	40	50	60	70	
		BUSES ^c	BUSES ^c	BUSES ^c	BUSES ^c	BUSES ^c	BUSES ^c	BUSES ^c	
1. <i>Conventional buses:</i>									
A. Front door only:									
1. Single door, single fare	3.0	80	50	35	25	20	—	—	1,000
2. Single door, prepayment	2.0	100	65	50	40	30	—	—	1,500
3. Double door, prepayment	1.2	130	90	70	60	50	—	—	2,500
B. Front and rear doors:									
1. Single door each location, prepayment	1.2	130	90	70	60	50	—	—	2,500
2. Double door each location, prepayment	0.7	165	125	100	85	70	—	—	3,500
2. <i>Articulated buses:</i>									
A. Front and center doors:									
1. Single door each location, prepayment	1.2	130	90	70	60	50	40	35	2,500
2. Double door each location, prepayment	0.7	165	125	100	85	70	60	55	3,800
B. Front, center, rear doors:									
1. Single door each location, prepayment	0.9	150	110	85	70	60	50	45	3,000
2. Double door each location, prepayment	0.5	180	140	120	100	90	80	70	4,900

^a Design should be based on busiest 20 min per stop.^b Decreases reflect increased boarding opportunities as door capacity increases.^c Maximum buses per bay per hour; assumes 15-sec clearance between buses.^d Assumes uniform bus arrivals without queuing.

Source: Computed.

TABLE 25

BUS BERTH CAPACITY FOR LINE-HAUL SERVICE UNDER VARIOUS UNLOADING CONDITIONS^a

UNLOADING CONDITION	UNLOAD- ING TIME PER PASSEN- GER ^b (SEC)	PASSENGERS ALIGHTING PER BUS							APPROX. HOURLY PASSENGERS (MAX.) PER BERTH ^d
		10	20	30	40	50	60	70	
		BUSES ^c	BUSES ^c	BUSES ^c	BUSES ^c	BUSES ^c	BUSES ^c	BUSES ^c	
1. <i>Conventional or articulated buses:</i>									
A. Single door available	1.7	110	75	55	45	35	35 ^e	25 ^e	1,500–1,800 ^e
B. Double door available	1.0	140	105	80	65	55	50	45	2,700–3,200 ^e
2. <i>Conventional or articulated buses:</i>									
A. Two single doors available	1.0	110	105	80	65	55	50	45	2,700–3,200 ^e
B. Two double doors available	0.6	170	135	110	90	80	70	65	4,000–4,500 ^e
3. <i>Articulated buses:</i>									
A. Three single doors available	0.8	155	115	90	75	65	55	50	3,500 ^e
B. Three double doors available	0.4	190	155	135	115	105	90	85	6,000 ^e

^a Design should be based on busiest 20 min per stop.^b Decreases reflect increased alighting opportunities as door capacity increases.^c Maximum buses per bay per hour; assumes 15-sec clearance between buses.^d Assumes bus arrivals without queuing.^e Articulated buses only.

Source: Computed.

TABLE 27

CBD LINE-HAUL BUS BERTH REQUIREMENTS^a WHEN 50 PERCENT AND 100 PERCENT OF PASSENGERS BOARD AT HEAVIEST STOP

PEOPLE LEAVING CBD IN PEAK HOUR ^b	CONVENTIONAL BUSES											ARTICULATED BUSES											
	50-PASS. BUSES PER HR	BUS BERTHS REQUIRED										BUS BERTHS REQUIRED											
		FRONT DOOR LOADING ONLY					FRONT AND REAR LOADING					FRONT AND CENTER LOADING				FRONT, CENTER, AND REAR LOADING							
		SINGLE FARE		PREPAYMENT			SINGLE DOORS		DOUBLE DOORS			PREPAYMENT		SINGLE DOORS		DOUBLE DOORS		PREPAYMENT		SINGLE DOORS		DOUBLE DOORS	
		50%	100%	50%	100%	50%	100%	50%	100%	50%	100%	50%	100%	50%	100%	50%	100%	50%	100%	50%	100%	50%	100%
1,000	20	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1,500	30	1	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2,000	40	2	3	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2,500	50	2	4	2	3	1	2	1	2	1	1	1	1	1	1	1	1	2	1	1	1	1	1
3,000	60	2	4	2	3	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	1	1	1
4,000	80	3	5	2	4	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	1	1	1
5,000	100	4	7	3	5	2	3	2	3	1	2	2	3	1	2	2	3	1	2	1	2	2	2
6,000	120	4	8	3	5	2	3	2	3	2	3	2	3	1	2	2	3	1	2	1	2	2	2
7,500	150	5	10	4	7	2	4	2	4	2	3	2	3	2	4	2	3	2	4	1	2	2	2
9,000	180	6	12	4	8	3	5	3	5	2	4	2	4	2	4	2	4	2	4	2	3	2	3
10,000	200	7	13	5	9	3	5	3	5	2	4	2	4	3	5	2	4	2	4	2	3	2	3
12,500	—	—	—	—	—	—	—	—	—	—	—	—	—	4	7	3	5	3	6	2	3	2	3
15,000	—	—	—	—	—	—	—	—	—	—	—	—	—	4	8	3	5	4	7	2	3	2	4

^a Add 1 berth for spare in all 50 percent cases and in all conditions where only 1 berth is required by the computations.^b Maximum 20-min volume expressed in hourly rate.

TABLE 29

LOCAL AND COMMUTER BUS TERMINAL PLATFORM LOADING CAPACITIES IN RELATION TO FARE COLLECTION PROCEDURES

FARE COLLECTION		PASSENGER HEADWAY (SEC)	DOORS USED (NO.)	DWELL TIME TO LOAD 60 PASS. ^{a, b} (SEC)	MIN. BUS HEADWAY (SEC)		EQUIV. MAX. CAPACITY (BUSES/HR)		EQUIV. PASSENGER LOAD		EFFECTIVE PASSENGER CAPACITY			
					QUEUED BUSES ^c	SINGLE BUSES ^d	QUEUED BUSES	SINGLE BUSES	QUEUED BUSES	SINGLE BUSES	40% IN PEAK 20 MIN		50% IN PEAK 20 MIN	
TYPE	METHOD										QUEUED BUSES	SINGLE BUSES	QUEUED BUSES	SINGLE BUSES
Double doors	None	0.8-1.2	2°	30-50	60	110	60	33	3600	2000	2900	1600	2400	1300
Free	None	1-2	2°	40-80	90	140	40	25	2400	1500	1900	1200	1600	1000
Prepaid	Platform barrier, turnstiles	1-2	2°	40-80	90	140	40	25	2400	1500	1900	1200	1600	1000
Other	Pay on exit, fare box	1-2	2°	40-80	90	140	40	25	2400	1500	1900	1200	1600	1000
Single coin or token	Pay on entry, fare box	2-3	1	120-180	190	240	20	15	1200	900	1000	1200	800	600
Odd-penny	Pay on entry, fare box	3-4	1	180-240	250	300	15	12	900	720	700	700	600	500
Multizone	Prepurchased tickets ^f	4-6	1	240-360	370	420	10	8	600	380	500	400	400	320
	Cash ^g	6-8	1	360-480	490	540	7	5	420	300	350	240	280	200

^a 40 through heaviest used door.^b Assumes 50 seats, 10 standees.^c Assumes that the next bus is always waiting behind the loading bus and can pull in and be ready to load within 10 sec (i.e., linear platform).^d Assumes that the next bus has to be summoned from a holding or storage area, involving a 60-sec delay and/or recovery time (linear or shallow sawtooth platform). With lower times, capacities would approach those for queued operation.^e Assumes 67-33 split between front and rear doors.^f Including fare registration by driver.

TABLE 26
LINE-HAUL BUS STOP CAPACITY (Loading Conditions Govern)

LOADING CONDITION	PASS. PER HOUR ^a	UNLOADING CONDITION	PASS. PER HOUR ^a
1. <i>Conventional buses:</i>			
A. Front door:		Simultaneous, rear door:	
1. Single door, single fare	800	1. Single door	1,200
2. Single door, prepayment	1,200	2. Single door	1,200
3. Double door, prepayment	2,000	3. Double door	2,200
B. Front and rear door:			
1. Single door, prepayment	2,000		
2. Double doors, prepayment	2,800		
2. <i>Articulated buses:</i>			
A. Front and center doors:		Simultaneous, rear door:	
1. Single door, prepayment	2,000	1. Single doors	1,200-1,500
2. Double doors, prepayment	3,000	2. Double doors	2,200-2,500
B. Front, center, rear doors:			
1. Single doors, prepayment	2,400		
2. Double doors, prepayment	4,000		

^a Values represent about 80 percent of those given in preceding tables for design purposes to reflect bus schedule variances. Passenger interchange values may be reduced another 15 percent to reflect on-bus turbulence. Source: Computed.

TABLE 28
BERTH CAPACITY FACTORS SUGGESTED
FOR ON-LINE AND OFF-LINE BUS STATIONS

BERTH NUMBER	ON-LINE STATIONS		OFF-LINE STATIONS	
	EFFICIENCY (%)	CAPACITY FACTOR ^a	EFFICIENCY (%)	CAPACITY FACTOR ^a
1	100	1.00	100	1.00
2	75	1.75	85	1.85
3	50	2.25	85	2.70
4	25	2.50	75	3.45
5	Negl.	2.50	75	4.20

CHAPTER THREE

INTERPRETATION AND APPRAISAL

THE POLICY CONTEXT

Bus priority treatments reflect the growing recognition of transit as an essential public service. Their installation, maintenance, and operation call for cooperative approaches among affected state, regional, and local governmental units, and transit operating agencies.

Bus priority measures should be complemented with appropriate policies that encourage and reinforce transit use. They should be viewed as part of an over-all transportation management strategy that deals with streets, parking, and transit service. They are effective only where service is

frequent, convenient, and inexpensive. It is not logical to provide bus priorities for service that is poor, overpriced, or virtually nonexistent. It is not rational to improve bus services into the city center and simultaneously increase the supply of low-cost downtown commuter parking. It is neither good transportation planning nor good investment policy to simultaneously build capital-intensive transit facilities and curtail bus service. Investment consistency is not attained by spending \$50 million to build a busway and then not giving buses priority of street use in the city center.

There is a need to identify basic urban transportation

goals, and to establish policies and investment decisions that reflect these goals. This policy context is prerequisite to providing bus priority measures that increase the peak-period capacity of urban roadways and improve the efficiency of the over-all urban transportation system.

TRANSPORTATION GOALS

Formulation of and consensus on transport goals is no easy task. The relative importance of specific objectives or criteria varies among the transit operator, transit user, motorist, and impacted community. Tradeoffs among goals, therefore, must be recognized—for example, diverting motorists to bus transport may shorten the duration of the peak period, and may increase peak bus loadings and equipment requirements. Similarly, an urban area that optimizes auto access by fostering freeway construction, proliferation of downtown parking, and/or a low-density auto-oriented development pattern may simultaneously erode bus service.

Urban transportation investment strategies should be directed toward providing a quality of service that is (1) consistent with the needs and preferences of travelers, (2) reflects their willingness and ability to pay, (3) conforms to the region's environmental standards, (4) helps direct regional growth potentials, and (5) accomplishes these objectives at least total cost over the long run. The urban transportation system should be designed to minimize user, construction, and community costs, including community disruption and social costs.

Because environmental quality and human displacement factors take increasing precedence over mobility requirements, it is essential that the transportation decision-making process assess community impacts and social costs. These factors are difficult to quantify in traditional benefit-cost terms. A more rational approach is to identify and compare basic cost and impact factors, from which tradeoffs can be identified and evaluated. This assessment should be done on regional, subarea, and corridor bases.

Metropolitan areas increasingly view improved bus (and rail) transit service as an environmentally acceptable alternative to additional highway construction. The objective of improved bus transport is to use existing streets now devoted to transportation more efficiently so that the growing travel demand in urban areas may be provided at minimum cost to society (16). Realization of this objective suggests the following bus service targets:

1. Reduce the use of private vehicles in peak periods. A general objective is to reduce peak-period auto trips about 10 percent on radial urban freeways. In reality, however, freeways will continue to operate at capacity, with a tendency to shorter peak periods as additional bus capacity is provided.

2. Increase the utility of urban space devoted to transportation. In addition to diverting existing auto drivers, there is need for new or improved bus operations to increase the number of people moved over present transportation rights-of-way. One target is to increase the number of people carried on a particular lane of a congested multi-lane urban road or freeway in the peak hour through bus

priority measures. Where commuter traffic is composed mainly of private cars, a desirable target would be to increase the number of people carried in a particular lane by at least 25 percent over a 3- to 5-year period. Where an additional lane is provided in the peak direction, for bus use, a 50 percent gain (in peak-period bus travelers) reflects a desired objective. This goal is stated in terms of persons actually counted, rather than in capacity terms, because it is necessary not only to provide the added capacity (which can easily exceed 100 percent) but also to attract bus riders.

3. Increase bus service reliability. The on-time performance of bus operations should be within 3 min 95 percent of the time. Operations that are subject to frequent delay cannot meet this standard in peak periods, yet reliability is one of the widely recognized service requirements that potential transit riders, especially commuters, seek. Bus priority measures afford an opportunity to substantially improve service reliability.

4. Increase peak-period efficiency. A reasonable target is to increase the efficiency of peak-period bus utilization by 15 to 25 percent. It should be possible to turn buses around for reuse several times in this period. Multiple peak-period trips by drivers are especially important where busway and other express services are involved. The heavy labor and equipment demands in peak periods determine fleet and manpower requirements, because they require resources that are largely unused during other parts of the day. Thus, improving peak-period bus service reliability and running times should help to reduce basic equipment and driver requirements.

5. Increase off-peak ridership. A reasonable target is to increase off-peak ridership by 15 to 25 percent, although this may be hard to achieve in North American cities. At a minimum, base-period off-peak demands should be retained at existing levels.

6. Reduce unit operating costs. A reasonable goal is to decrease unit operating costs (other than labor) by 3 to 5 percent a year to help offset rising labor costs.

7. Increase nondriver mobility. A desirable goal is to decrease the access time to major activity centers for the young, old, poor, and handicapped. Although it is costly to work toward this target as a single-purpose effort, it may be attainable when coupled with efforts to meet other goals. Community support may be needed since it is unlikely that the extra costs would be covered by additional revenues.

8. Reduce air pollution and noise emission levels. Reducing the number of vehicles in urban areas would probably reduce vehicle emissions in proportion to the number of vehicles displaced. Because the short-range target for reducing the number of vehicles is 15 percent, this also represents a reasonable vehicle emission reduction rate. Coupled with this goal is the need to control bus noise emissions.

A POLICY PERSPECTIVE

Achievement of the preceding objectives calls for optimizing urban bus services by measures that (1) can be controlled by bus operators (i.e., express bus services); (2) can be implemented jointly by the bus company and the com-

munity (i.e., elimination of curb parking along bus routes or installation of bus lanes; (3) require full community support (i.e., reduced bus fares); and (4) result from improved technology (i.e., multi-door pollution-free buses).

Traffic-Transit Integration

Planning, design, and location of major road systems should reflect transit needs. Provision should be made for transit rights-of-way within or adjacent to radial freeways in large metropolitan areas, especially where population exceeds 1,000,000. Designs should recognize specific bus needs, such as bus ramps, bus turnouts, and bus priority entry to metered freeway ramps.

Successful bus priority treatments call for more than planning and design. Implementation involves adequate advance publicity to achieve public support and compliance. Provisions for maintenance, monitoring, policing, and (in some cases) emergency services must be ample. Cooperative working arrangements are essential among transit operating agencies, municipal traffic departments, and state transportation officials—in operations and management as well as planning and design. *Agencies should recognize that the movement of people must take precedence over the movement of vehicles.*

Full community support of traffic and transit improvements is essential. The prohibition of peak-hour curb parking along bus routes remains one of the simplest and most cost-effective methods of improving bus operations, but only if enforcement can be effective.

Downtown Growth and Bus Priorities

There is a strong interdependence between public transport and the center city. Public transport makes possible high land-use and employment concentrations; simultaneously, the existence of these concentrations makes capital investments in public transport capacities into the city center feasible without extensive land area or terminal requirements. Increased transit patronage, in turn, permits more effective use of the downtown by avoiding extensive land areas devoted to streets and parking.

Continued office building developments in many downtown areas will increase peak-hour travel demands, which best can be met by improved public transport. In large centers, for example, an increase of 10,000 employees could create difficult movement problems if these peak-hour movements were to be served by automobiles alone. Meeting air quality and energy conservation standards further limits reliance on commuter car trips to and from many downtown areas.

The nature and extent of public transport improvements—including bus priorities—must, therefore, reflect downtown growth potentials, development objectives, and environmental constraints. Comprehensive street traffic management schemes that incorporate busways, contra-flow and normal-flow bus lanes, bus streets, ramp metering with bus priorities, and/or traffic signal overrides have important applicability. Auto-free zones that buses may traverse often enhance the downtown pedestrian environment.

The extent to which bus (and rail) transit use should be encouraged by inhibiting auto travel depends on downtown

employment density and reliance on public transport. Auto-use constraints emerge, or can be established, as (1) busways and rail transit systems are developed, (2) downtown land use intensifies, (3) urban toll roads are built, and (4) downtown parking supply is stabilized or reduced.

Downtown Parking Policy

Parking availability and costs are an important determinant of modal choice. Consequently, downtown parking policies should be consistent with efforts and investments designed to improve public transport. Off-street parking contributes to the economy of many cities and is usually essential before curb parking can be eliminated. However, abundant low-cost commuter parking in the city center may diminish public transport patronage and potentials.

Increases in downtown parking supply should be balanced against the consequences of encouraging peak-hour auto use. The location and pricing of urban parking facilities should complement, rather than compete with, public transport. This complementarity is especially desirable where one-half or more of all CBD commuters come by public transport. It calls for transferring parking from the city center to intercept points along express transit lines.

Downtown parking supply constraints and increased all-day parking rates are significant where major transit facilities exist or are being developed. All-day parking rates of \$0.50 to \$1.50 are not consistent with \$5- to \$10-million-per-mile busways, and they limit the viability of outlying park-and-ride operations. Adjustment of parking rates to favor short-term parkers could help limit peak-hour vehicular traffic where adequate express transit exists. It also represents a step toward motorists paying the true social and economic costs of the downtown parking spaces they occupy.

Bus (or rail) travel to the CBD should cost less than the corresponding out-of-pocket costs to drive and park (time included), as follows:

1. The round-trip bus fare should be less than the daily CBD parking rates and bridge tolls (based on prevailing car occupancy).
2. Bus (or rail) service should match or improve on automobile door-to-door times to the city center.

Where highway capacity is constrained, the interception or diversion of automobiles at outlying express transit stops should be encouraged. An integrated strategy of peripheral parking and complementary express bus service provides an effective early action alternative to increasing downtown parking supply (26).

Land Development Considerations

Bus service potentials can be improved by land-use planning that clusters employment and residential areas. Linear concentrations of multi-family dwellings along bus routes and high-density developments near focal points of transit systems should be encouraged. Subdivisions and planned unit developments should arrange street networks to promote bus route continuity; cul-de-sacs and other street discontinuities should be limited. New town plans, such as the Runcorn and Redditch experiences in England, should

incorporate special bus rights-of-way around which major residential and commercial areas can be organized.

Bus Design and Technology

Changes in bus design offer promise for improving the quality of service. Doors designed to permit two people to enter or exit simultaneously would significantly reduce passenger loading delays. Platform-height bus loading is also desirable to minimize dwell times at heavy passenger loading points.

There is a pressing need to increase peak-hour driver productivity, especially for peak-period express bus services. This suggests larger, higher capacity, perhaps articulated buses that would improve driver productivity by servicing larger numbers of passengers per unit of labor input, particularly on long express runs. Articulated single-deck buses can also provide more door space per passenger (and consequently shorter dwell times) than double-decked vehicles.

Bus technology should be directed toward improving propulsion systems that minimize or eliminate the need for costly ventilation systems in tunnels. This may involve technologies that relate to gas turbine or dual-propulsion (internal combustion/electric) vehicles with low exhaust emission rates, or no exhaust at all. Catalytic converters in diesel exhaust systems can also reduce bus emissions.

Further study should be given to platoon operation of buses in subways to increase capacity in central areas. Platoons of two or three buses would not normally produce queuing or operating problems in trunk-line service. Automation of bus operations in line-haul express service—the “dual-mode” concept—remains a desired long-range objective.

Transit As a Community Service

Recognition of public transportation as an essential community service is consistent with the provision of bus priority measures. Service should be acceptable to the community within the constraints of existing and future

resources. Reduced transit costs should be considered in the public interest.

The transit system should be designed, operated, and maintained so that it will attract patrons in such numbers as to assure its continuing effectiveness as a means of public transportation and a reasonable alternative to the private automobile. Efforts should be made to attract patrons by improving the quality and quantity of service, interfaces with other transportation modes, schedule convenience, the reasonableness of fares, equipment comfort, the design and maintenance of the bus stop environment, and the marketing of bus service.

Bus service improvements and extensions should be evaluated not only for economic considerations or profitability but also as a required public service that provides mobility for transit-dependent groups and, in the broader sense, attracts new patrons from competing modes. The over-all objective is to optimize return on investment of total transportation expenditures, and to minimize land impacts. Transit system improvements, including bus priority treatments on urban highways, should be designed so that initial measures for alleviating urgent problems of congestion or social disruption will not physically or financially impede over-all development of the evolving transit system.

Efficient bus utilization of highway facilities may involve revised routing patterns and operating policies. Additional labor and equipment costs associated with diverting motorists to buses may arise. In these cases, the rationalization for bus priority treatments and the improved bus service depends on the external benefits—the peak-hour bus service costs as related to the costs and impacts associated with providing comparable peak-hour road capacity.

Greater community recognition and support of metropolitan bus services is essential. This calls for nonuser charges to keep fares at reasonable levels, to maintain existing bus services, and to allow for service improvements. It calls for public commitment to bus service coordination and improvement programs. It calls for community support of bus priority measures, including implementation, management, and enforcement.

CHAPTER FOUR

APPLICATION—PLANNING AND DESIGN GUIDELINES: FREEWAY-RELATED BUS PRIORITY TREATMENTS

This chapter sets forth planning and design guidelines for freeway-related bus priority treatments, including busways, bus lanes, bus ramps, and freeway bus stops. General planning implications are discussed first, followed by a detailed description of warrants, planning concepts, and design guidelines for each type of treatment.

GENERAL PLANNING OVERVIEW

Freeway-related bus priority treatments are essential to effective express bus services and freeway traffic operations. Busways, reserved bus lanes on freeways, and bus priority ramps can increase the peak-period person-capacity and

help achieve fast, dependable, bus rapid transit services. They can provide medium-sized urban areas with the benefits of rapid transit at relatively low capital costs. In large urban areas, bus rapid transit can form a valuable supplement to rail service, covering low-density corridors and giving interim service in corridors ultimately intended for rail service.

A few strategically located bus priority treatments can achieve regional rapid transit. Buses, in contrast to rail transit, can operate in mixed traffic where conditions permit, thereby allowing potential economies in capital investments. Bus rapid transit systems do not have to be constructed in large increments, nor must they form a completely separate network. (High-platform rail rapid transit must be fully grade separated to maintain reliable schedules, and usually requires auxiliary feeder bus systems. "Light" rapid transit, which may operate at grade in outlying areas, requires reserved track and preference at points of conflict with surface traffic.)

Planning Guidelines

Urban freeway planning principles have important transferability to freeway bus priority treatments. These include: (1) balancing capacities with demands, (2) avoiding excessive route convergence, (3) consistent interchange design, (4) movement continuity, and (5) lane density equalization.

The following planning guideline factors are significant in achieving efficient utilization of urban freeways by buses and other high-occupancy vehicles:

1. The identification of major overload points on existing freeways and anticipated overloads on proposed freeways provides important guides as to where special bus priority facilities should be built. This approach is valid to the extent that the future road network has been committed and estimated future highway loads are realistic.

2. It is not generally feasible to remove existing freeway lanes from auto use in the heavy (flow) direction and to give these lanes to buses. If the freeway is already congested, reducing the lanes available to cars will further increase delay. The over-all loss in person-time to motorists will exceed the time savings achieved by bus patrons. (The principal exceptions are where auto travel to the city center must be reduced to meet environmental, energy conservation, or air quality requirements.) When a bus lane is added in the existing flow direction, it is reasonable to expect a gain in peak-hour auto flows equal to the auto "equivalents" of the buses removed.

3. Right-hand freeway lanes are not usually desirable for exclusive bus use because of frequent weaving conflicts with entering and exiting traffic.

4. Standardization of freeway entrance and exit ramps to the right of the through traffic lanes will permit the use of median lanes by buses either in normal or contra (reverse) flows. Special bus entry and exit to and from the median lanes can be provided without interfering with normal auto traffic on the right-hand ramps.

5. Metering of freeway ramps with bus bypass lanes should be introduced where the techniques will improve mainline through-flow and reduce bus congestion. Other

high-occupancy vehicles, and trucks, could also use the bus bypass lanes. Metering may not alleviate congestion resulting from lane-use imbalances at freeway-to-freeway interchanges. Metering usually requires available alternative routes.

6. Street-level bus stops—where buses leave the freeway for passenger pickup and delivery—are generally preferable to turnouts from freeway lanes. They can provide added convenience to patrons at minimum cost, and bus bypass lanes on metered on-ramps can minimize delay to buses.

7. Effective downtown passenger distribution facilities are essential complements to regional bus rapid transit services. Downtown distribution should maintain service dependability, and minimize time losses resulting from general traffic delays. Distribution may take place in bus streets (or lanes), in bus tunnels, or in special terminals.

8. Busways should be of economical design. They should be built for lower per-mile capital costs than rail transit lines. This will help to offset the higher operating costs normally associated with bus service, and be a realistic approach to providing bus facilities that may serve interim functions. The need for shoulders along busways should be assessed in terms of low bus volumes, infrequent bus breakdowns, and the low probability of delays to opposing traffic when stalled buses are passed.

9. Busways should be designed to allow for possible future conversion to rail or other fixed-guideway transit, with provisions for maintaining service during the transition period. A 50- to 60-ft right-of-way would generally provide sufficient width for stations, with space for continuity of service during the conversion period.

10. Busways should extend beyond the normal queuing distances from freeway convergence points, and park-and-ride facilities should be provided for convenient auto/bus transfer. Ideally, busways should penetrate high-density residential areas, traverse the city center, and provide convenient distribution to major downtown activities. Off-street distribution in the central area should provide at least three stops at ¼- to ½-mile intervals; linear stations should be encouraged in an attempt to keep bus tunnel cross-sections within street rights-of-way.

11. There may be merit in redirecting "busway emphasis" to developing facilities within the CBD, and on the close-in miles of radial corridors adjacent to it. Major bus priority treatments in the United States have focused mainly on the suburb-to-CBD trip component and provide little benefit to the majority of bus riders, who generally live within 4 to 5 miles of downtown. Arterial street bus lanes, bus streets, and grade-separated busways in or on approaches to the CBD would benefit these travelers. The two types of bus service are complementary, thereby permitting bus lanes on freeways and arterials in the same corridor where traffic density warrants.

12. Segregation of bus and auto traffic should be actively pursued in new town development, as well as in existing urban areas. The Runcorn (England) New Town Busway is an important first step toward this objective.

13. Radial freeways in urban areas that exceed 1,000,000 population should provide reservations for future express

transit (or special-purpose vehicle use) either within the median or alongside the facility.

Application Potentials

The applicability of specific treatments depends on (1) the intensity and location of existing and future demands, (2) the suitability of existing and proposed freeways to meet these demands, and (3) the location and extent of peak-hour congestion. The generalized warrants for freeway-related bus priority treatments given in Table 30 reflect these factors. The number of existing and future peak-hour buses and peak-hour passengers, the potential time savings to these travelers, and downtown development intensity quantify the conditions under which various bus priority treatments should be implemented. The minimum number of buses per hour and minimum time savings reflect the extent of capital investment required and the associated impacts to auto travel.

The urban highway network with its existing and future elements, loadings, and speeds forms the foundation for express bus services. Special bus roadways and facilities complement freeways in achieving efficient utilization of the highway network for movement of people. Bus priority treatments may be desirable wherever environmental factors, air quality requirements, and energy conservation concerns call for a reduction in radial vehicle-miles of travel.

Where highway facilities operate above service level D, mixed traffic operation is more efficient than providing exclusive bus lanes or roadways. Ramp metering with bus priority bypasses, and short bus bypass roads upstream of bottleneck areas, will have widespread applicability. Reserved lanes for buses, trucks, and car pools (where enforcement can be maintained) may provide greater over-all service than exclusive bus lanes.

Where large numbers of buses are involved, and where projected traffic demands far exceed freeway capacity so that queues or slowdowns will extend for miles, busways or bus lanes on freeways should be considered. These may take the form of exclusive lanes designated for buses (e.g., I-495 in the New York area), physically separate bus roadways along the freeway (e.g., San Bernardino Freeway Busway in the Los Angeles area) or parallel to the freeway within the same corridor (e.g., the proposed Milwaukee Transitway).

BUSWAYS

Busways—special roadways designed for exclusive or predominant use by buses—operate in metropolitan Los Angeles, metropolitan Washington, D.C., and Runcorn, England. They are an integral part of rapid transit plans for Atlanta, Milwaukee, and Pittsburgh, and have been proposed in several other cities.

Busways may provide (1) line-haul express transit service to the city center, (2) feeder service to rail transit lines, and (3) short bypasses of major congestion points. They should segregate buses from other types of traffic, and should include ancillary passenger-bus interchange and parking facilities. They may be constructed at, above, or below grade, either in separate rights-of-way or within freeway corridors. They may be designed as “open” sys-

tems in which buses can enter or leave at intermediate points, or as “closed” systems in which buses operate over the entire length of busway.

Applicability

Busways—unlike most other bus priority measures—are capital-intensive in that they involve construction (or use) of a separate roadway facility. Busway development (other than as short “queue jumpers” or short connector roads) depends on the intensity of downtown employment, population of the urban area, constraints to additional urban freeway construction, and the prevalence of peak-hour congestion.

Consideration should be given to developing line-haul busways wherever the following basic conditions are met:

1. Design-year urban population should exceed 750,000; CBD employment, 50,000; and peak-hour CBD cordon person-volumes, 35,000 (symmetrical city).
2. There should be at least 40 buses and 1,600 passengers potential to the busway in the design year. (Where railroad rights-of-way are utilized, these volumes could be reduced under certain circumstances.)
3. Buses utilizing the busway should save at least 5 min over alternative bus routings.
4. Current highway demands in the corridor exceed capacity; and environmental, social cost, and/or traffic conditions preclude providing additional road capacity.

Downtown busway development should be considered where peak-hour bus speeds are less than 5 to 6 mph, where the congested area extends for more than a mile, and where surface-street priority options cannot be effectively developed.

Busway development also should be considered where one or more of the following conditions are met:

1. Freeway flow cannot be restored to level of service D with mixed traffic by ramp metering, ramp closures, or other simple controls.
2. Contra-flow bus lanes are not feasible because traffic flow conditions and roadway geometry prevent their use. (Where bus priorities such as metering of contra-flow operations are effective, busway development can be deferred.)
3. Short (less than 1 mile) bus bypass lanes or ramps to bypass congested interchanges, lane drops, or high-volume on-ramps, are neither feasible nor enforceable.
4. Rail rapid transit along the corridor will be warranted within 20 years.
5. Travel time benefits accruing to bus passengers will exceed the purchase and development costs of the busway on an annual basis.

Busways should be built instead of additional freeway mileage when (1) busways can penetrate major activity centers whereas freeways would disrupt or displace them, (2) additional freeways would converge with existing freeways and tend to create serious overloads or lane imbalances, and (3) core-oriented transportation policies encourage commuter transit travel.

TABLE 30

SUMMARY OF WARRANTS FOR FREEWAY-RELATED BUS PRIORITY TREATMENTS

TYPE OF TREATMENT	PLANNING PERIOD (YR)	DESIGN YEAR ^a RANGE IN ONE-WAY PEAK-HOUR		DESIRED AVERAGE PEAK-HOUR BUS TIME SAVINGS (MIN/BUS)	TOTAL PEAK-HOUR USER SAVINGS ^b	BASIC LAND-USE PARAMETERS	OTHER RELEVANT CONDITIONS
		EXPRESS BUS VOLUME	BUS PASSENGER VOLUME				
1. Busway:							
(A) Special right-of-way	10-20	40-60	1,600-2,400	5	Positive ^c	Urban population, 750,000; CBD employment, 50,000; floor space, 20 million sq ft	Direct penetration of non-freeway corridor. Special access to or distribution within centers. Stations required. Within CBD, bus speeds under 6 MPH; and/or CBD over one square mile in area.
(B) Freeway median	10-20	40-60	1,600-2,400	3	Positive ^c		Freeway congested, ramp metering insufficient. Contra-flow lane not feasible, stations required.
(C) Railroad right-of-way	10 10	20-30 40-60	800-1,200 1,600-2,400	3-5 2-3	Positive ^c		Existing unused railroad grade available. Urban development related to discontinued rail service. Interim use of right-of-way acquired for rail transit. Stations required. Direct penetration of nonfreeway corridor.
2. Reserved freeway lane:							
(A) Normal flow	5	60-90	2,400-3,600	5	Positive		Freeway congested, ramp metering insufficient. Queue bypass lane upstream from bottleneck. Corridor level of service for other vehicles reasonable. Required to meet environmental or air pollution standards.
(B) Contra flow	5	40-60	1,600-2,400	2-3	Positive ^c		Freeway congested, ramp metering insufficient. Unbalanced flow permits reversing lane attaining level of service D in off-peak directions. Intermediate stops not required. Freeways, six or more lanes with no left-hand access.
3. Other:							
(A) Toll plaza bypass	5 5	15-20 20-30	400-600 600-800	5 2-3	Positive		Toll barrier meters highway, good operation downstream. Adequate reservoir area on approach to toll station.
(B) Exclusive ramp to mixed-traffic lanes	5 5	10-20 5-10	400-600 200-400	2 3	Positive		Mixed-traffic lane has good operating conditions.
(C) Metered freeway ramp with bus bypass lane	5	10-15	400-600	1	Positive		Alternate surface route available for metered traffic. Express buses leave freeway to make intermediate stops.
(D) Bus stops on freeways	5	5-10 ^d	—	5	Positive		Convenient pedestrian access to stop. Stops on ramps result in undue delay. Minimum passenger use 50 per hour. Generally provide at surface level in conjunction with metered ramps.

^a Base year should represent at least 75 percent of design year.^b Bus passenger time savings plus bus operator cost savings plus savings (or minus delays) to other road users, relative to "do nothing" alternative.^c Normally other users experience time savings when buses are removed from traffic stream.^d Stopping, not counting through express buses.^e Minutes per boarding passenger.

Planning Factors

The geography of the urban region and the nature of its street system will have important bearing on the extent, type, and configuration of busways. The underlying objective is to provide effective express transit with a minimum of special construction. Busways should extend beyond the normal queuing distances from freeway convergence points. Rights-of-way for busway extensions should be protected and reserved wherever possible.

Locational Considerations

The location of busways with respect to freeways should depend on (1) alignment opportunities and constraints, (2) costs, (3) adjacent land-use patterns and potentials, (4) passenger modes of arrival at stations, (5) interchange and station frequency, (6) freeway geometry, and (7) bus service requirements. The relative merits of busway locations on separate rights-of-way, alongside freeways, and within freeway medians are summarized in Table 31.

Busway locations in a separate right-of-way (or corridor) are preferable where penetration of high-density areas is essential, underground construction is required, joint land development potentials are good, there are no freeways in the corridor to be served, and busway stations rely on walk-in traffic. Separate busways provide the greatest location flexibility, best serve high-density areas, and achieve optimum functional relationships with high-density residential areas. Intermediate stations and access ramps can be provided readily. Countering these advantages are the land costs and environmental impacts, and implementation delays associated with developing new rights-of-way.

Exclusive bus roadways within a freeway right-of-way may be located either within the median or along one side of the freeway. They could adapt to a staged transportation corridor development, and result in low implementation costs and minimum community disruption. Factors to be assessed include:

1. Busway locations within a freeway median are preferable where freeways are suitably located, most riders arrive by bus, and construction costs make it essential to minimize transit rights-of-way, and alternate alignments require subway construction. These treatments are relatively simple to achieve, usually involve lower capital costs, and have minimum impact on ramp or interchange geometry.

2. Busway locations along one side of a freeway are preferable where most patrons arrive by car and very wide corridors or rights-of-way exist.

Busways developed along abandoned railroad lines or on rights-of-way that become available by reducing active railroad trackage can reduce land acquisition costs and community impacts. They may, however, involve protracted periods of negotiation. Moreover, many rail rights-of-way, like some freeways, do not penetrate major bus market areas.

System Configuration Criteria

Busway configuration criteria are shown in Figure 23. Factors involved include:

1. Radial character. Busways should radiate outward from the city center. Crosstown lines should be developed only where clearly warranted by land-use and travel densities.

2. Market penetration. Ideally, busways should penetrate high-density residential areas and provide convenient downtown distribution. They should serve both high-density (urban) and low-density (suburban) markets.

3. Through service. Through routing patterns are preferable whenever operating and demand conditions permit. Through service increases passenger convenience and simplifies movements in the city center. However, because of schedule variances, through service may not be advisable on long suburban routes.

4. Simplified route structure. Busways should minimize

TABLE 31
ALTERNATIVE BUSWAY LOCATION OPTIONS,
IN RANK ORDER OF PREFERENCE

FACTOR	IN SEPARATE TRANSIT CORRIDOR "PENETRATION"	IN MULTI-MODAL TRANSPORTATION CORRIDOR		
		WITHIN MEDIAN	ALONGSIDE MEDIAN	
			ON ONE SIDE	VARIABLE
Highway design simplicity	Good (1)	Good (2)	Fair (3)	Fair (4)
Cost minimization	Poor (4)	Yes (1)	Fair (2)	Fair (3)
Cross-street transit access	Good (1)	Good (2)	Good (2)	Good (2)
Pedestrian access	Good (1)	Fair (4)	Fair (3)	Fair (2)
Access to parking	Fair (3)	Fair (4)	Good (2)	Good (1)
Multi-use developments	Good (1)	Selected cases only (4)	Fair (3)	Fair (2)
Adjacent development catalysis and coordination	Good (1)	Fair (4)	Fair (3)	Fair (2)
Station location frequency (miles)	1/3-1	1/2-2	1/2-2	1 1/2-3

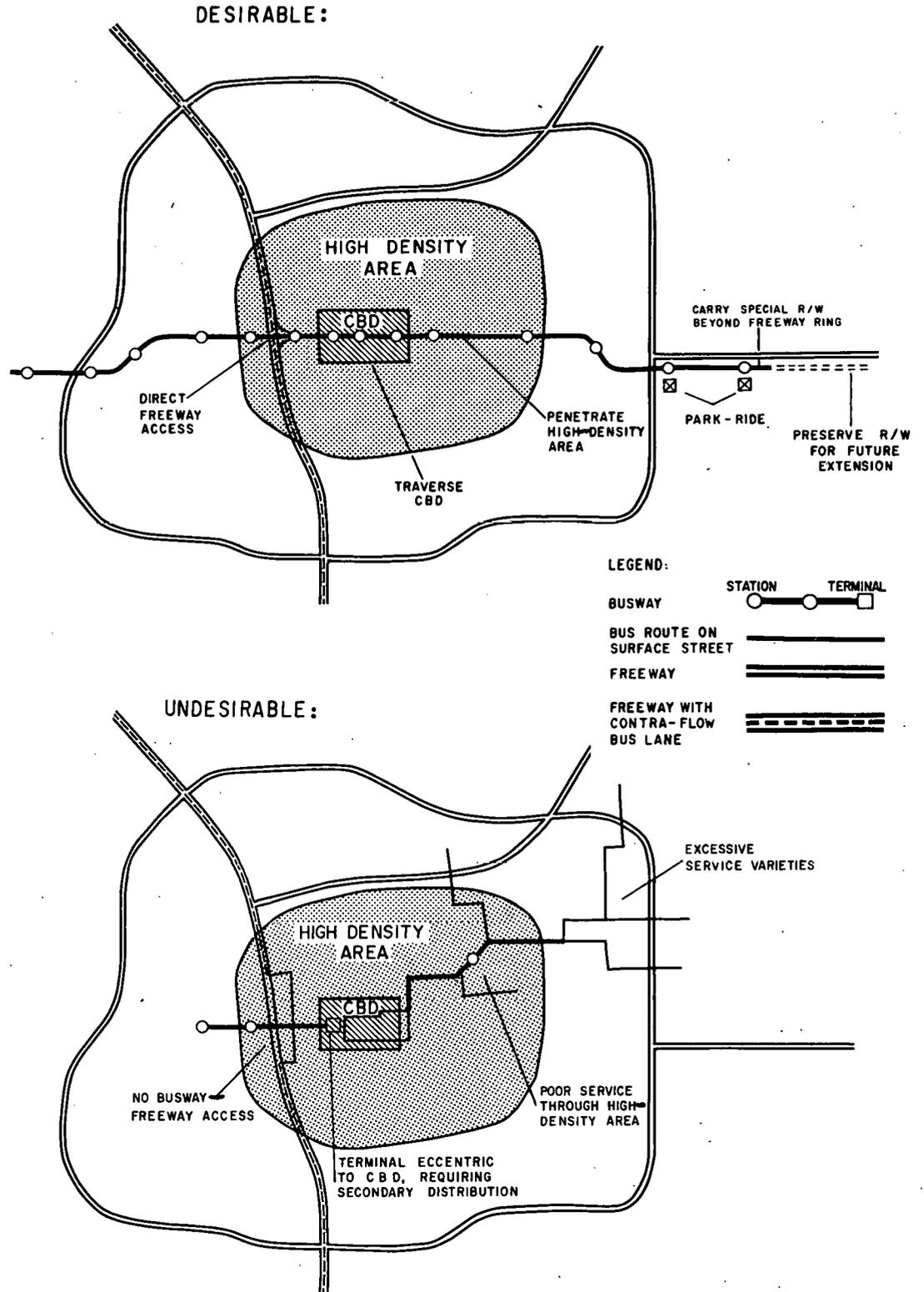
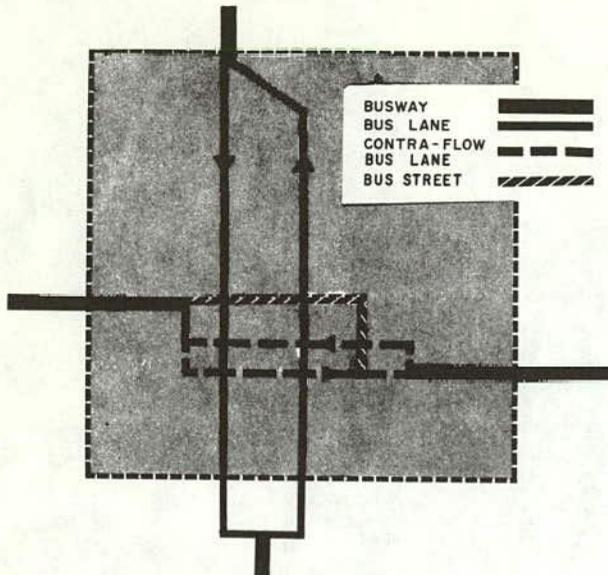


Figure 23. Desirable and undesirable busway configurations.

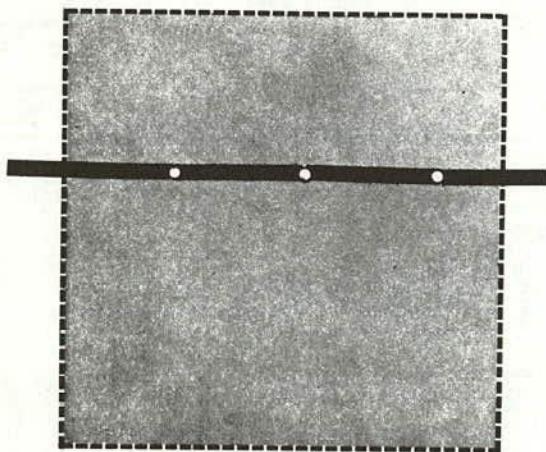
the number of branches and complex routing patterns should be avoided. The varieties of service should be minimized consistent with needs to promote route identity, maintain high service frequencies, and simplify station berthing requirements.

5. High operating speeds. Portal-to-portal speeds between the city center and outlying areas should be comparable to those by car. This calls for good geometric design and sufficient distance between stations.

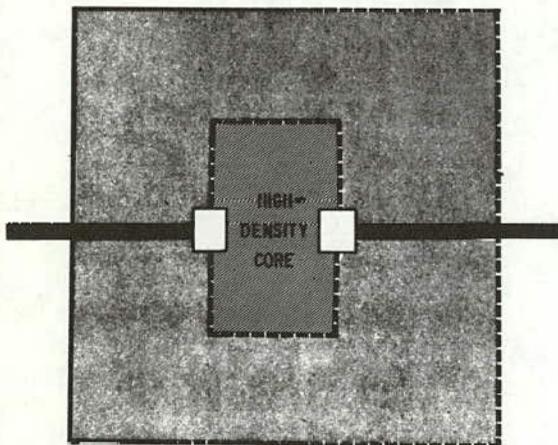
6. Station spacing. Station spacing, where stations are



BUSWAYS TIED TO BUS STREETS AND/OR BUS LANES



BUSWAY TRAVERSES CBD



BUSWAYS TIED TO TERMINALS

Figure 24. CBD busway distribution concepts.

provided, should vary inversely with population density. Close station spacing ($\frac{1}{4}$ to 1 mile) should be provided where passengers walk to stations; wider station spacing is feasible where people ride buses to stations ($\frac{1}{2}$ to 1 mile) or drive to stations (1 to 3 miles). The need for stations is diminished by the ability of buses to leave busways for collection and distribution.

7. Convenient transit, pedestrian, and auto interchange. Park-and-ride and, in some cases, bus transfer facilities should be provided in outlying areas where population densities are too low to generate sufficient walk-in patronage.

8. Maximum driver productivity. The number of peak-hour passengers per bus driver should be maximized through (a) service configurations that allow multiple trips in peak-hours, and (b) use of high-capacity (e.g., articulated) vehicles.

Downtown Distribution

The downtown end of the express bus trip offers an excellent opportunity to achieve time savings over automobile travel. The separation of buses from other traffic is more significant on the approaches to and (where conditions permit) within downtown, than it is in outlying areas. Moreover, commitment to capital costs for busways in radial corridors calls for parallel commitments to downtown distribution—either in special off-street facilities or through the allocation of special streets or lanes to buses. A city that elects to build a busway is, in effect, establishing its transportation policy.

Typical distribution systems for busways in the city center are shown in Figures 24 and 25. Express buses should provide their own downtown distribution without having to rely on secondary distribution systems. Ideally, downtown distribution should be off-street, permit through service, and provide at least three stops at $\frac{1}{4}$ - to $\frac{1}{2}$ -mile intervals in the downtown. (In practice only the Runcorn, England, Busway follows this concept.) Other factors include:

1. Downtown distribution can be provided by bus streets and bus lanes that connect to busways, with traffic signal priorities for buses at key locations. Downtown bus streets, contra-flow bus lanes, and median bus lanes can also provide early-action express bus service during the interim period while off-street distribution is being constructed. They are preferable to normal-flow curb bus lanes because they (a) promote a clear sense of transit identity, (b) are relatively self-enforcing, and (c) are removed from right-turn and marginal frictions.

2. Downtown distribution should be off-street in bus tunnels or ways whenever through routing is essential and surface street options or terminals are not feasible.

3. Downtown bus terminals on the edge of the CBD core can be provided whenever the CBD is sufficiently compact to serve major generators within a 5- to 10-min walk (i.e., $\frac{1}{4}$ to $\frac{1}{2}$ mile), or where adequate secondary distribution systems exist.

Design Criteria

Busway design criteria should provide acceptable ways of safety and service. They should foster economy in design, and enable busways to be built for lower unit costs than rail lines. Minimizing busway cross-sections, for example, will allow facilities to be located in corridors where they might otherwise be precluded.

Busway Use

Busway design should be consistent with anticipated use of the facility and the planned mode of operation. Commercial buses of more than 18 passengers and operated by professional drivers should be allowed to use busways (and contra-flow freeway bus lanes). Busway design should also permit use by emergency vehicles (ambulances, fire trucks, police cars). School buses should not be permitted.

Taxis and limousines may be permitted under special conditions. Busway design may also anticipate, and hence allow for, use by trucks and multiple-occupancy cars in some cases.

Busway Types

Busway designs can be grouped into several categories according to level of service, direction of flow, and arrangement of lanes. Design criteria and examples were prepared for two basic service levels and three basic busway configurations.

Class A Busways.—Provide freeway or rail rapid transit levels of service and would be completely grade separated. They are generally applicable in large urban areas where express buses may operate nonstop at high speeds over long distances or for bypassing freeway sections that operate at a relatively low level of service (D, E, or F) throughout the peak period. They should connect with freeways and provide access to downtown terminals or distributor busways. The Shirley and San Bernardino Busways typify Class A busways.

Class B Busways.—Provide service comparable to arterial streets or light rapid transit lines, and could incorporate some at-grade intersections. They would serve shorter-distance trips (3 to 6 miles), particularly in medium-sized urban areas, and provide relatively greater station frequency. The Red Arrow Busway (Philadelphia) and the Runcorn (England) Busway typify Class B busways.

Busways also can be grouped by direction of flow and placement of shoulder as shown in Figure 26.

Normal-flow busways provide a standard two-lane road with optional outside breakdown lanes. They are well suited for most busway applications, because they employ conventional right-hand operations with optional breakdown lanes on the outside.

Special-flow busways provide two one-lane roads and a central breakdown lane. They afford economy of width where breakdown lanes are required.

Contra-flow busways provide two one-lane roads and a central breakdown lane. Buses keep to the left of the center line. This design permits common island station platforms, which minimize station security, supervision, maintenance, and vertical transportation requirements. It has potential

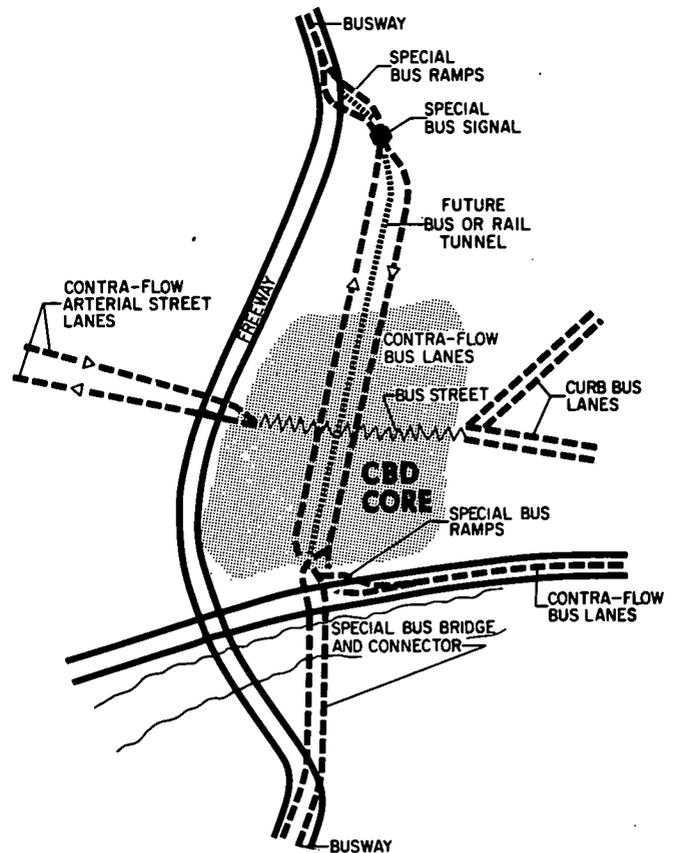


Figure 25. Illustrative coordination of bus priorities in the downtown area.

applicability where stations are frequent, tunnel construction is not extensive, intermediate access is not essential, and strict control over use can be maintained.

The normal-flow busway should be used whenever trucks and/or car pools might use the bus lanes.

Design Elements

Typical design standards for Class A and Class B busways are summarized in Table 32. They reflect AASHTO high-

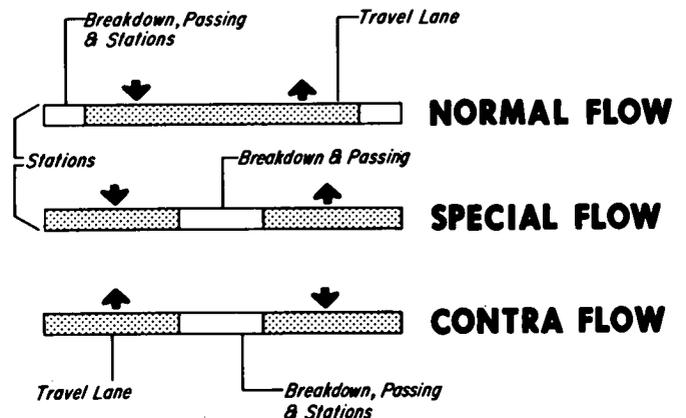


Figure 26. Busway types.

TABLE 32
SUGGESTED BUSWAY DESIGN CRITERIA

ITEM	CLASS A BUSWAY	CLASS B BUSWAY
Loads	H-20-S-16-44	H-20-S-16-44
Design speed (mph):		
Desirable	70	50
Minimum	50	30
Lane width (ft):		
With paved shoulders	12 ^a	11-12 ^a
Without paved shoulders	13 ^a	12 ^a
Paved shoulder width ^b (ft):	8-10	6-8
Total paved width (ft):		
Normal flow	26-44	24-40
Special flow	30-36	
Contra flow	30-36	
Minimum viaduct width ^c (ft)	28	28
Minimum tunnel width ^d (ft)	31	31
Minimum vertical clearance (ft):		
Desirable	14.5-18 ^e	14.5
Absolute minimum		12.5
Min. lat. dist. to fixed ob- structions ^f (ft):		
Left	3.5	2
Right	6	3
Maximum superelevation (ft/ft)	0.08 ^g	0.08 ^g
Min. radius of horiz. curves (ft):		
70 mph	1600	1600
60 mph	1150	1150
50 mph	750	750
40 mph	450	450
30 mph	250	250
Absolute min. radius ^h (ft):		
Conv. to conventional rail	250	250
Convertible to light rail	100	100
Nonconvertible	30	30
Maximum gradients (%):		
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 <i>K</i> -values ⁱ :		
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 (ft):		
With paved shoulders	12 ^j	12 ^j
Without paved shoulders	14 ^j	13 ^j
Paved shoulder width (ft)	8	8
Total paved width (ft)	14-22	13-20

^a Increase lane width 1 ft 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 of the selected rail system.

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

way design standards modified as appropriate for bus operations. They will achieve safe, efficient bus movement, economy of development, and permanency of investment. An effort has been made to derive busway design standards that are realistic in scale, and which result in development costs and right-of-way requirements that are less than for rail transit. The width of a busway will have important bearing on the ease with which it can be fitted into an existing community. Design standards include:

1. Loads. The structure should be designed to accommodate AASHTO H20-S-16-44 live loads.

2. Design speeds. Minimum design speeds of 50 mph for Class A busways and 30 mph for Class B buses should be used, with desirable speeds of 70 and 50 mph, respectively. A busway may incorporate various sections having different design speeds, but the changes should be few and gradual.

3. Lane widths. Busway lanes should be 12 ft wide except for constricted areas and around terminals, where 11-ft lanes are acceptable. The present trend in bus design toward an 8.5-ft vehicle width calls for lane widths of at least 12 ft to achieve smooth flow at moderate speeds on two-lane two-way busways. On high-speed busways that do not have paved shoulders, 13-ft lanes should be provided.

4. Shoulders. Buses should be able to pass stalled vehicles. This can be accomplished (a) by providing shoulders for disabled vehicles, (b) by providing narrow unpaved border (usually 2 to 4 ft wide) on both sides of the paved roadway, and/or by use of the opposite-direction lane. Busways can be developed with and without full-width shoulders.

Full-width design allows for buses to pull off the traveled way far enough to cause only minor disturbance to the flow of through traffic. This design is recommended only where the busway must be designed for possible use by private automobiles or trucks (e.g., car pools, and peak weekend traffic). Shoulders should be 6 to 8 ft wide for Class B busways and 8 to 10 ft wide for Class A busways.

Shoulders may be omitted where exclusive use of normal-flow busways by buses is anticipated, or where extensive structure or tunnel sections are involved. Peak bus volumes of 2 to 3 per minute each way can be accommodated on conventional two-lane roads without shoulders or median division. These bus volumes reflect 6,000 to 9,000 peak-hour, one-way passengers—volumes which when significantly exceeded may suggest rail transit as a viable option.

The percentage of time that outbound buses will delay inbound buses as a result of stalled vehicles is given in Table 33 for 6- and 12-sec clearance-time (gap) intervals. These computations are based on random (Poisson) bus arrivals. They indicate that a stalled bus would delay suc-

^g May be reduced to 0.06 in regions where roadway icing is a consideration.

^h Inner lane edge.

ⁱ Length of vertical curve = $K \times$ algebraic difference in grades. The *K*-values given conform to current AASHTO policy.

^j Refer to Table 19 for minimum ramp width on curves. Increase lane width 1 ft when nonmountable-type curbs are used adjacent to travel lane.

TABLE 33
PERCENTAGE OF TIME INBOUND BUSES WOULD BE DELAYED
BY OUTBOUND BUSES

INBOUND BUSES, V_1 (BUSES/HR.)	PROPORTION OF TIME INBOUND BUSES DELAYED (%)											
	OUTBOUND BUSES, V_2 , ON 6-SEC INTERVAL ^a						OUTBOUND BUSES, V_2 , ON 12-SEC INTERVAL ^a					
	40	60	90	120	180	250	40	60	90	120	180	250
40	0.4						1.6					
60	0.6	0.9					2.3	3.3				
90	0.9	1.3	1.9				3.3	4.7	6.7			
120	1.2	2.0	2.5	3.3			4.2	6.0	8.6	10.9		
180	1.7	2.5	3.6	4.7	6.7		5.7	8.2	11.7	14.9	20.3	
250	2.2	3.2	4.7	6.1	8.8	11.5	7.2	10.3	14.7	18.7	25.6	32.1

^a Gap.

Source: Computed, as follows: t = time required for buses to pass stalled bus (gap); V_1 = number of inbound buses per hour; V_2 = number of outbound buses per hour. The probability of 0 buses arriving in t sec = e^{-r_1} inbound and e^{-r_2} outbound, where $r_1 = V_1 t/3600$ and $r_2 = V_2 t/3600$. The probability of 1 or more buses arriving in both directions = $(1 - e^{-r_1})(1 - e^{-r_2})$, the values given above.

cessive vehicles about 10 percent of the time assuming (a) 120 inbound and 120 outbound buses and (b) a 12-sec required gap. For lighter bus flows and smaller gaps, lesser delays would result. A 5-mile busway carrying 500 buses per day would average less than one breakdown per week, based on the reported bus breakdown experience of the I-495 bus lane approach to the Lincoln Tunnel.

5. Total paved width. Total paved width (between stations) ranges between 24 and 44 ft for normal-flow busways and between 30 and 36 ft for special-flow and contra-flow busways. Minimum viaduct roadway widths are 28 ft and minimum tunnel envelope widths are 31 ft.

6. Vertical clearances. Vertical clearances should be sufficient to accommodate buses plus any other vehicles that might ultimately use the facility. Where convertibility is anticipated, or desired, rail car clearance requirements must be considered.

A minimum clearance of 14.5 ft should be used to allow for possible truck use as well as future increases in bus height. Clearances for existing rail systems vary from 14 ft for third-rail systems up to 18 ft for overhead contact (catenary) systems. An absolute minimum vertical clearance of 12.5 ft for Class B busways would accommodate the maximum 11-ft height of most current urban buses.

7. Lateral clearances. Lateral clearances to fixed obstructions reflect current highway standards. These values should apply to noncontinuous obstructions, such as bridge piers. Continuous obstructions, such as retaining walls or parapets, may tolerate closer clearances. Left-hand clearances should not be less than 2 ft for Class B busways and 3.5 ft for Class A busways. Right-hand clearances should be 4 and 6 ft, respectively.

8. Gradients. Maximum gradients should reflect current highway practice, except where convertibility to rail systems is desired. Long grades at or near the maximum values should be avoided wherever possible.

Where convertibility to rail is planned desirable grades should not exceed 3 to 4 percent. (The exception is where

light rail systems are being considered for future installation.)

Main-line grades should not exceed 5 to 6 percent, with an absolute maximum of 8 percent.

Ramp grades should not exceed 8 percent, with an absolute maximum of 10 percent.

9. Vertical curves. Criteria for vertical curvature should also conform to AASHTO practice (27). The length of vertical curvature should be determined by the requirements for minimum safe stopping distances, and be governed by (1) the algebraic sum of the gradients and (2) the design speed of the busway.

The adoption of AASHTO K -values for busway design appears to be a prudent approach. Where substantial economies are essential, slightly lower values may be allowed. The K -value could theoretically be reduced on crest vertical curves, when applied exclusively to buses, because the height of the driver's eye above the pavement is 6.5 to 7 ft for buses (as compared with 4 to 4.5 ft for automobiles). A similar reduction in K -values for sag vertical curves might be made, considering the higher headlight mounting positions on buses. Counteracting these reductions, however, is the more critical nature of passenger safety—particularly for standees—during emergency stops, as well as the possibility of future bus vehicle designs with lower driver eye and headlight heights, and the use of busways by taxis, limousines, trucks, and, in some cases, car pools.

10. Normal cross slopes. Normal pavement cross slopes on busways should be between 1 and 2 percent on through pavements and between 4 and 6 percent on shoulder and border areas.

11. Horizontal curvature. Horizontal curvature should conform to AASHTO practice. Absolute minimum radii should be determined by bus vehicle capabilities and by the limitations of future rail systems. Most rail systems (excluding light rail systems) cannot negotiate curves of less than 250-ft radius. Horizontal curves of 250-ft radius should be provided for 30 mph; 750-ft, for 50 mph; and

1,600-ft, for 70 mph. Superelevation should not exceed 0.06 ft per foot where roadway icing is a factor and 0.08 ft per foot elsewhere.

Transition curves should be provided only where busways are located in freeway rights-of-way, and where transition curves follow those along the freeways.

12. Ramps. Class A busway ramps should be designed for 30 to 35 mph and Class B busway ramps for 15 to 25 mph. Lanes should be 12 ft wide where shoulders are provided and 13 to 14 ft otherwise. Total paved ramp widths should range from 13 to 22 ft.

Minimum ramp designs should be used only for relatively short distances, although the unpaved border areas can provide a limited amount of additional width for maneuvering around stalled vehicles.

13. Merging and diverging sections. Special design criteria should apply to busways where ramps enter or leave main-line busways or freeway and where turnout lanes are provided at busway stations.

Ramp exits should have a 12:1 taper ratio to assure adequate ramp identification and visibility. Beyond the point of lane divergence, the tangent section should be long enough to allow a comfortable rate of deceleration.

Ramp entrances normally should have a 50:1 taper ratio; this may be reduced to as little as 20:1 where ramp bus speeds and volumes are low.

Turnout lane design at busway stations should be based

on ease of negotiation by buses. Taper ratios of 30:1 are permissible on Class A busways and 20:1 on Class B busways.

14. Pavement widening on busway curves. Pavement widening on curves should provide additional lateral width for maneuvering and for the overhang of various parts of the vehicle. Pavements should be widened 1.5 to 2 ft on curves having radii of 1,000 ft or less, depending on design speed and busway width (Table 34). These values are slightly greater than current AASHTO policy, because they accommodate a 40-ft long, 8.5-ft-wide design vehicle whereas the AASHTO values reflect a 30-ft long, 8.5-ft-wide design vehicle. Designs for a single-unit bus will also accommodate a 60-ft-long articulated bus, because the latter requires similar maneuvering room.

15. Widths of pavements for ramps. Most urban buses are designed with minimum turning radii (inner rear wheel) as small as 17 ft. At this radius, the outer front wheel turns on a radius of 42 ft, producing a wheelpath 25 ft wide. This path reduces in width as the inner radius increases, but it is still a significant factor on many curved ramps.

The pavement widths required at various radii to include shoulders and traveled lanes are given in Table 35. Values are given for three cases: single-lane ramps, no passing; single-lane ramps with provision for passing; and two-lane ramps.

TABLE 34
PAVEMENT WIDENING RECOMMENDED FOR
CURVES OF TWO-WAY TWO-LANE BUSWAY

NORMAL ROAD-WAY WIDTH (FT)	DESIGN SPEED (MPH)	PAVEMENT WIDENING ^a (FT) FOR CURVE WITH RADIUS OF					
		500 FT	750 FT	1000 FT	2000 FT	3000 FT	4000 FT
24	30	1.5	1.0	0.5	0	0	0
	40	2.0	1.0	1.0	0	0	0
	50		1.5	1.0	0.5	0	0
	60			1.5	0.5	0	0
	70				1.0	0.5	0
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 1.5 may be disregarded.

Bus Tunnel Ventilation

Bus tunnels require both supply and exhaust fans to control air quality. The amount of ventilation supplied will determine the air quality within the tunnel for a given powerplant, bus volume, and system operating pattern. Factors involved include:

1. Air quality considerations. Diesel engines remain the primary source of power for urban transit buses, because the turbine engine, although tested extensively, has not been placed in general use. These powerplants emit various amounts of smoke, odor, and eye-tearing formaldehydes, which detract from the comfort level of a given environment. They also emit oxides of nitrogen and carbon monoxide, which become health hazards in sufficient concentrations.

Carbon monoxide levels (21) govern ventilation requirements for turbine-powered operation, whereas nitrogen oxides govern diesel air quality needs. Carbon monoxide

TABLE 35
PAVEMENT WIDTHS RECOMMENDED FOR BUS RAMPS

CONDITIONS	PAVEMENT WIDTH (FT) FOR INNER PAVEMENT EDGE RADIUS OF								
	50 FT	75 FT	100 FT	150 FT	200 FT	300 FT	500 FT	1000 FT	TANGENT
Case 1—One-lane, one-way, no passing	22	19	17	16	16	15	15	14	12
Case 2—One-lane, one-way, with provision for passing stalled vehicle	39	31	28	25	24	23	22	22	20
Case 3—Two-lane, one-way or two-way	45	37	34	31	30	29	28	27	24

emissions from the diesel are low in comparison with their oxides of nitrogen emissions; thus, ventilation that dilutes the oxides of nitrogen to acceptable levels will also achieve acceptable monoxide levels.

Ranges of ventilation requirements for diesel and turbine-powered bus operation in tunnels are shown in Figure 27. Specific requirements should reflect established air quality standards.

Earlier studies found that odor is a more serious factor than hazard from toxic gases (28). In this context, ventilation requirements that compensate for odor and toxic fac-

tors are comparable when the air quality standards are in the range of 50 ppm carbon monoxide and 5 ppm for oxides of nitrogen.

2. Cost implications. The air quantities required to ventilate bus tunnels will increase basic tunnel costs 20 to 30 percent for diesel buses and 10 to 20 percent for gas-turbined buses (27). However, relatively short (1,200 to 1,500 ft) bus tunnels generally could be developed without significantly increased ventilation costs.

3. Design guidelines. The following bus tunnel ventilation design guidelines should be considered:

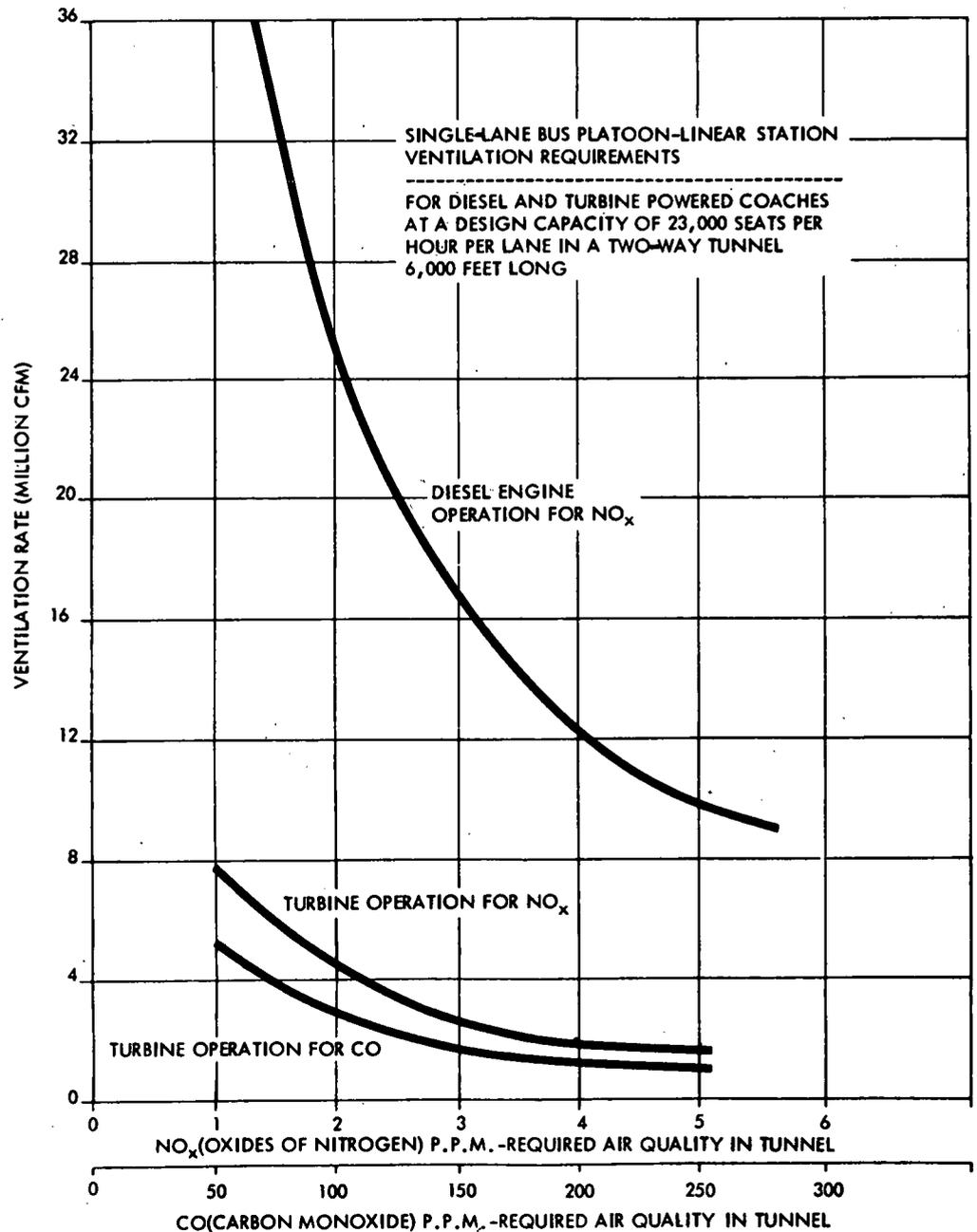


Figure 27. Ventilation airflow required for bus operation in a tunnel. (Calculated by Smith, Hinchman and Grylls Assoc.)

- (a) Length of bus tunnels should be kept to a minimum.
- (b) Careful consideration should be given to the location of fresh-air and exhaust openings, because normally they will be located in heavily congested areas. Fresh-air openings should be located where the atmosphere is not already contaminated. Discharge openings in most instances should be located above street level, and in some instances stacks may be higher than adjacent buildings. Ventilation equipment areas should be located to minimize costs and environmental impact.
- (c) Bus exhausts should be extended vertically above the roof of the bus at the left rear corner. This would allow the use of long thin exhaust hoods over loading platforms to provide effective capture of exhaust gases. Supply air could enter from grilles along the vertical sides of loading platforms to provide an upward draft of fresh air around the bus.
- (d) In the tunnel proper, fresh air should be introduced low, and exhaust air should be taken out in or near the ceiling. Ventilation should be transverse.
- (e) In loading and unloading areas, consideration should be given to providing walls that separate the bus tunnels from the passenger areas with openings the size of the bus doors in the walls. These openings could be protected with air curtains to prevent contamination of the passenger area. This arrangement would also make it much easier to provide climate control in passenger loading and unloading areas.

4. Where conditions permit, a continuous opening between the ceiling of the bus tunnel and the median area separating traffic lanes on the street could be provided. Fresh air could be introduced at the lower portion of the tunnel and allowed to exhaust by gravity through the continuous opening in the median.

This treatment is illustrated in Figure 28. Where roadway width and environmental conditions permit, 10- to 15-ft ventilation openings could be provided to reduce ventilation requirements and costs. A minimum 80-ft roadway right-of-way would be required to provide four 12-ft travel lanes and 10-ft sidewalks. At key locations, left-turn lanes could be provided over the busway ventilation opening.

Design Examples

Typical busway design examples illustrate cross sections, construction, station, transition, and control treatments for busway designs in separate rights-of-way, alongside freeways, and in freeway medians. They encompass minimum and optimum conditions. Choice of designs should reflect specific local factors.

Cross Section

Typical busway cross sections are shown in Figures 29 and 30. Full shoulder designs for special-flow and contra-flow busways are generally less than those for normal-flow operations, whereas minimum design cross sections are smallest for normal-flow busways (Table 36).

1. Normal Flow (Fig. 29). Minimum design calls for a 32- to 34-ft section (24- to 26-ft roadway plus two 4-ft shoulders). Full shoulder design calls for a basic 36- to 46-ft section. (The smaller dimensions apply to Class B busways.)

Lane widths should be increased 1 ft where nonmountable curbs are used. Roadways should be pitched about 1 percent and shoulders 3 to 4 percent.

Where busways are located alongside or adjacent to freeways, a minimum 4-ft separation should be provided. Where busways are located within an arterial median (Class B busways) a 32-ft envelope is suggested.

2. Special and Contra-Flow Busways (Fig. 30). Minimum design calls for two 13-ft lanes separated by a 4-ft median. The median should be flush for special-flow operations and raised and mountable for contra-flow operations. The raised median tends to reinforce the separation of opposing traffic in an "unnatural" left-hand contra-flow operation.

In the full shoulder design, the center separation is increased to 10 ft, allowing it to be used as a breakdown lane. It can accommodate a stalled bus with only minor interference to bus flows.

Over-all width requirements are 4 to 6 ft wider than normal flow for minimum designs, whereas most full shoulder designs are up to 8 ft narrower. A minimum 38- to 44-ft envelope is required where busways are located within or alongside freeways.

Special Construction Sections

Suggested design details for elevated, depressed, tunnel, and underpass busways cross sections are shown in Figures 31 and 32.

Lateral clearances to piers, walls, and parapets are based on standard AASHTO practice. The higher design speeds of Class A busways require 1- to 2-ft greater clearance than the Class B busway. Minimum clearances and minimum envelopes are summarized in Tables 37 and 38, respectively.

Both minimum and full shoulder designs are shown for elevated and depressed sections. Where full shoulders are maintained through special construction areas, minimum widths of 6 ft for normal flow and 10 ft for special and contra-flow are specified. Cost considerations will generally dictate the use of the minimum designs where elevated or depressed sections are of significant length.

Ramp Sections

Ramp sections are shown in Figure 33. A major design consideration is the need for buses to pass stalled vehicles. Accordingly, cross-section "envelopes" should not be less than 18-feet for one-way ramps. A minimum design (without shoulders) should be utilized only in restrictive situations, and then only for limited distances. A minimum paved width of 20 to 22 feet should be maintained wherever possible. Two-way ramps would achieve construction economies.

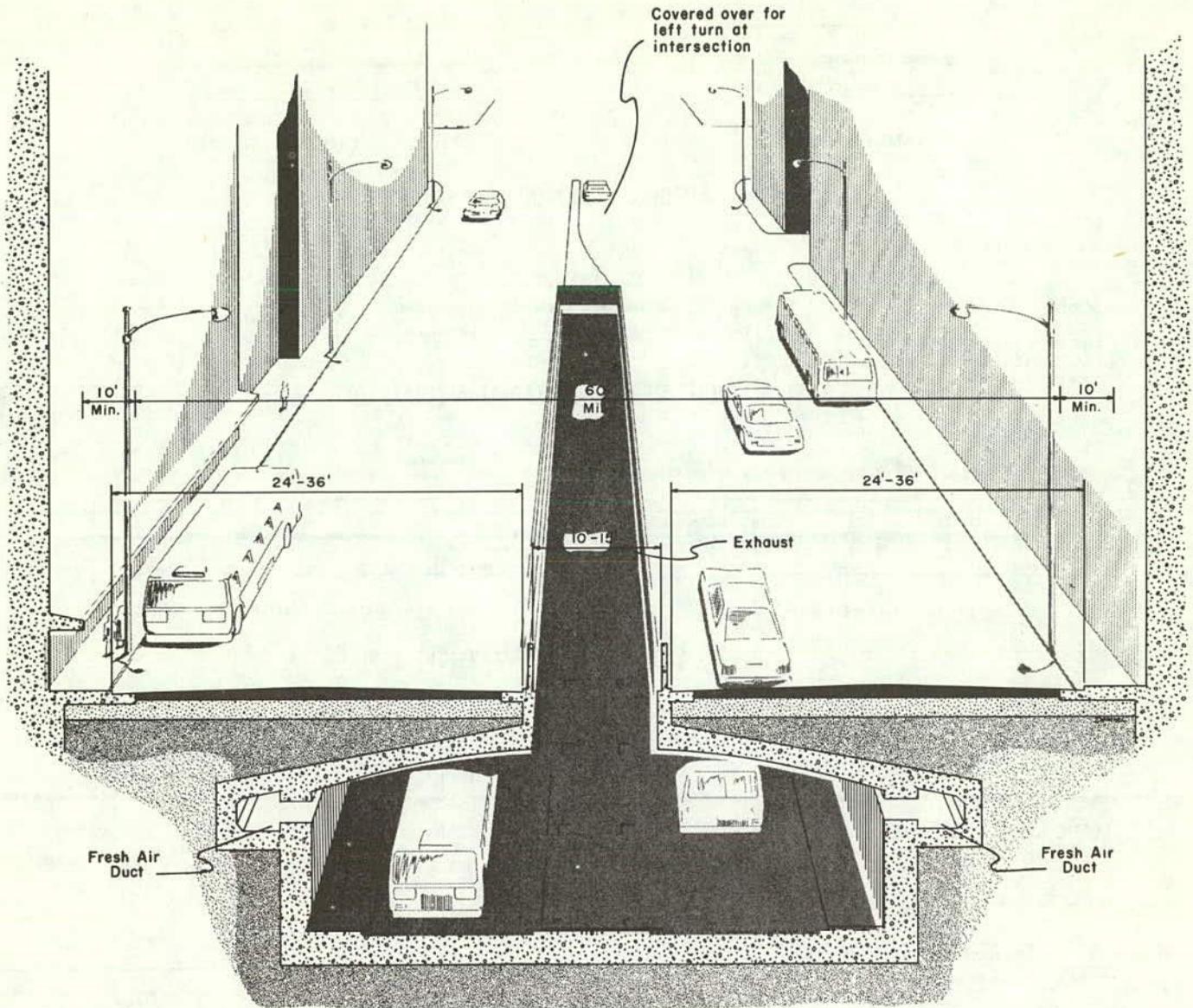


Figure 28. Possible treatment of bus subway along arterial street.

Special Treatments in Freeway Medians

Busway design should be carefully coordinated with overall freeway construction. Typical examples of buses in urban freeway medians are shown in Figure 34.

Busway envelopes within freeway medians range from 45 to 65 ft, depending on placement of piers and location of stations. Normal-flow busways adapt to the placement of a pair of piers, one on each side of the busway. Special-flow and contra-flow busways adapt to the placement of a single pier within the median busway lane.

Busways in freeway medians can share shoulders with adjacent freeway lanes where restrictive right-of-way conditions prevail (Figure 35). A minimum freeway median envelope of about 52 ft can readily incorporate both busway and shoulders. Flexible traffic posts should be installed at the edge of the busway travel lanes and a nonmountable median should separate opposing bus flows.

Station Design

Busway station design has important bearing on the operating characteristics, construction complexity, and cost implications of busway systems. Separate station designs and operating procedures are required for downtown and line-haul stations. Passenger boarding practices and rates, fare collection procedures, and bus service frequencies must be considered.

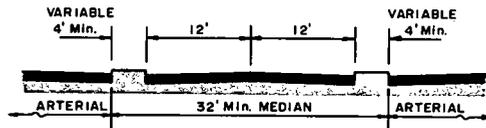
1. Planning objectives. Station design should minimize cross-section widths consistent with good operating practice. Where right-of-way conditions permit, it is desirable to provide bypass opportunities for buses, especially where express and local services operate on the same roadways. Ideally, loading and unloading delays should affect only the particular bus involved and high-volume multi-berth stations (especially in the downtown area) should have by-



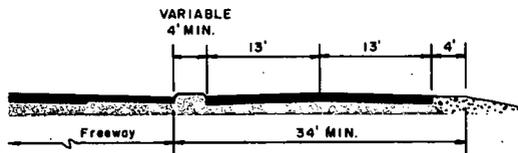
SPECIAL RIGHT-OF-WAY (A)

- (A) CLASS 'A' BUSWAYS 13' LANES; 6'-10' SHOULDERS
 CLASS 'B' BUSWAYS 12' LANES; 6'-8' SHOULDERS
 (B) CLASS 'B' BUSWAY
 (C) CLASS 'A' BUSWAY

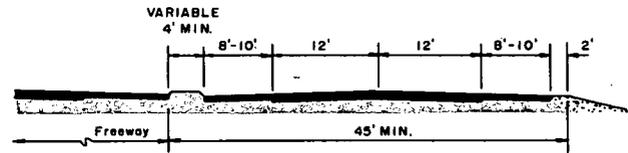
NOTES: 1. LANE WIDTHS MAY BE INCREASED ON CURVES.
 2. ADD 1 FT. TO LANE WIDTH WHERE NON-MOUNTABLE CURBS ARE UTILIZED ADJACENT TO LANE.



SPECIAL RIGHT-OF-WAY ARTERIAL MEDIAN (B)

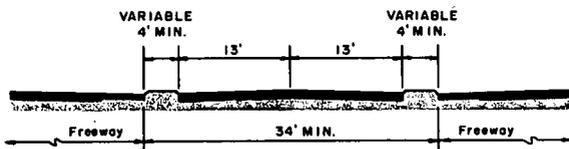


MINIMUM DESIGN

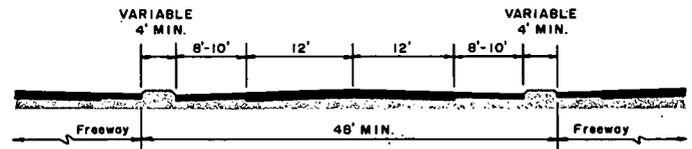


FULL SHOULDER DESIGN

ALONGSIDE FREEWAY (C)



MINIMUM DESIGN



FULL SHOULDER DESIGN

FREEWAY MEDIAN (C)

Figure 29. Typical sections, normal-flow busways.

pass capabilities that allow bus arrival and departure in different sequences. These requirements, in turn, should be balanced against land availability, construction feasibility, and costs.

2. Station platform criteria. Station platform design criteria are shown in Figure 36. The use of parallel versus shallow pull-through sawtooth loading will depend on site characteristics and space availability.

Single parallel platforms should be at least 6 ft and preferably 10 ft wide. Shallow (single) sawtooth platforms should be at least 10 ft wide at the point of minimum width.

Two-sided island platforms should be at least 11 ft wide, with width increasing to 23 ft where pedestrian access is provided at the center.

A minimum station length of 80 to 100 ft allows for two bus berths.

Pedestrian walkways should be at least 5 ft wide, stairways at least 6 ft, bridges at least 8 ft, and tunnels at least 10 ft.

The number of station entrances should be based on

anticipated patronage requirements. Location should reflect surface street geometry, land-use requirements, access needs, and local design considerations. At least two street access points, preferably at midblock, generally should be provided in downtown areas.

Sufficient vertical transportation should be provided to prevent undue passenger accumulation at platforms. Major station entrances should provide at least one "up" escalator and one stair when the rise is greater than 12 ft, and at least one additional "down" escalator when the rise is greater than 30 ft. Multiple-berth central stations (where used) should provide at least one stair and one "up" escalator per platform.

3. Line-haul stations. Stations on radial busways should be of simple design. Often, minimum-type facilities can be provided, including an open platform with a small shelter. More elaborate facilities may be required at stations with park-ride service.

Station design should (1) minimize cross-section width and (2) provide for passing of disabled vehicles. It is also desirable, wherever possible, to (3) prevent pedestrians

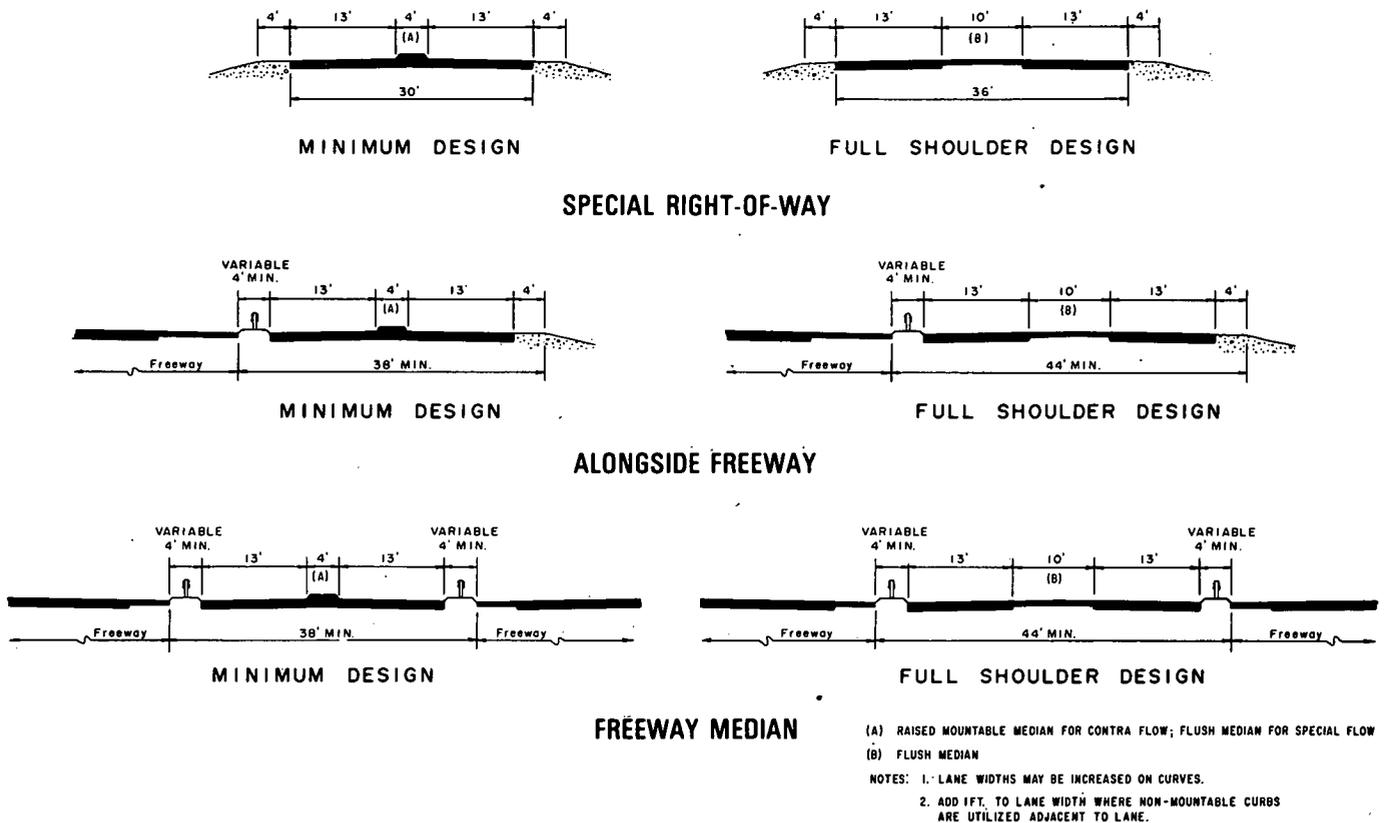


Figure 30. Typical sections, contra-flow and special-flow busways.

from crossing busways and (4) allow express buses to pass stopped vehicles. Meeting the first two objectives calls for minimum envelope widths of 34 to 36 ft for normal-flow busways and 50 ft for contra-flow busways. Meeting the last two objectives calls for minimum cross sections of 50 to 60 ft for contra-flow busways and 60 ft for normal-flow busways. Station design may allow on-vehicle fare collection. Prepayment, where required, should allow one person to collect fares and monitor passenger flow.

Typical line-haul station designs for normal-flow and contra-flow busways are shown in Figures 37 and 38. They range from minimum designs to designs that contain full turnouts, with divisional islands and isolated stopping roadways.

4. Downtown station concepts. Downtown busway stations should provide sufficient capacity to serve anticipated peak hour loadings and to realize the capacities of approaching line-haul busways. *Passenger boarding-alighting requirements at the heaviest downtown stations will govern the capacity of the system.*

The following principles influence central area busway station design:

1. Station dwell times and berthing requirements should be minimized. This objective requires (a) prepayment of fares, (b) separation of major passenger loading and unloading areas, and (c) provision of multiple stops within the downtown area. A minimum of three downtown stops generally should be provided.

2. Downtown berthing requirements should be based on

the peak 20-min passenger volumes. The number of loading and unloading positions could be estimated from the values presented in Chapter Two. The efficiency of successive berths should be reduced, especially where passing opportunities are limited. One spare berth can be added to the computed requirements. At least three loading positions should be provided per station.

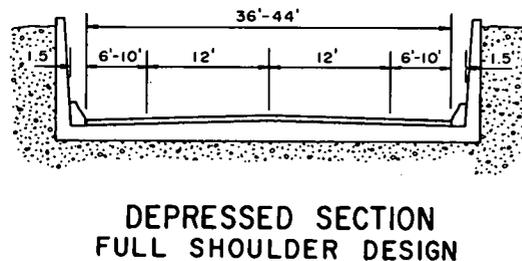
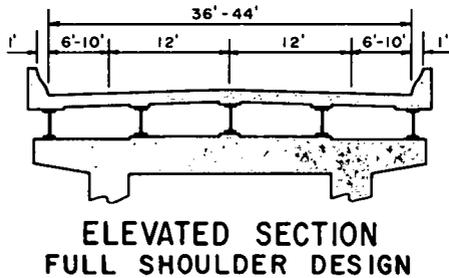
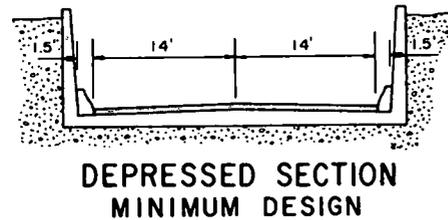
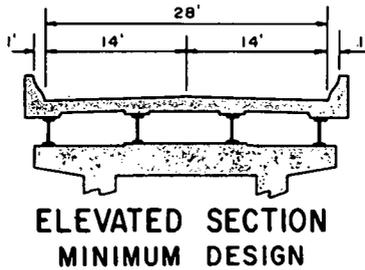
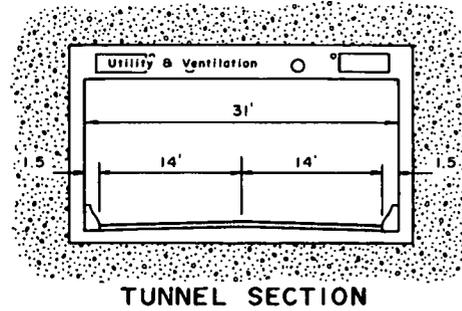
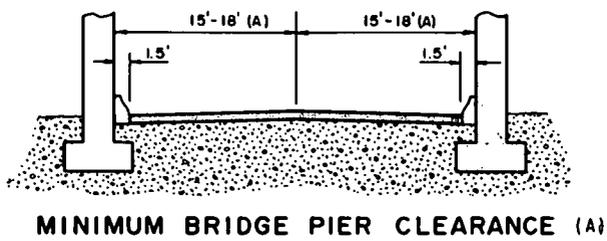
3. Provision should be made for bypassing stopped buses where right-of-way and construction conditions permit. Ideally, buses should be able to pull in and out of designated berths independently. In underground operations, because of right-of-way and column placement constraints, it may be necessary to provide bus passing opportunities on approaches to stations.

4. Busway stations should be developed within existing street rights-of-way wherever possible. Linear designs are generally preferable to sawtooth, transverse, or diagonal platform arrangements because (a) they better fit in available rights-of-way, particularly where busways are over or under streets; (b) they reduce turning maneuvers required by buses; (c) they simplify column spacing; (d) they adapt to varying bus lengths; and (e) they may not require mezzanines.

5. Separation of stations by direction may be desirable to (a) reduce cross-section requirements and (b) reduce pedestrian concentrations.

6. One-way busways may be necessary in areas of restricted rights-of-way to reduce station cross-sectional areas.

7. Pedestrian loading areas should be enclosed from bus



(A) CLASS 'A' BUSWAYS - 36' BETWEEN ABUTMENTS;
CLASS 'B' BUSWAYS - 30' BETWEEN ABUTMENTS.

- NOTES: 1. LANE WIDTH MAY BE INCREASED ON CURVES
2. SPECIAL CONSTRUCTION SECTIONS FOR NORMAL FLOW, CLASS 'A' BUSWAYS CAN ALSO APPLY TO SPECIAL FLOW CONDITIONS

Figure 31. Special construction sections, normal-flow busways.

zones for underground operations. This will help to simplify ventilation requirements in the pedestrian areas.

8. Stations and station passenger entry should be arranged so that they can be controlled by one person.

9. Station designs that obviate mezzanine levels can reduce costs, especially where bus tunnel construction is involved.

TABLE 36
RECOMMENDED TYPICAL BUSWAY CROSS-SECTION WIDTH

BUSWAY TYPE	FLOW	WIDTH (FT)	
		MINIMUM DESIGN	FULL SHOULDER DESIGN
Class B	Normal	24 ^a	36-40
Class A	Normal	26 ^a	40-44
Class A	Special	30	36 ^a
Class A	Contra	30	36 ^a

^a Suggested general application to achieve cross-section economy with good operating efficiency.

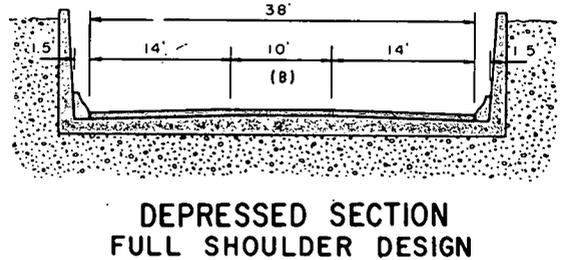
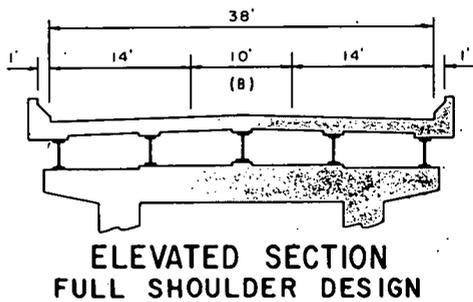
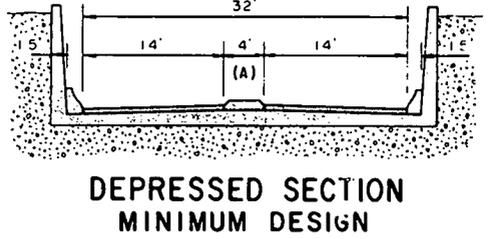
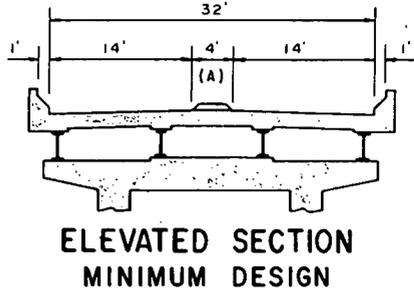
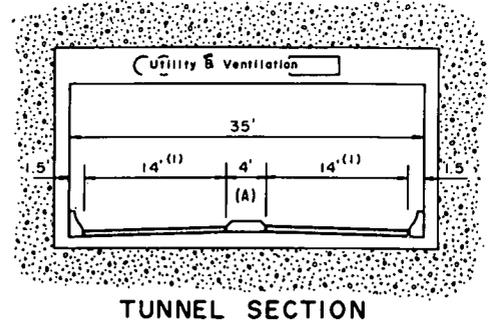
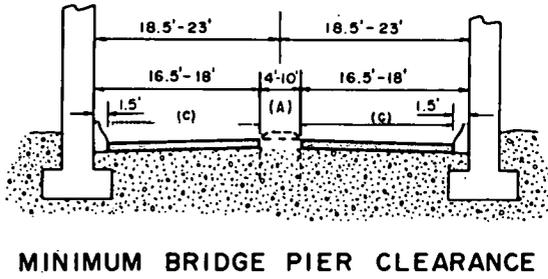
TABLE 37
RECOMMENDED MINIMUM BUSWAY CLEARANCES AT SPECIAL CONSTRUCTION SECTIONS

TYPE OF BUSWAY	OBSTACLE	MINIMUM DISTANCE (FT) FROM EDGE OF LANE	
		LEFT EDGE	RIGHT EDGE
Class A ^a	Bridge pier	4.5	6.0
	Parapet ^b	3.0	3.0
	Tunnel wall ^b	3.5	3.5
	Retaining wall ^b	3.5	3.5
Class B ^c	Bridge pier		4.0
	Parapet ^b		3.0
	Tunnel wall ^b		3.5
	Retaining wall ^b		3.5

^a Based on 12-ft lanes.

^b Clearance width includes safety or barrier-type curb.

^c Based on 11-ft lanes.



- (A) RAISED MEDIAN, MOUNTABLE
 - (B) FLUSH MEDIAN
 - (C) CONTRA FLOW 15' MINIMUM LANE WIDTH
SPECIAL FLOW 16.5' MINIMUM LANE WIDTH
- NOTE: LANE WIDTH MAY BE INCREASED ON CURVES

Figure 32. Special construction sections, contra-flow and special-flow busways.

10. Normal-flow underground busways are preferable to contra-flow operations under minimum design and minimum cost conditions. They allow the opposite-direction lane to be used for emergency passing at stations and they do not require passenger mezzanines.

Examples of normal-flow and contra-flow downtown busway stations are shown in Figures 39 and 40. The range of options provides a guide to bus station planning and design, as follows:

1. Option A (similar to rail transit) will prove most economical in bus tunnel operations. Options B and C (with continuously alternating platforms) are applicable where column placement is not critical (i.e., elevated busways). Options D and E are applicable only under special conditions.

2. Option F (contra-flow) can be used in above- or below-grade operations, especially where convertibility to rail transit is envisaged. Option G (contra-flow) is limited to unusually wide streets.

TABLE 38
MINIMUM BUSWAY ENVELOPES REQUIRED,
SPECIAL CONSTRUCTION SECTIONS

ITEM	BUSWAY ENVELOPE WIDTH ^a (FT) FOR			
	NORMAL FLOW		SPECIAL FLOW ^b	CONTRA-FLOW
	CLASS A	CLASS B		
Between bridge piers	36	30	40-46	37-46
Tunnel	31	31	35	35
Depressed	31-47	31-47	35-41	35-41
Elevated	30-46	30-46	34-40	34-40

^a Total horizontal width required, excluding tunnel wall or other supporting structure.

^b Where Class A normal-flow criteria are not used.

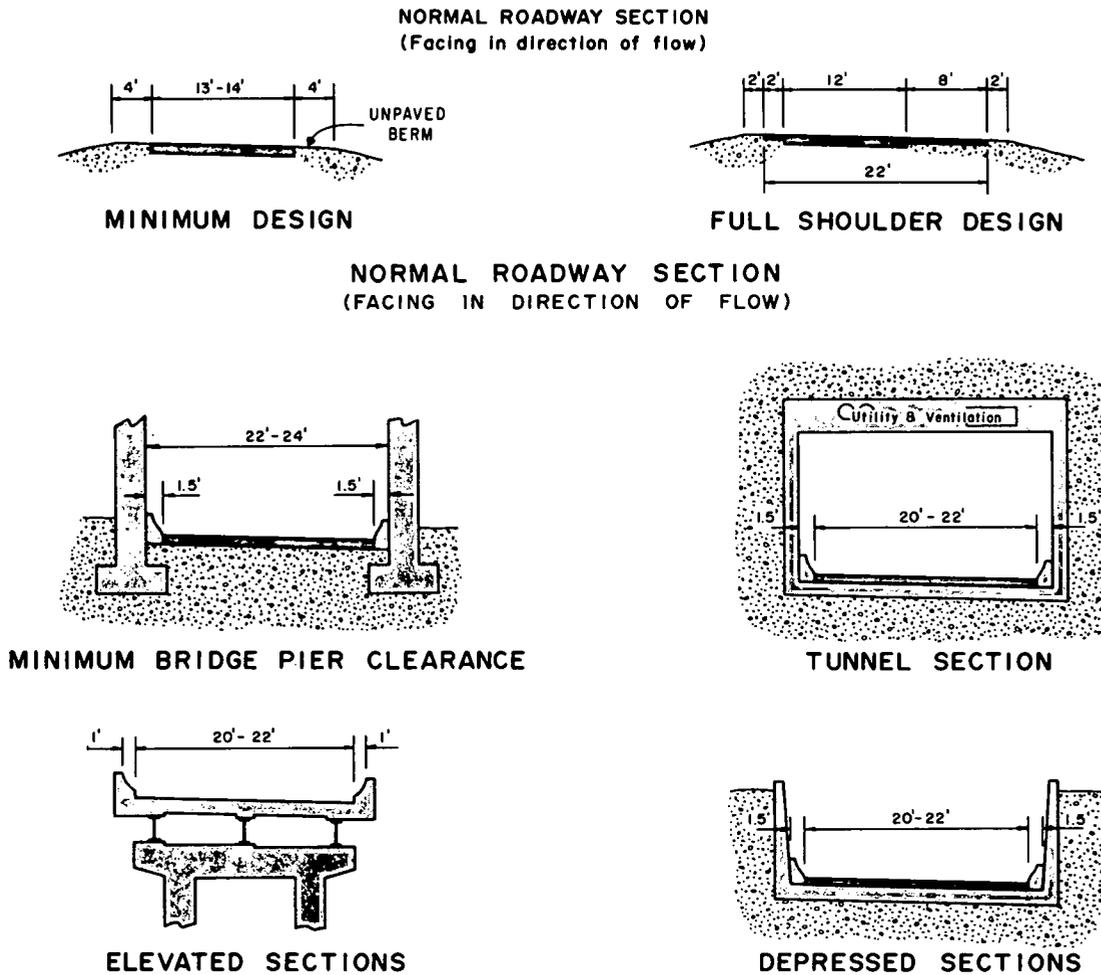


Figure 33. Busway ramp sections.

Transition Treatments

Special transition treatments should be provided wherever busways begin, end, or branch. Transition from busways to freeways can be made (a) directly within the freeway median or (b) via special structures to assure all freeway entrances and exits to the right of through traffic lanes. Transitions can be coordinated with freeway ramp systems wherever a substantial proportion of buses leaves the busway via local streets.

Traffic engineering approaches to intersection channelization and freeway ramp design standards have direct carry-over into busway transition design. These include (a) separation of conflict and decision points, (b) simplicity of driver choice, (c) clarity of major entry-exit and conflict points, and (d) coordination of roadway geometry with traffic control devices.

Busway-freeway transition treatments are shown in Figures 41 and 42, intermediate busway access to freeways and cross streets in Figure 43, and busway junctions in Figure 44.

Transition treatments for diamond and partial cloverleaf interchanges have important applicability (Figs. 41 and 42). These interchange designs are increasingly used because of their desirable operational and impact features.

Both involve only one exit point per interchange and both eliminate main-line freeway weaving. The diamond provides economy of space; the partial cloverleaf eliminates left turns from intersecting roads.

Transitions at contra-flow busways should include some means whereby errant vehicles are prevented from entering the busway. The consequences of a motorist mistakenly operating on a left-hand facility could be far more critical than with normal flow. "Escape" ramps for cars should be provided, along with some means of positive control at bus entry ramps (Fig. 42).

A minimum width of about 75 ft is required in which to provide intermediate access from busways in freeway medians to adjacent freeway lanes or to cross streets (Fig. 43).

Where high-speed operations are desired on both legs of a busway junction, grade separations should be provided.

Bus junctions with intersecting flows of 3 to 5 buses per minute (180 to 500 per hour) can be accommodated at-grade by traffic signal or STOP sign control (Fig. 44). At these locations, speeds on busway branch routes, and in some cases main-line speeds, should be restricted. The traffic controls should give priority to main-line busway flows over entering or exiting buses. Similarly, buses enter-

ing busways should yield the right-of-way to cars leaving freeways on exit ramps.

Typical busway ramp terminal details are shown in Figure 45. These details conform to contemporary freeway design standards. The convergence rate in merging sections will vary between 20:1 and 50:1, depending on ramp speeds. Exit ramps should have a 12:1 taper to assure good ramp visibility and identification.

Typical at-grade busway-ramp and arterial street intersection details are shown in Figure 46. A minimum inside turning radius of 30 ft should be provided. Single-lane openings should be at least 20 ft wide to accommodate vehicle overhang. Flared sections of at least 60 ft should be provided wherever possible.

Class B Busway Treatments

Class B busways should be developed in a manner analogous to light rail (limited tramline) transit facilities. They can combine at-grade and grade-separated treatments and can be located in arterial street rights-of-way. They can utilize narrow rights-of-way in urban and suburban areas, especially where streets and land development follow rectangular grids. In these cases, rights-of-way approximately one lot wide can be acquired, and the busways can be developed at grade (Fig. 47). Minor streets can terminate in loops or cul-de-sacs to eliminate intersectional conflicts with the busway. Bus-actuated signals can be provided at major crossings where physical, cost, environmental, or traffic conditions do not warrant grade separation.

Care should be exercised in the traffic operating strategies associated with busways within arterial street medians. Entry and exit to the bus lanes should be by means of appropriately located slip ramps located in mid-block (Fig. 48). At signalized intersections, buses should operate on the same phase as the through traffic on the parallel artery. Left turns across the busway should be from protected storage lanes, and should be governed by a special signal phase. Economical use of median space can be achieved by providing far-side bus stops at locations where left-turn storage lanes are provided.

Class B busways also have applicability in new communities or large planned-unit developments. Busways can penetrate residential developments, with streets and parking located along the outside perimeter. This will reduce walking distance to bus stops, and achieve a synergistic transit-land use relationship.

Convertibility

Busways should be readily convertible to fixed-guideway transit, where 20-year patronage forecasts indicate rail transit (or its equivalent) as a viable option. This implies reserving cross sections of sufficient width to (1) accommodate rail transit and (2) maintain bus service during the interim construction period, at least in the peak travel direction.

Meeting these requirements calls for minimum cross sections of 50 ft for special and contra-flow busways and 60 ft for normal-flow busways. These cross sections will

also allow for bus operations through stations during the construction period, as follows:

1. Figure 49 shows how busways can be converted to rail transit. Where normal-flow busways are converted, (1) a pair of temporary bus lanes should be provided on the outside of the existing busway; (2) then the tracks should be constructed in the median area; and finally (3) the temporary busways can be removed. Where contra- or special-flow busways are converted, a temporary single lane one-way busway should be provided either in the median or along one side.

2. Figure 50 shows how station areas could be converted. To minimize right-of-way requirements, temporary busways should cover tracks and temporary bus platforms should be provided at the end of high-level stations.

Obviously, the exact method of transition should reflect specific local conditions. Service continuity must be balanced against both initial and conversion costs, especially where busways are viewed as an interim measure (service life 10 years or less). The basic configurations of the bus and rail travel lanes should minimize the need for temporary busway construction. In all cases where conversion is planned, grades, curvatures, and structures should be sufficient to accommodate rail transit.

Illumination

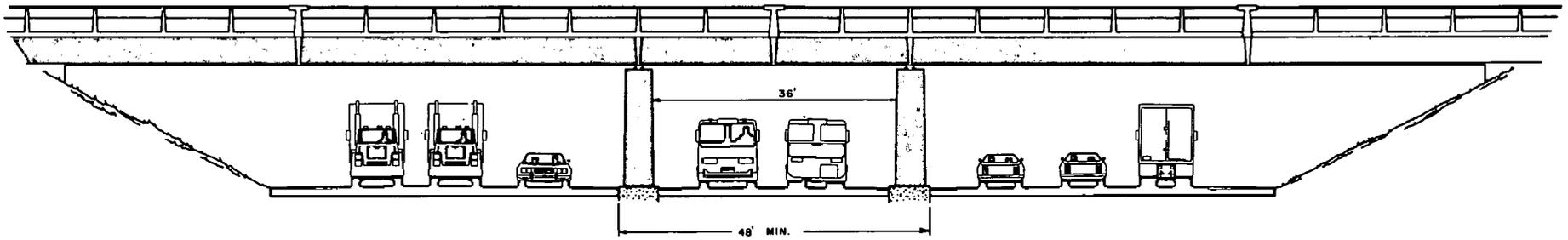
Busway illumination should be governed by general freeway practice in the area, especially where the busway is located adjacent to or within the freeway. Illumination of main-line busways, where provided, should approximate 1.5 to 2.0 footcandles and points of entry and exit should be clearly illuminated to this intensity. Illumination of stations is essential to passenger safety, security, and amenity—a minimum intensity of 2.0 to 3.0 footcandles is desirable.

Traffic Controls

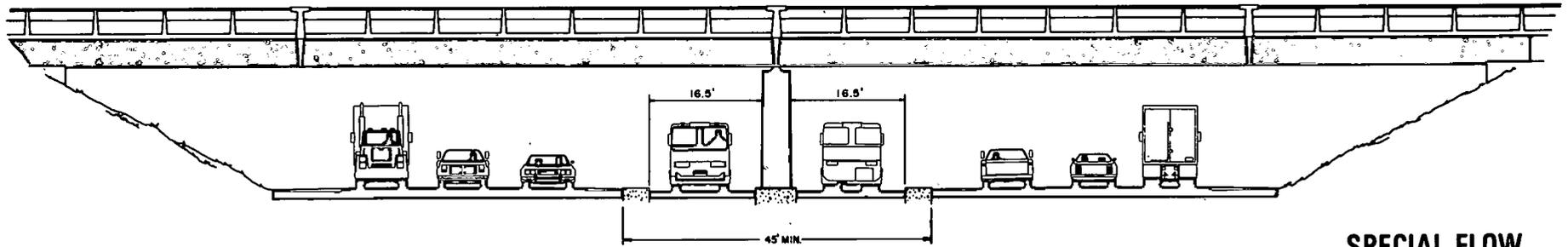
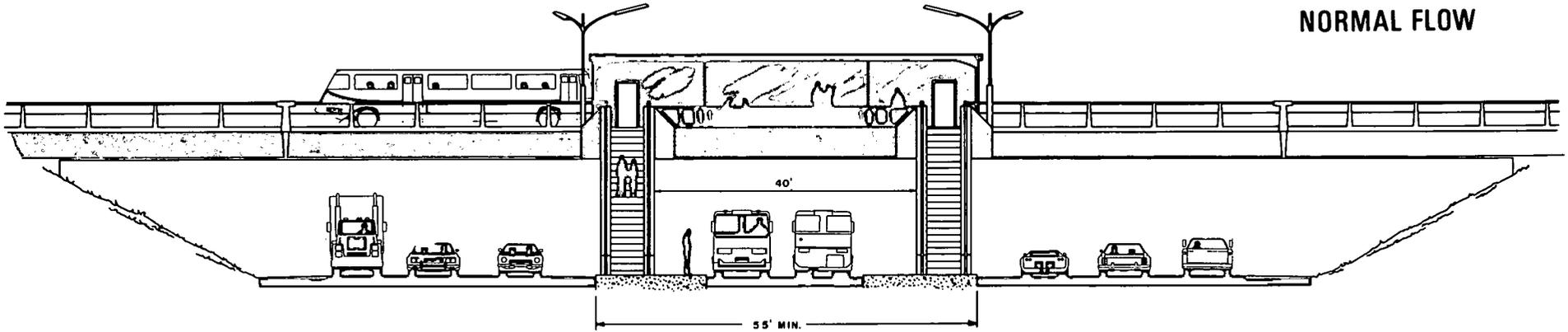
Suggested pavement markings for busways are shown in Figure 51. Normal-flow busways should be separated by two 12-in. yellow lines 24 in. apart. Twelve-inch yellow lines should be located along the inside edge of special-flow busways. Contra-flow bus lanes should be delineated by 12-in. yellow lines, with 24-in. yellow lines at 45 deg from the travel path located in the median area. Six-inch yellow lines should delineate the edge of roadway. KEEP RIGHT signs should be located alongside normal- and special-flow busways and KEEP LEFT signs should be located along contra-flow busways.

Typical signs and markings for special bus ramps leading from freeway lanes are shown in Figure 52a. The bus ramps should be painted out by 24-in. solid white lines, 45 deg to the travel path, at 10- to 20-ft intervals. A special series of bus signs—white-on-green for bus information and white-on-red for bus-only movements—should be carefully located, both on the approach to and at the take-off point.

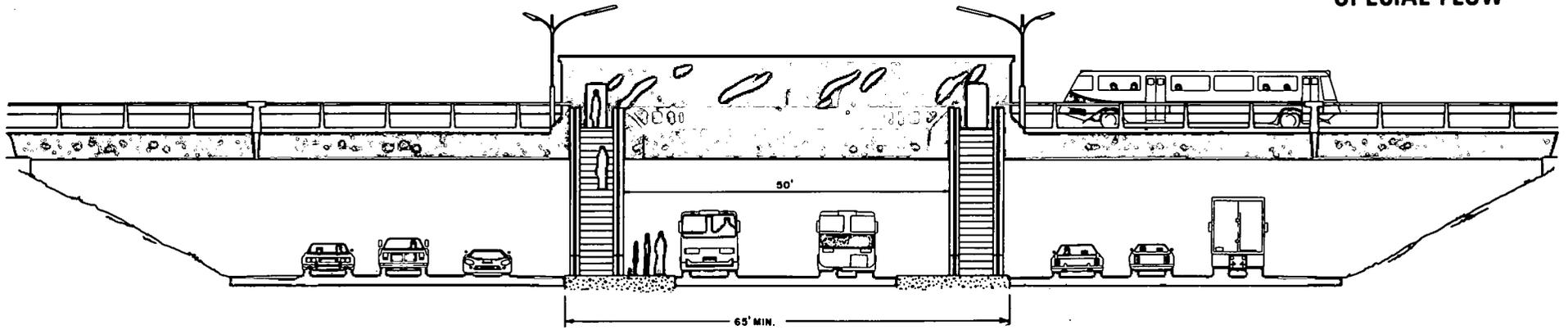
Similar treatments should be applied where busways, and bus ramps, intersect with arterial streets (Fig. 52b). Stan-



NORMAL FLOW



SPECIAL FLOW



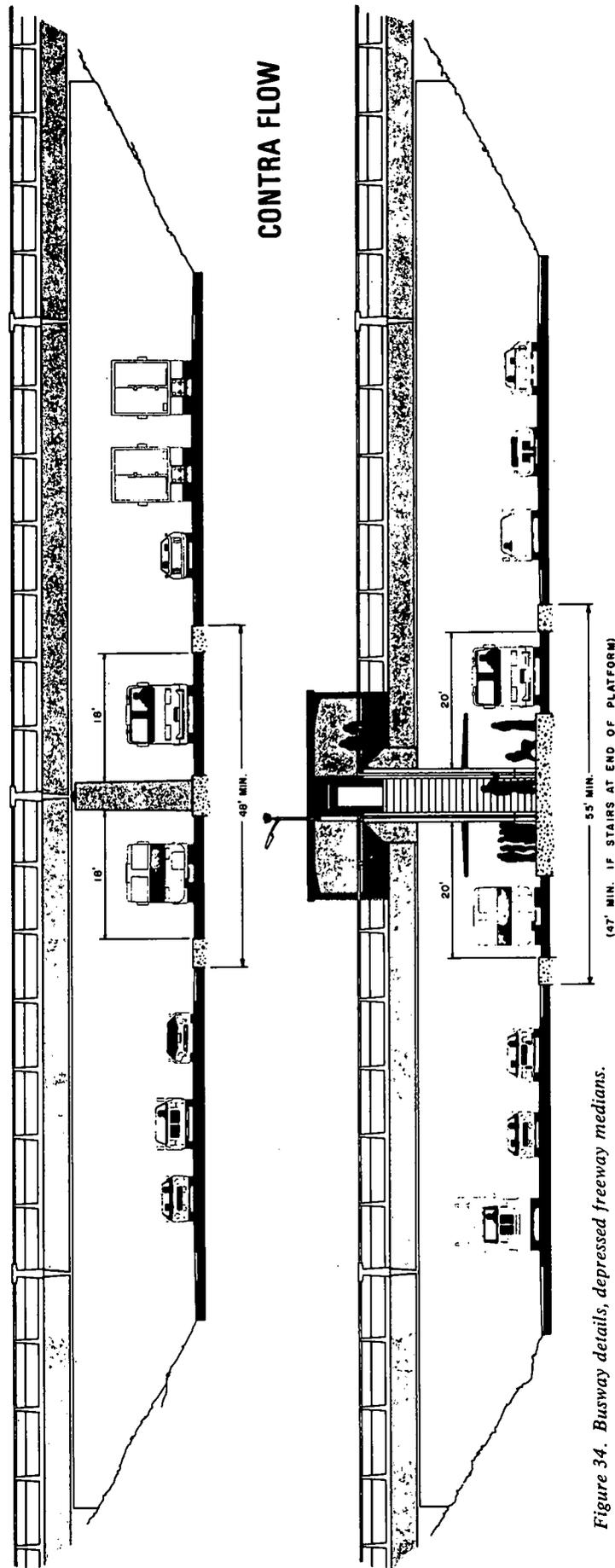


Figure 34. Busway details, depressed freeway medians.

Standard black-on-white signs reading NO LEFT (OR RIGHT) TURN EXCEPT BUSES should be placed along the arterial street. The bus ramps should be painted out by 24-in. wide solid lines, 45 deg from the travel path and 4 ft apart.

RESERVED FREEWAY LANES

Reserved freeway lanes for buses provide a cost-effective approach to bus priorities in radial highway corridors for peak-hour congestion and heavy bus volumes. They apply freeway traffic operations and control techniques to reserved lanes for buses and/or other designated vehicles (such as emergency vehicles, trucks, or high-occupancy cars). They involve minimum physical construction, and they can speed bus service where stations or intermediate access are not required.

The lanes may be reserved in the normal or in the opposite direction of peak traffic flow during the morning and/or evening peak periods. Contra-flow freeway bus lanes are found along I-495 in New Jersey, the Long Island Expressway in New York, the Southeast Expressway in Boston, and U.S. 101 in Marin County, California. A short normal-flow bus lane exists on the 9th Street Expressway Spur in Washington, D.C.

Applicability

Reserved bus lanes should be provided only where the total number of bus passengers in the heavy direction of flow is equal to or greater than the "typical" lane-carrying capacity of automobile passengers. They will generally have applicability in areas of major route convergence, where they should extend, wherever possible, beyond the points of peak-hour backup. Preference should be given to use of median (inside) lanes by buses; these lanes are usually removed from ramp conflicts and weaving traffic.

Conditions generally will be more conducive to contra-flow freeway bus lanes. Experience with normal-flow bus lanes is limited because of weaving problems and because bus flows have never equaled the capacity of a freeway lane. Normal-flow bus lanes are usually not practical to implement because where freeways are free-flowing in the peak periods, the lanes are not needed to improve bus

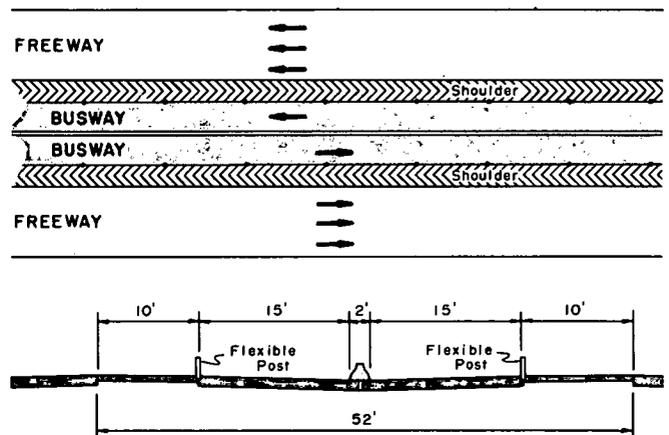
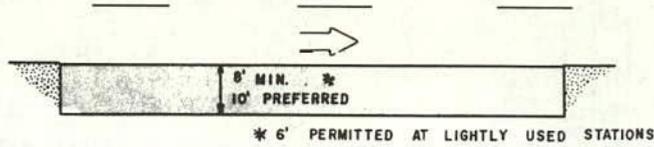
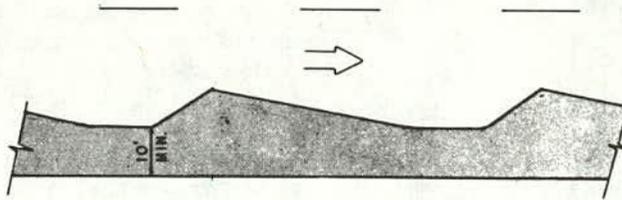


Figure 35. Common freeway-busway shoulders.

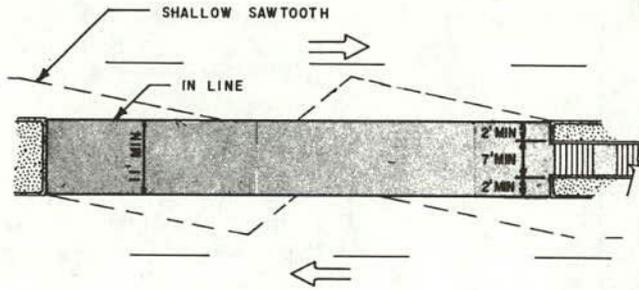
IN-LINE PLATFORM



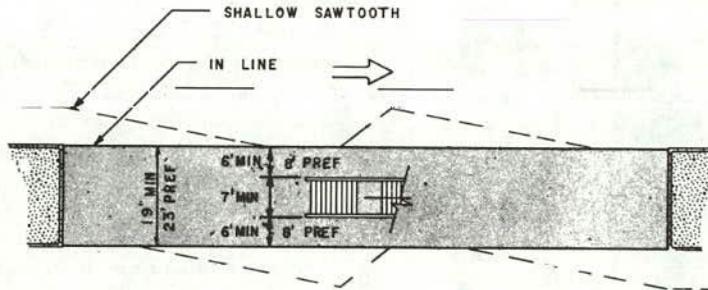
SHALLOW SAW TOOTH PLATFORM



TWO-SIDED PLATFORM, ACCESS AT END



TWO-SIDED PLATFORM, ACCESS AT CENTER



PEDESTRIAN WALKWAY DIMENSIONS:

MIN. WIDTH OF UNOBSTRUCTED WALKWAY	5'
MIN. WIDTH OF PEDESTRIAN BRIDGE	8'
MIN. WIDTH OF PEDESTRIAN TUNNEL	10'
MAX. SLOPE OF PEDESTRIAN RAMP	15%
PREFERRED MAXIMUM	10%
MIN. HEADROOM	8'
PREFERRED MINIMUM	10'

STAIRWAYS:

MIN. TREAD WIDTH	6'
LENGTH	1.73 X RISE
MAX. RISE BETWEEN LANDINGS	8'
MIN. LENGTH OF LANDINGS	4.5'

Figure 36. Busway station platform criteria.

speeds. Conversely, where freeways operate near or beyond capacity, provision of exclusive bus lanes would substantially reduce person-capacity and increase total person-delay. Moreover, normal-flow lanes are difficult to enforce.

Normal-Flow Bus Lanes

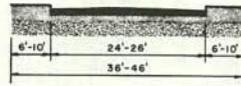
Bus lanes should be provided in the normal direction of traffic only where ample reserve capacity exists or where the lanes represent an addition to the total road capacity in the flow direction, such as achieved through widening or unbalanced operations (as proposed for South Capitol Street Bridge, Washington, D.C.

Enforcement may be difficult unless a physical barrier separates the bus lanes from mixed-traffic lanes, and the

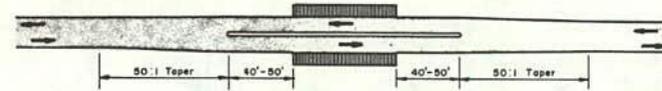
lanes are relatively long (more than a mile). Introduction of a physical barrier technically makes the facility a busway rather than a bus lane. The following criteria should be met:

1. The number of person-minutes saved by the bus riders at least equals the person-minutes lost by general traffic. This criterion can usually be met only where an additional bus bypass lane is provided for buses upstream from the bottleneck. It could be relaxed where community policy explicitly desires to reduce auto travel to meet air-pollution standards.
2. A normal-flow bus lane has at least 60 to 90 buses in the lane during the busiest hour of use where it involves

MINIMUM DESIGN

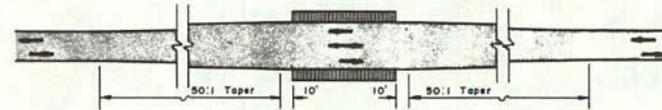
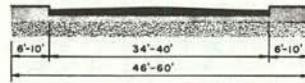


MINIMUM DESIGN WITH MOUNTABLE ISLAND

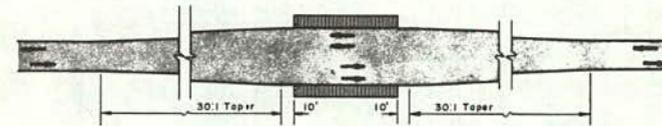
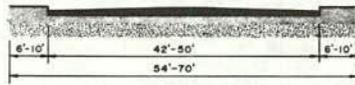


* FOR MINIMUM DESIGN TO ALLOW PASSING OF STALLED BUS, ON SAME SIDE OF ROAD, INCREASE ROADWAY WIDTHS TO 20 FEET. STATION ENVELOPE WILL BE 56 TO 66 FEET.

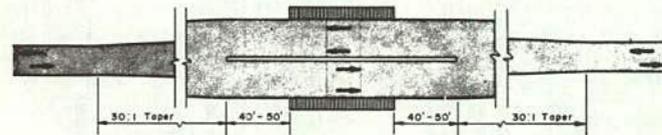
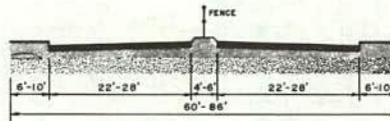
SINGLE-LANE BYPASS



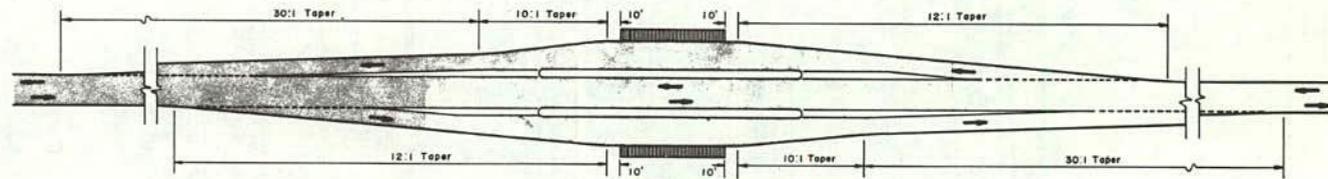
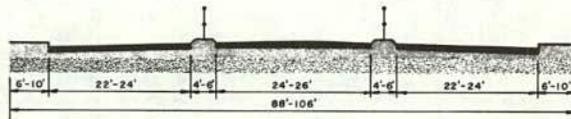
FULL TURNOUTS



FULL TURNOUTS W/ DIVISIONAL ISLAND



ISOLATED STOPPING ROADWAYS (SPECIAL CONDITIONS ONLY)



- NOTES:
- DESIGNS ALSO APPLY TO SPECIAL FLOW BUSWAYS
 - DIMENSIONS ARE SHOWN FOR CLASS 'A' BUSWAYS
 - FOR CLASS 'B' BUSWAYS:
 - REDUCE MINIMUM CROSS-SECTION WIDTH 2 FEET
 - REDUCE MINIMUM TAPER TO 30:1
 - REDUCE MINIMUM TAPER TO 20:1

Figure 37. Normal-flow busway stations.

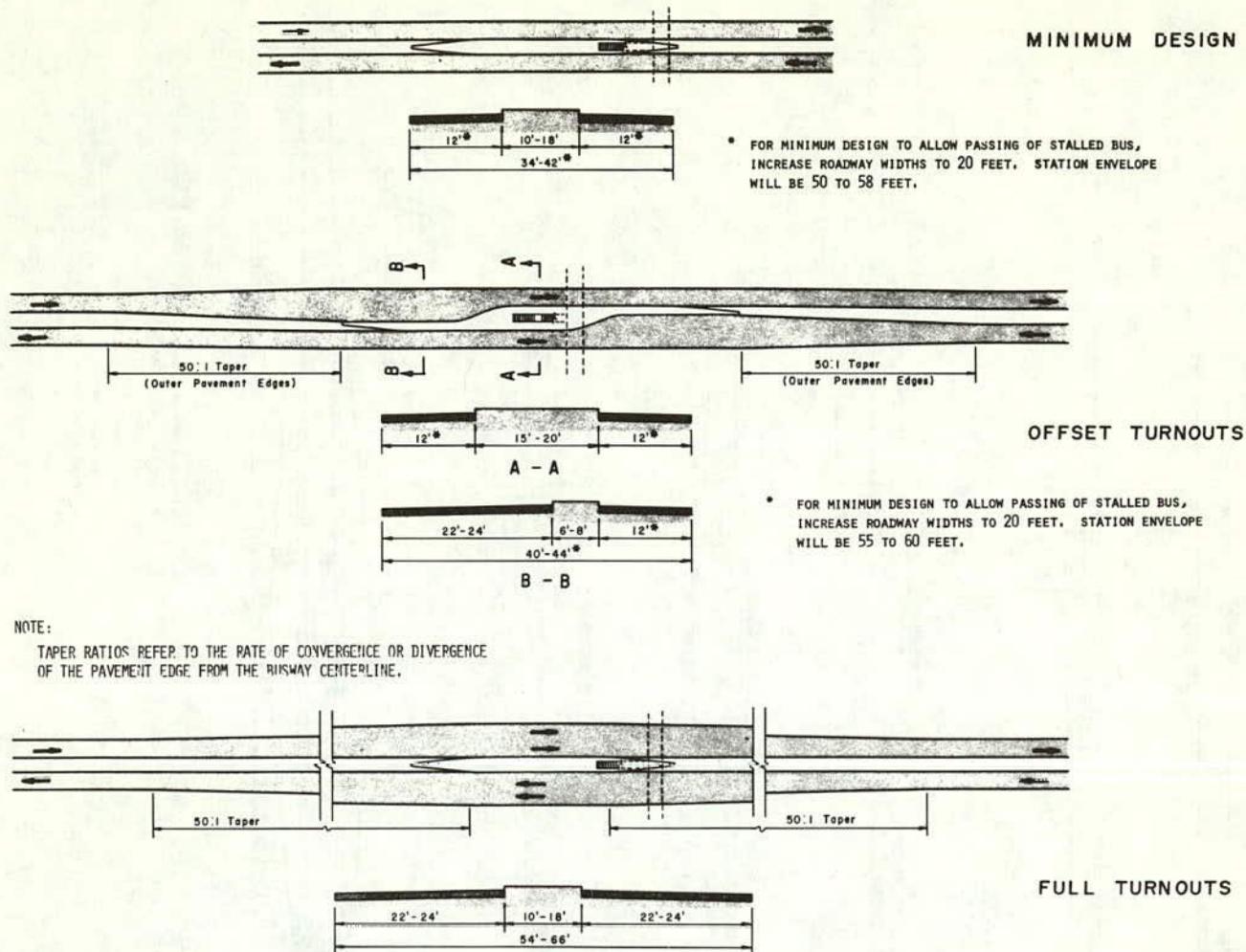


Figure 38. Contra-flow busway stations.

adding a lane. Where an existing freeway lane operating at capacity is preempted, peak bus volumes should exceed 300 per hour (a corridor volume found only in a few metropolitan areas).

Contra-Flow Bus Lanes

Contra-flow or "wrong way" bus lanes using a portion of the roadway that serves relatively light opposing traffic flow will not reduce peak-directional highway capacity or efficiency. They are an adaptation of the reversible-lane concept applied to urban freeways for more than three decades. Costs are minimal, and enforcement is easy because cars are highly visible to police patrols.

Buses can use single contra-flow lanes where mixed traffic could not do so safely because: (1) the bus lane traffic stream is homogenous, variation in vehicle performance is minimal, and there is no need for overtaking slower vehicles; (2) buses are highly visible to other drivers, especially when emergency flashers are used; (3) professional bus drivers are generally well-trained, experienced, and highly disciplined; and (4) bus lane volumes are relatively low (generally under 200 vehicles per hour), making risk

of a collision no greater than on an undivided urban arterial or rural highway.

Factors that should be recognized in design and planning include: the need to remove median barriers at crossovers or transition points; blocking of the exclusive lane by accidents or stalled buses; safety; possible congestion in the remaining off-peak directions; and the general difficulty of providing stations and interim access for buses. Successful application is contingent on a high directional imbalance in traffic volumes.

Contra-flow freeway bus lanes should be applied only on freeways with more than four lanes where peak-hour traffic is highly unbalanced. As volumes become more balanced, a higher number of buses is required to offset the time losses to opposing traffic resulting from lane reductions. The following conditions should prevail:

1. The freeway is at least six lanes wide.
2. All normal freeway entrances and exits are to the right of the through traffic lanes.
3. The freeway preferably is illuminated wherever PM contra-flow operations are planned.
4. Freeway travel in the off-peak direction can be ac-

commodated in the remaining lanes at level of service D or better.

5. There is a minimum of 40 to 60 buses per hour in the design year and each bus on the average saves 2 to 3 min.

6. The contra-flow bus lane generally produces time savings to bus passengers that exceed the time losses imposed on traffic in the opposite direction. Meeting this broad criterion calls for an increase in the minimum number of peak-hour buses as traffic in the off-peak direction approaches capacity.

The minimum number of peak-hour buses to warrant a contra-flow lane can be derived from the following approximate relationship (29):

$$B = V_o (t_1/t_2) (o_1/o_2) \tag{8}$$

in which

- B = minimum number of buses per hour;
- V_o = total traffic in peak hour in the off-peak direction;
- t_1 = time lost per vehicle in the off-peak direction;
- t_2 = time savings per bus using the bus lane;
- o_1 = persons per vehicle in the off-peak direction; and
- o_2 = persons per bus using the bus lane.

This equation states that the minimum number of buses needed to warrant a contra-flow bus lane must be equal to or greater than the number of automobiles in the off-peak direction weighted by the ratio of car-to-bus passenger occupancies for the off-peak and peak directions, respectively, and the ratios of expected car and bus travel times. Results of the equation, based on the speed-volume relationships identified in the *Highway Capacity Manual*, are given in Table 39 and shown in Figure 53 (20, Fig. 9-11).

On eight-lane freeways where car volumes in the off-

peak direction can be accommodated in two lanes, a buffer lane should separate bus and car travel and provide bus passing breakdown opportunities (Fig. 54).

Design and Operating Features

Design and operation of contra-flow lanes is similar to that for reverse-flow freeway (and arterial) lanes used by general traffic. However, the lighter bus volumes and lower probability of breakdowns makes a single-lane operation feasible. Shoulders or periodic turnouts along the median edge of the freeway should provide refuge wherever possible.

Lane Designation

Contra-flow bus lanes should be provided adjacent to the median. Length of the bus lane will depend on (a) extent of freeway congestion and (b) locations where entry and exit can be provided safely.

Hours of Operation

Contra-flow bus lanes should be provided for a minimum continuous period of two hours to facilitate lane identification and enforcement.

Intermediate Access

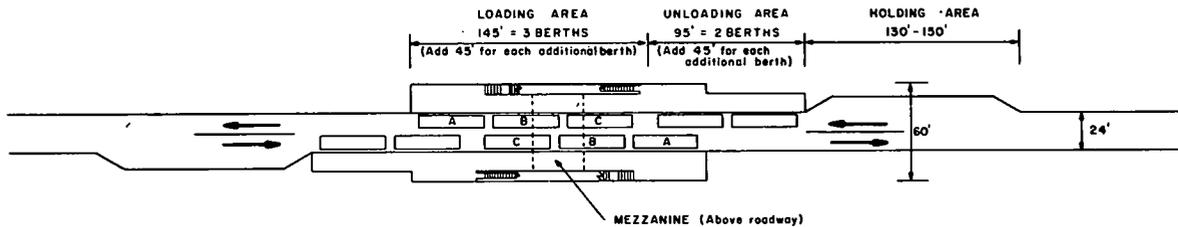
Special bus ramps can be located in wide freeway medians leading to or from the reversible bus lanes. These ramps should be limited to points where major bus volumes enter or leave; they require that normal highway access be provided to the right of through traffic (Fig. 55).

TABLE 39
APPROXIMATE MINIMUM BUS VOLUMES REQUIRED
FOR CONTRA-FLOW BUS LANE ^a

TOTAL PEAK-DIRECTION DEMAND (VEH/HR)	MINIMUM BUS VOLUME REQUIRED FOR OFF-PEAK DIRECTION VOLUME (VEH/HR) OF														
	900	1200	1500	1800	2100	2400	2700	3000	3300	3600	3900	4200	4500		
3600	34	41	90	135	205	288	365	495	693	1701	3130	5355	7594	I ^b	
3900	14	22	36	54	82	115	146	198	277	680	1252	2142	3038		
4200	10	17	28	42	63	89	112	152	213	524	963	1648	2337		
4500	8	13	21	32	48	68	86	116	163	401	736	1260	1787		
4800	5	9	14	22	33	46	58	79	111	272	501	857	1215		
5100	4	6	10	15	23	32	41	55	77	189	342	595	844		
5400	2	3	5	8	12	17	22	30	42	102	187	320	454	II ^b	
6300	1	1	2	3	4	6	8	11	15	37	68	117	166		
7200	1	1	1	2	3	4	5	6	9	23	42	72	103		
8100	—	—	—	1	1	2	2	4	5	13	23	40	57		
	III ^b														

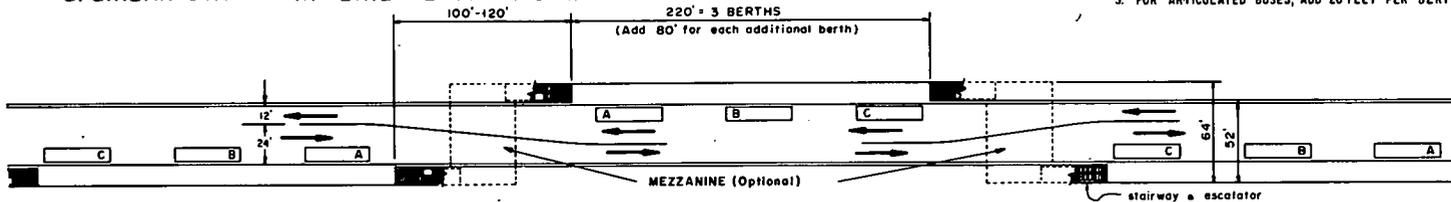
^a Assumes an occupancy factor of 1.5 and 50 for automobiles and buses, respectively.
^b I—These bus volumes exceed most urban bus fleets and fall outside the domain of practical application.
 II—The domain of practical application—involves hourly bus volumes ranging from about 40 to 200.
 III—Volumes of under 40 buses per hour do not usually warrant contra-flow lanes.

A. LINEAR STATION, MINIMUM DESIGN

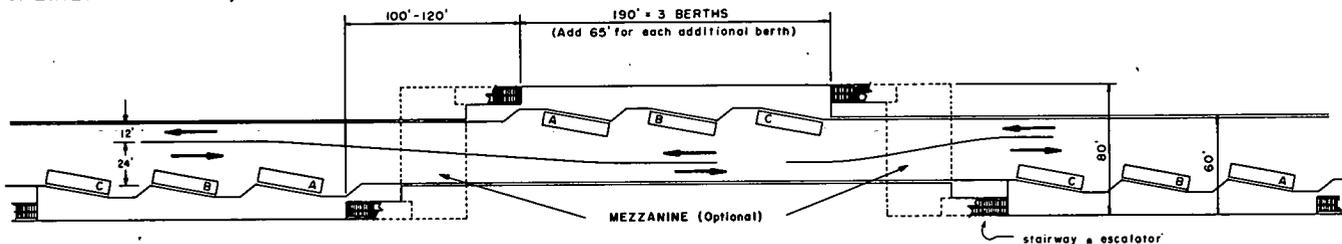


- NOTES:
1. FOR OPTIMUM EFFICIENCY, SEPARATE BERTH POSITIONS FOR LOADING AND UNLOADING SHOULD BE USED.
 2. HOLDING AREAS MAY BE USED FOR BUS STORAGE AND/OR EMERGENCY PARKING.
 3. FOR ARTICULATED BUSES, ADD 20 FEET PER BERTH.

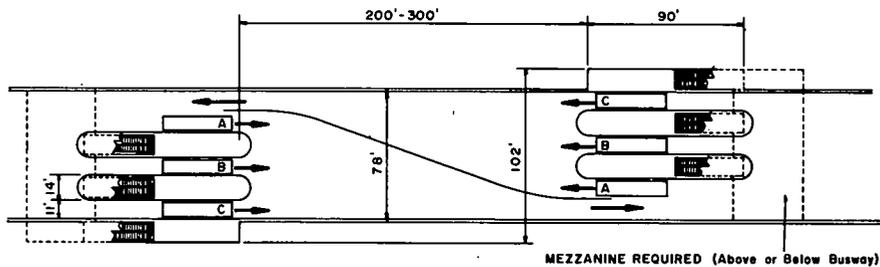
B. LINEAR STATION IN-LINE PLATFORMS WITH PASSING



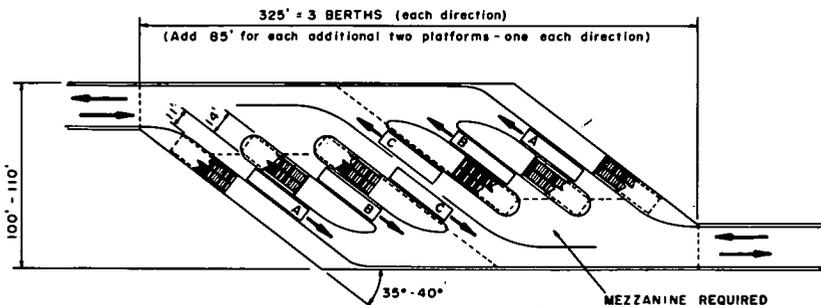
C. LINEAR STATION, SHALLOW SAWTOOTH PLATFORMS



D. LINEAR BULB STATION, TRANSVERSE PLATFORMS



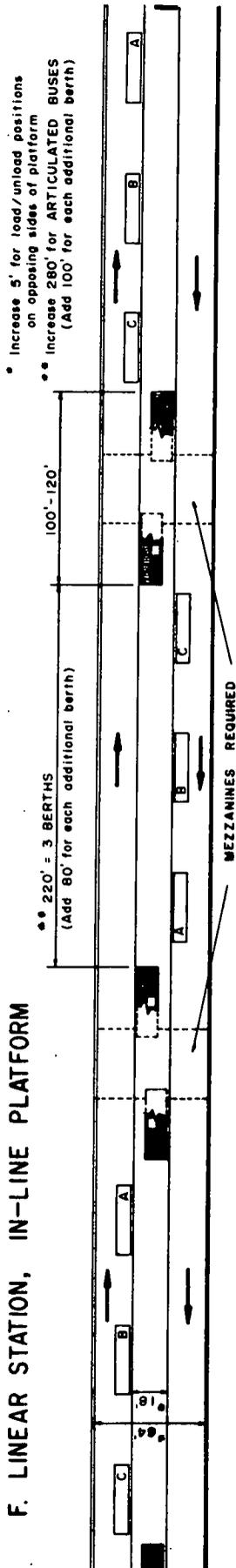
E. LINEAR BULB STATION, DIAGONAL PLATFORMS



NOTE: OPTIONS D AND E ARE LIMITED TO SPECIAL CONDITIONS, AND WILL NOT GENERALLY BE APPLICABLE.

Figure 39. CBD station concepts, normal-flow busway.

F. LINEAR STATION, IN-LINE PLATFORM



G. LINEAR STATION, SHALLOW SAWTOOTH PLATFORM

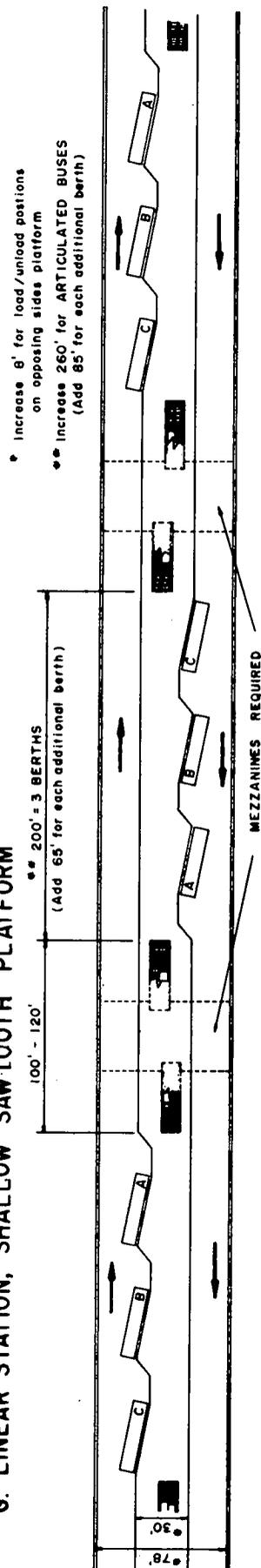


Figure 40. CBD station concepts, contra-flow busway.

Traffic Separation

Removable flexible traffic posts should separate the bus lane from opposing traffic flows (Fig. 56). Buffer lanes may separate opposing bus and car traffic on eight lane freeways where (1) volume conditions permit, and (2) high operating speeds are desired.

Operating Speeds

Bus operating speeds of 35 to 50 mph will generally prove adequate. These same speeds should apply to car traffic in opposing lanes.

Lane Width

Contra-flow bus lane widths should increase in relation to operating speeds—from at least 11 ft at 35 mph and 12 to 13 ft at 50 mph to 17 ft at 70 mph. Lanes should be at least 11 ft wide, with 13-ft lanes preferred.

Transition Treatments

Transition treatments are especially important, because it is at beginning and end points where the segregation of buses from general traffic takes place. Typical transition treatments are shown in Figure 57. A toll plaza provides a natural transition point because speeds are low and enforcement is relatively simple. Transitions also can be located at (1) the junction of two freeways, by providing special bus ramps before the points of road convergence; and (2) directly from normal freeway lanes.

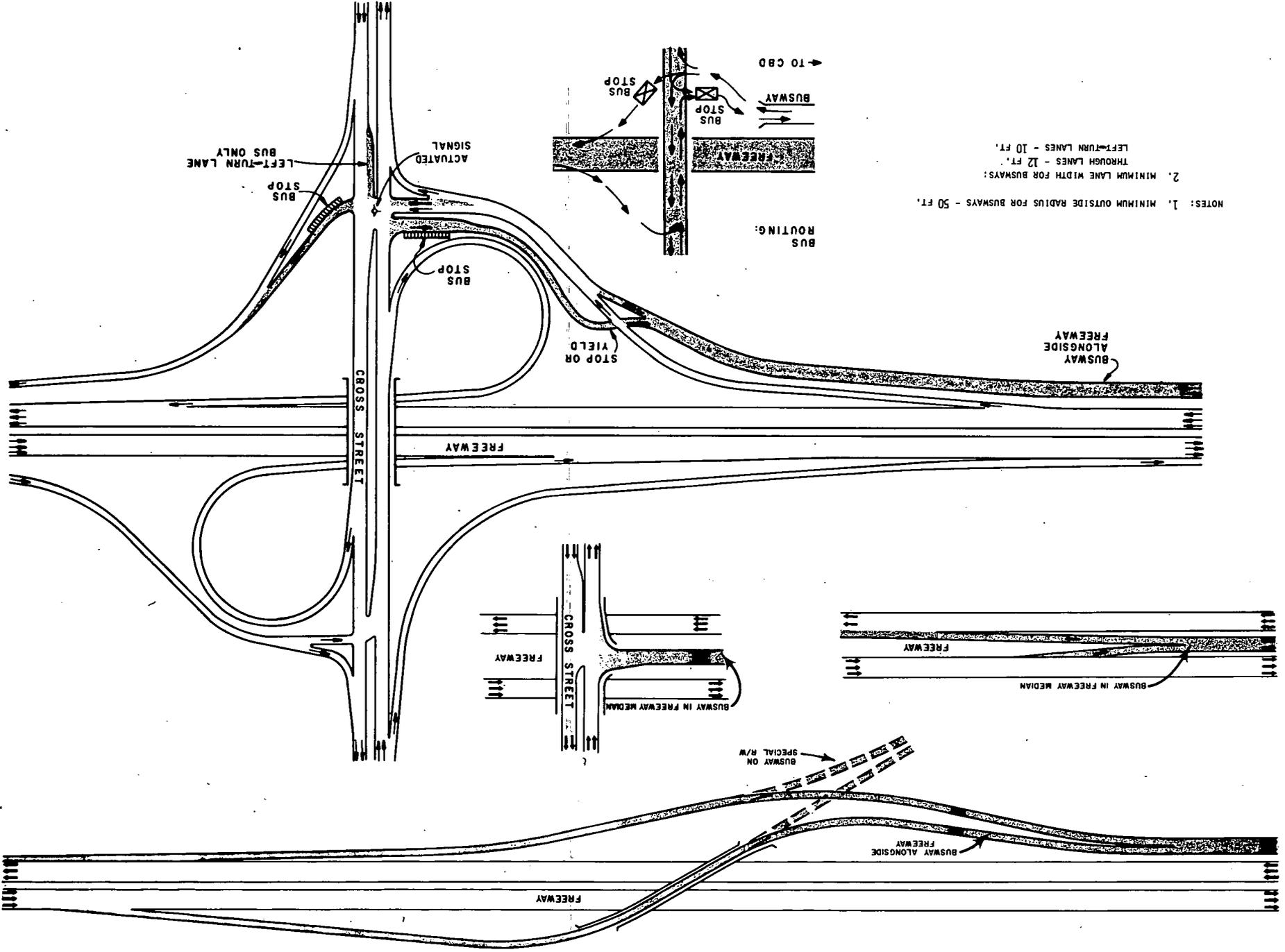
Transition design-details are shown in Figure 58, as follows:

1. The transition should be located on a tangent section of roadway where approach visibility is not constrained.
2. The transition point should be located at least 1 mile downstream from where buses enter the freeway with 1/2 mile as the absolute minimum distance. This distance will allow buses to weave from right- to left-hand freeway lanes during heavy traffic periods.
3. The transitions should be sufficiently abrupt to discourage general traffic use, but could be extended where trucks share the bus lanes. A 20-ft-wide transition lane should be provided on a 6 to 8 deg angle. This corresponds to a minimum median opening of 150 to 200 ft.
4. Flexible traffic posts should be mounted on 20-ft centers in the transition area and on 40-ft centers elsewhere along the contra-flow bus lane. The taper for through traffic should approximate the design speed (i.e., 50 mph, 50:1.)

Typical advance signing of a transition point is shown in Figure 59. Specially designed bus information signs spaced at successively closer intervals guide buses into the reversible lanes.

Traffic Controls

Contra-flow bus lanes should be separated by traffic posts spaced at 40-ft intervals and delineated by either solid or dashed white lines. Because the freeway space occupied by contra-flow bus lanes will function as normal-flow lanes



- NOTES: 1. MINIMUM OUTSIDE RADIUS FOR BUSWAYS - 50 FT.
 2. MINIMUM LANE WIDTH FOR BUSWAYS:
 THROUGH LANES - 12 FT.
 LEFT-TURN LANES - 10 FT.

for most of the day, pavement markings delineating the lanes could conform to standard highway practice (i.e., dashed white lines). Alternatively, solid white lines, such as used on Chicago's Lake Shore Drive reversible-lane operations, could be delineated.

Typical signs are shown in Figure 60. Signs reading BUSES 35 (or BUSES 50) should control bus speeds in the contra-flow direction. Signs reading LEFT LANE CLOSED, ON-COMING BUSES should be located along the right-hand side of the roadway, and immediately above the bus lane on street-crossing structures.

Overhead lane-control signals provide a more positive (and costly) means of lane-use allocation. These signals could be automatically actuated from a central control point. They could be located on special signal bridges or on freeway overcrossing structures.

Buses traveling in contra-flow lanes should operate with flashers and headlights on. This will increase their visibility to on-coming traffic and should improve safety.

Contra-flow bus lanes can be installed at low initial costs; however, provision must be made for their maintenance and enforcement (\$80,000 to \$100,000 per mile per year per lane). Tow trucks are necessary and should be included in the operations plan. Stalled buses should be removed speedily, preferably within 10 minutes.

Priority Vehicle Lanes

Use of freeway lanes by buses, trucks, and, as desired, multiple-occupancy cars extends the bus-lane concept to other types of priority vehicles. It is, in essence, an application of traffic management principles to urban freeway operations. Where multiple-occupancy cars use priority lanes, single-lane operations should be avoided. Thus, normal-flow special-purpose lanes may be more appropriate than contra-flow lanes.

In these cases, the median (left) lane should be designated for priority vehicle use. The right lane is generally not appropriate because other traffic must enter and leave the traffic stream from this side, implying numerous potential conflict points. Middle-lane reservation is also inappropriate because other traffic would have to cross it and reduce the effectiveness of a reserved lane.

1. The median lane is traditionally occupied by higher-speed traffic. Replacing it by a special-purpose lane may reduce the range or variance of speeds.

2. Lateral friction is lowest in the left lane because it has flow on only one side.

3. The left lane is generally least affected by traffic turbulence, particularly that caused from right-hand egress/ingress.

4. The left lane will discourage short trips, as too many merge/diverge movements are involved, and the distance required to reach it may be long.

5. Enforcement of use of the left lane is easier than for any other lane, because only assigned traffic should be in the lane.

The median lanes should be delineated by double yellow lines. Access to and from the lanes should be spaced at minimum two-mile intervals.

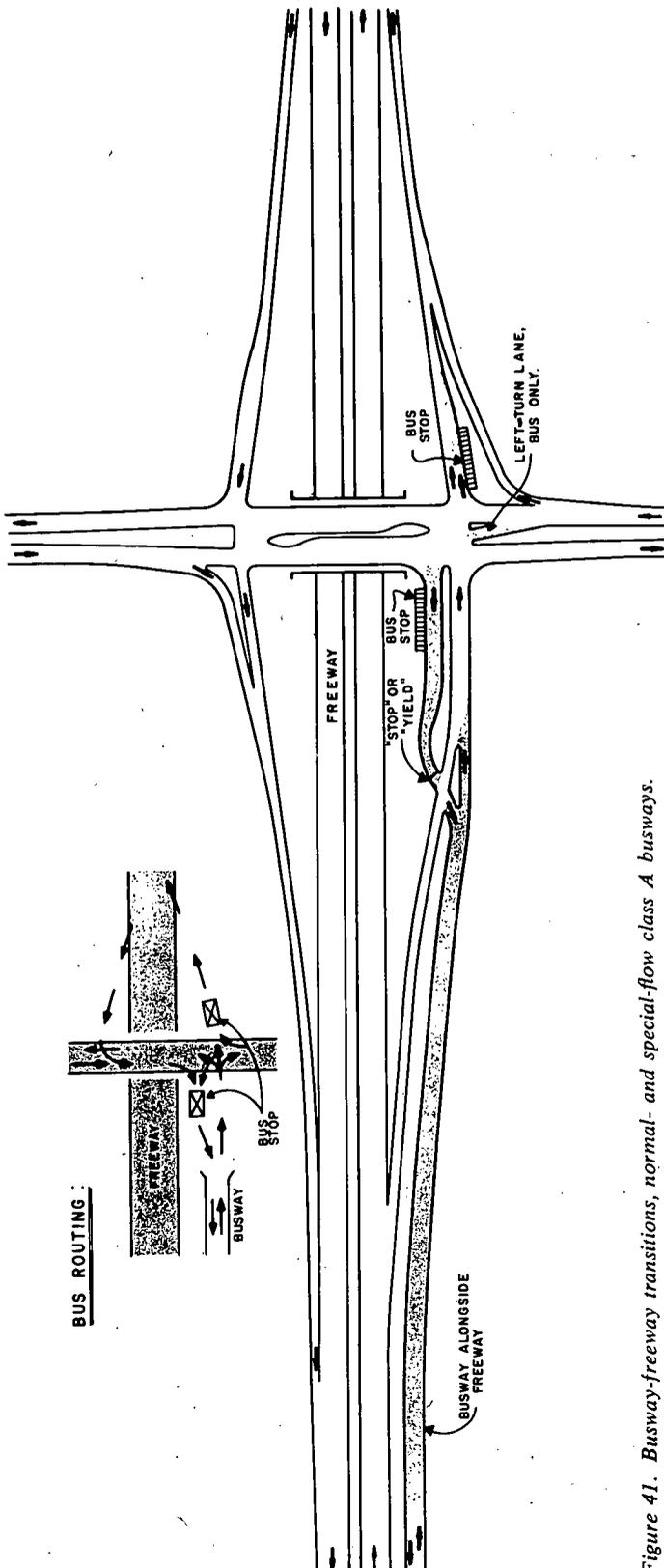
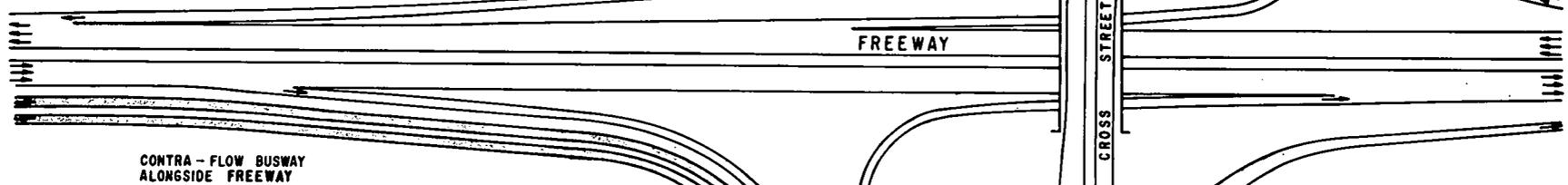
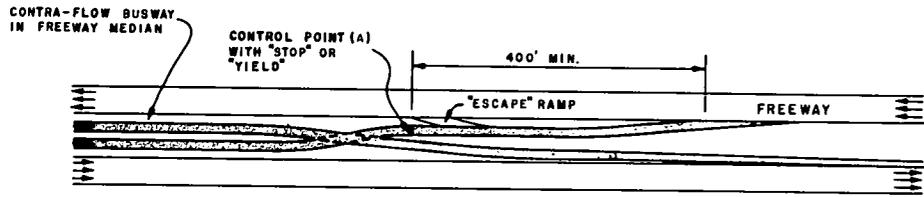
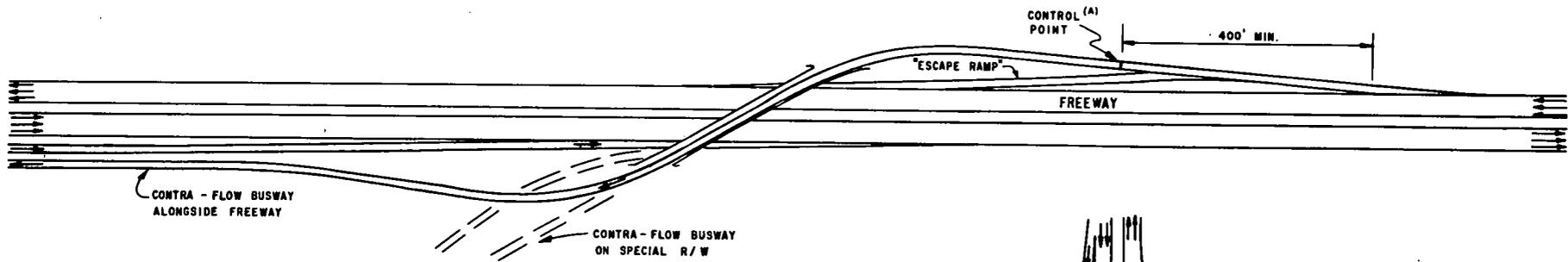
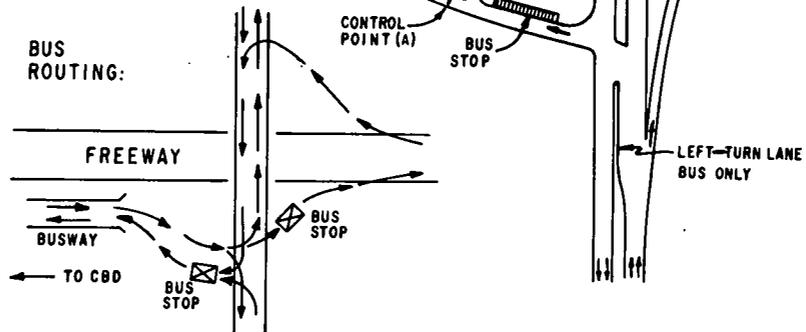


Figure 41. Busway-freeway transitions, normal- and special-flow class A busways.



(A) POSITIVE CONTROL (GATES OR SIMILAR DEVICES) IS RECOMMENDED AT ENTRANCES TO CONTRA-FLOW BUSWAYS.

- NOTES: 1. MINIMUM OUTSIDE RADIUS FOR BUSWAYS - 50 FT.
 2. MINIMUM LANE WIDTH FOR BUSWAYS:
 THROUGH LANES - 12 FT.
 LEFT-TURN LANES - 10 FT.



BUS PRIORITIES IN MIXED FREEWAY FLOW

Most freeway bus operations will take place in mixed freeway traffic. Thus, measures that assure steady freeway flow will simultaneously benefit bus passengers. As long as freeways operate above level of service D, mixed-traffic operations are more efficient than providing exclusive bus lanes or roads. (This allows buses to reach speeds of 50 mph.)

Person-delay—even where freeway congestion develops—often can be minimized by expediting general traffic flow, rather than by reducing freeway capacity for cars and giving it to buses. Thus, mixed operation of cars and buses with bus priorities (viz., upstream of bottlenecks) will have wide applicability. Treatments such as special bus ramps to or from freeways; metering of ramps with special bus bypass lanes, and bus stops alongside or adjacent to freeways can be applied singly or in combination to expedite bus flows at minimum costs and with minimum delay to other road users.

Ramp metering can keep main freeway lanes operating at reasonable speeds, thereby benefiting bus and car flow.

Bus ramps can bypass queues, reduce travel distances, and promote continuity in a system of bus priority treatments.

Bus stops are essential to provide access to tributary areas, as well as afford transfer to car or bus.

Bus Bypass at Metered Freeway Ramps

Preferential bus entry to freeways can be provided at locations that are controlled by ramp metering. Special traffic signals on entrance ramps allow only those vehicles to enter the freeway that can be accommodated without reducing mainline speeds. Cars are required to wait a few moments at ramp signals, although those on short trips may divert to parallel routes to avoid waiting. Where ramp metering is effective, bus bypass lanes around automobile queues can be provided inexpensively.

Ramp metering improves mainline flow and artificially creates queues for buses to bypass. It has the advantage of giving buses time savings on their entering and traversing the freeway. Implementation costs are minimal.

Applicability

Ramp metering with bus bypass lanes is especially applicable in corridors with relatively low peak-hour bus passenger demands and frequent peak-hour congestion. It enables buses to enter and leave freeways for passenger loading with minimum delay. Simultaneously, metered ramp control systems maintain the demand flow rate along freeways at a level less than or equal to the critical lane density. Factors to be considered are:

1. Ramp metering should be applied wherever urban freeways operate below level of service D (Fig. 61). Freeway lane density generally should exceed 40 to 50 vehicles per mile.

2. Adequate parallel surface routes and ramp storage capacity must be available. Otherwise queues of vehicles waiting to enter the freeway will block local street circulation.

3. Ramp metering works best downstream from a major

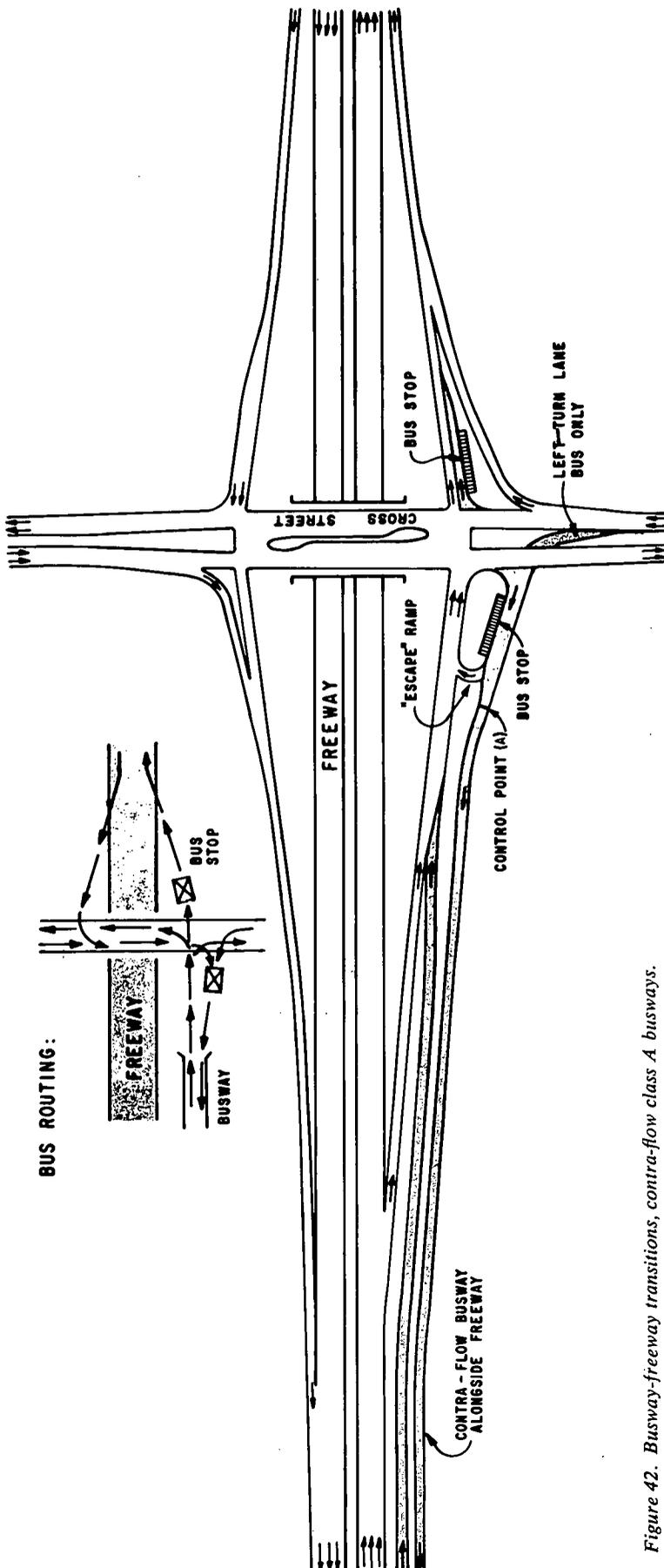


Figure 42. Busway-freeway transitions, contra-flow class A busways.

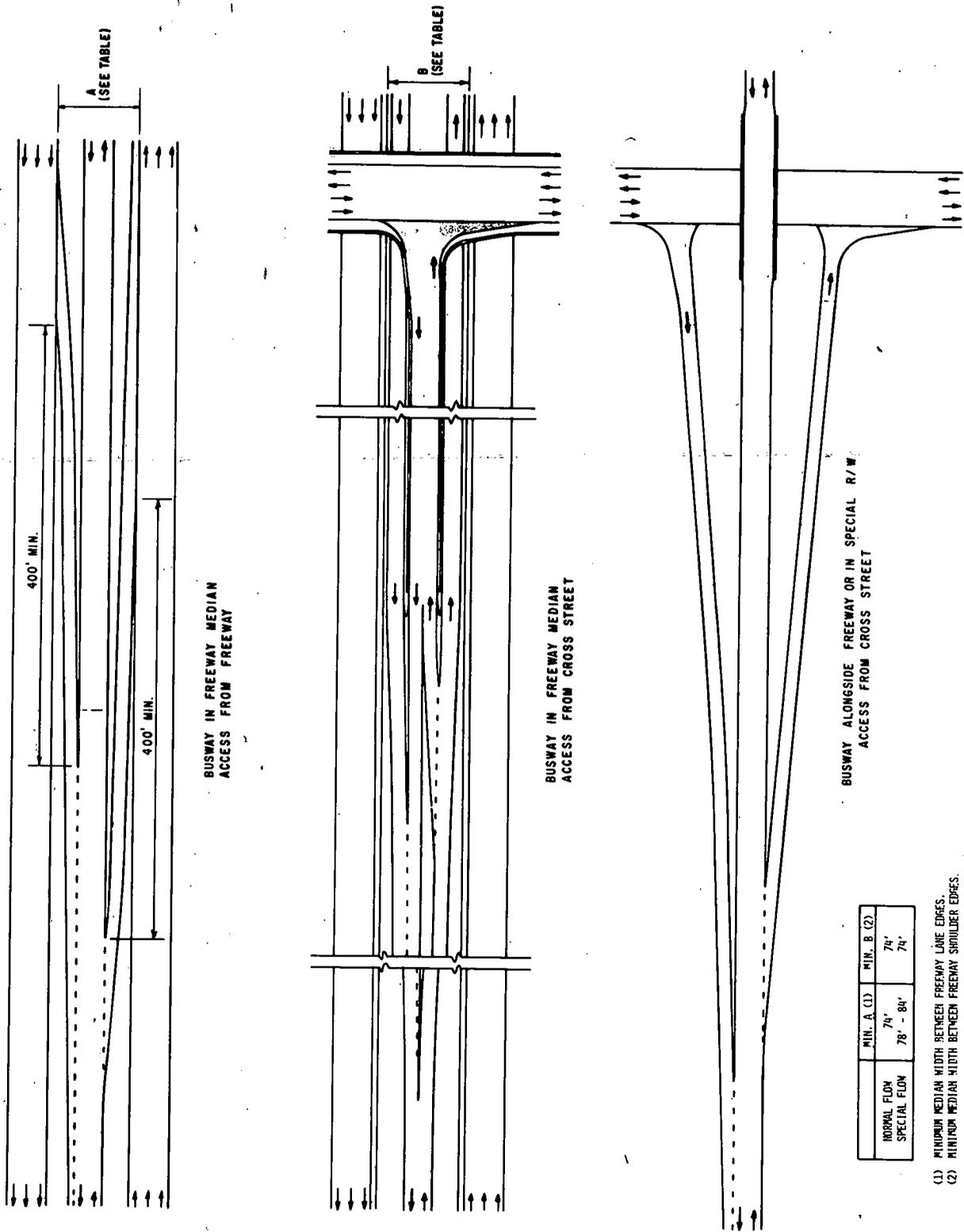
generator. It should not be applied where freeway-to-freeway movements, freeway convergence points, or freeway lane-drops cause overloads or queues.

Where bus bypass lanes are provided, the following additional criteria should be met:

1. Design-year peak-hour bus volumes ideally should ex-

ceed 10 buses, with an average time savings of 1 min per bus. However, in view of the low installation costs (usually pavement markings and signs), bus priorities could be installed with lower volumes. The bus bypasses could also be used by car pools and trucks at selected locations.

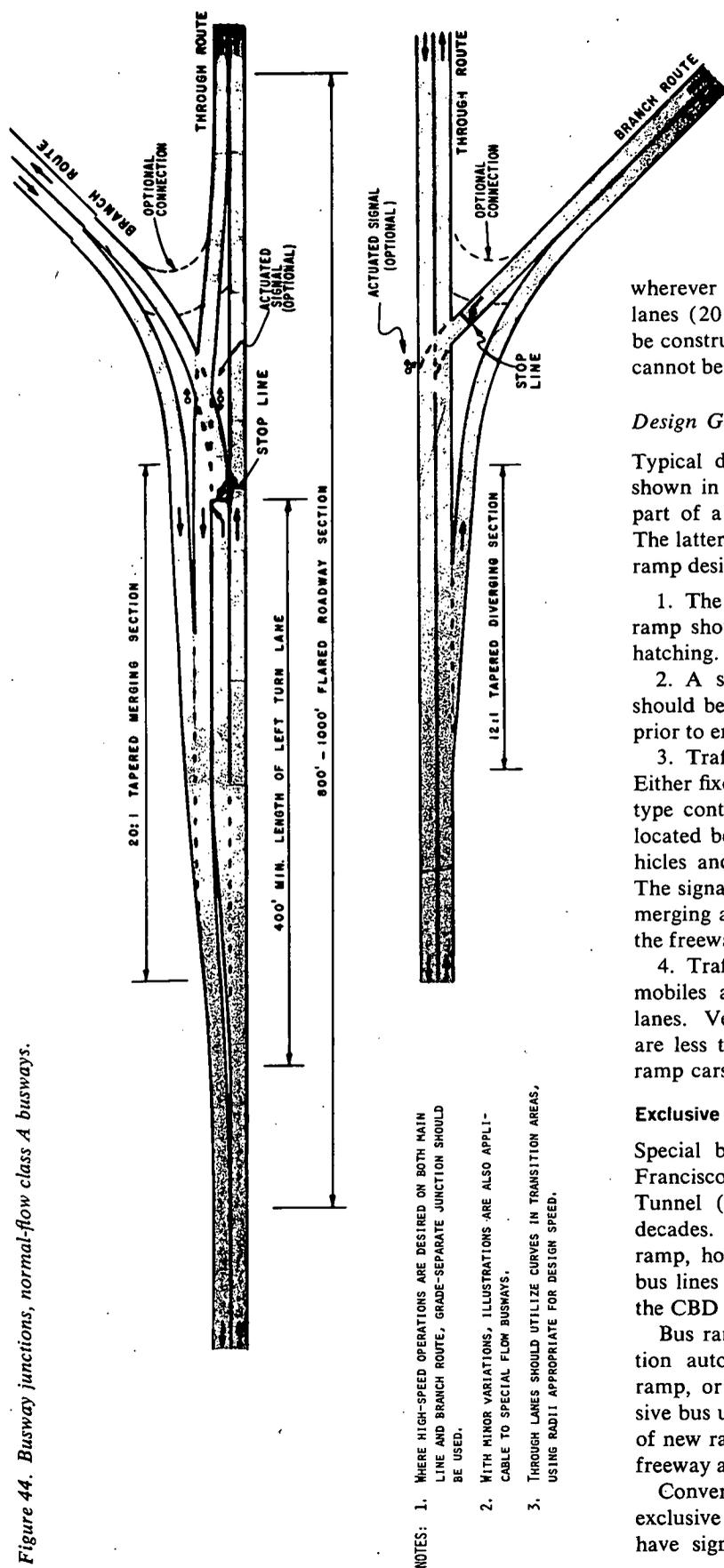
2. Bus bypasses can be provided on existing ramps



	MIN. A (1)	MIN. B (2)
NORMAL FLOW	74'	74'
SPECIAL FLOW	78' - 84'	74'

- (1) MINIMUM MEDIAN WIDTH BETWEEN FREEWAY LANE EDGES.
- (2) MINIMUM MEDIAN WIDTH BETWEEN FREEWAY SHOULDER EDGES.

Figure 43. Busway access, normal- and special-flow class A busways.



wherever the ramps plus shoulders are equivalent to two lanes (20 ft wide). Alternatively, special bus ramps could be constructed where bus demands exist and existing ramps cannot be readily widened or redefined.

Design Guidelines

Typical designs for bus priorities at metered ramps are shown in Figures 62 and 63. The bus bypass lane can be part of a conventional auto ramp or be fully segregated. The latter option could be incorporated in new freeway and ramp design.

1. The shoulder of the right-hand lane of the freeway ramp should be "painted-out" for cars with 45-deg cross-hatching. Buses should operate on this shoulder area.

2. A single-lane entrance to the main freeway lanes should be provided. Buses should merge with ramp traffic prior to entering the freeway.

3. Traffic signal controls should meter automobile traffic. Either fixed-time (i.e., 2 sec green, 10 sec red) or actuated-type controls could be used. Presence detectors could be located beyond the traffic signal to assure clearance of vehicles and to preclude queues in the freeway entry area. The signals should be a sufficient distance from the freeway merging area to permit vehicle acceleration before entering the freeway lanes.

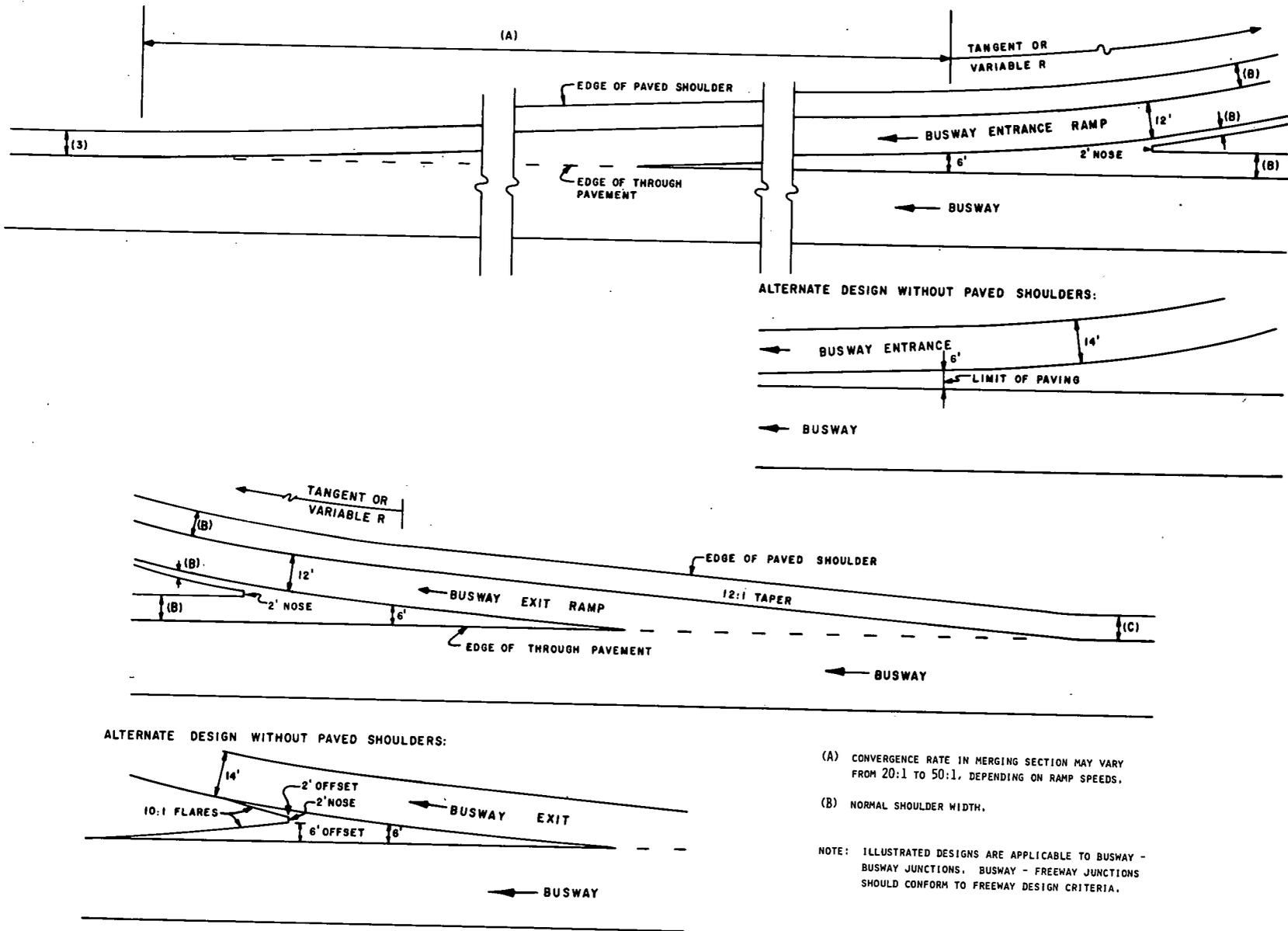
4. Traffic-responsive ramp controls can release automobiles as gaps become available on the main freeway lanes. Vehicle densities can be recorded and when they are less than a critical value (e.g., 50 vehicles per mile) ramp cars could be released.

Exclusive Bus Access to Freeway Lanes

Special bus ramps have been integral parts of the San Francisco-Oakland Bay Bridge (California) and Lincoln Tunnel (New York) express bus operations for several decades. The most significant example of a special bus ramp, however, is Seattle's Blue Streak bus service; eight bus lines use the reversible lanes of I-5 to enter and leave the CBD via the Columbia-Cherry reversible ramp.

Bus ramps can be provided by (1) building a combination auto-bus ramp, (2) constructing an exclusive bus ramp, or (3) converting an existing auto ramp to exclusive bus use. The choice will depend on balancing the costs of new ramps against the impacts of auto ramp closures on freeway and arterial street traffic operations.

Conversion of an existing general-purpose ramp to an exclusive bus ramp usually involves little cost, but may have significant impact on established automobile traffic



(A) CONVERGENCE RATE IN MERGING SECTION MAY VARY FROM 20:1 TO 50:1, DEPENDING ON RAMP SPEEDS.

(B) NORMAL SHOULDER WIDTH.

NOTE: ILLUSTRATED DESIGNS ARE APPLICABLE TO BUSWAY - BUSWAY JUNCTIONS. BUSWAY - FREEWAY JUNCTIONS SHOULD CONFORM TO FREEWAY DESIGN CRITERIA.

Figure 45. Ramp terminal details, class A busways.

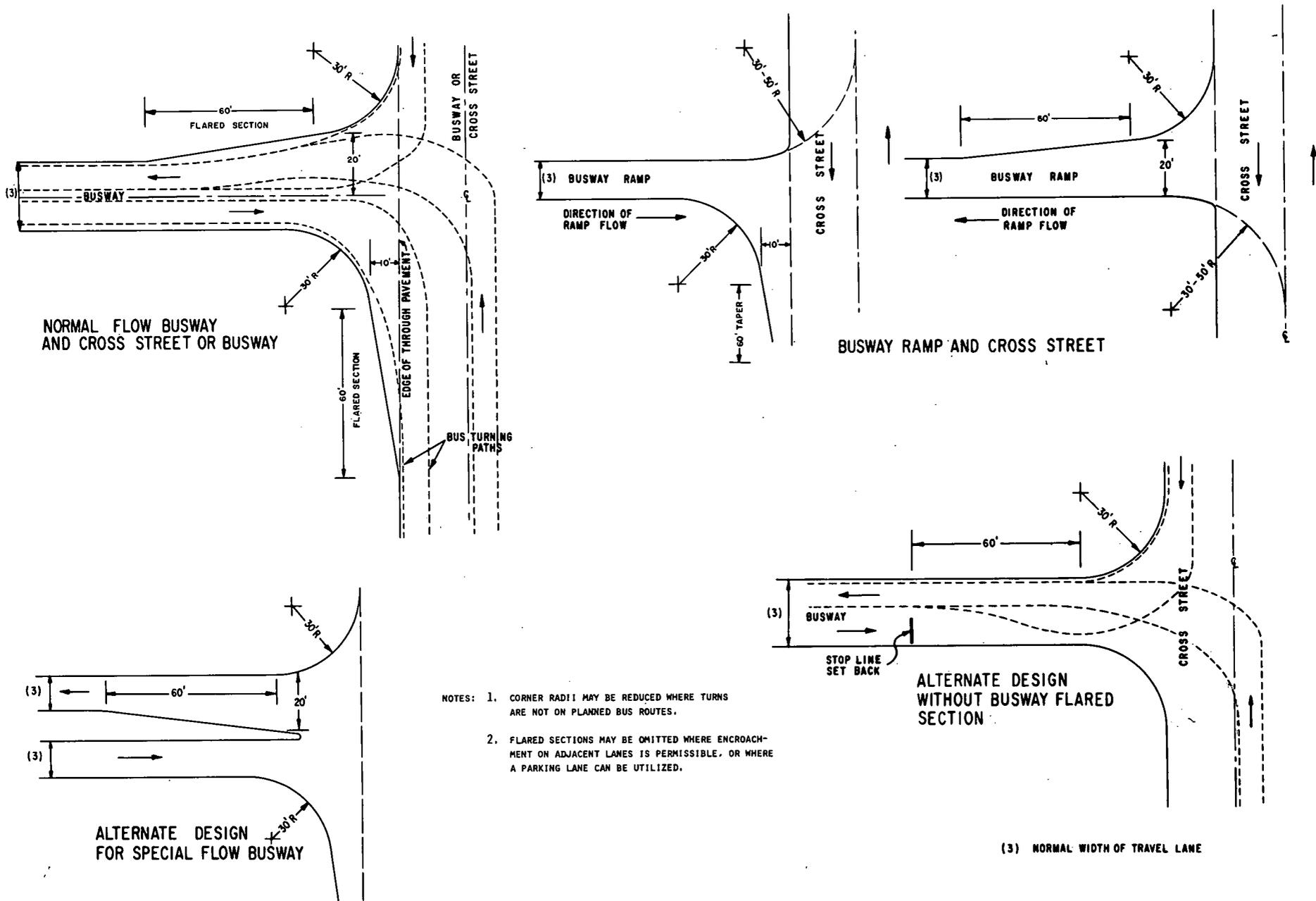
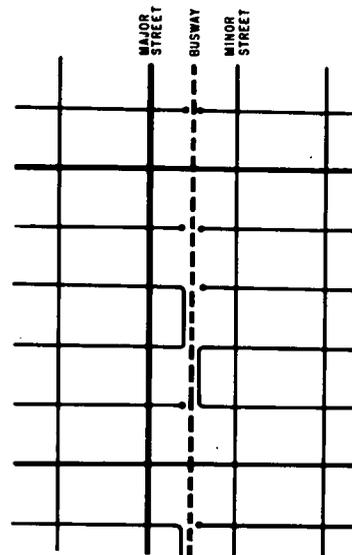
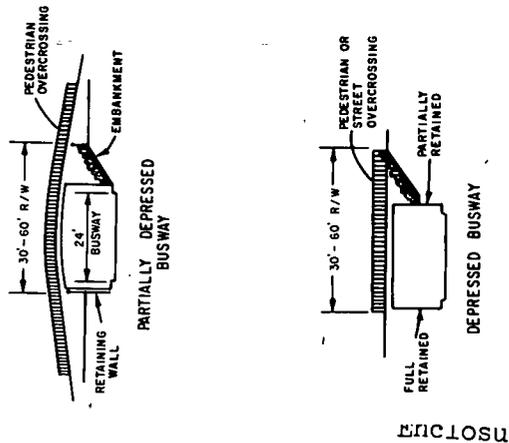
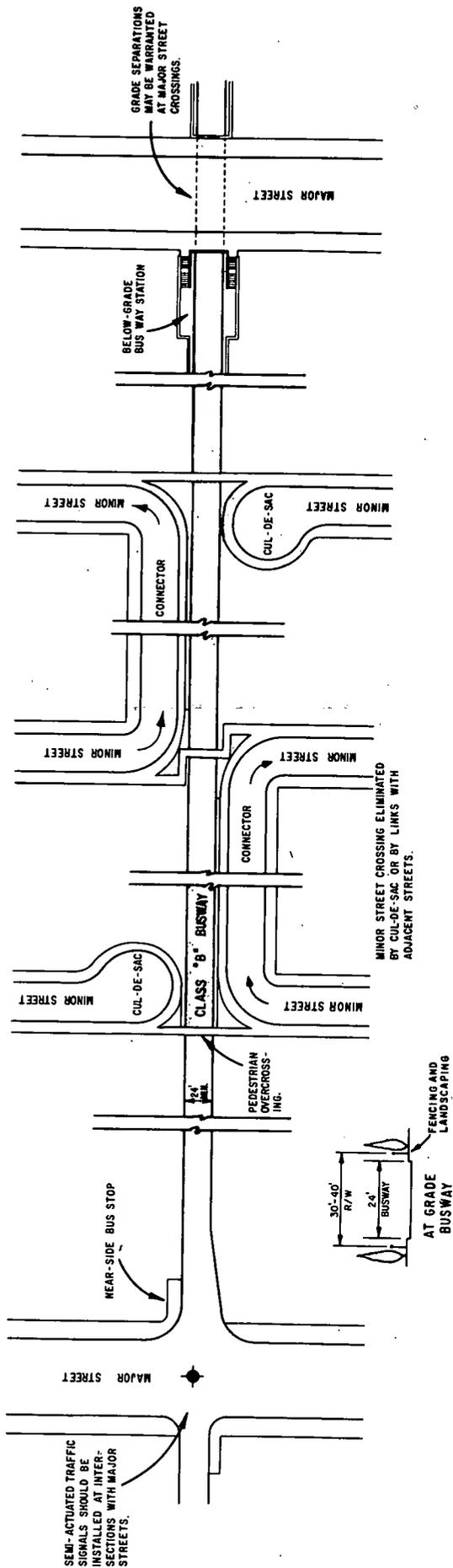


Figure 46. At-grade intersection details, normal-flow busways and busway ramps.



MIDBLOCK BUSWAY SUPERIMPOSED ON STREET GRID

Figure 47. Midblock busway concept, class B busways.

patterns. Construction of exclusive bus ramps will minimize conflicts and facilitate bus movement to special generators, but may involve substantial costs.

Applicability

An exclusive bus ramp should be provided when one or more of the following conditions exist:

1. The ramp serves a facility with high travel demands (e.g., bus terminal, transfer station, major park-ride facility, sports complex, civic center).
2. The ramp provides access that would otherwise be slow, circuitous, or impossible. (For example, if it allows buses to reach a reserved bus lane directly, or reduces bus mileage between points.)
3. The ramp should accommodate as many bus passengers as cars would carry in the same lane. Accordingly, it should serve at least 40 to 60 buses during the peak hour and/or 400 buses per day.

Design Guidelines

Geometric standards and traffic controls for busways generally apply to exclusive bus access roads and ramps. Design speeds, however, should typify those for ramps rather than for the main line. Bus breakdown requirements suggest a minimum two-lane design, even where one-way operation is anticipated. For limited distances, however, single-lane design is acceptable where shoulder areas (paved or unpaved) can provide refuge for disabled buses. Single-lane reverse-flow bus ramps may be provided where conditions permit.

Bus Bypass of Queue or Congestion Point

Where freeway congestion results from a bottleneck caused by lane reduction or convergence, and where physical or environmental conditions preclude elimination of the bottleneck through normal road construction, special bus bypass facilities may be appropriate. These bypass roadways may involve (1) short sections of busways or separated roadways, (2) physically segregated bus lanes, and (3) a specially designated lane through a toll plaza. Treatments generally should be implemented upstream of the bottleneck, rather than through it, and should allow bus operations in mixed traffic operations outside of the congested area.

A queue bypass lane for buses upstream from a bottleneck, with buses metered back into the general traffic stream at the head of the queue, may provide significant benefits. The San Francisco-Oakland Bay Bridge toll plaza lanes reserved for buses and car pools illustrate this concept. However, nontoll applications are viable provided buses can be effectively segregated from other traffic and bypass lane use can be effectively enforced.

Applicability

Bus bypass of queues should be considered wherever there are more than 60 design-year peak-hour buses, and where each bus is expected to save at least 5 min. Adequate sight distances at the beginning and end points are essential. Conditions should allow providing bus priority facilities without reducing highway capacity through the bottleneck.

Where bus bypasses at toll stations are provided, there should be at least 10 buses per hour, each saving 5 min, or 15 buses per hour, each saving 2 to 3 min. Adequate approach reservoir capacity is essential to minimize car-queues across entry to the bus lanes.

Bus bypass or "queue jumpers" may be temporary pending road construction to alleviate the bottleneck. Alternatively, they can be an integral part of expressway traffic management strategies, particularly in view of contemporary attitudes relating to environmental impacts associated with highway construction.

Bus bypass lanes may be provided in areas where land and construction are relatively inexpensive, whereas mixed traffic can prevail downstream where widening or new construction is far more costly. Where bottlenecks can be eliminated through construction or operations, the need for bus bypass facilities is reduced.

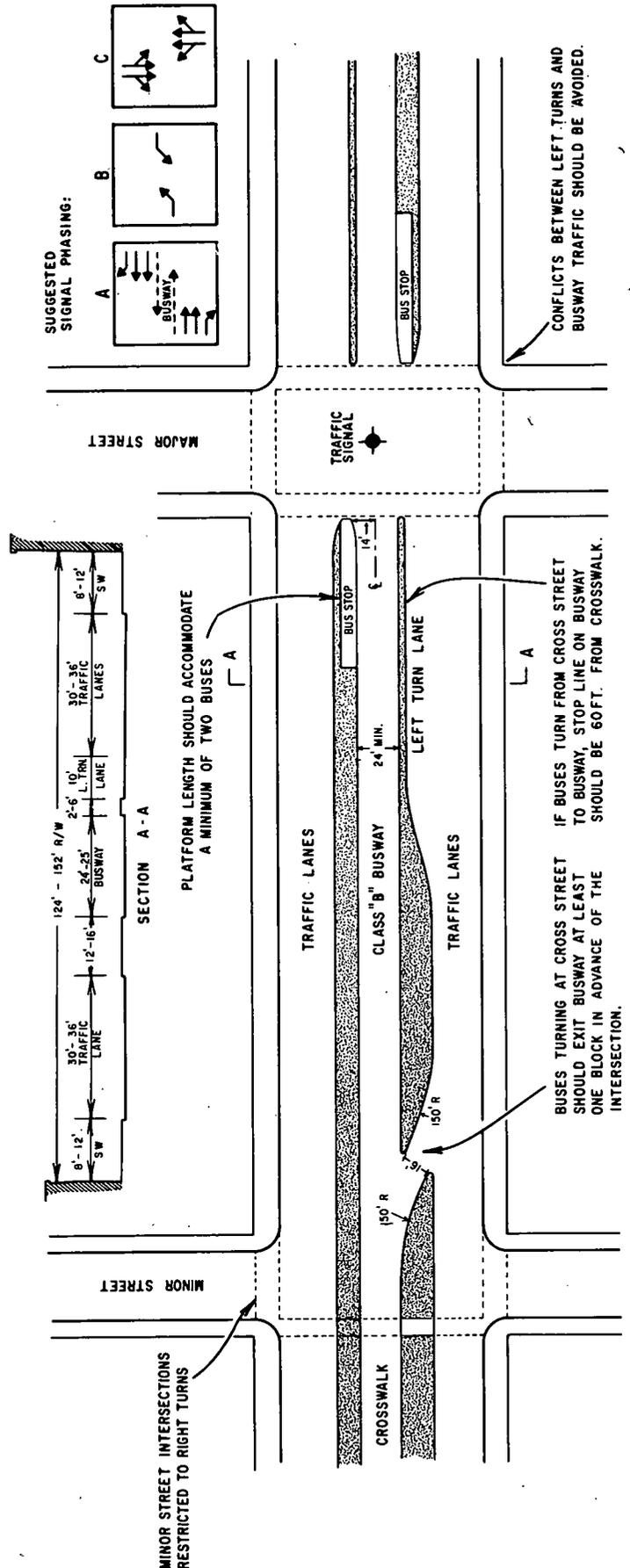
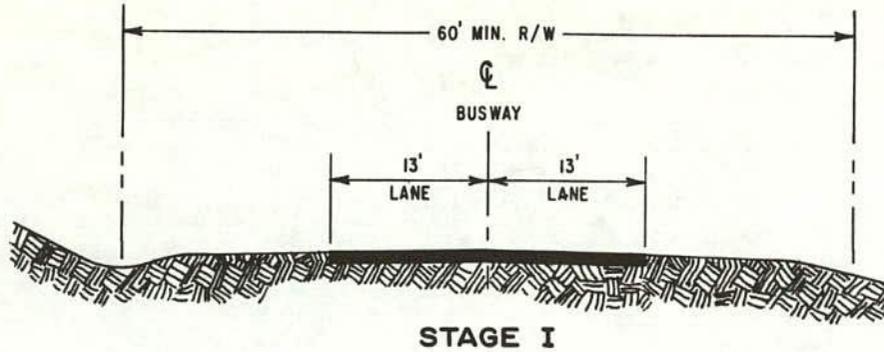
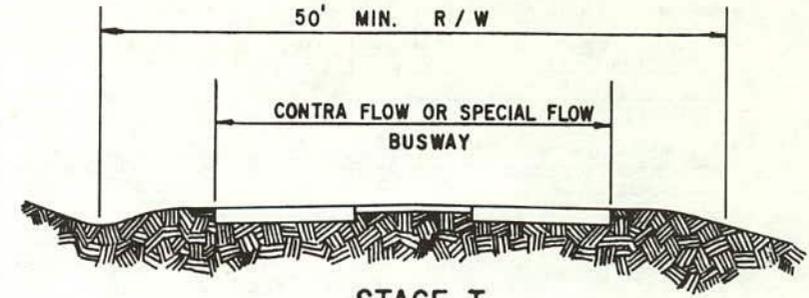


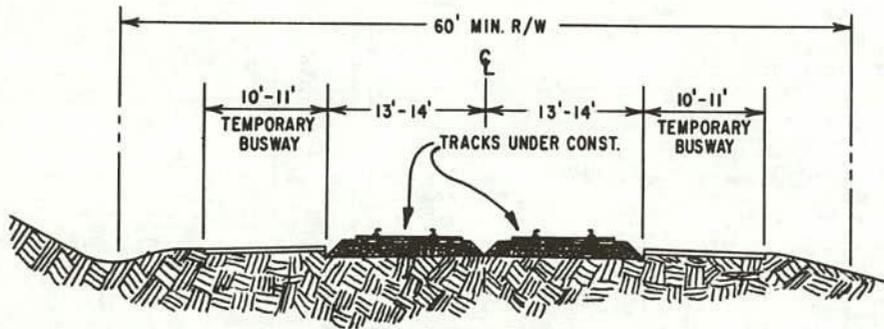
Figure 48. Busway in arterial median, class B busway.



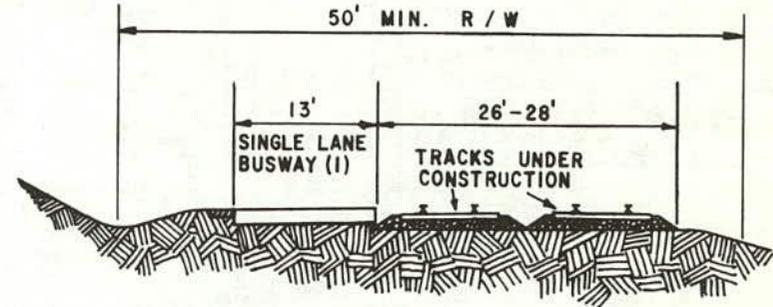
STAGE I



STAGE I

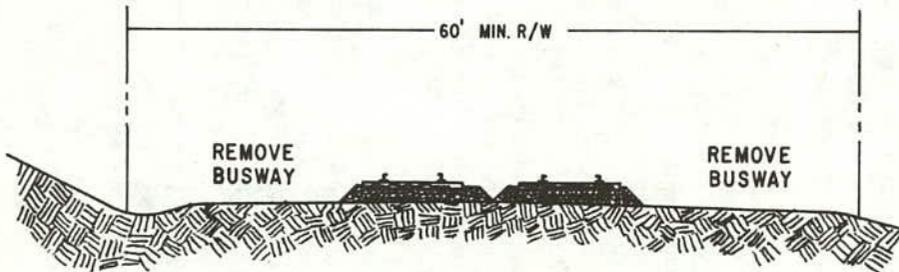


STAGE II

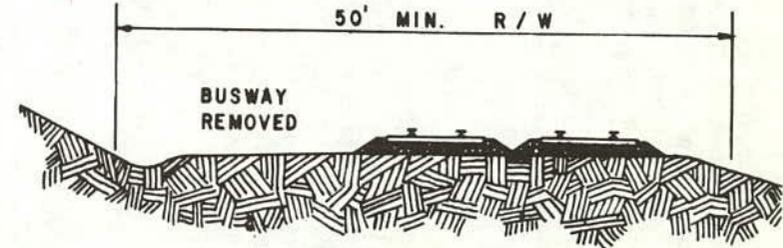


STAGE II

NOTE: WITH TRACKS SPACED AT 26 TO 28 FEET ON CENTERS, SINGLE LANE BUSWAY (STAGE II) CAN BE LOCATED BETWEEN TRACKS.

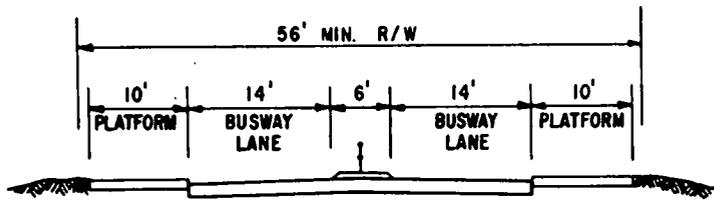


STAGE III
NORMAL FLOW

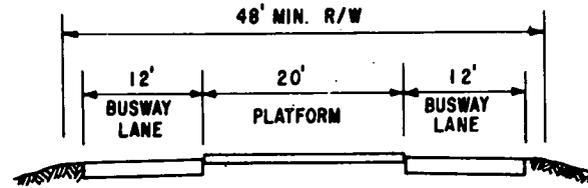


STAGE III
SPECIAL AND CONTRA FLOW

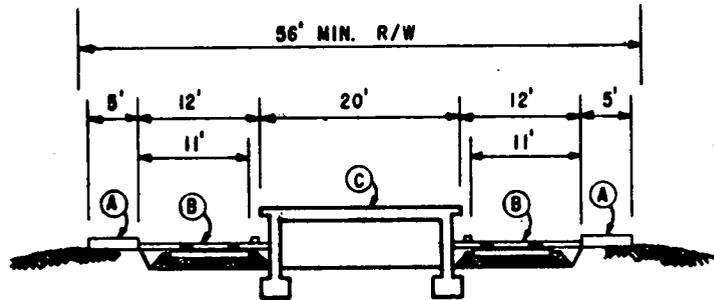
Figure 49. Rail conversion staging, normal-, special-, and contra-flow busways.



STAGE I

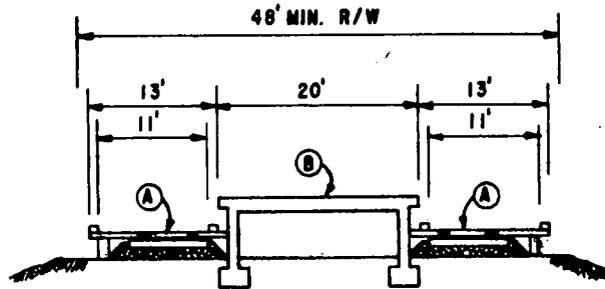


STAGE I



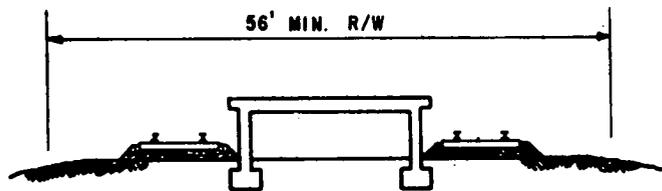
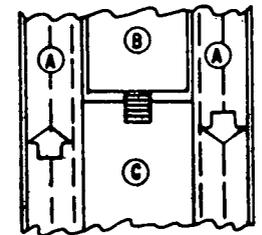
STAGE II

- Ⓐ TEMPORARY BUS PLATFORMS,
- Ⓑ COMPLETED TRACKS WITH COVER FOR TEMPORARY BUSWAY.
- Ⓒ HIGH-LEVEL PLATFORM UNDER CONSTRUCTION.

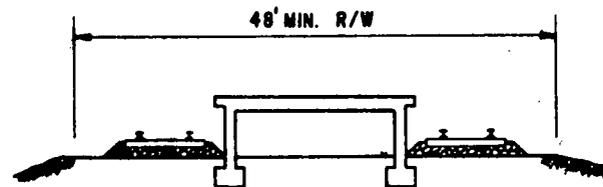


STAGE II

- Ⓐ COMPLETED TRACKS WITH COVER FOR TEMPORARY BUSWAY.
- Ⓑ HIGH-LEVEL PLATFORM UNDER CONSTRUCTION.
- Ⓒ TEMPORARY BUS PLATFORM AT END OF HIGH-LEVEL PLATFORM



STAGE III
NORMAL FLOW



STAGE III
CONTRA FLOW

Figure 50. Rail conversion staging, normal- and contra-flow busway stations.

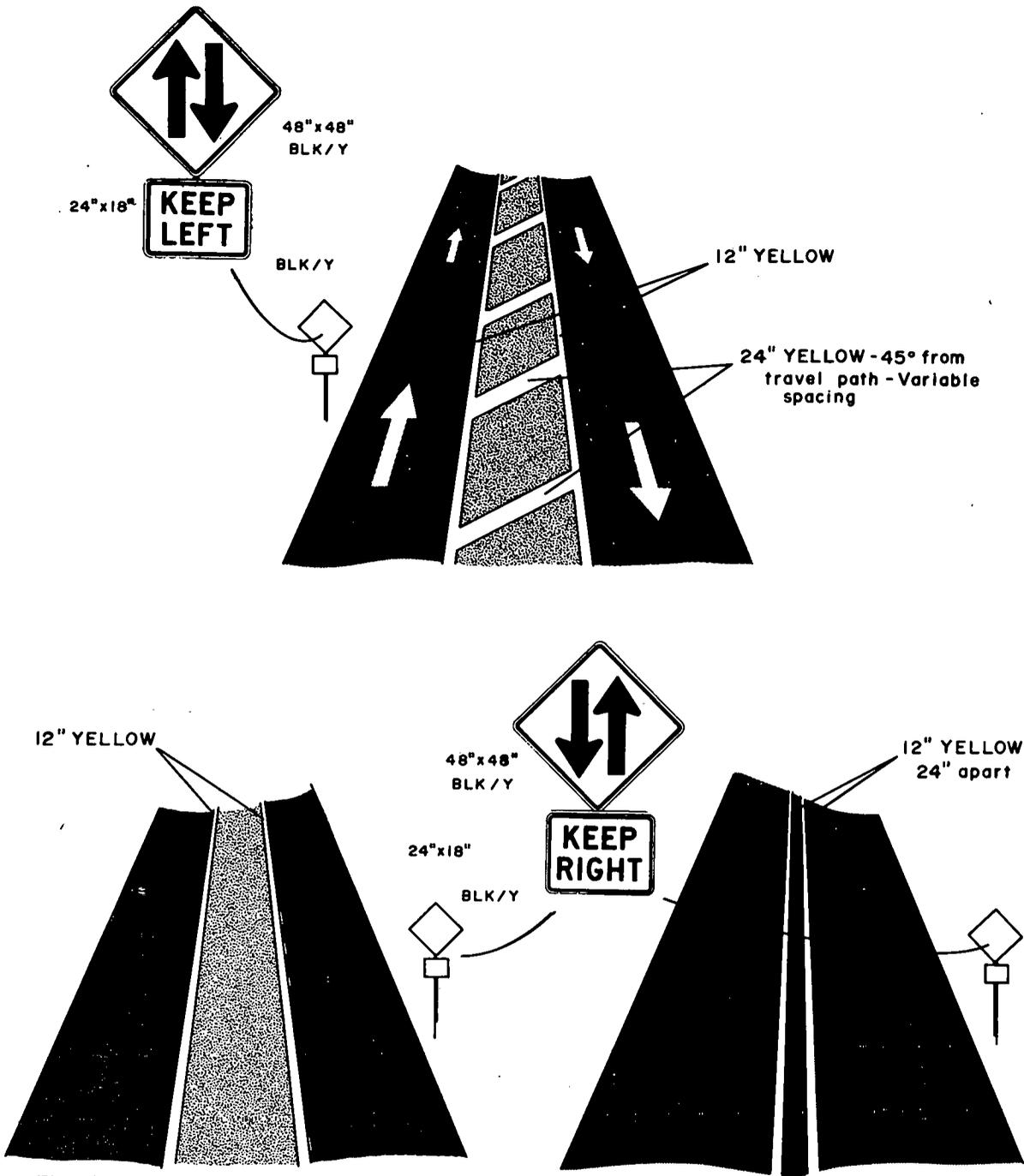


Figure 51. Typical busway markings.

Design Guidelines

Examples of bus bypasses of expressway bottleneck areas (Fig. 64) show how bus bypass lanes may be provided in conjunction with lane drops, expressway convergence points, and toll plazas. The following principles underlie bus bypass lane design:

1. Bus bypass lanes should be provided upstream of the bottlenecks. These lanes should reenter the normal traffic stream before the bottleneck. Capacity of the bottleneck itself should not be reduced.

2. It is essential that bypass roadways be longer than the normal maximum upstream queues. They should extend sufficiently beyond the normal length of queues resulting from lane reductions or toll collection. Their exact lengths should be determined by actual field observations with allowances for growths in traffic. Bus bypass lanes also should be long enough to avoid the prolonged queues that result from regular breakdowns under heavy flow conditions. The lanes should extend at least 300 to 500 ft beyond the normal queue lengths. They should be accompanied by general measures that facilitate merging at the

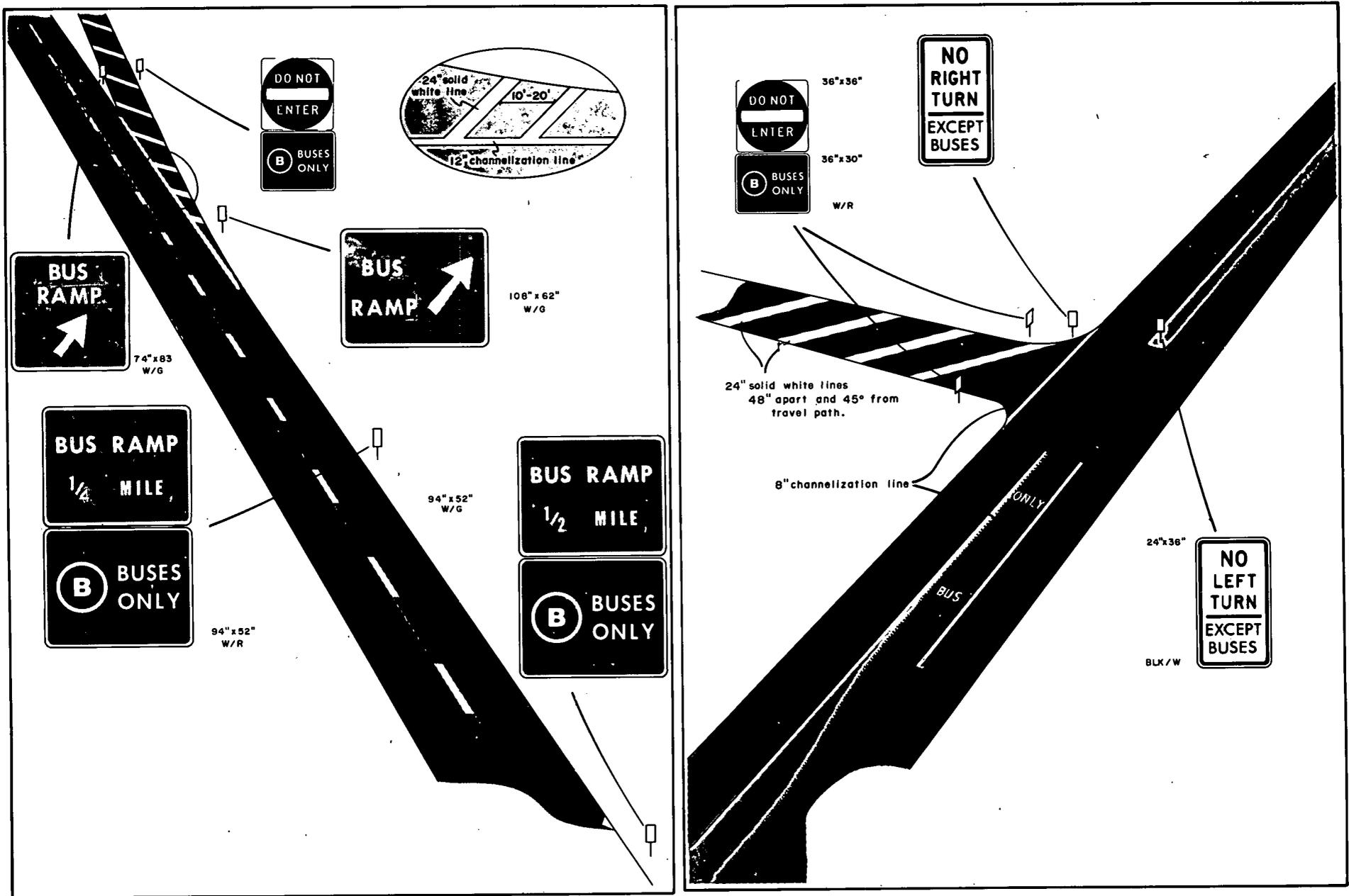


Figure 52. Typical signs and markings for bus ramps.

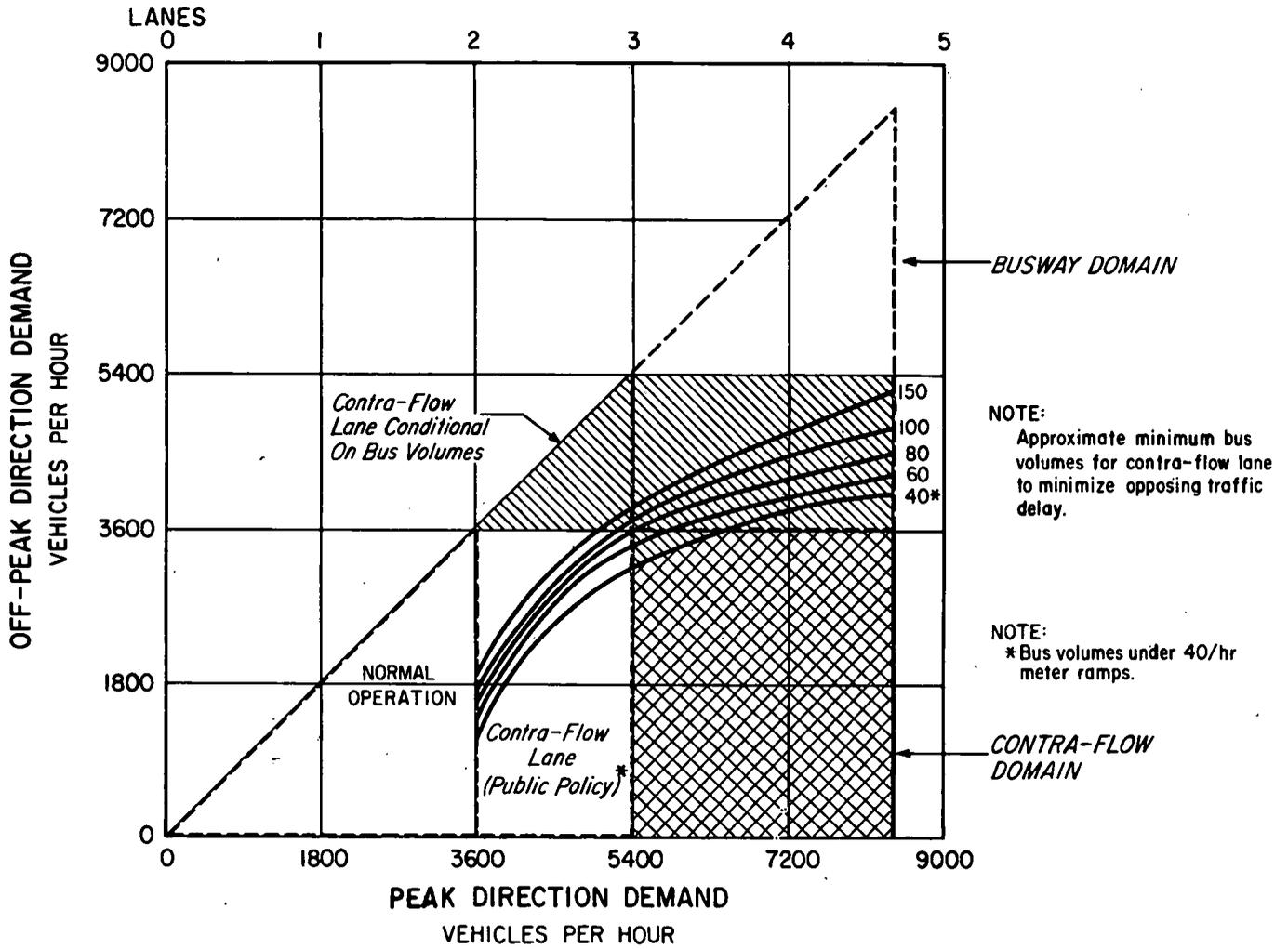


Figure 53. Contra-flow bus lane concept, 6-lane freeway.

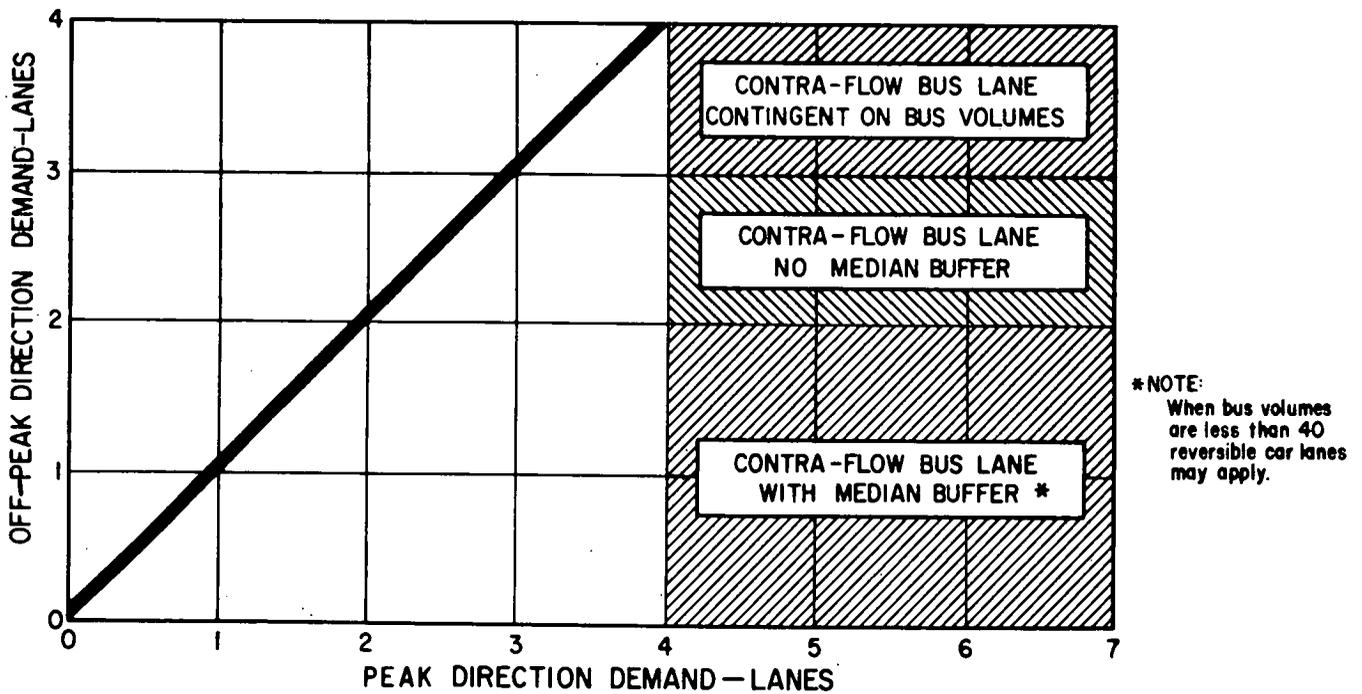


Figure 54. Contra-flow bus lane concept, 8-lane freeway.

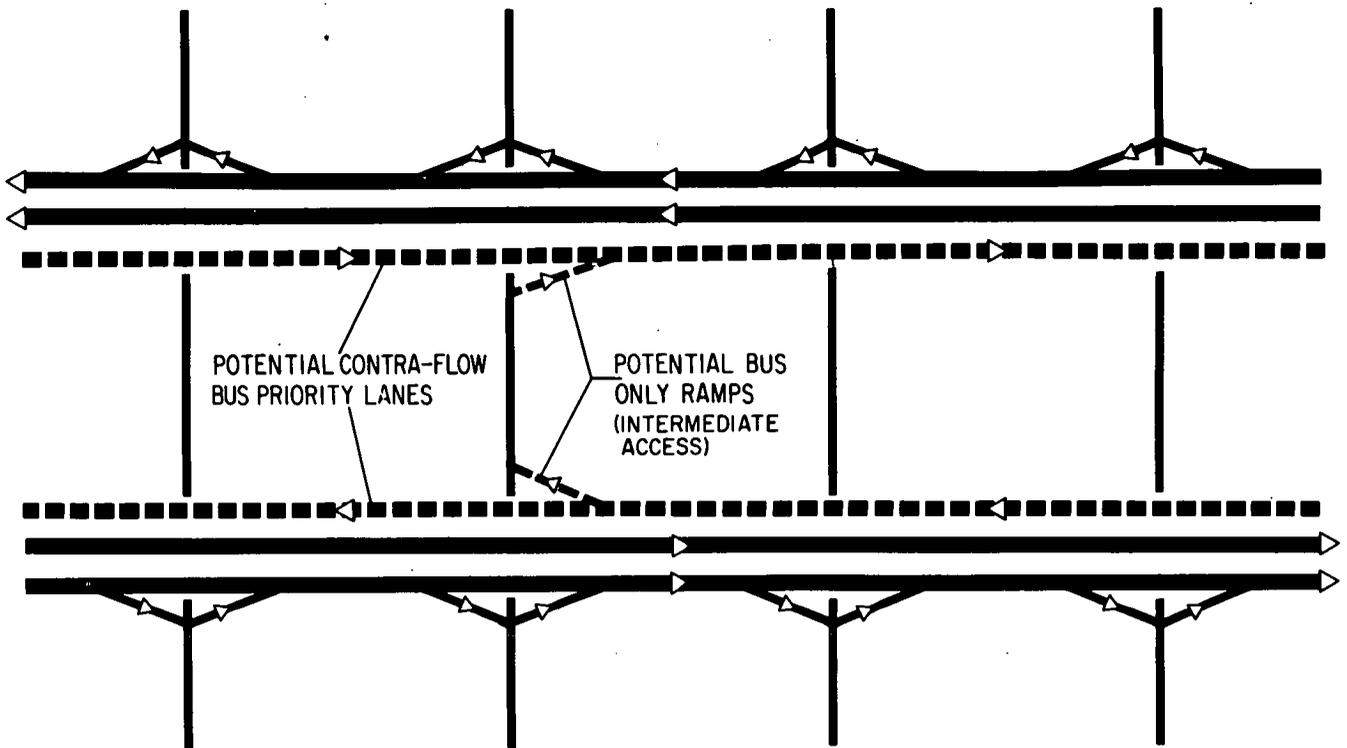


Figure 55. Contra-flow bus lanes in relation to standard right-hand freeway lanes.

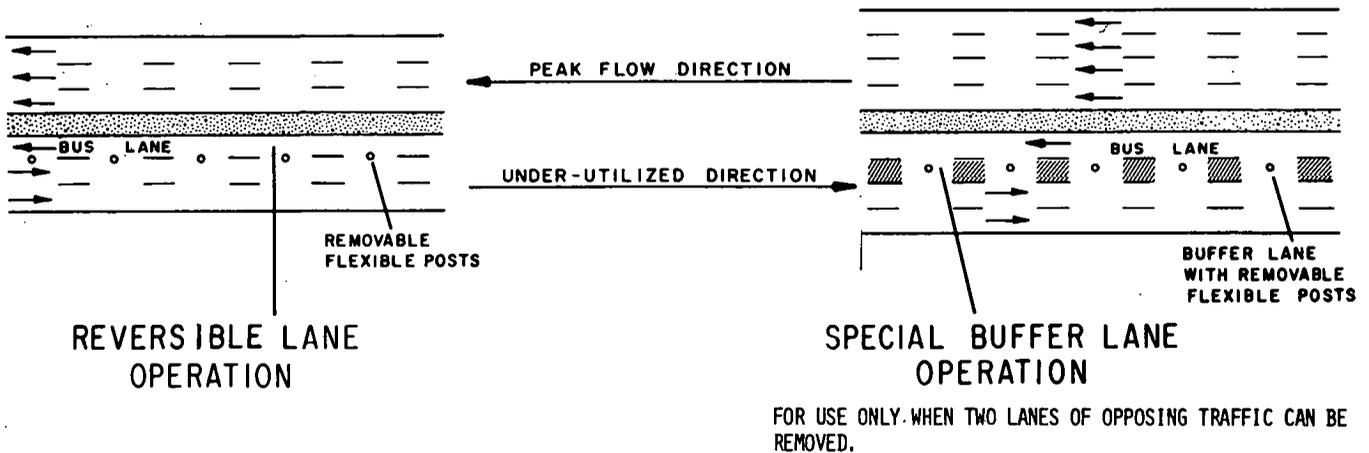


Figure 56. Contra-flow freeway bus lane.

bottlenecks and that minimize queue lengths for general traffic.

3. Bus bypass lanes should be physically segregated from adjacent highway lanes. Cross-sectional requirements can be minimized by using mountable curbs, thereby allowing a single (11 to 12 ft) lane.

4. Bus bypass lanes also should be designed for use by trucks and, in some cases, multiple-occupancy cars. In these cases, a strategy of increasing permissiveness should be utilized to progressively add additional vehicle types to the bus lanes. The limiting factor will be the admittance rate at the point of reentry to the main freeway lanes. In

exceptional cases (as downstream from toll plazas), highway lanes may be metered to produce gaps in traffic.

5. Bus lanes at toll plazas should generally traverse the center of the plaza. This will tend to equalize distribution of auto traffic on each side of the toll plaza and achieve more effective use of available toll plaza lanes. In view of slow speeds on toll plaza approaches, lane segregation can be provided by traffic posts, spaced on approximately 20 ft centers. During off-peak periods, bus priority lanes through toll plazas could be closed and buses could be directed into normal traffic lanes.

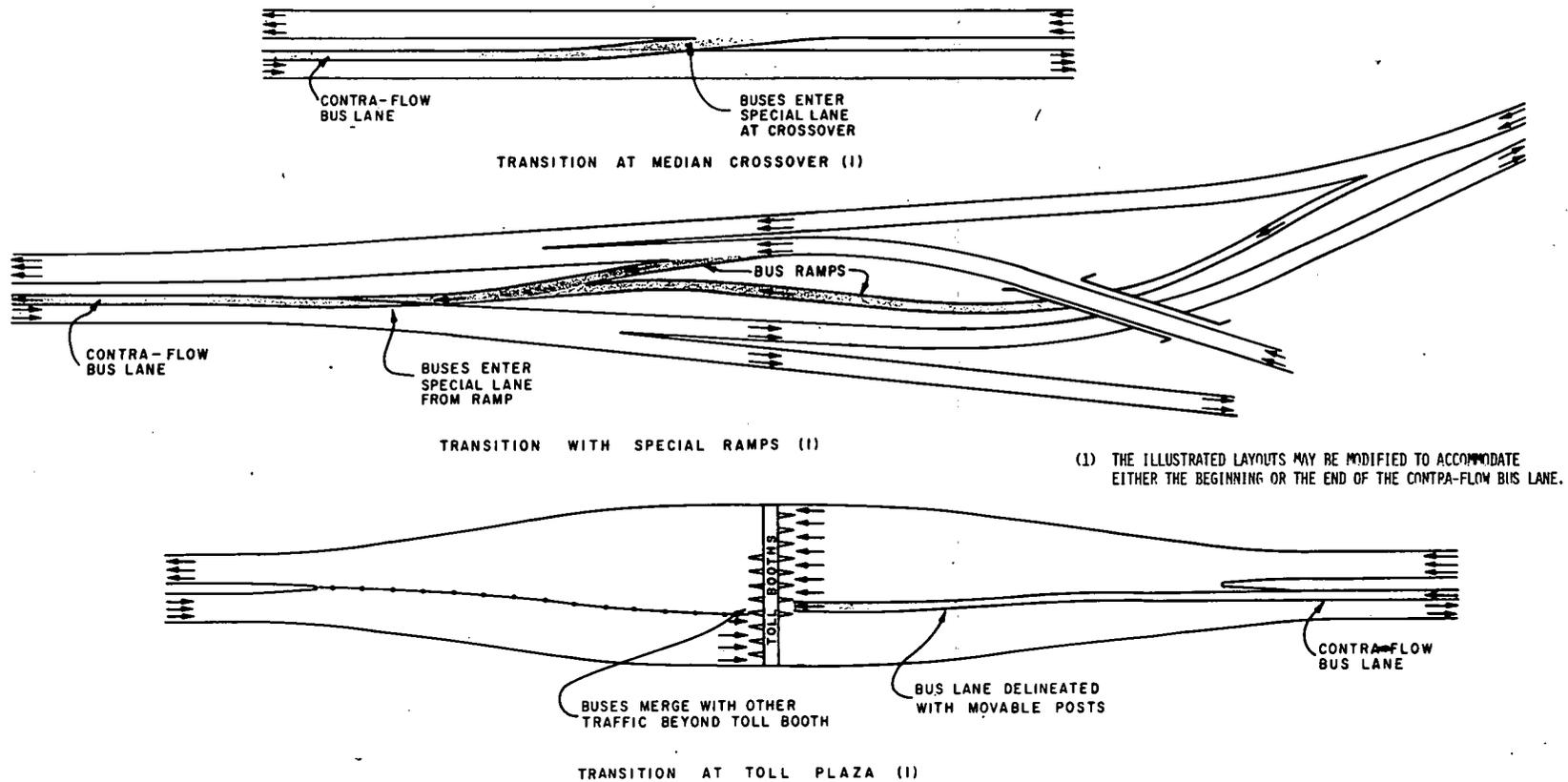


Figure 57. Transition sections, contra-flow freeway bus lanes.

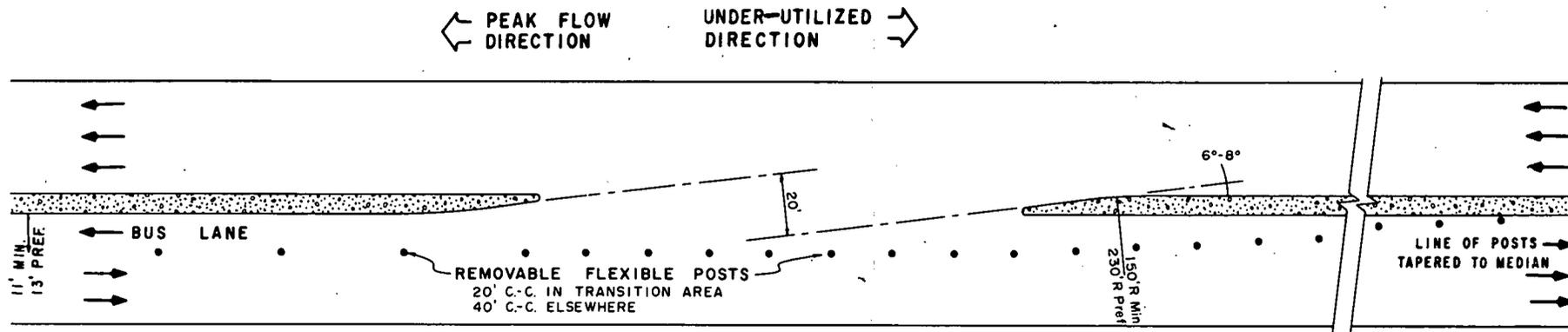


Figure 58. Transition details, contra-flow freeway bus lanes.

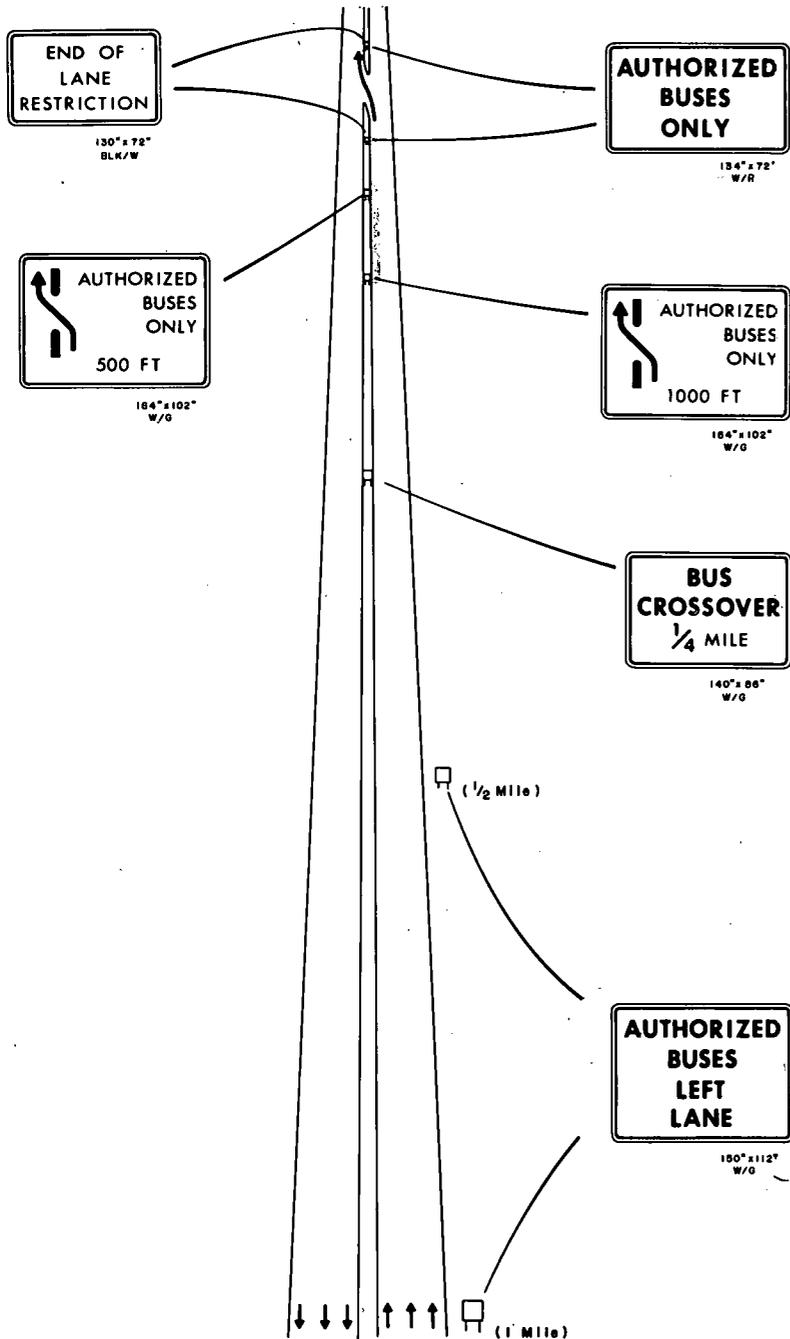


Figure 59. Typical contra-flow lane transition signing.

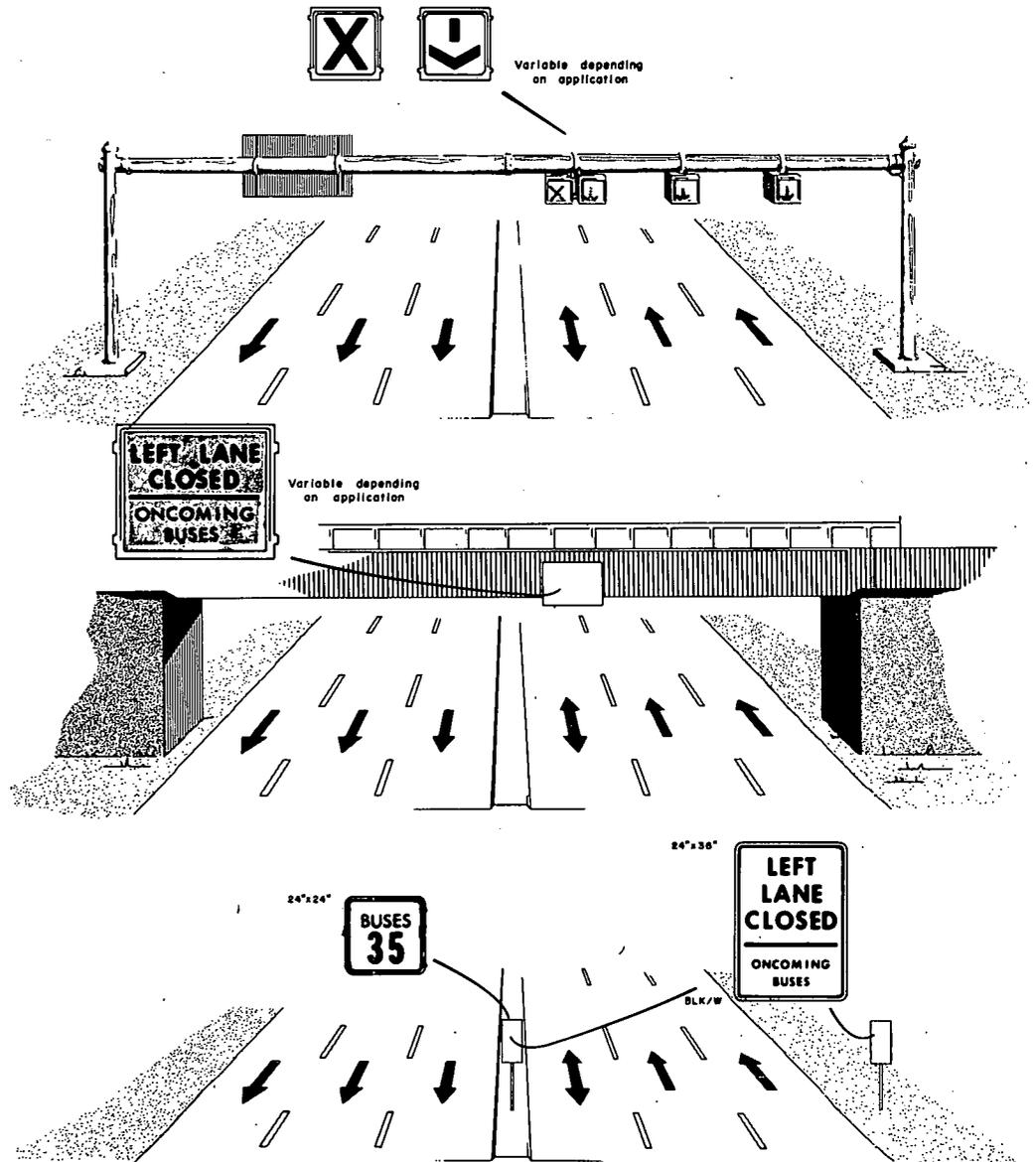


Figure 60. Typical contra-flow lane signing.

Bus Stops on Freeways

Express buses often require intermediate stops on freeways to receive and discharge passengers. Although these stops may reduce bus operating speeds, they are essential to provide desired service levels and optimize bus patronage. Stops in urban areas may obviate travel among slower surface speeds; stops in rural areas may provide direct service to communities without requiring time-consuming off-expressway travel (30).

Applicability

Passenger accessibility underlies the provision of freeway bus stops. Bus stops along freeways or adjacent frontage roads can (1) serve patrons living in nearby high-density residential areas; (2) facilitate patron transfer between rail transit, express bus, and local bus; and, (3) accommodate passenger interchange to transit-oriented parking facilities. Feasibility depends on the relationship of specific freeways to land-use, street, and local transit patterns and their estimated use relative to the passengers delayed and the costs of development. The bus operator may require stops to maximize patronage and revenues while simultaneously desiring to maintain high speeds and minimize passenger delays. Bus stop frequency that reduces the quality of service to through passengers should be minimized. Public agencies that finance and construct bus stops desire cost-effective application of their funds.

Within this context, the following broad guidelines should be used in assessing the need for freeway-related bus stops:

1. Bus stops should be provided along urban freeways or on adjacent frontage roads or ramps wherever there are at least 10 boarding passengers per day and 5 to 10 buses in the peak hour.
2. In exurban and rural environments, there should be at least 2 buses per peak hour. These broad-gauged guides reflect current practice; most bus stops in Los Angeles and other California communities serve less than 100 boarding passengers per day.

Major highways in suburban and rural areas are sometimes converted to freeways without adding parallel frontage roads. Where the old highway was served by buses making stops at intersections that are converted to interchanges, bus stops generally should be included in the design of the new facilities. These provisions are essential to maintain bus service without requiring circuitous detours.

Location and Planning Factors

The location of freeway bus stops will be influenced by (a) density of population in the adjacent tributary area; (b) pedestrian, car, and bus access for potential transit users; (c) growth possibilities; (d) forecasts of future use of an expressway by buses, including estimates of prospective riders; (e) nearby generators such as hospitals, universities, shopping centers, employment complexes, or housing developments; (f) major intersecting transfer routes; and (g) major outlying parking areas.

The guiding criterion in locating and planning freeway bus stops is the need to balance time savings and losses among the various classes of road users to maximize patron convenience yet minimize person-delay. Bus stop planning should (1) minimize time losses to buses, (2) minimize delay imposed on the general traffic stream by stopped buses; and (3) offset the increased delay to through passengers by the benefits gained by passengers using the stop.

Spacing between stops should be conditioned by bus service and land-use factors. Principles that apply to busway stations should also apply to bus stops along freeways; however, minimum distances between successive freeway stops should reflect the problems of reentry into the main travel lanes. Accordingly, stops should not be spaced closer than one mile apart.

Bus stops generally should be provided at street level in urban areas. Bus stops on freeways usually should be limited to rural conditions where (a) there are no parallel frontage roads and (b) interchange configurations are not conducive to street-level stops.

The reasons underlying this strategy are apparent:

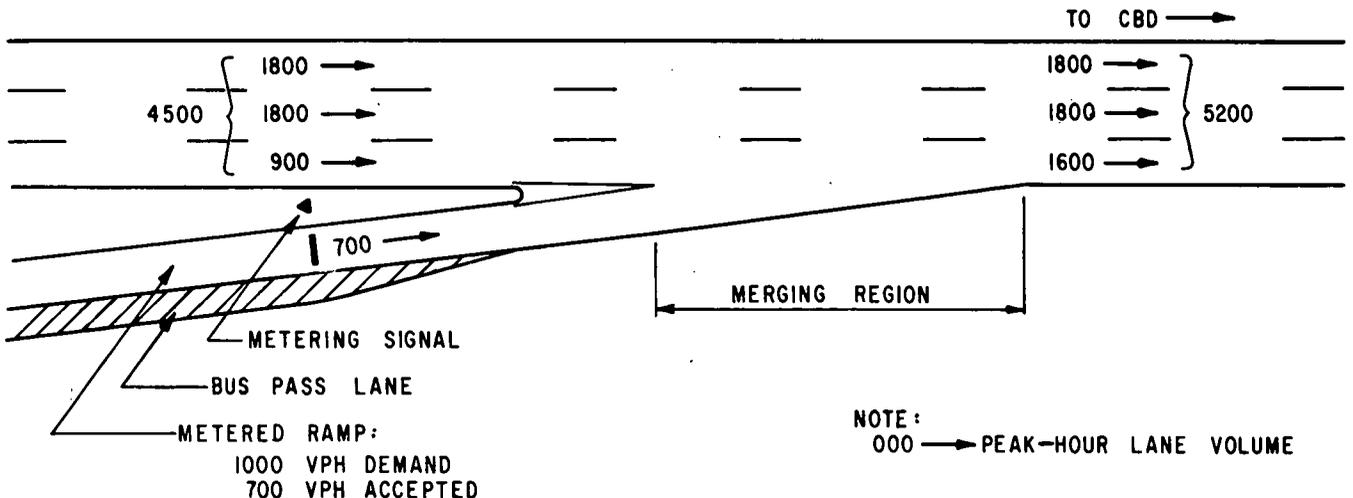


Figure 61. Ramp metering example.

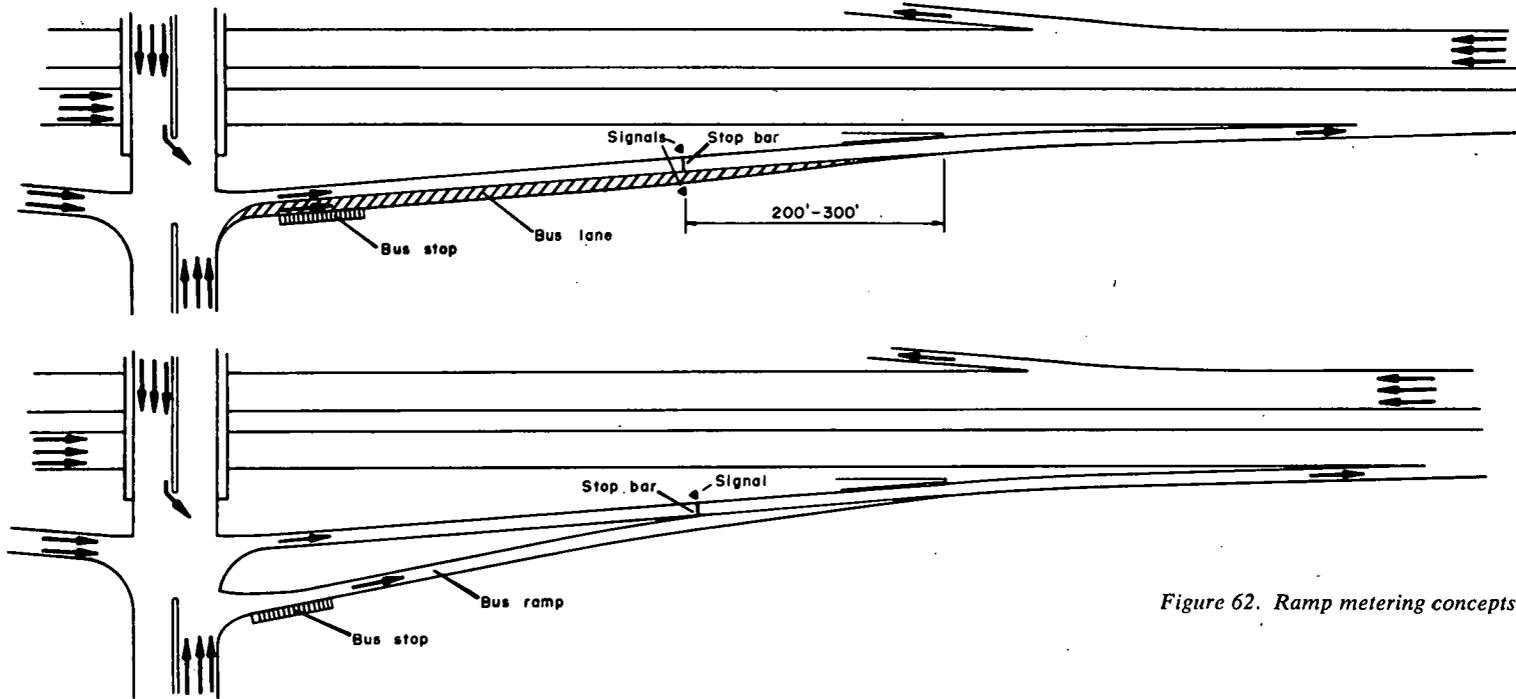


Figure 62. Ramp metering concepts.

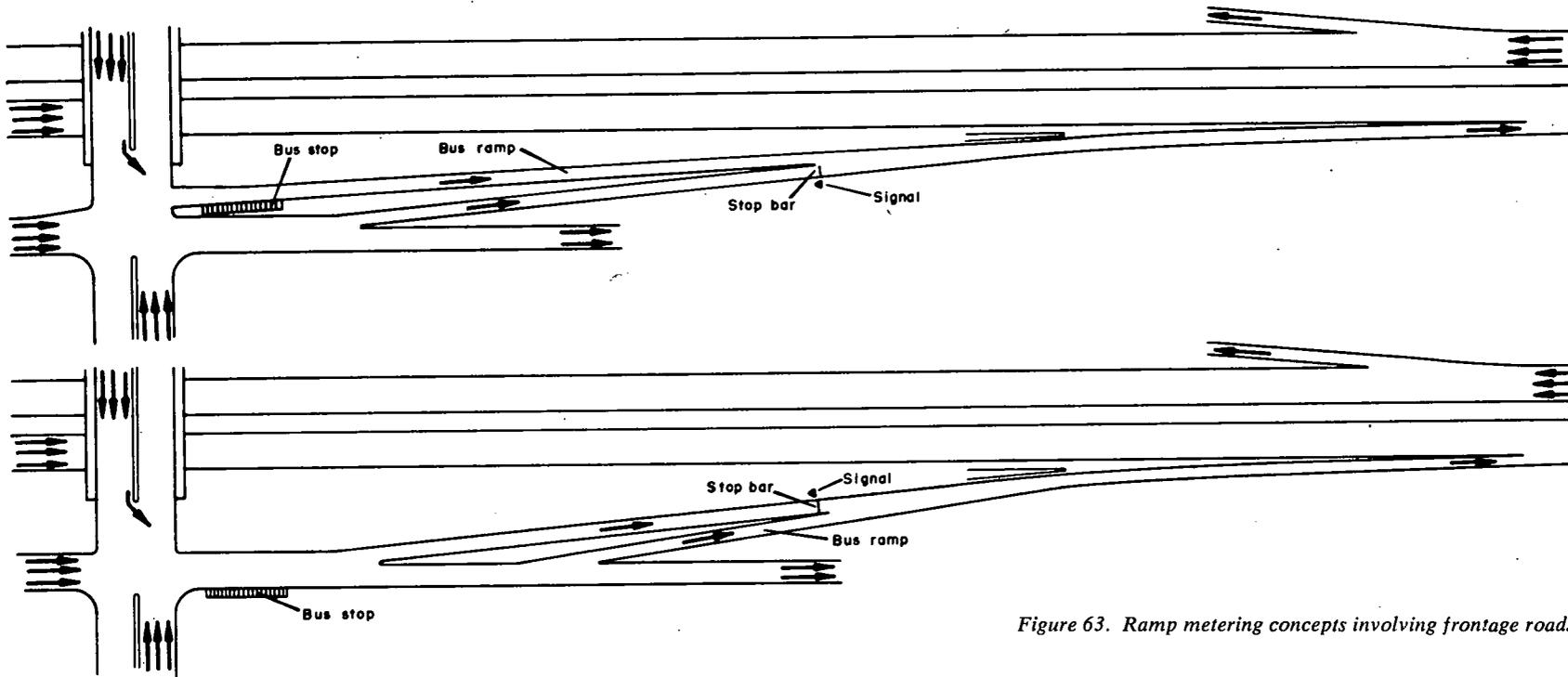


Figure 63. Ramp metering concepts involving frontage roads.

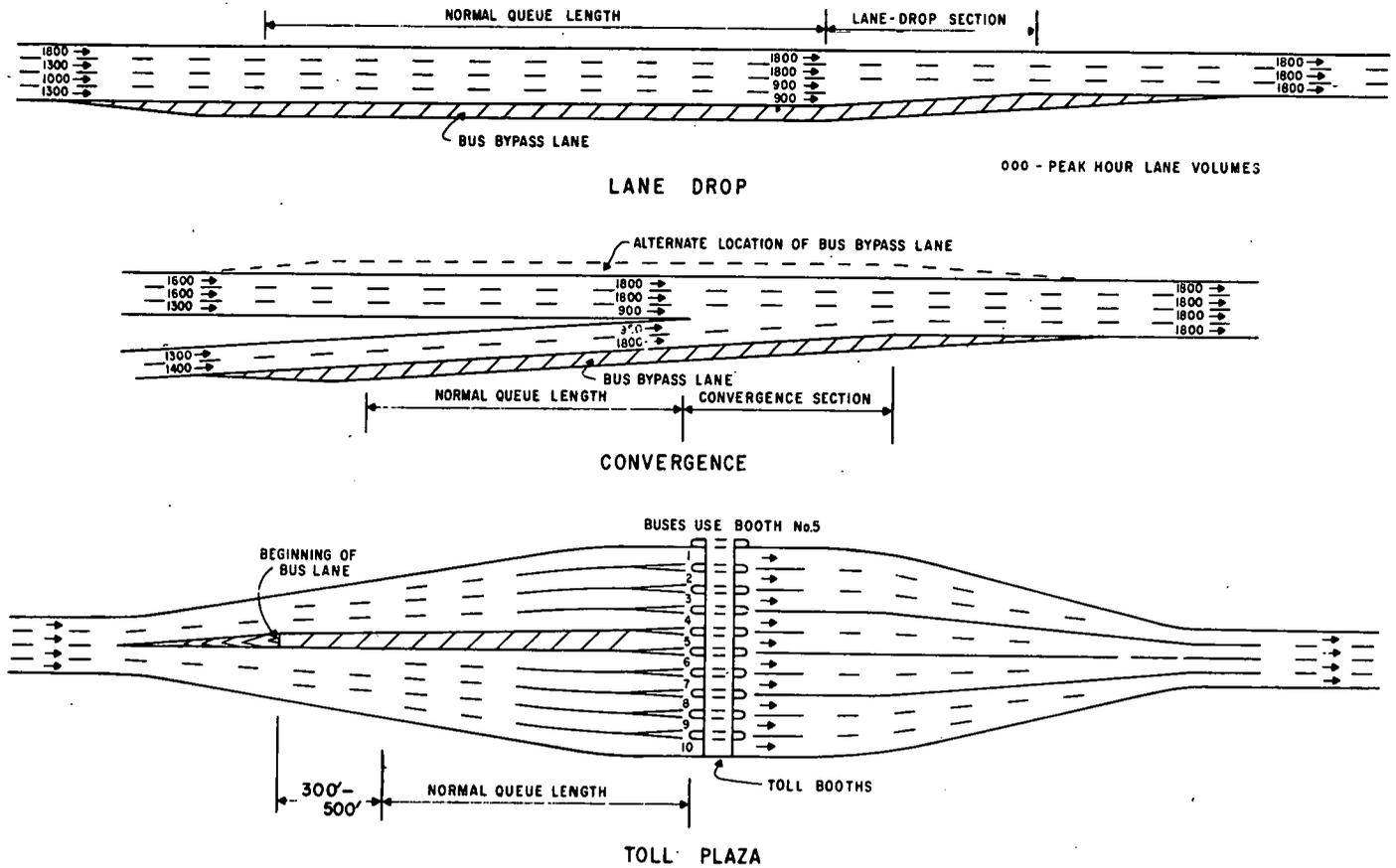


Figure 64. Bus bypass lanes upstream from bottleneck.

1. Many freeways are not well located with respect to major areas of existing and potential bus patronage. They serve more as conduits for nonstop bus runs.

2. Freeway-level stops are not generally cost-effective when the additional construction costs are assessed against actual (or potential) users.

3. Freeway-level bus stops require local bus transfers on, under, or above crossing streets. This can impede auto flow on these streets or, alternatively, require costly widening.

4. Street-level stops with priority treatments at metered on-ramps provide safer and more convenient pedestrian access. They require simpler construction because they eliminate the need for (1) acceleration-deceleration lanes, (2) special pedestrian fences, (3) stairs and escalators, and (4) additional bridge widths to accommodate bus stops at freeway level or intersecting cross streets. (Where pedestrian fences are required to preclude pedestrian crossings of main freeway lanes, a minimum two-lane width is needed to permit passing of stalled buses.)

Street-level bus stops may be appropriate as a first stage of ultimate construction of more elaborate facilities at freeway level. The latter can be incorporated in the initial design and built when warranted by actual demands. This staged development should be assessed against the added costs of constructing the stop separately as compared with making it part of the initial freeway construction.

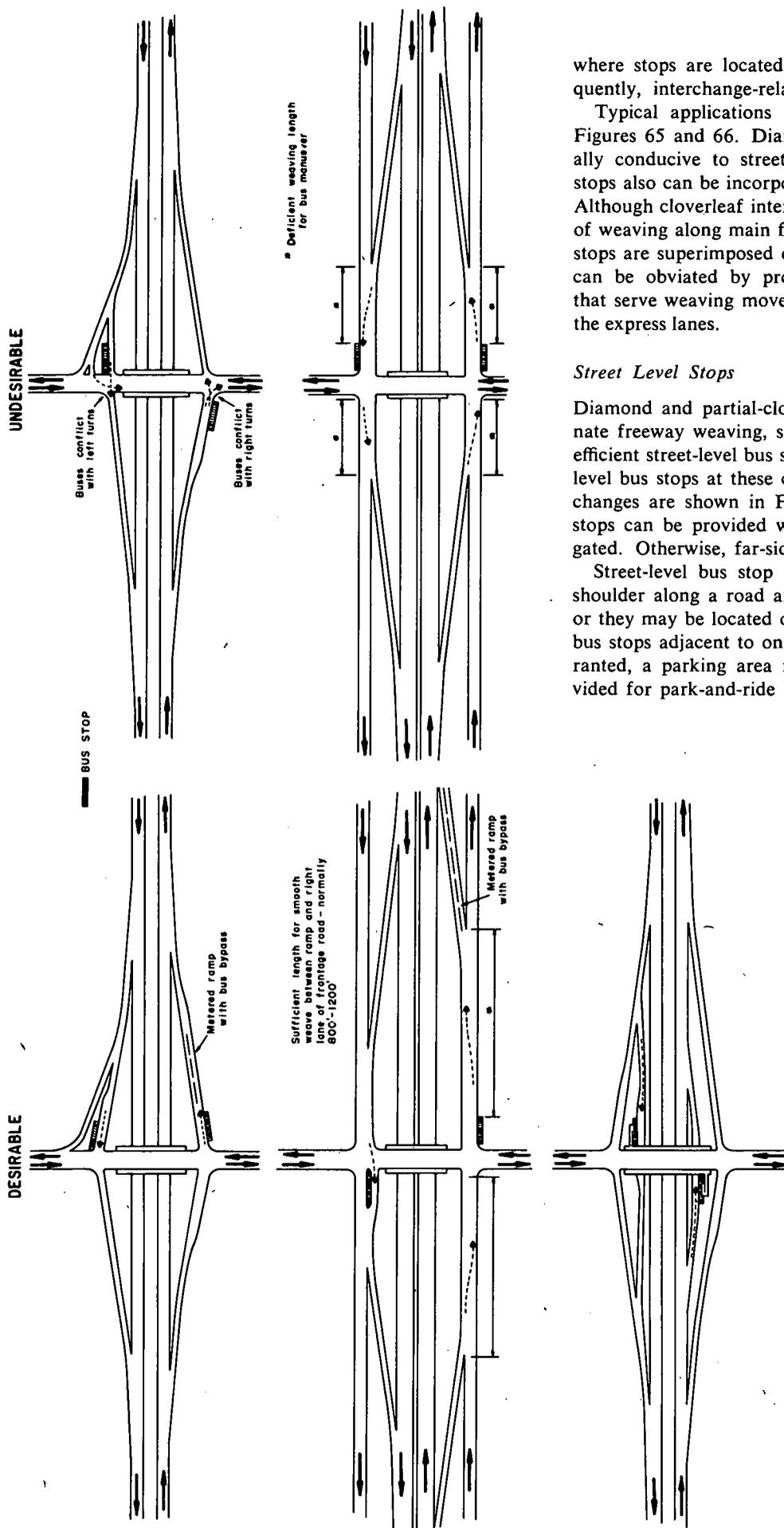
Design Guidelines

Design and placement of freeway bus stops are largely influenced by the configuration of existing interchange ramps. Freeway-related bus stops should be located to minimize conflicts between buses, general traffic, and pedestrians. The alignment of turnouts should permit bus movements into and out of loading areas without adverse effect on traffic flow and freeway safety and without discomfort to the passengers.

These objectives can be achieved by (1) removing bus stops from through travel lanes, (2) removing bus stops from weaving sections along freeways, (3) segregating bus stops from right and left turns and weaving conflicts at street level, (4) preventing direct pedestrian crossings of ramps, and (5) minimizing walking distances from bus stops to surface streets. These principles also influence the application of near- and far-side stops.

Bus stops at freeway level should be isolated from the through freeway lanes. Where a bus stop location on a freeway is not within an interchange area, adequate deceleration and acceleration lanes should be provided. Where bus stops are located at an interchange, access usually should be via ramps or collector roads, not directly to and from through lanes. (Freeway bus stops in cloverleaf interchanges are an exception.)

Bus stops should provide pedestrian access to both sides of freeways. This may call for special pedestrian crossings



where stops are located between street crossings. Consequently, interchange-related stops should be encouraged.

Typical applications of these principles are shown in Figures 65 and 66. Diamond-type interchanges are generally conducive to street-level stops; however, street-level stops also can be incorporated into cloverleaf interchanges. Although cloverleaf interchanges produce serious problems of weaving along main freeway lanes, especially where bus stops are superimposed on weaving sections, this condition can be obviated by providing collector-distributor roads that serve weaving movements and permit bus stops off of the express lanes.

Street Level Stops

Diamond and partial-cloverleaf interchange designs eliminate freeway weaving, simplify freeway design, and allow efficient street-level bus stops. Suggested designs for street-level bus stops at these cloverleaf and diamond-type interchanges are shown in Figures 67 and 68. Near-side bus stops can be provided wherever right turns can be segregated. Otherwise, far-side stops should be provided.

Street-level bus stop ramps may consist of a widened shoulder along a road area adjacent to the ramp roadway or they may be located on a separate roadway. Generally, bus stops adjacent to on-ramps are preferred. Where warranted, a parking area near the bus stop should be provided for park-and-ride and kiss-and-ride patrons.

Figure 65. Freeway bus stop concepts, diamond interchange.

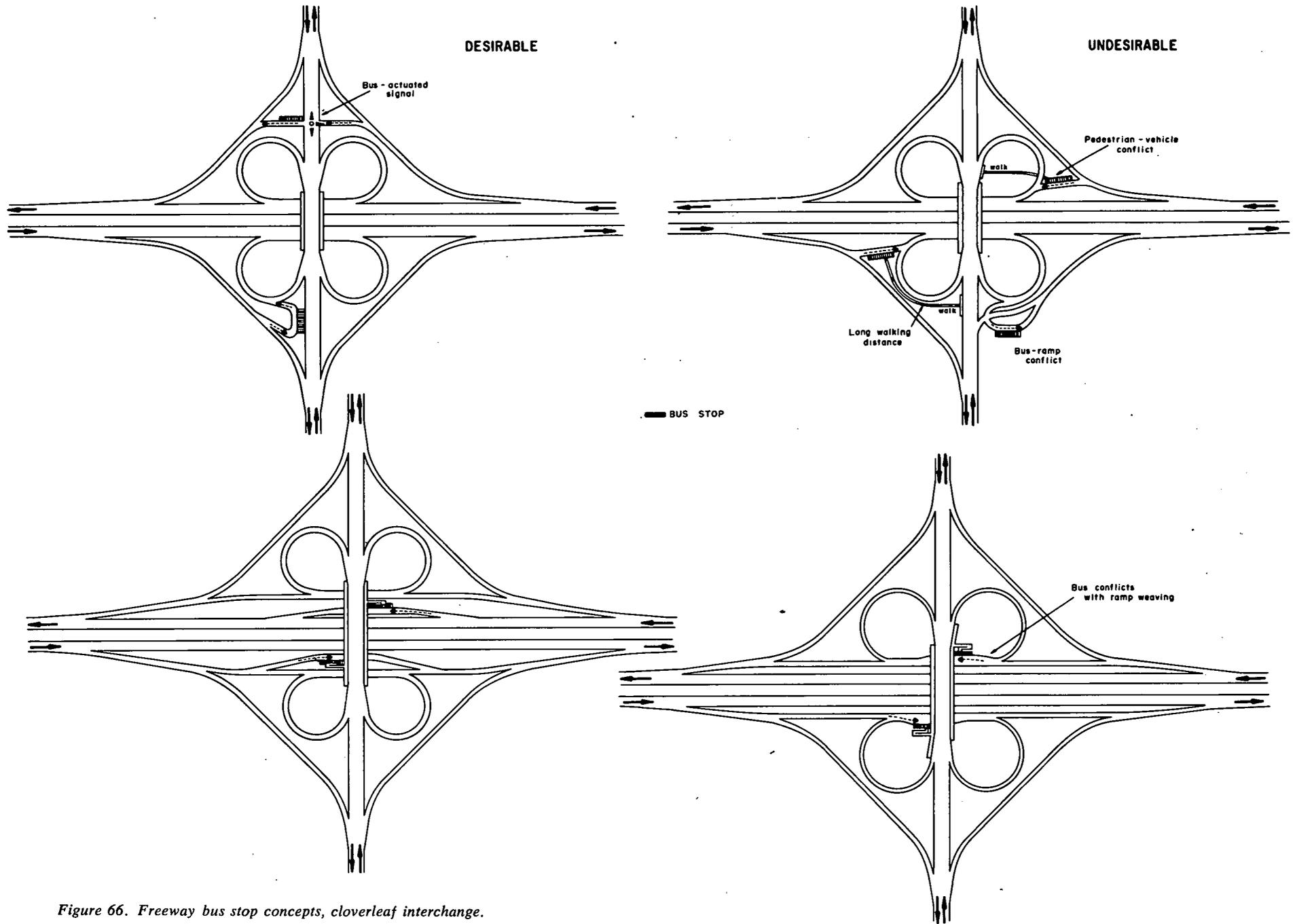
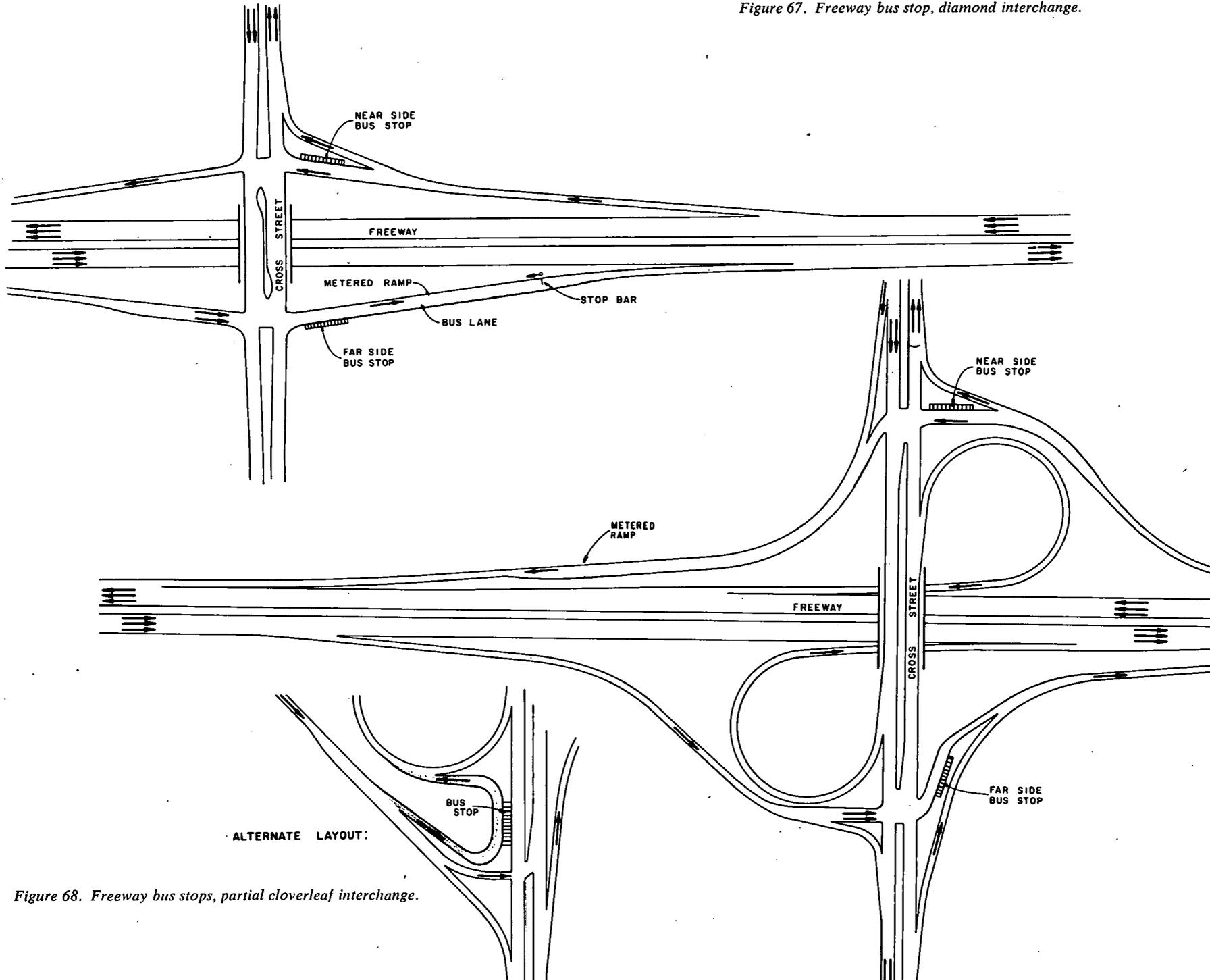


Figure 66. Freeway bus stop concepts, cloverleaf interchange.

Figure 67. Freeway bus stop, diamond interchange.



ALTERNATE LAYOUT:

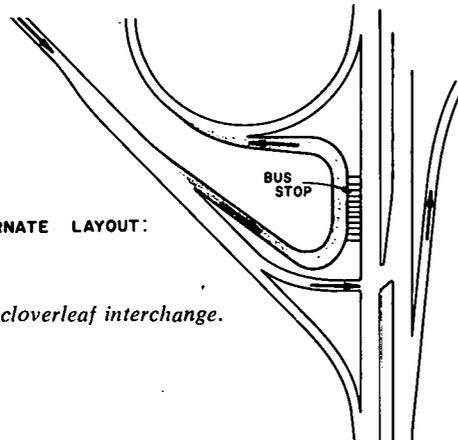


Figure 68. Freeway bus stops, partial cloverleaf interchange.

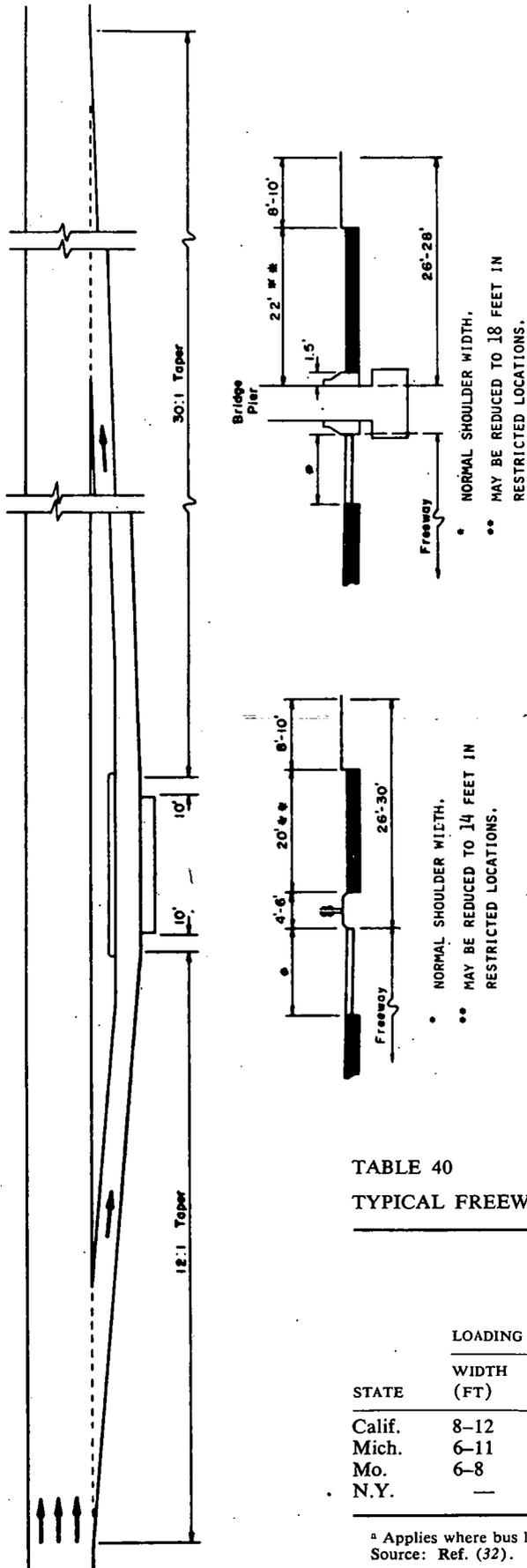


Figure 69. Bus stop on freeway level.

Freeway-Level Stops

Design details for bus stops at freeway levels, shown in Figure 69, reflect contemporary practice (Table 40). The following guidelines apply to freeway-level bus stops, both at and between interchanges:

1. Bus stops generally should be located on a separate roadway at least 20 ft wide to permit buses to pass a standing or stalled bus and to physically preclude pedestrians from entering onto the main freeway lanes. Where positive pedestrian separation is not essential, the bus lane width could be reduced to 12 ft. In all cases, overtaking capabilities should be provided to allow for schedule adjustments and vehicle breakdowns.

2. Bus stop design should be governed by busway station criteria. Platforms should be adequate for the anticipated number of buses that would load and unload simultaneously. Stops should be at least 80 ft long to allow two buses to simultaneously load and unload. Pedestrian loading islands should be at least 5 to 6 ft wide, preferably 8 ft wide. This affords a pedestrian level of service C for 25 persons on a 40-ft platform (see Ref. 31). Illumination should be consistent with that at busway stations.

3. Acceleration and deceleration lanes should be at least 100 ft long.

4. Provision should be made to keep pedestrians off the freeway lanes by fencing or other suitable means. Where pedestrians are required to cross a ramp at grade, a crosswalk should be painted and illuminated.

5. Bus shelters (including benches) visible from the roadway, and (where feasible) telephones, should be provided. In cold climates, a fully heated enclosure designed to minimize policing problems is desirable. A safe short path for pedestrians to reach the bus stop should be provided. Bus schedule and route information signs should be provided in the shelters.

6. Advance signing of bus stops is desirable to provide clear identity for approaching drivers and passengers.

TABLE 40
TYPICAL FREEWAY BUS STOP CHARACTERISTICS

STATE	LOADING PLATFORM		BUS STOP LANE			LOCATION OF BUS STOP	
	WIDTH (FT)	LENGTH (FT)	WIDTH (FT)	TAPER	SIDEWALK WIDTH (FT)	ADJACENT TO FREEWAY	ALONGSIDE RAMP AT STREET LEVEL
				LENGTH (FT)			
Calif.	8-12	70-250	12 ^a -20	75-150	5-8	X	X
Mich.	6-11	70-430	10-24	80-196	3-8	X	X
Mo.	6-8	80-150	—	—	—	X	X
N.Y.	—	50-120	—	100	5	—	X

^a Applies where bus lane is contiguous to a diamond-type ramp.
Source: Ref. (32).

APPLICATION—PLANNING AND DESIGN GUIDELINES: ARTERIAL-RELATED BUS PRIORITY TREATMENTS

This chapter contains planning and design guidelines for arterial-related bus priority treatments, including bus streets, bus lanes, traffic signal preemption, and bus stops. General planning implications are discussed first, followed by a detailed description of warrants, planning concepts, and design guidelines for each type of treatment.

GENERAL PLANNING OVERVIEW

Most urban bus services operate along city streets and converge in the city center. Even in cities with extensive freeway mileage, express bus patronage usually represents only 10 to 15 percent of the peak-hour bus travel. Buses often carry more peak-hour travelers than do automobiles on downtown streets.

Thus, bus priority treatments along arterial streets have broader applicability than freeway-related treatments, although their impacts on modal split and travel times are likely to be less dramatic, as follows:

1. Arterial priority treatments serve both local and express bus routes, whereas freeway-related treatments effectively serve only express buses carrying passengers on relatively long journeys to the CBD or other major generators.
2. Freeways in many cities bypass the city center and are often poorly located in relation to corridor travel demands. In contrast, arterial streets penetrate both the city center and tributary residential areas.
3. Arterial streets may provide downtown distribution for express bus services, especially in the interim periods until off-street bus facilities are constructed.

Bus priorities along arterial streets represent a minimum-cost approach to increasing road-use efficiency, improving bus service, and enhancing the bus transit image. They include: (1) CBD bus priority measures that benefit downtown bus services, and (2) corridor priority measures that expedite line-haul local and express movements through intermediate and outlying areas. Downtown bus priority treatments far outnumber those along corridors, mainly because bus flows are heaviest within the CBD. Corridor treatments, which remain to be more fully developed, offer excellent potential for increasing urban mobility and altering modal choice patterns.

Planning Guidelines

Bus priorities along arterial streets form a logical component of traffic management strategies that specialize street use by spatially and temporally segregating bus from car traffic. Treatments should be developed as part of a system of improvements that expedite general traffic flow and bus service. This system should (1) reduce bus and car travel times, (2) improve bus service reliability and sched-

ule adherence, (3) improve passenger safety, (4) increase bus service "visibility" (or route identity), and (5) reduce bus operating costs. Improved on-schedule operation may make it possible to provide additional bus runs without more equipment or cost.

Planning and implementation should be done as part of over-all areawide corridor (or CBD) traffic improvement programs. Principal steps include (1) inventory and reconnaissance of existing conditions, (2) identification of transit and traffic service deficiencies, (3) evaluation of alternative improvement strategies, and (4) development of a recommended improvement program based on costs, effectiveness, and ease of implementation.

Coordination of land-use patterns, street routes, bus service requirements, and bus priority treatments calls for assessing the following:

1. Street widths and curb parking controls.
2. Traffic volumes and volume-to-capacity ratios.
3. Locations of major parking facilities.
4. Locations of major stores, office buildings, and other traffic generators.
5. Bus routing patterns.
6. Passenger loading requirements along curbs.
7. Bus and car travel times and delay.
8. Pedestrian, vehicle, and bus conflicts.
9. Goods and service vehicle loading requirements.

The following planning guidelines are significant:

1. General traffic improvements and road construction should be coordinated with bus service to improve the overall efficiency of street use. Buses usually benefit from street and traffic improvements that reduce over-all delay. The range of transit-related traffic improvements includes grade separations to bypass delay points; street extensions to improve traffic distribution or provide bus routing continuity; traffic signal improvements such as system coordination, modernization, and bus preemptions or overrides; intersection channelization improvements; turn controls that exempt buses; bus turnouts for loading and unloading; bus stop lengthening or relocation; longer curb radii and corner rounding; effective enforcement and extension of curb parking regulations; improved spacing of bus stops; and bus shelters. One-way street routings can improve bus service except where (a) curb passenger loading and, hence, curb bus lane capacity cannot be reduced or (b) one of the one-way street couplet is eccentrically located in relation to principal transit destinations.

2. The prohibition of curb parking, at least during the peak hours, should be prerequisite to establishing bus lanes. This measure (a) makes an additional lane available to moving traffic, thereby substantially increasing capacity;

(b) reduces delays and marginal frictions resulting from parking maneuvers; and (c) allows buses easier access to stops.

3. Bus routes should be restructured as necessary to make full use of priority lanes and streets. Buses may be shifted from other streets to build up patronage, provided they do not exceed lane or street capacity or create passenger inconveniences. Peak-hour (one-way) bus volumes ranging from 60 to 90 will help "enforce" the bus lanes without creating excessive queuing. Other factors include:

- (a) Simple and direct bus routes should provide convenient services to major employment areas, retail stores, and community facilities.
- (b) Major thoroughfares with excess street capacity or highly unbalanced flows, and streets with relatively minor traffic flows and high bus concentrations, are conducive to bus lane and bus mall development.
- (c) It may be necessary to provide additional bus loading capacity where additional bus flows are introduced into the downtown area. Loading space often can be increased by providing median bus lanes with loading islands or contra-flow bus lanes on one-way streets. Off-street bus loading platforms or terminals may be necessary in some instances.

4. Bus priority treatments should reduce both the mean and the variance of average journey times. Because the absolute time savings may be small in many situations, emphasis should be placed on increasing service reliability. A 10 to 15 percent decrease in bus running times in bus priority areas is a desirable objective.

5. A wide application of bus lanes is necessary before schedule speeds can increase sufficiently to produce significant operating economies and/or encourage additional riding. Extended bus lanes on radial arterial streets could produce important benefits in service dependability. A saving of 1 min per mile (as by raising bus speeds from 10 to 12 mph) could produce a 4-min saving, if achieved over the entire length of a typical bus journey.

6. Bus lane and bus street installation should recognize the service needs of adjacent land uses, which often result from long-established development patterns. Many older buildings provide access for deliveries and shipments only through front entrances, a condition which may preclude development of bus streets and make implementation of peak-period bus lanes difficult. Service requirements are especially significant where contra-flow bus lanes are provided.

Deliveries should be restricted during the hours the priorities are in effect, or provided (a) from the opposite side of the street where appropriate, (b) from side streets, or (c) (ideally) in off-street loading bays.

7. Design of bus lanes should reflect available street widths and prevailing operating practices:

- (a) Bus lanes should be at least 10 ft wide except in special cases.
- (b) Signs and pavement markings should be an integral part of treatments; however, special lane signal controls are not usually necessary.

(c) Right turns by nonbus traffic can be allowed in curb bus lanes wherever it is not feasible to eliminate such turns. Right-turning cars could be allowed in the block preceding their turns, or alternatively in 250 ft before the intersection if blocks are more than 350 ft in length.

8. Bus lanes should be provided wherever possible without reducing the lanes available to through traffic in the prevailing direction of flows. This may entail eliminating parking or narrowing lanes to provide additional lanes; elimination of left-turn lanes; and/or use of reversible-lane operations.

9. Effective enforcement of bus lanes is essential. Bus lane proposals should be accompanied by active enforcement programs.

10. Emergency vehicles (police cars, fire equipment, ambulances) should be allowed to use bus lanes and bus streets. Taxis should be permitted in bus lanes wherever less than 60 buses use the lane in the peak hour.

11. The high proportion of peak-hour urban travelers using buses in downtown areas suggests increased consideration of (a) bus streets and (b) bus priorities in auto-free zones. Bus streets can provide early-action, cost-effective downtown distribution for radial busways. They can penetrate major activity areas, especially retail centers to provide (a) improved transit service, (b) larger pedestrian precincts, and (c) improved pedestrian amenities.

Application Potentials

Bus priority treatments should be provided along arterial streets when they will minimize total person-delay. This basic goal should be subject to (a) land use considerations, (b) environmental constraints, and/or (c) policy objectives to maximize transit use in specific corridors. These corollary objectives are especially important in the city center where bus flows are heavy, pedestrian movements are concentrated, street space is limited, and environmental quality is paramount. Thus, although in theory each bus lane should carry as many people in the peak hour as are carried by car in the adjacent lane, this ratio may be relaxed in specific cases. Moreover, service continuity requirements may justify treatments that do not meet specific bus volume warrants.

Traditionally, bus lanes were located on streets with the highest bus volumes. These streets often carried 60 to 100 buses (or more) in the flow direction, and their transit orientation often dated back to street railway operations. It was only natural, therefore, for bus lane warrants to reflect the number of peak-hour buses.

The Institute of Traffic Engineers warrants require 60 peak-hour buses for curb bus lanes and 75 peak-hour buses for median bus lanes. The Transport and Road Research Laboratory (Great Britain) uses criteria of 40 buses or 2,000 passengers in the peak hour (Table 41). Both criteria assume at least one bus present in each city block during the peak hour.

2. The Baltimore bus lane warrant represents a more flexible approach to arterial bus lane development. It states that "when the number of transit riders carried in one lane in a particular artery equals the number of occupants in

TABLE 41
CURRENT RESERVED BUS LANE WARRANTS

AGENCY	12 HOUR BUSES	PEAK HOUR		BUS-TO-CAR PASSENGER RATIOS
		PASSEN- GERS	BUSES	
Institute of Traffic Engineers:				
Curb transit lane	400	N.A.	60	1.5 Peak hour
Median transit lane	500	N.A.	75	1.5 Peak hour 1.0 Daily
Transport and Road Re- search Laboratory	—	2,000	40	Not cited
Baltimore	—	—	—	Same as average carried in adjacent lanes dur- ing peak hour.

Source: Ref. (1).

automobiles in an adjoining traffic lane, then the bus (or transit rider) is entitled to the exclusive use of the first lane" (33).

3. Bus lane warrants based on theoretical simulation studies carried out in France are summarized in Table 42, which gives the number of buses required to balance time losses and savings of public and private transport services when bus lanes are established. The minimum number of buses per hour depends on (1) the number of traffic lanes available, (2) their level of saturation, and (3) average bus occupancy. The simulation studies indicate a minimum of 25 to 30 buses per hour on nonsaturated roads and 40 to

60 buses on over-saturated roads, assuming 50 passengers per bus.

Contemporary practice suggests that established warrants should be broadened; there are many examples of bus lanes and bus streets that carry less than 30 buses per hour. The number of buses per hour necessary to justify arterial bus priority treatments should be influenced by planning policy as well as traffic considerations. For example, bus priority lanes on a main shopping street may be desirable to improve "transit visibility" and might be justified by a lower number of buses per hour than median bus lanes or curb bus lanes on other streets. Also, bus malls that penetrate the heart of commercial areas may be desirable for lower peak bus volumes than normally considered for justifying arterial bus lanes.

Arterial bus priority warrants should also reflect person-capacity and enforcement factors. From the standpoint of person-capacity, 20 to 30 buses per hour (800 to 1,200 seats) can accommodate more people than are usually carried in cars in an equivalent arterial street lane (600 to 700 persons per hour). From the standpoint of enforceability, bus lanes work best when there is generally a bus in view in peak periods (35). This generally calls for 40 to 60 buses per hour. At or above this volume, buses tend to preempt curb lanes when "no stopping" controls are implemented.

Suggested warrants for arterial-related bus priority treatments set forth in Table 43 reflect these factors. Specific warrants are established for (1) bus malls, (2) main street curb bus lanes, (3) other curb bus lanes, (4) median bus lanes, (5) contra-flow bus lanes, and (6) related arterial treatments. Relevant land-use and street considerations, as well as bus and passenger volume levels, are identified. Because most treatments are not capital intensive, the warrants are generally less stringent than those for busways and other freeway-related bus priority treatments.

The need, location, hours, corollary regulations, and administrative mechanisms (i.e., intensified enforcement) to make the proposed measures successful will vary among cities. The legal rights of cities to enact bus street or bus

TABLE 42
MINIMUM NUMBER OF BUSES PER HOUR
JUSTIFYING A RESERVED BUS LANE

NUMBER OF LANES FROM WHICH THE BUS-ONLY LANE IS TAKEN	A. Same Direction: Buses Replacing a Normal Traffic Lane				
	OVER-SATURATED ROAD			NONSATURATED ROAD	
	50- PASS. BUS	70- PASS. BUS	90- PASS. BUS	30- PASS. BUS	50- PASS. BUS
2	60	45	35	45	30
3	45	30	25	40	25
4	40	30	25	35	25
5	40	30	25	30	25
	B. Reserved Lane: In Same Direction Replacing Parking Lane: 15-20 buses/ hr				
	C. Reserved Lane: In Opposite Direc- tion on One-Way Streets: 15-20 buses/hr				

Source: Ref. (34).

TABLE 43
SUMMARY OF WARRANTS FOR ARTERIAL-RELATED BUS PRIORITY TREATMENTS

TYPE OF TREATMENT	PLAN- NING PERIOD (YR)	MINI- MUM DAILY BUS VOLUME	RANGE IN ONE-WAY PEAK-HOUR VOL.		STREET CHARACTERISTICS	RELATED FACTORS
			BUS	PASS.		
Bus streets	5-10	200	20-30	800-1,200		Commercial frontage. Part of CBD plan. Available alternative traffic routes.
CBD curb bus lanes, main street	1-5	200	20-30	800-1,200		Commercial frontage.
Curb bus lanes	1-5	300	30-40	1,200-1,600	At least 2 lanes available for other traffic in same direction.	
Median bus lanes	1-5	600	60-90	2,400-3,600	At least 2 lanes available for other traffic in same direction. Ability to separate vehicular turn conflicts from buses.	
Contra-flow bus lanes, short segments	1-5	200	20-30	800-1,200		Essential part of bus routing pattern necessary to serve generators or reduce bus miles.
Contra-flow bus lanes, extended	1-5	400	40-60	1,600-2,400	At least 2 lanes available for other traffic in opposite direction. Signal spacing greater than 500-ft intervals.	Ability to provide service.
Bus preemption of traffic signals	1-5	100	10-15	400-600	Where not constrained by pedestrian clearance or signal network requirements.	
Special bus signal and bus-actuated signal phases	1-5	50	5-10	200-400	Bus lanes at access points to busways or terminals; or where special bus turning movements must be accommodated.	
Special bus turn provisions	1-5	50	5-10	200-400	Wherever vehicular turn provisions are located along bus routes.	
Bus turnouts	1-5	100	10-15	400-600	Points of major passenger loadings on streets with more than 500 peak-hour autos using curb lanes.	
Bus shelters	1-5	—	—	—		100 or more boarding and/or transferring passengers per day and/or daily person waiting time is at least 1,000 min.

lane legislation will also have important bearing on implementation feasibility. Full official and public support is essential. For these reasons, the suggested warrants must be construed as broad-gauged guides in developing specific urban needs.

BUS STREETS AND AUTO-FREE ZONES

Bus streets represent a major commitment to downtown transit and development. They fully separate bus and car traffic, increase bus service reliability, enhance bus identity, and provide downtown distribution for regional express

routes. They enhance pedestrian access, and, when accompanied by amenities, can improve the downtown environment.

In the United States—and to some extent in Europe—bus streets and auto-free zones are motivated by environmental planning considerations rather than by bus flow requirements alone. The two best-known American examples are Nicollet Mall in downtown Minneapolis, and the 63rd and Halsted bus streets in Englewood (Chicago). Additional CBD bus streets have been proposed for Atlanta, Dallas, Hartford, St. Louis, and Vancouver. Short sections

of bus streets are found in several English cities, including Chatham, London, Newcastle-on-Tyne, Oxford, Rugby, Sunderland, and Tynemouth. Bus streets are also found in Helsinki, Liege, Madrid, Rome, and Stockholm.

Applicability

Bus streets provide an early-action cost-effective downtown option for distribution to busways, freeways, bridges, tunnels, and transportation centers. They may be warranted where high bus volumes traverse narrow streets as part of downtown redevelopment proposals. They may include the last block of an arterial street, a dead-end street at the end of several bus routes, a "bus loop" necessary to change directions at a major bus terminal, a downtown bus mall, and bus circulation through an auto-free bus zone. Four typical applications are shown in Figure 70. Included are:

1. Terminal approach. Exclusive bus access can be provided adjacent to a downtown bus terminal and/or on links connecting the terminal to express highways or busways.

2. Bus loop. A series of bus-only streets forming a loop may be appropriate where streets terminate and extended bus layovers are required.

3. Short connector links. Short sections of bus-only roadways may be desirable to achieve direct service where street continuity is limited and bus service over arterial streets is circuitous and slow.

4. Bus-pedestrian mall. Downtown bus streets (or bus malls)—as incorporated in urban redevelopment projects—provide direct bus access to major generators. They are designed to simultaneously improve pedestrian amenity and bus access. Bus malls could operate throughout the day or be limited to peak hours (i.e., full time versus part time). Taxis and, during off-peak periods, service vehicles can use bus streets.

5. Auto-free zone. The elimination of automobiles from major portions of downtown areas is becoming common in European cities with narrow, discontinuous, highly convergent street patterns. Buses are allowed to traverse the auto-free precincts to maintain route continuity and serve major activities. Removal of cars helps to increase bus speeds.

Reserving streets for public transport can improve bus service. However, care must be taken to select streets that provide maximum advantage to public transport without excessively hindering other traffic and access to adjacent premises.

Generally, bus streets should serve major concentrations of bus flow resulting from the convergence of individual lines onto a single street. They should penetrate the heart of the city center, providing priority access to major activity concentrations. They should represent logical extensions of bus lanes on approaching arterials or freeways and they should be integrally tied to pedestrian mall development.

The general conditions conducive to pedestrian mall development also apply to bus malls. There is need to provide reasonable access to shops and offices, allow essential delivery and emergency services, and accommodate dis-

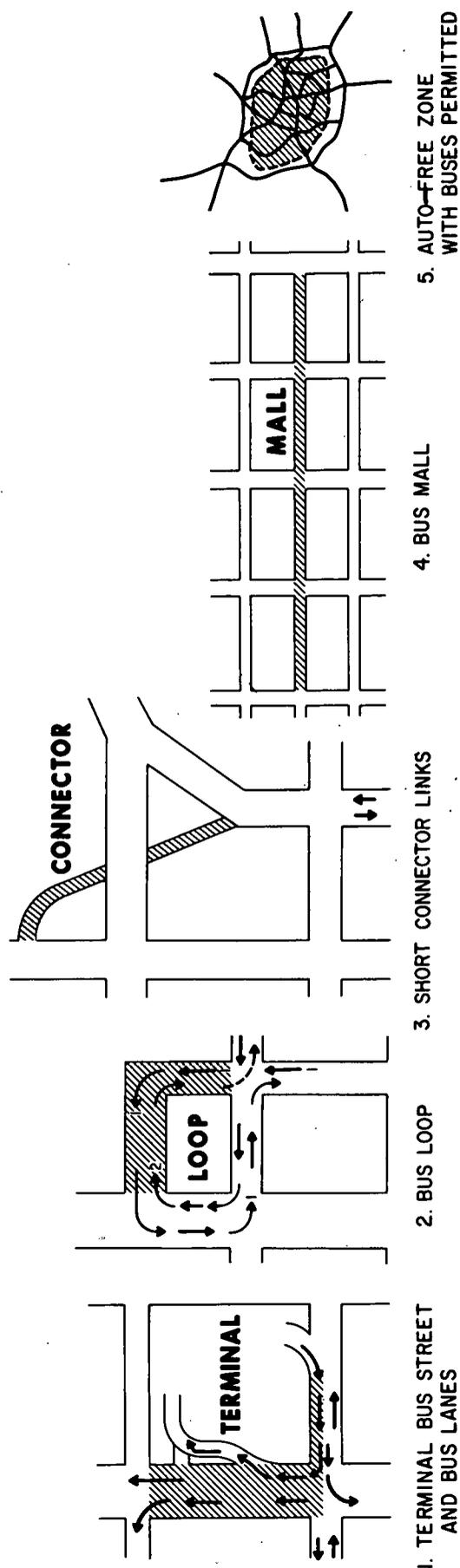


Figure 70. Bus street concepts.

placed automobile traffic on parallel streets. Factors to be considered include:

1. Bus streets should penetrate major retail and office centers. The objectives are to (a) maintain transit service, (b) provide increased areas for pedestrians (i.e., 24-ft-wide bus streets), and (c) improve pedestrian amenity in other ways (benches, shrubs, flowers).
2. At least 200 buses should use the bus street daily in each direction of travel.
3. A minimum of 20 to 30 buses and/or 800 to 1,200 people should use the bus street in each direction during the peak hour.
4. Parallel traffic routes should be available to which displaced car traffic can be diverted. These routes should provide movement continuity around the traffic-free area. Reserve capacity, although desirable, may not always be possible to provide.
5. Service and access to adjacent properties must be maintained. This involves (a) access via alleys or parallel streets and/or (b) street access via the bus mall during off-peak periods.
6. There should be no major parking garages located along the bus street; the presence of these garages makes exclusive bus use difficult.

There are many opportunities for downtown bus streets, provided necessary emergency services and goods movement services are maintained. Often, however, vehicular access requirements of the downtown street (street capaci-

ties, internal circulation requirements, and locations of off-street parking) may limit or preclude designation of downtown "transit-only" streets.

The nature, extent, and durations of bus streets should be adjusted to allow for essential services. One variant might be to allow local car access in bus lanes, but prohibit through traffic (as in Johannesburg, South Africa). Alternatively, midblock access bays could be provided for off-peak goods delivery.

Design and Operating Features

Bus street design should provide sufficient capacity for moving buses, passing stalled vehicles, and loading passengers. Designs should also allow for emergency vehicle use and, where permitted, taxis and service vehicles. Service vehicles may use bus streets during night hours, and during off-peak hours where suitable alternate service facilities are unavailable. Typical examples of bus-street design and lane configuration are shown in Figures 71 and 72.

Lane Requirements

The number of bus lanes should depend on the level of present and anticipated peak-hour demand, as follows:

1. High bus volumes. Where unusually heavy bus volumes exist (more than 100 each way in the peak hour), as along State Street in Chicago and Market Street in Philadelphia, buses should occupy the entire street, using median and curb bus lanes in each direction. Median pedestrian islands should extend the entire length of the bus lane or, alternatively, they could be staggered to allow wider loading areas.
2. Intermediate bus volumes. In most cases, peak bus flows can be accommodated in a single lane each way. This permits expansion of sidewalks and narrowing of roadway in conjunction with over-all downtown development objectives. The widened sidewalks afford greater pedestrian amenity by reducing sidewalk congestion and by incorporating street furniture, landscaping, sidewalk vendors, and outdoor cafes. All bus loading and unloading would take place along the curbs. Where bus volumes exceed 60 per hour, a third lane should be provided to facilitate passing. This greater width should also be provided where midday servicing of buildings takes place directly from the bus street.
3. Low bus volumes. Taxis should be permitted to use bus streets where peak one-way bus volumes are less than 60 per hour.

Roadway Width

Bus streets generally should provide two-way routing to assure passenger loading and unloading on the same street, and to utilize available curb capacity. A minimum 22-ft-wide roadway should be provided, allowing buses to pass stalled vehicles in the opposite lanes. Greater widths may be appropriate to accommodate heavier bus volumes, mid-day service requirements, and taxis.

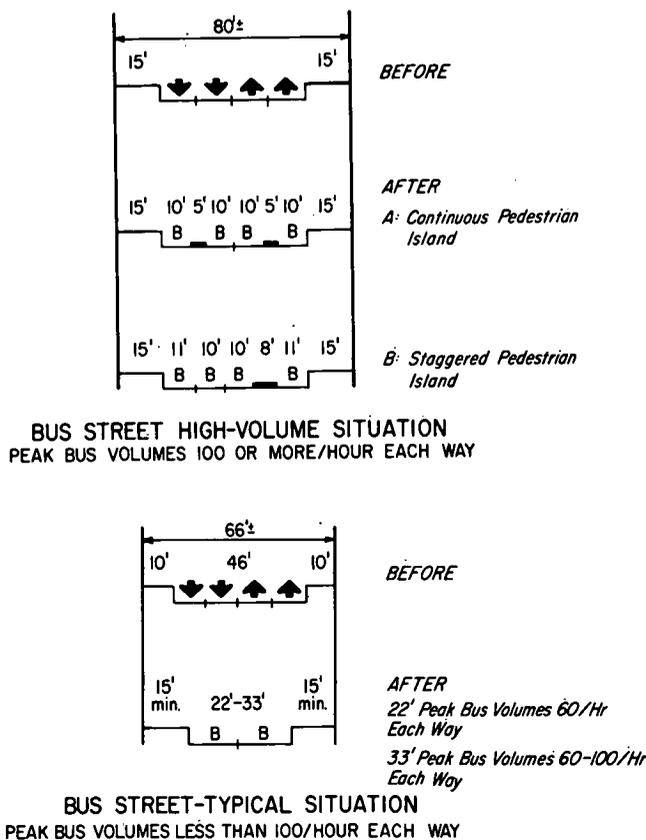


Figure 71. Downtown bus street concepts.

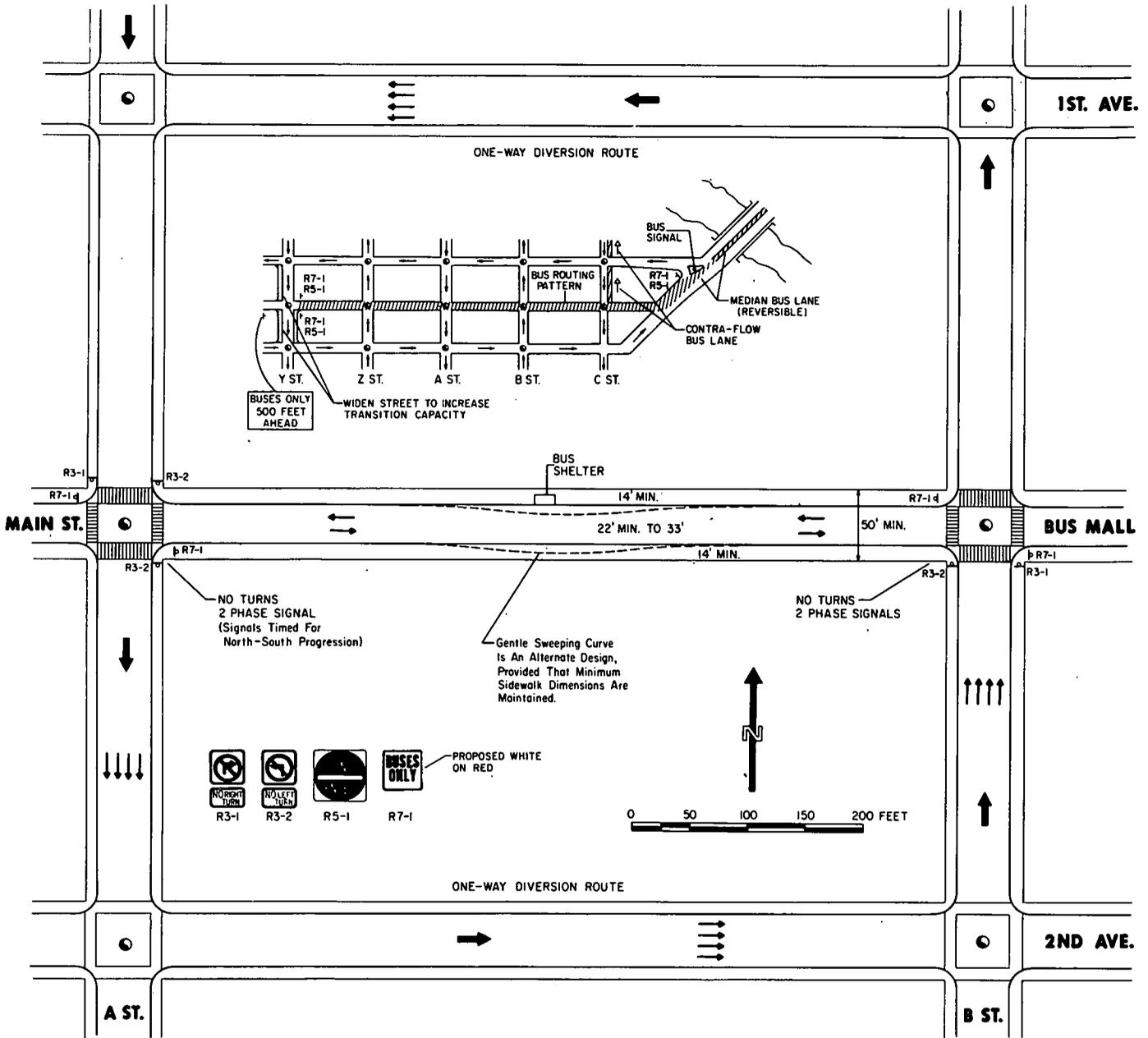


Figure 72. Bus street design concept.

Sidewalk Width

Sidewalks should be at least 15 ft wide wherever possible. Gradually “meandering” bus roadways (such as Nicollet Mall) should still maintain this sidewalk width. Bus movements may be defined by special textured pavement as an alternate to curbing.

Transition Treatments

Terminal points should take advantage of natural changes in street configuration. The diversion of auto traffic to parallel streets should be direct, preferably by means of right turns. Additional width may be necessary on streets where transitions take place to accommodate the additional

traffic volumes. Contra-flow, median, and/or curb bus lanes may be used to facilitate bus entry and exit.

Traffic Controls

Traffic capacities of parallel streets should be increased to accommodate displaced traffic. This may entail additional one-way routings as well as further restriction of curb parking.

Turns off of the bus street by buses, taxis, and service vehicles should be prohibited in the core area. This will permit conflict-free pedestrian crossings at intersections, and two-phase signal operations.

Traffic signals may be timed to optimize cross-street

progression. They can also incorporate bus preemption features.

Ancillary Features

Planting, kiosks, bus shelters, and waiting areas should be located along the bus street. Consideration should be given to eliminating surface parking lots, especially where they can be served from other streets. "Temporary" retail stores may be located on bus streets (such as found in Toronto and New Haven) to maintain pedestrian continuity.

BUS LANES

Bus lanes are a common form of priority treatment. These lanes are used exclusively by buses or shared with taxis and right-turning vehicles. They are located along curbs or in street medians, and they operate with or counter to automobile traffic flow. They generally involve removing a travel lane from automobile use and giving it over to bus use.

Bus lanes are sometimes implemented in conjunction with one-way street routings and curb parking prohibitions. In these cases, there is usually no net loss in street capacity. In other cases, buses normally dominate the lanes used and the designation of bus priority lanes causes no appreciable change in automobile capacity.

The ability to redistribute auto traffic to adjacent lanes or streets is an important prerequisite. Equally significant is the need to maintain services and deliveries to adjacent land use. The benefits from bus lanes should outweigh the problems of curb lane availability and enforcement, added traffic in remaining lanes, longer travel distances where turn restrictions are imposed, and changes in delivery schedules for services to adjacent land uses.

Bus lanes should serve major concentrations of buses in areas of frequent bus congestion. Consequently, most bus lane opportunities will be found in the central business district and its radial approaches where bus routes converge and where speeds are usually less than 10 mph.

Although bus lanes along radial arterial streets will have principal applicability in larger metropolitan areas, CBD bus lanes can be applied in almost every city wherever bus routes converge on one or two streets and passenger loading and unloading concentrate in a small area. Dwell times may be more important than volumes, because buses may require 30 to 60 sec for unloading and loading at CBD stops. As a matter of policy, therefore, the curb lanes of one or two blocks of a medium-sized city (50,000 to 150,000 persons in central city; 100,000 to 300,000 metropolitan population) could be designated as bus lanes regardless of bus volumes.

Lane Delineation and Controls

Bus lanes should be clearly delineated from other traffic lanes by either physical separation or painted lines. Painted lines have low installation costs, are easy to install, do not affect water drainage and snow removal, can be readily modified, and allow bus access around parked or stalled vehicles. They are, however, difficult to enforce and could achieve a high incidence of illegal use.

Traffic islands facilitate enforcement and provide better pedestrian refuge. However, they increase installation costs, may affect drainage, and make snow removal difficult. Mountable curbs can partially alleviate blockage where vehicles are stalled and can be used to advantage to separate median and contra-flow bus lanes.

Precast concrete channel blocks represent a rational compromise where problems of snow removal are not critical (3).

Traffic control standards specified in the Manual of Uniform Traffic Control Devices (37, and similar publications for countries outside the United States) can be applied to bus lanes. The following additional controls should be provided:

1. Pavement markings. Bus lanes should be clearly delineated from other traffic, as shown in Figure 73. Normal-flow curb bus lanes should be separated by a white line 8 to 12 in. wide. Median bus lanes should be separated from traffic in the same direction by solid white lines and from traffic in the opposite direction by a double 6-in. yellow line. Contra-flow bus lanes should be separated from traffic in the opposite direction by a double 6-in. yellow line or by mountable median dividers.

Eight-foot-high messages reading **BUS ONLY** or **BUS LANE** should be delineated at least once in each block, and twice where blocks exceed 300 ft in length. A large **B** could be placed in the bus lane as an alternate to the messages.

2. Signs. Special post- or mast-arm-mounted **BUS ONLY** or **BUS LANE** signs should be installed in each block. Where blocks exceed 300 ft in length, a second sign should be installed. Signs should be mounted over the bus lanes where possible.

Bus lane signs should be standardized. Suggested approaches to standard signs of this type are shown in Figure 74. White lettering should be used on a red (or coral) background. Messages should be as brief as possible to convey essential information. Redundant wording should be eliminated to allow highly visible 36 x 42-in. or 30 x 36-in. signs. Where clearance is restricted, 24-in.-wide signs could be used. "Bus only" information should be emphasized. Primary messages should use a minimum 6-in. letter height; secondary messages should not be more than $\frac{2}{3}$ of the size of the primary message, but never less than 4 in. Symbols should form an integral part of the sign, in general accord with the trend toward graphic signs. The symbol **B**, or some other simple logo, is preferable to depicting an entire bus. An inverted trapezoid provides a sign shape that might be adopted.

Illuminated bus lane signs and/or special bus lane control signals are optional. Cost considerations, however, will generally limit or preclude their installation.

Curb Bus Lanes, Normal Direction of Flow

Curb bus lanes in the normal direction of flow are, and will probably remain, the most ubiquitous bus lane treatment. They are found in more than 20 cities in the United States and Canada, and in a number of European cities—Baltimore, New York City, San Francisco, and Washing-

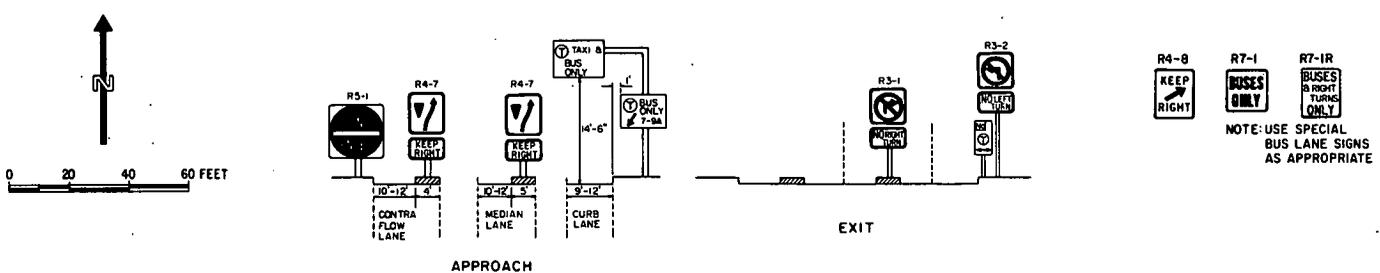
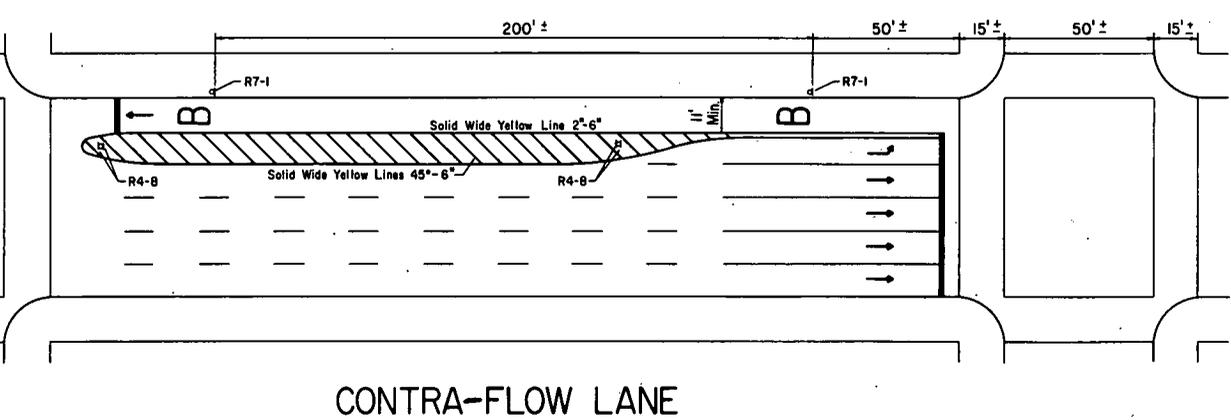
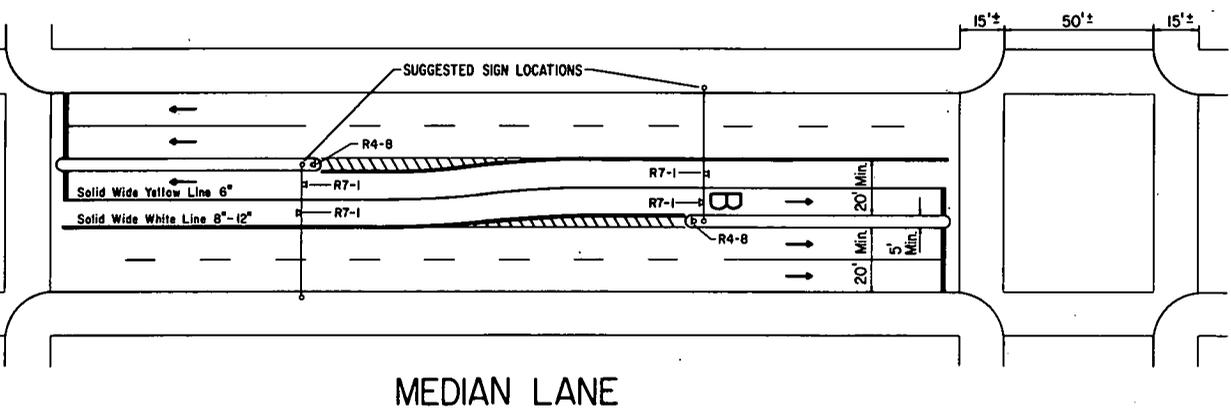
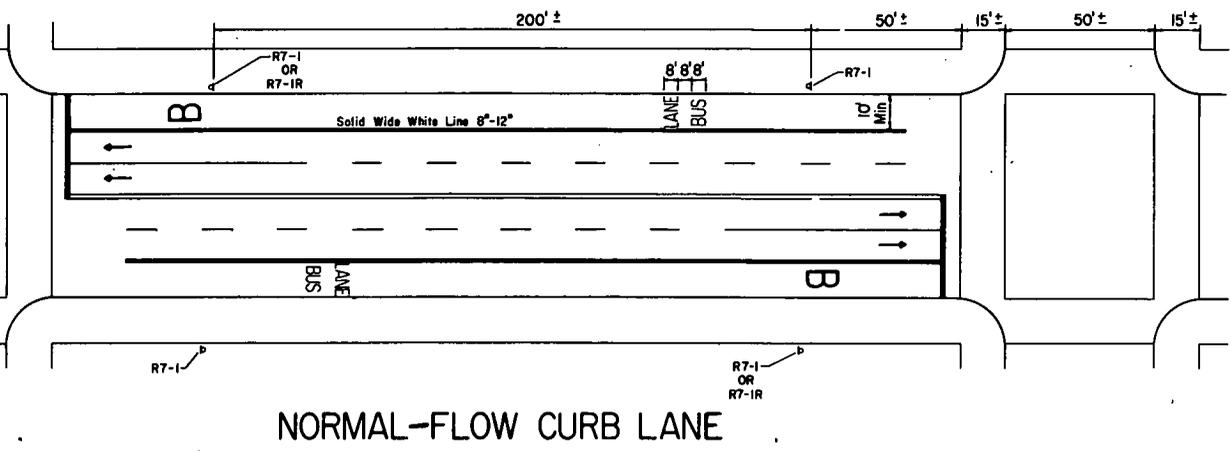


Figure 73. Typical bus lane markings and signs.

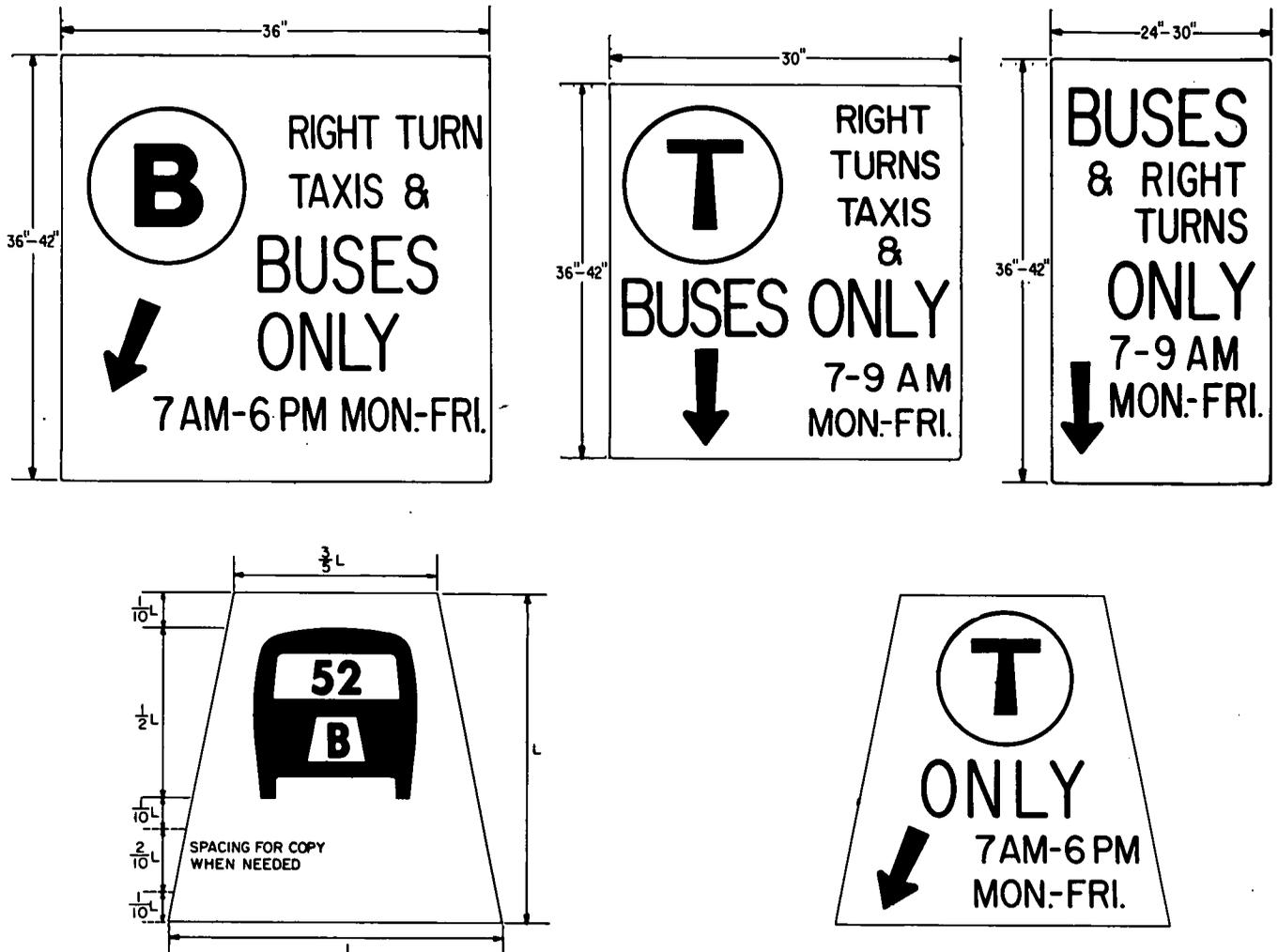


Figure 74. Typical bus lane signs.

ton in the United States and London, Madrid, Milan, and Paris in Europe have extensive installations. They are easy to implement and involve minimum street routing changes at little cost. However, they are often difficult to enforce and may produce only marginal benefits to bus flow. In several European cities, taxis use the lanes and represent the dominant vehicle flow.

Applicability

Curb bus lanes should be installed whenever the following general conditions apply:

1. There is no parking or standing along the curbs during hours that the bus lane is in effect.
2. The bus lane does not reduce peak-hour, peak-direction traffic capacity, except where such reductions are an integral part of regional transportation policy objectives. Where the bus lane preempts a lane used by automobiles, sufficient capacity should be provided in remaining lanes or on parallel streets to accommodate displaced traffic. Where curbside parking is prohibited for the first time and the parking lane is allocated to bus use, there is no reduction in street capacity.

3. There are at least two other moving lanes for general traffic in the same direction. This criterion could be relaxed on two-way, four-lane streets where left turns are prohibited during peak hours.

4. Curb access of service and vehicles to abutting property can be reasonably prohibited during the periods of bus lane operation. It should be possible to provide building services (loading, unloading, maintenance) from the rear of a building and/or during off-peak hours.

5. The number of existing and potential peak-hour bus passengers equals the average number of passengers carried by car in the adjacent lanes. This value could be reduced to 80 percent in the CBD, because downtown curb lane efficiency is less than that in other lanes because of marginal frictions.

6. There are at least 30 to 40 buses and 1,200 to 1,600 people one way in the peak hour. Where lanes are in effect all day, there should be at least 300 buses. But flow rates should approach 60 buses per hour during the busiest 20-min period.

7. Where bus lanes traverse the principal shopping street, the required number of buses can be reduced. In these cases, there should be at least 20 to 30 buses one way in

the peak hour. Where lanes are in effect all day, there should be at least 200 buses.

Design and Operating Features

Typical examples of curb bus lane arrangements, design, and operations are shown in Figures 75, 76 and 77. Design standards and practices should be consistent with those normally employed in the urban area. An attempt should be made to maximize the number of moving traffic lanes, rather than providing optimum lane widths. Other factors to be considered include:

1. Hours of operation. Lanes may be reserved for buses throughout the day, or during peak hours only. Lanes may be maintained during off-peak periods where (a) off-peak bus volumes exceed the minimum hourly warrant and (b) the transit identity of the street is to be emphasized.

2. Length. Bus lane length should depend on street, bus routing, and congestion patterns. The length of a lane increases its utility, but short lanes can be useful where (a) extensive time savings are anticipated, (b) access to a terminal is improved, and (c) buses can effect a movement forbidden to other vehicles.

3. Width. Bus lanes should be at least 10 ft wide (Fig. 75). In special cases, however, 9-ft lanes could be used. Lanes may have to be widened along curves to accommodate bus turns.

4. Street utilization. Bus lanes should be provided without reducing through vehicle capacity in the heavy traffic direction wherever possible. This may entail prohibiting left turns along two-way arterial streets.

Bus lanes could be incorporated in reversible-lane operation plans. Thus, on six-lane streets four lanes could be designated in the heavy travel direction, with the curb lane giving priority to buses; a similar arrangement could apply on five-lane streets (Fig. 76). During off-peak periods, when bus lanes are inoperative, curb parking could be permitted and normal flow resumed. (In this context, arterial curb bus lanes proposed in St. Louis in 1955 (38) called for (a) use of two reversible center lanes on six-lane streets for inbound morning and outbound evening traffic flow; (b) exclusive use by buses and right-turning cars of a curb

lane in the flow direction during morning and evening peak hours on three major transit routes; (c) closing of "feed in" streets during rush hours on the flow side only; and (d) at certain signal-controlled intersections, 10-ft curb setbacks for a distance of 150 ft ahead of intersections to provide storage for right-turning vehicles, eliminating use of the reserved transit lane for right turns.)

5. Lane use. Lanes should be used by buses, emergency vehicles, and, where conditions permit, right-turning vehicles. Taxis may use the lanes where peak volumes are under 60 buses per hour.

6. Right turns by general traffic. Turning movements by other vehicles should not impede bus lane operation. Right turns by vehicles other than buses may be provided to the extent necessary for traffic circulation. The prohibition of right turns improves the efficiency of bus operations, especially where pedestrian crossings are heavy. Right turns should be prohibited where pedestrian crosswalk volumes exceed 300 persons per hour and where movements can be diverted to parallel streets before the start of the bus lane or where they can be replaced by three left turns, as is possible in one-way street networks. Where right turns are permitted, the vehicles should be allowed to enter the bus lane about 250 ft on the approach to the intersection (Fig. 77). It may be necessary to use traffic signals to segregate bus movements from right-turning traffic.

7. Left turns by general traffic. It may be necessary to prohibit left turns on two-way streets to increase lane efficiency.

8. Bus operations. No buses should leave the bus lane except to make a turn or in an emergency to pass a stalled vehicle. Far-side or midblock bus stops would permit the bus lane to be used for right turns.

9. Left turns by buses. Left turns by buses should be accomplished by means of buses weaving from curb to median lanes. Under special circumstances special signal controls can be provided similar to those used in Wiesbaden, Germany (1, p. 316).

10. Traffic controls. Bus lanes should be delineated by solid white lines and pavement markings as previously described.

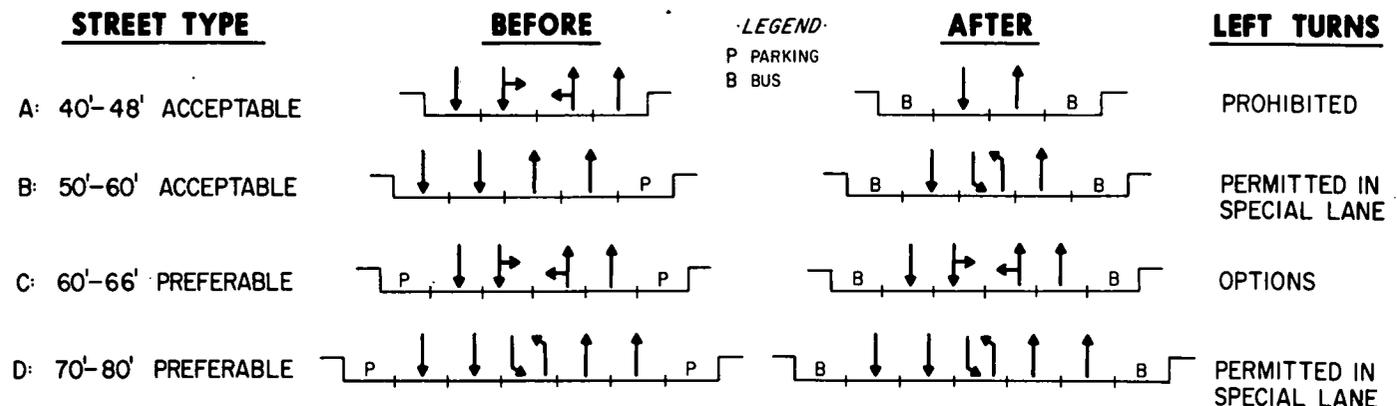


Figure 75. Typical curb bus lane configurations on two-way streets.

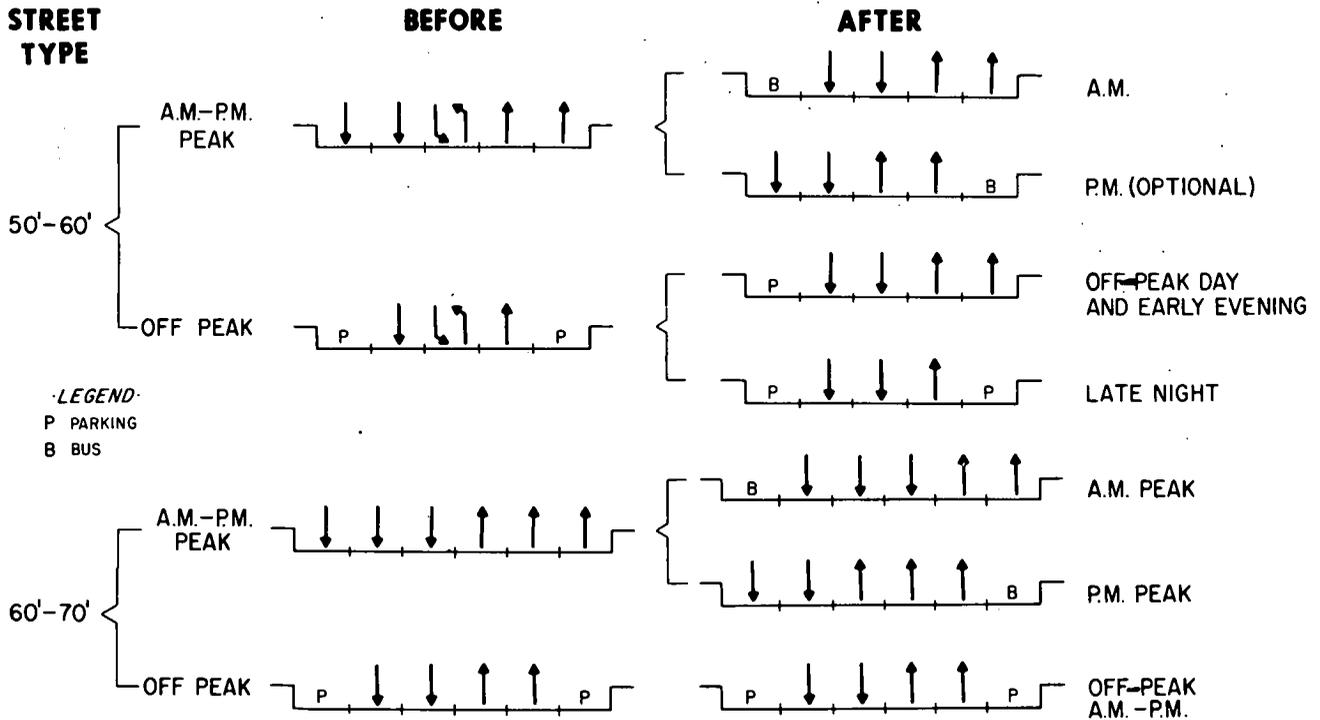


Figure 76. Curb bus lane options in relation to unbalanced flow on two-way streets.

Median Bus Lanes

Median bus lanes are an outgrowth of streetcar operations. Examples include Washington Street, Chicago; Market Street, Philadelphia; and Canal Street, New Orleans.

These lanes are removed from traffic conflicts along the curb, and they allow right turns to be made without conflicting with buses. However, they require wide streets with provisions for service stops and pedestrian refuge in median areas. Passengers are required to cross active traffic lanes to reach bus stops. Left turns must be prohibited or controlled to minimize interference with buses.

Median lanes are well suited for express bus service along wide multilane arterials; local bus service could remain in curb lanes. Buses in the median, operating nonstop or limited stop, could exceed peak-hour auto speeds. Where median lanes take the form of a two-directional roadway, a Class B busway at grade is created.

Applicability

Median lanes should be installed whenever the following general conditions apply:

1. The bus lanes replace street railway operation in the center of the street, and the precedent for center-of-street loading is established.
2. Curb access requirement or enforcement factors preclude exclusive bus use of curb lanes. (Chicago, for example, has no curb bus lanes in the Loop.)
3. A wide median exists and can be paved for buses without eliminating trees or otherwise impacting the environment.
4. The street is wide enough to allow at least two

general-purpose traffic lanes, or one traffic lane and one parking lane, on each side of the median lane.

5. The street is wide enough to allow for passenger loading platforms. Minimum street widths range from 50 ft for a single median lane on a one-way street to 65 ft for double median lanes on a two-way street.

6. Conflicting left turns are prohibited or channeled into lanes outside the median.

7. The number of existing and potential bus passengers at least equals the average number of passengers carried by car in the adjacent lanes throughout the 12-hr base period, or, alternatively, the periods that the lanes are in effect. Where peak-hour median lanes are provided, buses should carry 1.25 times the number of passengers carried by cars in the adjacent same-direction lanes.

8. There are a minimum of 60 to 90 peak-hour buses serving 2,400 to 3,600 people using each median lane. Where lanes operate throughout the day, they should carry 600 buses per day.

Design and Operating Features

Typical examples of median bus lane arrangement, design, and operations are shown in Figures 78 and 79. These examples assume two moving travel lanes on each side of a median bus lane; somewhat more restrictive widths could be used where the median lanes are part of an over-all street devoted to buses. Other factors to be considered are:

1. Hours of operation. Median lanes should usually be in effect throughout the day. However, part-time (i.e. peak-hour or 7:00 AM-6:00 PM) lanes could be provided.
2. Length. Bus lane length should depend on bus routing patterns. Ideally, bus routes should operate the entire

length of CBD median lanes without intermediate entry and exit.

3. Width. Bus lanes should be at least 10 ft wide for one-way operation, and 20 to 22 ft wide for two-way operations. However, 9-ft bus lanes may be used in unusually restrictive conditions.

4. Pedestrian islands. Pedestrian islands may be continuous or may alternate. Continuous islands permit the bus lane(s) to maintain a constant position in the roadway. Alternating islands provide economy of space in that they require one rather than two pedestrian areas at any given location. This treatment saves a minimum of 5 ft of width, but requires constant meandering of the bus lane(s).

- (a) Pedestrian islands should be at least 5 ft wide and 100 ft long. Under very restrictive conditions 4-ft-wide islands may be used, and the length should be 5 ft greater than that of the longest bus using the zone. Islands, where not continuous, should be located at the near side of intersections in conjunction with near-side bus stops.
- (b) Pedestrian islands may be (1) raised wood or concrete platforms or (2) painted islands protected by stanchions. Continuous raised platforms are especially desirable in conjunction with two-way bus lanes.
- (c) Pedestrian access to safety islands should be permitted at the near-side crosswalk. Where islands extend an entire block, access also may be provided from a far-side crosswalk.
- (d) Side protection of pedestrian areas may be provided by splash plates; pipe posts connected by chains or rails; stanchions; or wire-mesh fencing.

5. Lane use. Lanes should be used only by buses and emergency vehicles. On one-way streets, other vehicles may use the bus lane within an intersection or immediately after passing through the intersection for the purpose of weaving from one side of the bus lane to the other, provided (a) these maneuvers can be made without undue interference and hazard and (b) vehicles leave the bus lane as quickly as possible after completing the weaving. During hours that the bus lanes are not operative, other vehicles may be permitted to use the lanes. Buses could continue to operate in the bus lanes and make service stops at designated locations.

6. Right turns by general traffic. Right turns by general traffic may be permitted, because these movements would occur independent of the bus lanes.

7. Left turns by general traffic. Left turns may be made from the left of median bus lanes on one-way streets. Left turns should be prohibited from two-way streets during hours that lanes are in effect.

8. Bus operations. Buses should not leave bus lanes except in an emergency to pass stalled vehicles. Buses leaving bus lanes should do so one block prior to making the turn; however, left turns by buses on a two-way street should be by means of special bus-actuated signals. Buses leaving the lane should not make additional service stops on the same street.

Bus lane entry should be similar to entry into a left-turn

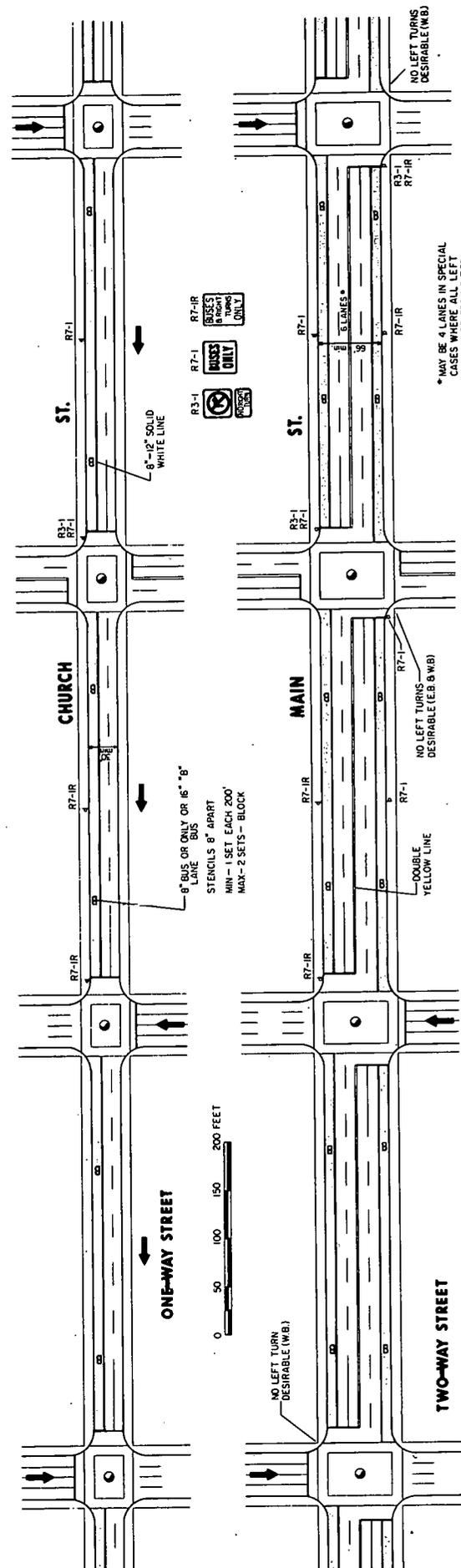
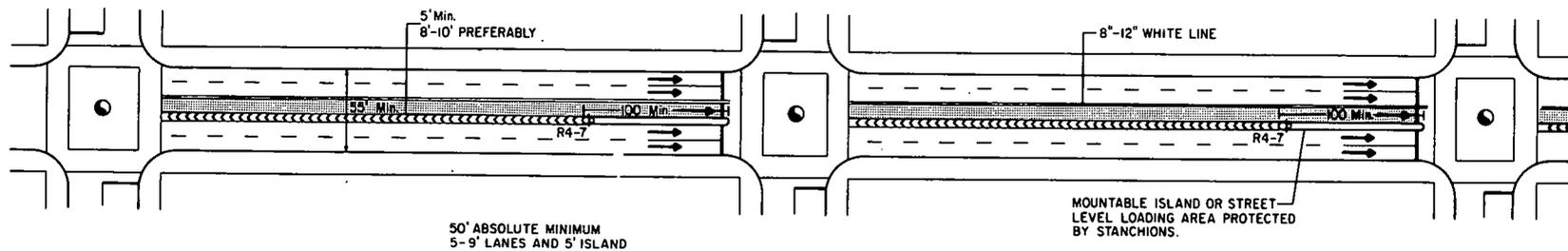
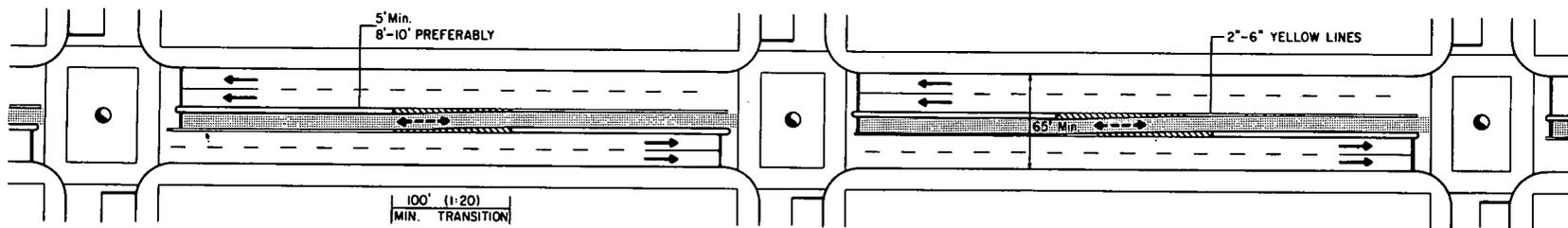


Figure 77. Curb bus lanes, normal flow.



**IA. ONE-WAY BUS LANE
ONE-WAY (OR 2 WAY) STREET**



**IB. REVERSIBLE ONE-WAY
BUS LANE TWO-WAY STREET**

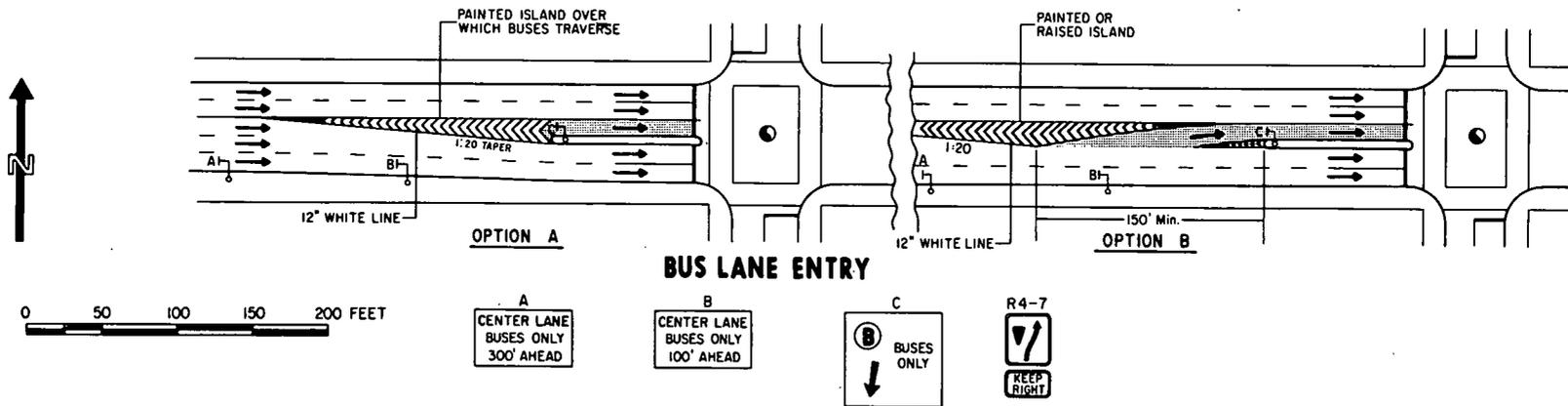
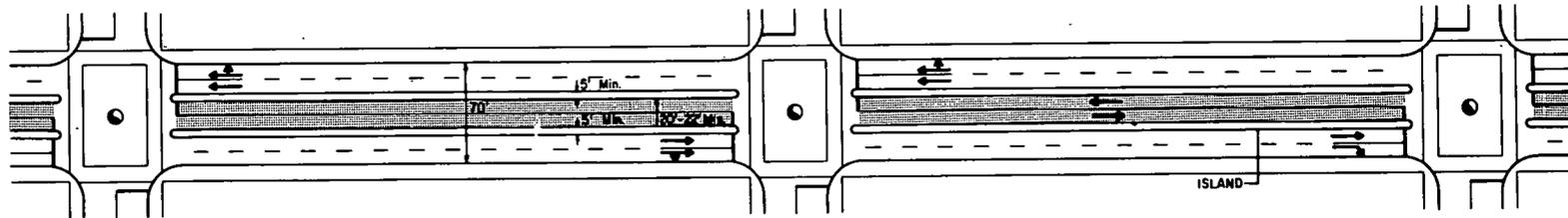
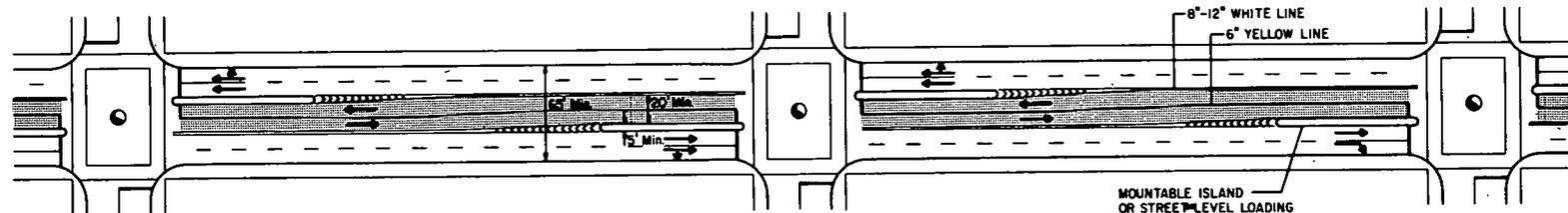


Figure 78. Typical one-way median bus lanes.



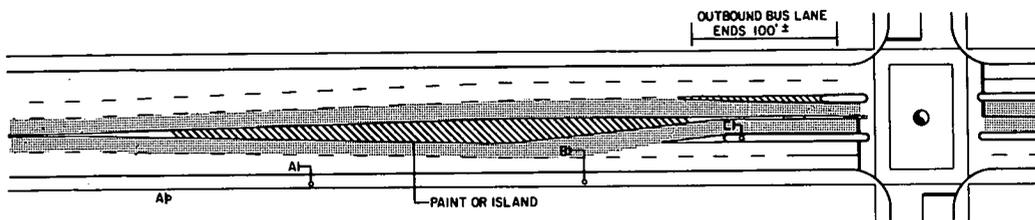
**2A. TWO-WAY BUS LANE
CONSTANT MEDIAN**



**2B. TWO-WAY BUS LANE
TWO-WAY STREET**



0 50 100 150 200 FEET



TYPICAL TRANSITION

A
CENTER LANE
BUSES ONLY
300' AHEAD

B
CENTER LANE
BUSES ONLY
100' AHEAD

C
BUSES ONLY

Figure 79. Typical two-way median bus lanes.

storage lane. Through traffic should be routed around the bus lane entry on a minimum 20:1 taper. As an alternative, the bus lane entry area could be cross hatched and buses could traverse the paint markings to enter the lanes directly.

Buses leaving the bus lane can merge directly with general traffic. Where left or right turns by major bus flows are required, special bus-actuated traffic signals should minimize conflicts with cars. Phasing should allow non-conflicting vehicle movements to occur simultaneously with bus flows.

9. Traffic controls. Bus lanes should be delineated from traffic in the same direction by 8- to 12-in. solid white lines, and from traffic in the opposite direction by double 6-in. yellow lines. A single 6-in. yellow line should separate opposing bus flows on two-way bus lanes.

Contra-Flow Bus Lanes

Contra-flow bus lanes enable buses to operate opposite to the normal traffic flow on one-way streets. They are found in Chicago, Harrisburg, Honolulu, Indianapolis, Louisville, Madison, San Antonio, and San Juan in North America; in more than ten English cities; in Marseille and Paris, France; and in Rome and Milan, Italy. The Louisville and San Juan installations, unlike most of the others, extend for considerable distances along arterial streets. The lanes are, in essence, a special application of unbalanced traffic flow to bus operations.

Buses using contra-flow lanes are separated from other traffic flows. Thus they are removed from conflicts with other vehicles and so are unaffected by peak-hour congestion (or backups) at signalized intersections. The lanes are relatively self enforcing, have high visibility, and can provide more direct bus routings, thereby reducing bus travel times and distances.

Contra-flow bus lanes can (1) retain existing bus routes when new one-way street patterns are instituted, (2) provide new service on existing one-way streets, (3) utilize available street capacity in the off-peak direction of flow, and (4) permit curb space on both sides of one-way streets to be used for passenger loading, thereby increasing bus loading capacity.

The lanes may complicate service and access to adjacent properties and they may create conflicts with left-turning traffic at intersections. Where traffic signals are closely spaced, buses would operate against the progression; otherwise, vehicle progression must be interrupted. Extended and balanced application calls for one-way street pairs.

Applicability

Contra-flow bus lanes perform the basic functions shown in Figure 80. They provide radial bus service along pairs of one-way arterial streets leading to the city center (as in San Juan, Louisville, and as what might be provided along Walnut and Chestnut Streets in Philadelphia). Street space within the corridor should be sufficient to allow bus lanes to be introduced without causing an unreasonable reduction in the level of service for other traffic.

They also provide downtown distribution for express bus

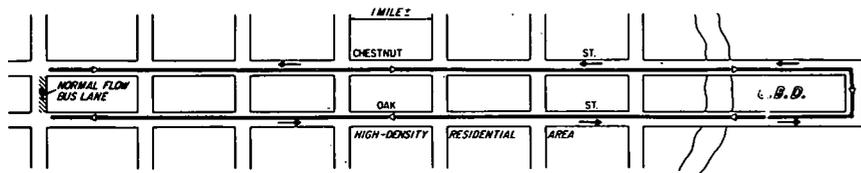
routes. Where curb loading capacity is limited, the contra-flow lanes create additional curb loading space (as proposed for the San Bernardino Busway service in downtown Los Angeles).

They likewise allow two-way bus service on one-way downtown and radial streets, especially where it is desirable to provide direct service to major passenger generators. Contra-flow operation is particularly appropriate where a wide major arterial is converted to one-way operation and paired with a narrower one-way street (as in Madison). It may be desirable (if street width permits) to have a normal-flow bus lane opposite the contra-flow lane on the same street. In this way, the advantages of one-way traffic operations (better signal progression, fewer conflicts, higher capacities) can be gained without impacting bus routings.

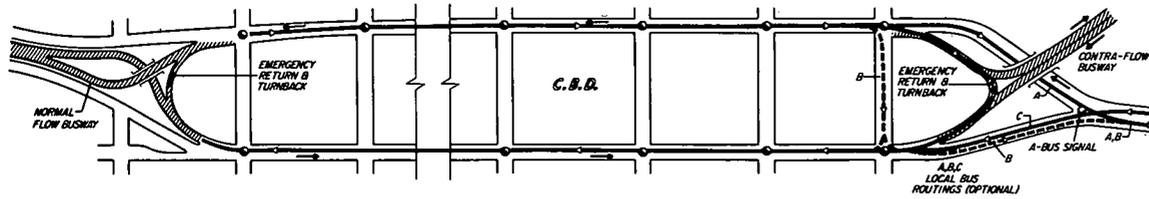
They also can provide short-circuit bus movements, on irregular or one-way street grids (as at Alamo Plaza, San Antonio), thereby reducing bus mileage.

Contra-flow bus lanes should be installed wherever the following general conditions apply:

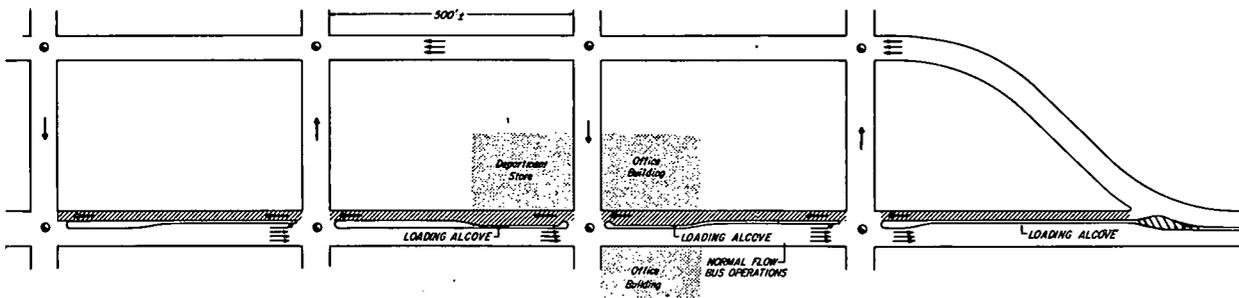
1. Curb parking and standing is prohibited during hours that bus lanes are in effect.
2. The bus lane does not reduce peak-hour, peak-direction traffic capacity, except where such reductions are an integral part of regional transportation policy objectives. (Where a bus lane preempts a lane used by automobiles, sufficient capacity should be provided in the remaining lanes or on parallel streets to accommodate the displaced traffic. Where curb parking is prohibited for the first time and the parking lane is allocated to bus use there is no reduction in street capacity. Where the downtown area is covered by a one-way grid system of sufficient capacity, the entire system will not be disrupted by establishment of contra-flow bus lanes.)
3. There are at least two lanes, preferably three, remaining for traffic in the opposite direction. An exception may be made for short segments of contra-flow bus lanes (less than two to three blocks) that provide bus turn-around facilities.
4. Traffic signals are spaced at greater than 500-ft intervals along the arterial streets affected.
5. The number of existing and potential peak-hour bus passengers in the contra-flow lane equals the average number of passengers carried by car in the remaining general traffic lanes in the same direction. This value could be reduced to 80 percent in the CBD, where curb lane efficiency is traditionally less than that in other lanes because of marginal frictions. (It would not necessarily apply to short contra-flow lane segments.)
6. There are at least 40 to 60 buses carrying 1,600 to 2,400 people one way in the peak hour. Where lanes are in effect all day, at least 400 buses should use the lanes. Bus flow rates should approach 60 buses per hour during the heaviest 20-min period.
7. A terminal turn-around area to change direction to reach a passenger transfer point, to reach a layover point, or to achieve curb loading/unloading off the main bus routes may justify contra-flow lanes of very short length (one to three blocks). Where these short segments of contra-flow bus lanes are installed there should be at least



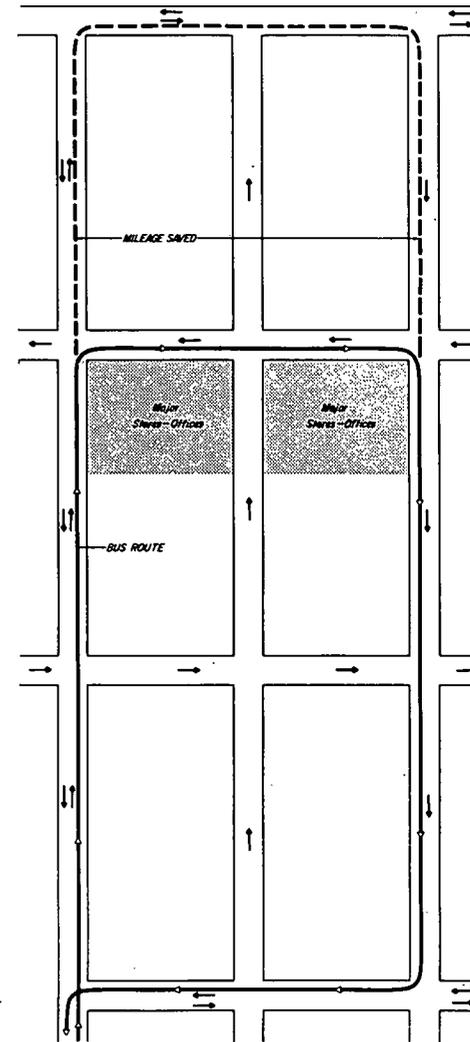
ARTERIAL CONTRA-FLOW BUS LANES



DOWNTOWN DISTRIBUTION FOR BUSWAYS



DOWNTOWN ACCESS TO MAJOR BUILDINGS AND STORES



DOWNTOWN CONTRA-FLOW LANES TO REDUCE BUS MILES

Figure 80. Contra-flow bus lane concept.

20 to 30 buses carrying 800 to 1,200 people one way in the peak hour, and at least 200 buses throughout the day.

8. Essential services and access to adjacent land uses can be maintained. Provision for necessary access to abutting properties must be worked out in advance to the satisfaction of property owners.

9. Peak-period congestion exists in the corridor to be served by contra-flow lanes.

Design and Operating Features

Typical examples of contra-flow bus lane arrangement, design, and operation are shown in Figures 81, 82, and 83. They show how paint and median islands can provide for left-turn and loading vehicles. The designs show three moving traffic lanes in the direction opposite to bus flow. Fewer traffic lanes could be provided in special cases. Other factors to be considered include:

1. Hours of operation. Contra-flow bus lanes should operate throughout the day. They can operate during peak periods only, provided curb parking is permitted in the bus lanes during off-peak hours (Louisville).
2. Length. Bus lane length should depend on bus routing patterns and street geometry. Locations where streets join or change direction may afford logical terminal points for contra-flow operations, particularly where the changes facilitate transition into and out of bus lanes.
3. Width. Bus lanes should be at least 12 ft wide, al-

though 10-ft lanes may be used where paint separation is used. General traffic lanes should be at least 10 ft wide. Contra-flow lanes could be provided on streets of 30-ft width, although 40 ft is a desirable minimum.

4. Traffic separation. Contra-flow bus lanes may be separated from the normal direction of travel by paint or physical channelization. Physical islands, may, however, pose maintenance problems where extensive snow removal is anticipated. Double solid yellow 6-in. paint lines should delineate 24-hr contra-flow lanes. Where the lanes operate part-time only, these lines can be broken. Painted pedestrian refuge islands should be complemented by stanchions and delineated by yellow diagonal markings. Physical islands should be mountable to permit buses to pass stalled vehicles. Islands should be at least 4 ft wide where they serve as pedestrian refuge or provide access for loading vehicles.

5. Lane use. Lanes should be used by buses and emergency vehicles. Taxis may be permitted in the lanes where peak bus volumes are less than 60 buses per hour.

6. Left turns by general traffic. Left turns by general traffic may be permitted where roadway and traffic conditions permit. Where it is not possible to provide special left-turn storage lanes, and where pedestrian traffic is heavy, left turns should be prohibited. Left-turn storage lanes can be incorporated in basic roadway designs.

7. Loading and curb access. Loading may be permitted during off-peak hours from bus lanes where the lanes can

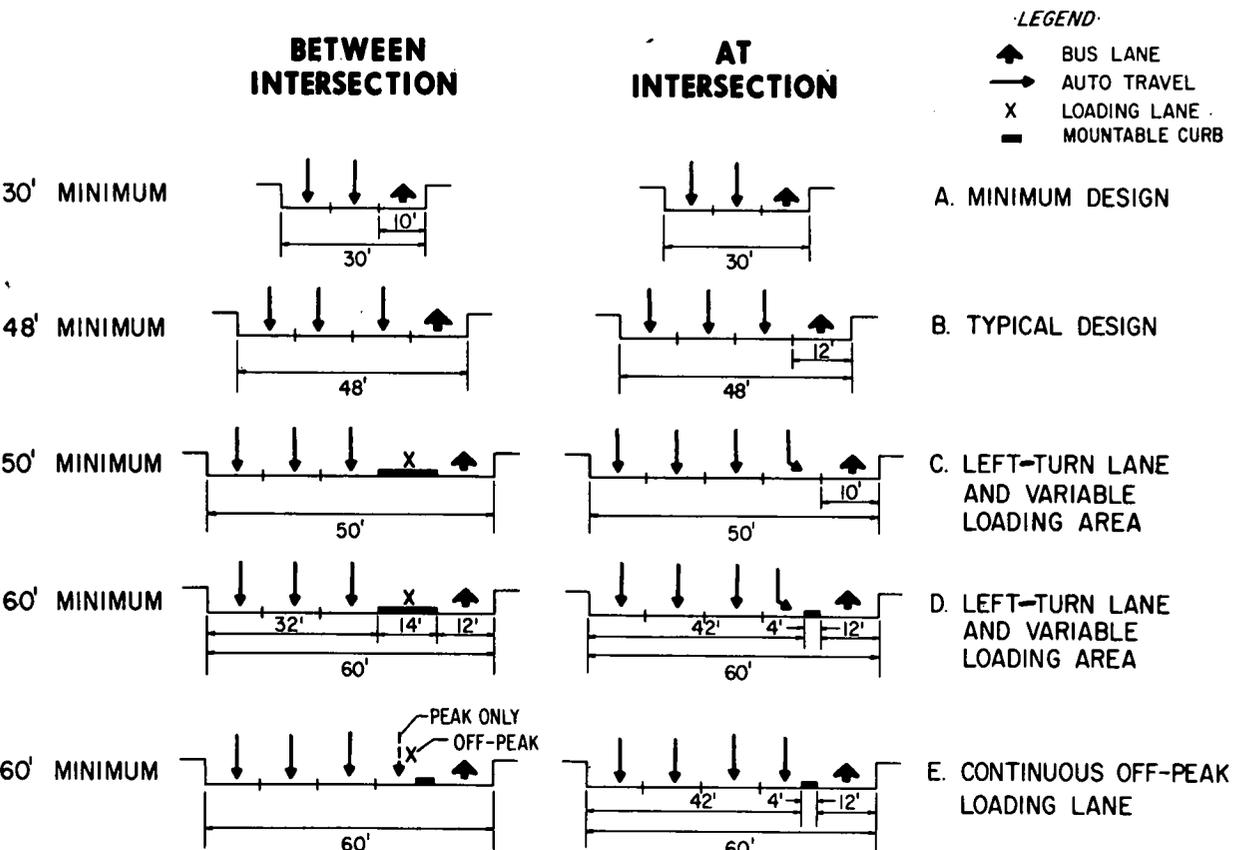


Figure 81. Contra-flow bus lane arrangements.

be widened to allow midblock passing of stopped vehicles. Loading should be done in the same direction as the bus lanes. In full-time contra-flow operations, the left lane of regular traffic flow (adjacent to the transit lane) may be used for loading/unloading service to adjacent properties when there are five or more lanes. Under these conditions a 4- to 5-ft island between the transit lane and the adjacent traffic lane may be desirable.

8. Driveway access. Access into driveways and parking facilities may be permitted across the bus lane.

9. Bus operations. Buses should not leave the bus lane except in an emergency to pass a stalled vehicle. Bus lane entry may be via turns from intersecting streets or directly from the artery on which the lane is provided. Bus lane exit may take place via right turns from the lane, or directly onto the artery where the lane terminates. Left turns by buses across general traffic should not be permitted except where special bus-preempted signals are provided. Transition treatments of general traffic at the terminal points of the bus lane should be designed similar to normal transitions from one-way to two-way traffic.

10. Traffic controls. Bus lanes should be delineated by yellow paint lines and appropriate pavement markings and signs as previously described. Standard lane-control signals, and variable-message, internally illuminated signs, although costly, may be used with part-time contra-flow lanes.

Traffic signal progression for buses may be difficult or impossible in view of (a) variable passenger loading times and (b) progression requirements for general traffic. It may, however, be possible to provide selective bus preemption of signals along arterial streets where only limited delay accrues to traffic in the opposite direction (Fig. 84a). This would compensate for travel against the "through-green band."

It may be desirable to optimize progression for buses where peak-hour person volumes carried by buses equal or exceed those carried by cars in the opposite direction and where buses operate express in the contra-flow lane (Fig. 84b). This determination should not be limited to existing conditions, but should reflect the person volumes potential to improved bus services. Relative bus and car use can be monitored, and traffic signals adjusted when conditions warrant.

BUS PRIORITIES IN MIXED TRAFFIC FLOW

Bus priority treatments in mixed traffic flow have widespread applicability. They include: (a) restriction of entry from side streets; (b) prohibition of curb parking or vehicle loading; (c) special turn provisions for buses; (d) bus actuation or preemption of traffic signals; (e) improved bus stops and turnouts; and (f) bus shelter installation. These preferential measures can be used in combination with bus lanes, busways, and bus streets.

Turn priorities for buses, for example, enable buses to retain their traditional routes while simultaneously increasing street capacity and reducing delay. Many peak-hour left-turn restrictions in Los Angeles exempt buses at locations where roadway width or capacity limitations pre-

clude providing left-turn lanes. Similarly, buses are exempt from left- or right-turn restrictions in the London Metropolitan Area, as part of a broad traffic management policy designed to keep buses on their traditional routes while simultaneously increasing street capacity.

Mixed traffic priority treatments are desirable where one or more of the following conditions apply:

1. Corridor capacity is extremely limited by topography or other barriers.
2. Only one or two continuous streets exist in a corridor.
3. There are less than 20 buses in the peak direction in the peak hour.
4. Allocating an exclusive lane for bus use would unduly reduce total corridor capacity for auto travel and produce forced-flow conditions.
5. Roadway widening is not feasible.

Traffic Signal Priorities

Adjustments of traffic signal timing at intersections to facilitate bus flow can substantially reduce average bus waiting times and can improve operating economy; bus delays at traffic signals usually represent 10 to 20 percent of overall bus trip times and nearly one-half of all delays (39). A short reserved bus lane upstream from a traffic signal, in conjunction with bus priorities through a signal, enables buses to bypass queues and move freely up to the intersection and then promptly through the signal either on the normal green or on a specially preempted phase.

Bus priorities at traffic signals—particularly special bus signal phases—are common in Europe and often have been an outgrowth of special tram signals. In Leicester, England, bus-actuated signals have significantly improved bus travel times, and in Southampton, England, signals will be timed to favor buses along a major artery leading to the city center. In Wiesbaden, Germany, the terminals of bus lanes are signalized to facilitate bus transition and turns to other lanes and streets. Bus priorities at signals are also found in Berne, Switzerland, and Montpelier, France.

An increasing number of examples are found in the United States. These include the special bus lane and signal phasing at the Cermak Road bus turn-around in Chicago. Bus actuation of traffic signals along East Main Street in Kent, Ohio, achieved more than a 10 percent increase in bus speed, and the bus preemption system installed in Louisville in conjunction with contra-flow bus lanes reduced bus travel times more than 20 percent. (Both applications were along arterial streets where cross-street progression was not provided.) The Urban Traffic Control System (UTCS) in downtown Washington, D.C., will afford a real-time test of bus preemption in a downtown signal network.

Bus signal adjustments include passive and active systems. Passive systems have no special bus detection; they involve (a) retiming of signals (as at isolated intersections), or (b) reordering of phases. Active systems depend on special bus detection; they involve (a) provision of a special bus phase, and (b) extension or recall of a normal phase.

Signal adjustments include (1) special bus phases and

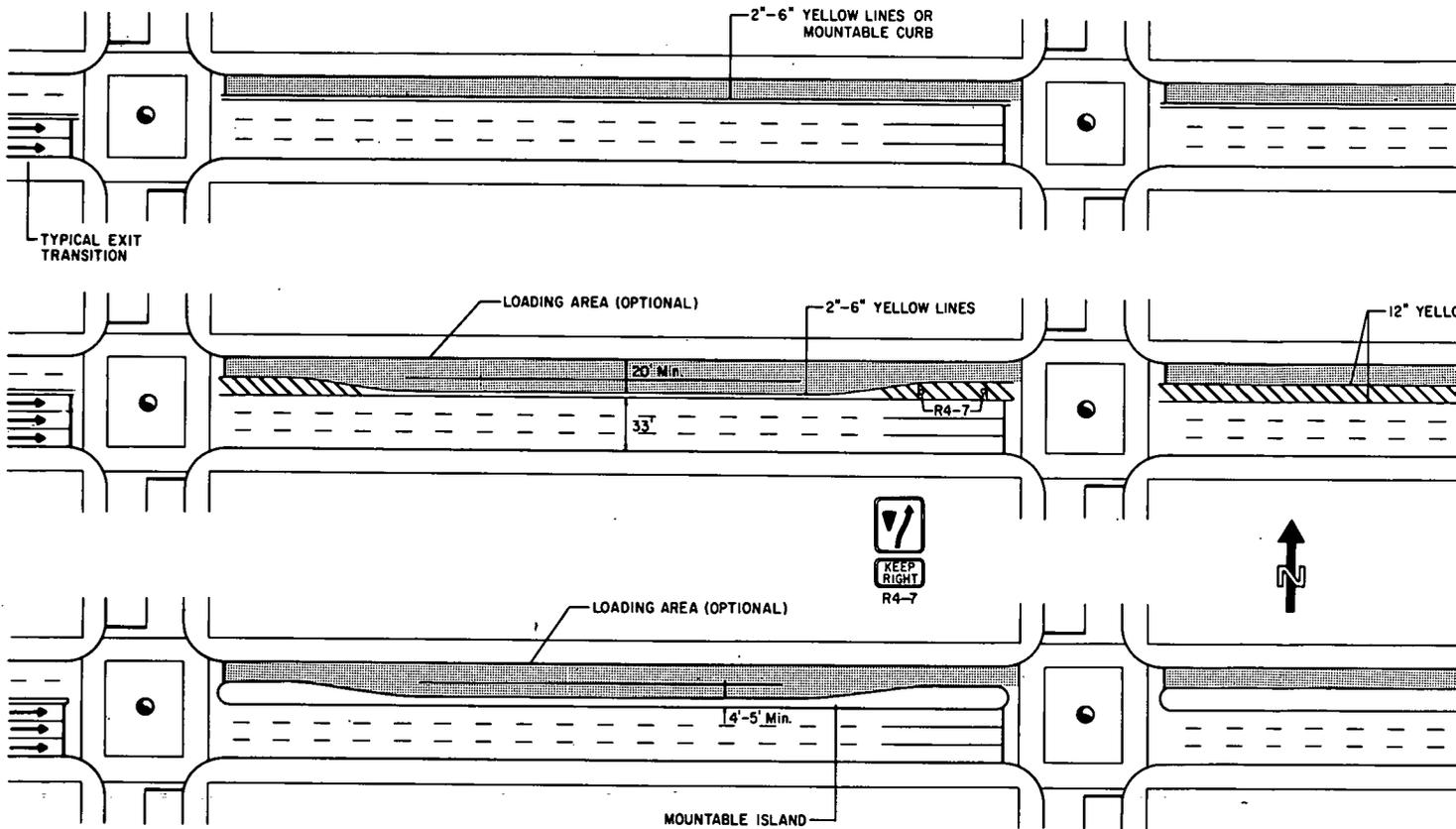


Figure 82. Typical contra-flow bus lanes.

(2) bus preemption and modification of normal phases. Special bus signal phases, actuated or fixed-time, provide positive periods in which buses can cross conflicting traffic streams. Typical examples include entrances or exits to bus lanes or terminals, and the signalization of bus lanes across rotaries. Bus preemption of signals may extend the artery given time when buses enter (or approach) an intersection to minimize person-delay.

Applicability

Implicit in providing bus priorities is a basic philosophy in traffic signal operations: should traffic signals be operated to move vehicles or people most efficiently? Within this context, bus priorities at traffic signals may be provided (a) along special bus roadways, or (b) under mixed-traffic conditions at isolated intersections along a given arterial street, or within an over-all signal network. Included are:

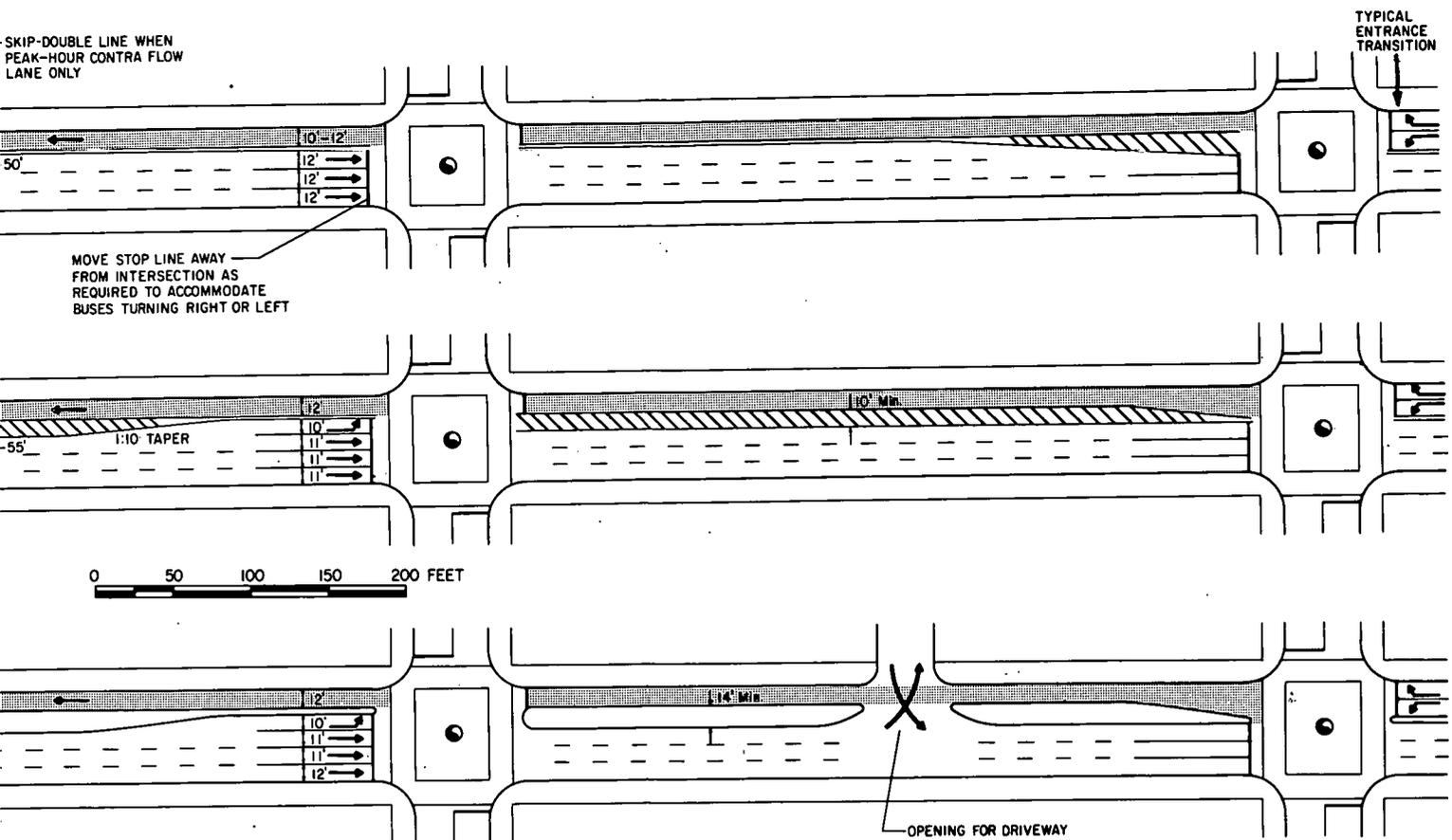
1. Special bus phases. Special bus phases should be provided wherever bus routes conflict with heavy traffic streams, and it is logical from a safety standpoint to separate these conflicts. Signalization of bus left or right turns across through traffic should be considered wherever buses are required to cross more than two traffic lanes with each lane carrying 500 or more vehicles in the peak hour.

2. Bus extension of artery green. Bus extension or re-

call of a normal signal phase should be considered whenever the following general conditions apply:

- (a) Bus preemption reduces total person-delay. The person-minutes saved by bus passengers exceed the person-minutes lost by side-street (auto) passengers. Meeting this condition calls for a specified minimum critical bus passenger volume (Fig. 85). This volume will vary among locations, depending on side-street auto volumes and coordination requirements. The objective is to reduce person-delay without adversely affecting signal network coordination.
- (b) There are at least 10 to 15 buses carrying 400 to 600 people in the peak hour and a daily volume of at least 100 buses.
- (c) The side-street green can be reduced and still provide adequate pedestrian clearance time.

The extension of artery green time by bus preemption will be constrained by signal network coordination requirements: preemption must take into account its effect on the entire signal network. Heavy pedestrian volumes and their associated clearance requirements, major (sometimes equal) intersecting bus volumes, and frequent intersection blockage—as found in downtown areas—will limit the nature and extent of signal timing modifications. Preemption will



not minimize total person-delay if it increases blockage and queuing on heavily traveled streets.

These factors suggest that the greatest potentials for bus preemption are along arterial streets at locations where side-street progression is not a significant factor. Bus preemption of downtown signals logically becomes part of over-all traffic improvement plans designed to improve street efficiency, but its merits have yet to be fully demonstrated.

Design and Operating Features

The normal method of timing signals at isolated intersections involves calculating an optimum cycle time after distribution of the available green time in proportion to the ratio flow (g) to saturation flow (s) for various phases (40). This method minimizes passenger car unit (PCU) delays. There is usually little variation in delay when cycles range from $\frac{3}{4}$ to $1\frac{1}{2}$ times the optimum cycle length.

Signal timing can be adjusted to favor a particular phase (viz., an artery serving a bus route) at the expense of other traffic. However, there has been no mathematical formulation of this "optimum" timing.

Detection of buses should take place before they reach the stop line. If detection occurs during the green time of

the artery phase, an extension of the green phase should provide sufficient time to allow buses to clear the signal. If detection occurs during the amber or red period for the artery, the artery green can be recalled in advance of its normal time. These timing adjustments would reduce the maximum delay to buses, assuming that the bus is not obstructed between the detection point and stop line. Thus, if T is the extension or advance time and R is the red time, the maximum delay to buses is $R - T$.

The basic bus preemption concept is shown in Figure 86. Modifications of green time should be done within the prevailing traffic signal cycle to maintain artery coordination with adjacent intersections and to preclude successive signals along a given street from operating on different cycle lengths. That is:

1. A minimum side-street green is required in each cycle. It should provide adequate time for pedestrians to cross the artery.
2. The artery green may be advanced up to a specified period before it normally takes place or extended up to this amount after it normally takes place.
3. The artery green should not be advanced and extended in the same period.

The extent that artery green time can be increased by bus preemption will depend on side-street volumes and

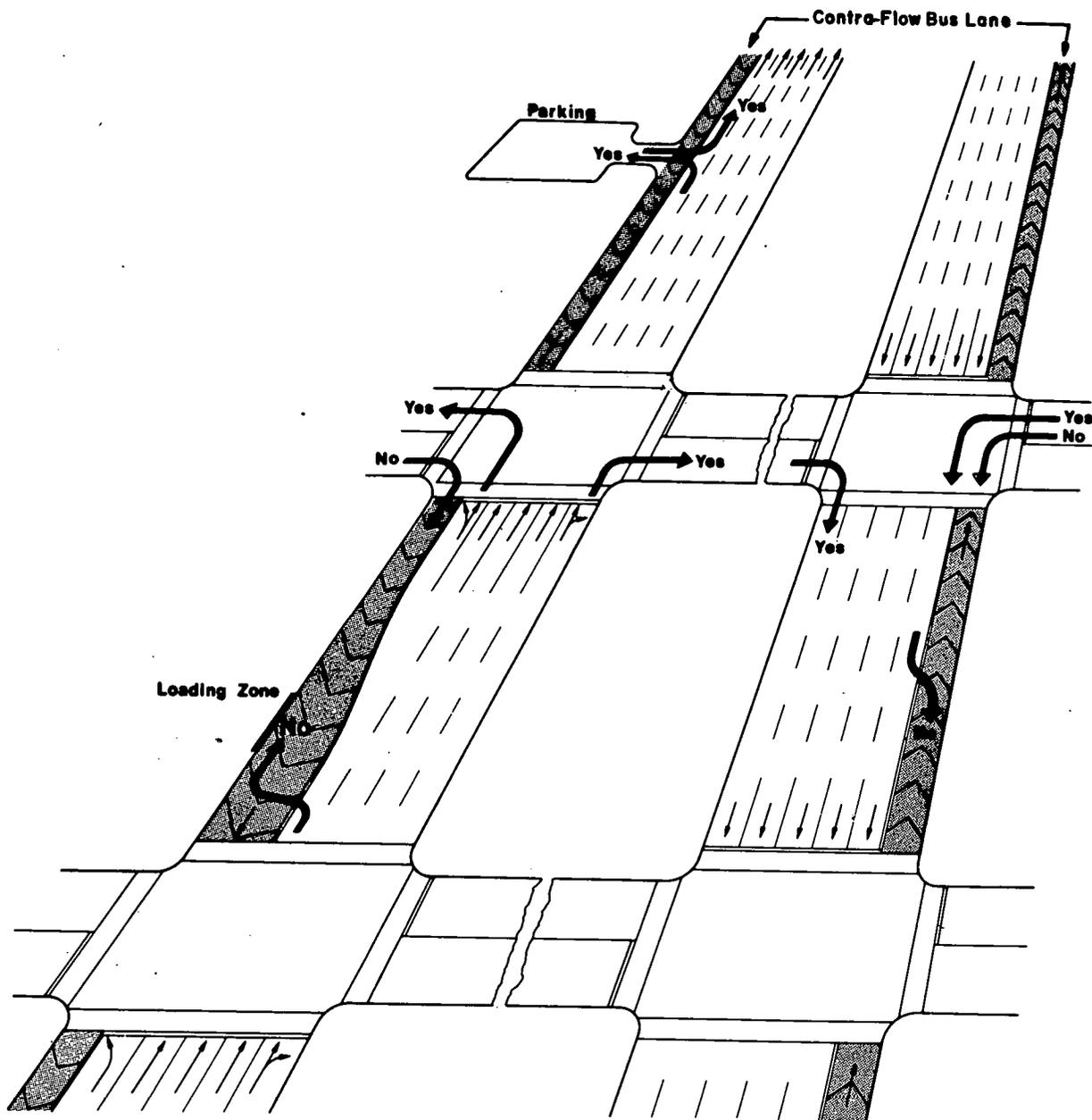


Figure 83. Operational characteristics of contra-flow bus lanes.

coordination requirements, prevailing cycle lengths, and artery roadway width. Typical effects of these variables on bus preemption green time ranges are shown in Figure 87, as follows:

1. Optimum conditions. At isolated intersections bus preemption could extend artery green time up to 10 sec for a 60-sec cycle, and 18 sec for an 80-sec cycle. These increases are viewed as a special case of "actuated" operation.

2. Constrained conditions. At intersections where coordination is provided on both streets, bus preemption could extend artery green time about 6 sec.

3. Variable conditions. At intersections where buses may preempt signals on either street, both artery and cross-street green time may be increased or decreased about 6 sec.

Bus preemption involves modifications of existing traffic controls. Transponders could be installed in buses and receivers could be installed in the local controllers. Alternatively, bus presence information could be transmitted directly to central computers.

Bus Stops

Properly located, adequately designed, and effectively enforced bus stops can improve bus service and expedite general traffic flow. Bus stop frequency, location, and length calls for careful analysis of passenger service requirements (demand, convenience, and safety), the type of bus service provided (local, limited-stop, or express), and the interaction of stopped buses with general traffic flow.

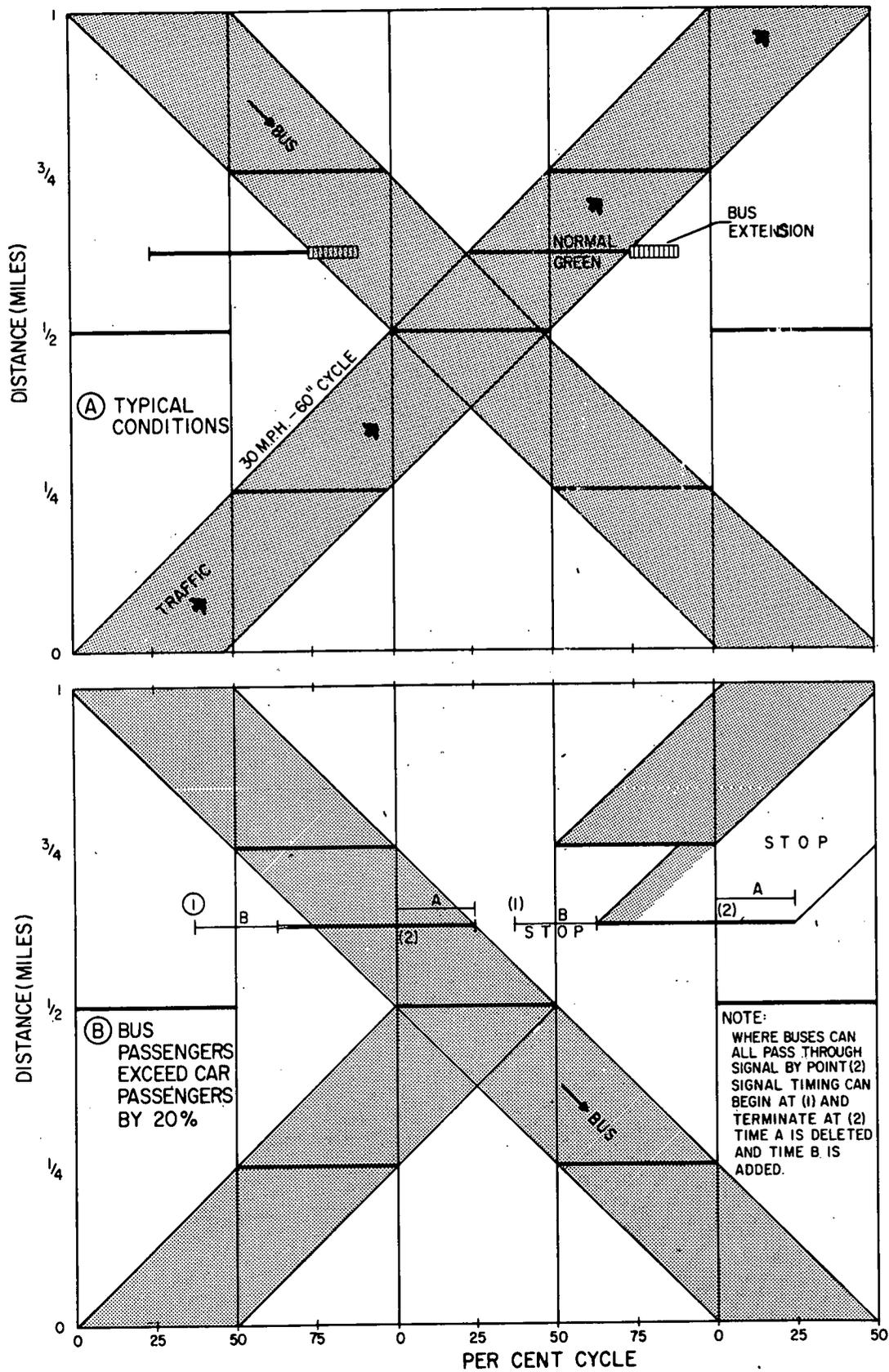


Figure 84. Arterial traffic signal timing, contra-flow bus lanes.

Planning Objectives

The following objectives underlie bus stop planning and design:

1. Maximum passenger convenience. Bus stops should be located near points of major traffic generation; they should encourage direct conflict-free pedestrian travel between generators and buses.
2. Maximum passenger safety. Passengers should be able to board and alight from buses with reasonable safety. Stopped buses should not adversely affect pedestrian and vehicle sight distance.
3. Minimum traffic interruption. Buses entering, leaving, or stopped at bus zones should not unduly interfere with moving traffic. Stopped buses should not block more than one traffic lane and departing buses should not swing beyond the lane adjacent to these stops.

Meeting these objectives requires bus stops of adequate length. This is a basic consideration, because properly designed bus stops expedite bus maneuvers, encourage compliance by bus drivers, and reduce interference with through traffic.

Bus Stop Frequency

Stop frequency generally should not exceed 8 to 10 stops per mile. Wider spacing may be appropriate along major arterials in low-density areas. Thus, buses should stop every block where city blocks are 500 ft or more long and every other block where blocks are shorter.

Superfluous bus stops should be avoided because each stop increases passenger delay and reduces bus speeds. Where consistent with safety and sight distance considerations, bus stops should be combined with mandatory stops for stop signs, traffic signals, and railroad grade crossings to reduce the number of stops along a given route.

Bus Stop Location

Bus stop locations should be standardized within each community to the extent that bus service requirements and traffic conditions permit. Stop locations usually involve a tradeoff between locational consistency and conflict mini-

mization. Thus, where conflicts would seriously impede bus and vehicle flow, stops should be either relocated to adjacent intersections or eliminated.

It is difficult to establish a fixed policy on bus stop location because many factors influence the location of bus stops and the choice of near-side, far-side, and mid-block locations. These factors include availability of curb loading space, location of existing stops, convenience of passenger transfer, and proximity to passenger destinations. Equally significant are bus routing patterns (through, right, or left); the directions of intersecting streets (one-way versus two-way); the types of traffic controls (signal, stop, or yield); traffic volumes and turning movements; and the widths of sidewalks and roads. For example, where the roadway pavement on one side of an intersection is substantially wider than the other, but bus stop is better located on the side with the wider pavement, if traffic volumes are comparable.

Typical examples of urban bus stops are shown in Figure 88. Although both near-side and far-side bus stops can be used, far-side stops should be encouraged wherever conditions permit.

Far-side bus stops are preferable where sight distance or signal capacity problems exist, where buses have use of curb lanes during peak travel periods, and where right or left turns by general traffic are heavy (Fig. 88A, B).

They are also preferable wherever buses turn left, because they allow sufficient maneuvering distance from curb to left lanes, and allow buses to stop after clearing intersections (Fig. 88 C). This may require an extra-long stop to permit buses to complete turning maneuvers. Where this is not feasible, it may be necessary to move the stop position to an adjacent intersection or, in the case of long blocks with light traffic, to use mid-block stops in advance of left turns. Desirable characteristics of far-side bus stops include the following:

1. They reduce conflicts between right-turning vehicles and stopped buses.
2. They provide additional intersection capacity by making the curb lane available for traffic.
3. They eliminate sight-distance deficiencies on approaches to intersections.
4. They encourage pedestrian crossings at the rear of the bus.
5. They require shorter maneuvering distances for the buses to enter and leave moving traffic. (This is not relevant where curb parking is prohibited.)
6. At signalized intersections, buses can find gaps for re-entry into the traffic stream. (This is not relevant where curb parking is prohibited.)
7. Waiting passengers can assemble along less-crowded sections of sidewalk.

Disadvantages of far-side stops include the following:

1. Intersections may be blocked if other vehicles park illegally in the bus stop, thereby obstructing buses and causing traffic to back up across the intersection.
2. Stops on a narrow street or within a moving lane may block traffic on both the bus route and the cross street.
3. A bus standing at a far-side stop obscures sight dis-

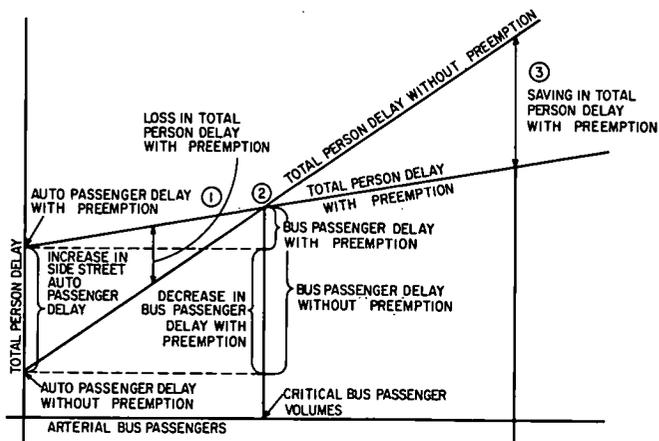


Figure 85. Person-delay functions. (Adapted from Ref. 39).

tance to the right of a driver entering the bus street from the right.

4. Where the bus stop is too short for occasional heavy demands, the overflow will obstruct the cross street.

Near-side bus stops are preferable where transit flows are heavy but traffic and parking conditions are not critical (Fig. 88 D). From the driver's point of view they are preferable because they make it easier to rejoin the traffic stream, particularly where curb parking is permitted in peak periods.

They are generally applicable where buses operate in median lanes, where signalized intersections are frequent, and where curb parking is permitted throughout the day. Buses stopping on approaches to intersections can use the distance of the intersection to reenter the main traffic flow. In cities where near-side stops have been long established as a carry over from street-car operations, the pattern should be retained.

Near-side bus stops can be provided where buses turn right and where right-turning traffic is not appreciable (Fig. 88 E). However, where right turns exceed 250 per peak hour the bus stop should be located prior to the intersection, possibly at mid-block. Near-side bus stops may also be applied in conjunction with median bus left-turn lanes on two-way streets (Fig. 88 F). Desirable characteristics of near-side bus stops include the following:

1. They create a minimum of interference at locations where traffic is heavier on the far side than on the approach side of the intersection.

2. There is less interference with traffic turning into the bus route from a side street.

3. Passengers generally board buses close to a crosswalk.

Disadvantages of near-side stops include the following:

1. Heavy vehicular right turns can cause conflicts, especially where a vehicle makes a right turn from the left of a stopped bus.

2. Buses often obscure STOP signs, traffic signals, or other control devices, as well as pedestrians crossing in front of the bus.

3. A bus standing at a near-side stop obscures the sight distance of a driver entering the bus street from the right.

4. Where the bus stop is too short for occasional heavy demand, the overflow will obstruct the traffic lane.

Mid-block bus stops are generally applicable in downtown areas where multiple routes require long loading areas that might extend an entire block. They can also be used where traffic, physical, or environmental conditions prohibit near or far-side stops, and where large factories, commercial establishments, or other major bus passenger generators exist (Fig. 88 G). Desirable characteristics of mid-block bus stops include the following:

1. Buses create a minimum of interference with sight distance of both vehicles and pedestrians.

2. Waiting passengers assemble at less-crowded sections of the sidewalk.

Disadvantages include the following:

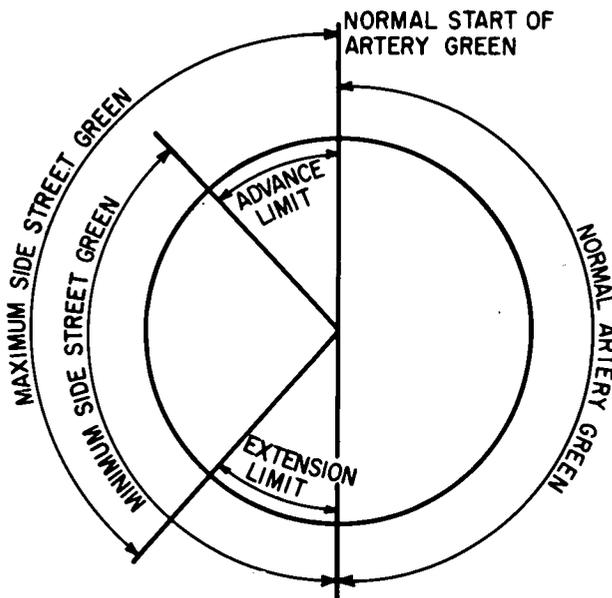
1. The removal of considerable curb parking may be required.

2. Patrons from cross streets must walk farther to board the bus.

3. Pedestrian jaywalking is more prevalent, thereby increasing vehicular friction, congestion, and accident potentials. (A mid-block stop should be located at the far side of a mid-block pedestrian crosswalk so standing buses will not block a motorist's view of pedestrians in the crosswalk.)

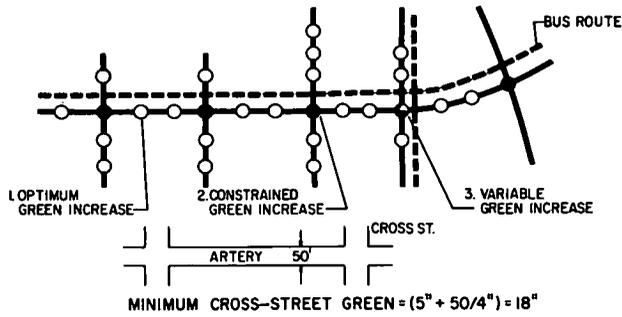
In alternative stop arrangements the locations of bus stops may be modified to reflect specific street routing and pedestrian travel patterns (Figs. 88 G, H, I, J, K). Bus stop locations should minimize pedestrian crosswalk movements at major transfer locations. These stop adjustments are feasible where a major directional imbalance exists in transferring passengers.

Alternate stop patterns (i.e., near side, far side, near side, far side) may be preferable to all-near-side or all-far-side patterns where signals are frequent if this pattern of stops allows buses to reach more signals on the green. For example, where two traffic signals are coordinated, the stops should be located alternately before and after the cross streets.



- 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.

Figure 86. Bus preemption signal cycle.



PREEMPTION CONDITION	60" CYCLE			80" CYCLE		
	ARTERY GREEN	RANGE ARTERY GREEN	CROSS-ST. GREEN	ARTERY GREEN	RANGE ARTERY GREEN	CROSS-ST. GREEN
1. ○ OPTIMUM ISOLATED CROSS-STREET INTERSECTION	33"	33"-42"	27"	44"	44"-62"	26"
2. ● CONSTRAINED (BY NETWORK CONSIDERATIONS)	30"	30"-36"	30"	40"	40"-46"	40"
3. ⊙ VARIABLE (BUS PREEMPTION EACH WAY)	30"	24"-36"	30"	40"	34"-46"	40"

Figure 87. Illustrative preemption strategy for arterial traffic signals.

Revision of stopping patterns in relation to street directions and signal locations usually involves small costs (relocation of the bus stop signs and adjustment of parking regulations). However, care should be exercised to avoid passenger confusion resulting from lack of stop consistency.

Bus Stop Length

Bus stops should facilitate passenger loading and unloading adjacent to the curb with a high degree of driver compliance. Bus stop lengths should reflect (1) the number of buses that each stop will accommodate simultaneously in each peak 20- to 30-min period, (2) the maneuvering requirements of buses to enter and leave the stop, and (3) the type of stop.

The number of bus loading positions depends on (1) the rate and nature of bus arrivals and (2) passenger service times at the bus stop. Bus stop and bus capacity requirements, based on a Poisson (random) arrival rate and a 95 percent confidence interval are summarized in Table 44. This table gives the number of bus berths that should be provided, allowing only a 5 percent chance that the bus bays will overload. Where peak-hour curb parking is prohibited, off-peak bus volumes should govern bus stop length. The criteria are as follows:

1. In areas with passenger service times of 20 sec or less, one bus berth should be provided for about every 60 peak-hour buses. This is the typical radial arterial street condition.
2. In areas where passenger service times average 30 to 40 sec, one berth should be provided for about every 30 peak-hour buses.
3. In areas with unusually high service times, one berth should be provided for about every 20 peak-hour buses.

Suggested ranges in bus stop lengths and the associated curb parking restrictions on intersection approaches are shown in Figure 89. These dimensions assume a single 40-ft bus; lengths should be adjusted accordingly for longer and shorter buses. Where bus service is infrequent (i.e., less than 4 buses in the peak hour and 2 buses per hour in the base periods), it may be necessary to balance desirable bus stop lengths with parking demands and enforcement feasibility. Similarly, where several buses are expected to use any given stop simultaneously, 45 ft should be added for each additional bus.

The following guidelines, including the prohibition of curb parking, are suggested for single-bus stops:

1. Far-side bus stops should range from 80 to 100 ft, measured from the rear of the stopped bus to the end of the first parking stall. This distance will increase to 115 to 135 ft where far-side stops are provided after buses turn right.
2. Near-side bus stops should range from 90 to 105 ft, measured from the front of the stopped bus to the front of the preceding parking stall.
3. Mid-block bus stops should range from 130 to 165 ft, measured from the front of the preceding parking stall to the rear of the next parking stall.

Bus stops should be clearly marked. Solid white 6- to 8-in. lane lines should separate the bus stop from adjacent traffic lanes. "Bus Stop" pavement stencils may be provided in areas of heavy bus flow.

Related Factors

Design, signing, maintenance, and enforcement of bus stops should maximize (1) compliance to regulations by buses and cars and (2) passenger convenience. Factors involved include:

1. Enforcement. Effective enforcement of complementary curb parking restrictions is essential. The best engineered bus stop is of little value if the attendant parking restrictions are not strictly enforced (41). Where buses must "double park" because their loading areas are occupied by parked or stopped vehicles, passenger safety is reduced and traffic flow is impeded.
2. Delineation. Bus stops should be conspicuously signed. Signs regulating parking should conform to the *Manual on Uniform Traffic Control Devices for Streets and Highways* (37). Standard red-and-white NO PARKING BUS STOP signs (R 7-107, or their graphic equivalent), placed parallel to the roadway, should be used. Additional pedestrian-oriented signs should clearly delineate the bus routes, including hours of operation and frequency of service; these signs should display the logo of the operating transit agency.
3. Passenger amenity. Passenger convenience should be a primary consideration. Adequate roadway lighting and (where passenger volumes warrant and land-use conditions permit) bus shelters should be provided. Sidewalk slabs should be provided along streets, with planted or grass parking strips. Roadway curbs should be of constant height to minimize passenger missteps when alighting from a bus at a lowered or sloping curb.

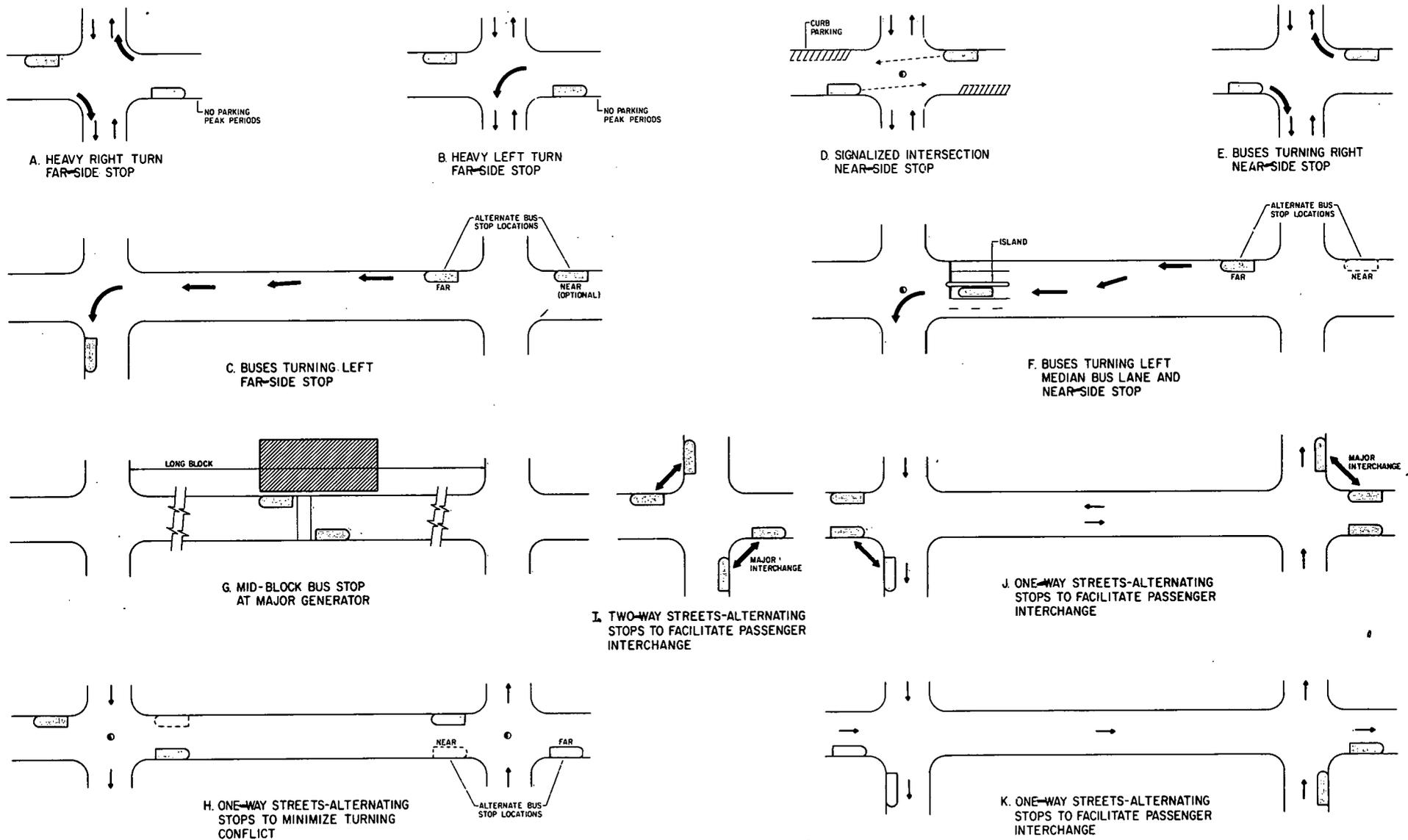


Figure 88. Typical bus stop locations.

At major transfer points or loading areas, and bus stations, pedestrian and vehicular movements should be separated.

4. Maintenance. Heavy snow should be removed from the full length of every bus stop so that the bus can pull in parallel and immediately adjacent to the curb. If snow is not removed, buses may be forced to stop in positions that interfere with traffic flow.

5. Curb adjustments. Where buses make right turns, it is desirable to increase the curb radii to permit buses to turn without swinging out into adjacent lanes or rubbing the corner curb. These requirements suggest a compound curve with a center radius of 25 ft and a radius of 100 ft at each end—or a simple curve of 35-ft radius. These dimensions may not be feasible where pedestrian volumes are heavy and/or sidewalk capacity is limited.

Recessed Bus Bay (Bus Turnouts)

Recessed-bay bus stops or "bus turnouts" have been successfully used in many cities, including Phoenix, Toronto, and Washington. They involve relocating the curb by flaring the street width. This allows passenger loading and unloading to be removed from the through travel lanes, thereby spatially separating stopped buses from moving traffic.

Applicability

Bus bays are especially applicable along arterial streets with high auto volumes, high over-all travel speeds, and relatively long bus dwell times. Heavy bus volumes are not essential; in these cases buses would already preempt curb lanes and reserved bus lanes may be appropriate. Recessed bus bays should be considered whenever the following general conditions exist:

1. Curb parking is prohibited, at least during the peak hours.

2. There are at least 500 vehicles in the curb lane during the peak hour.

3. Bus volumes are inadequate to justify an exclusive bus lane. At least 100 buses per day and 10 to 15 buses carrying 400 to 600 passengers in the peak hour traverse the street.

4. The average bus dwell time generally exceeds 10 sec per stop.

5. Right-of-way width is adequate to allow constructing the lane without adversely affecting sidewalk pedestrian flow.

Bus turnouts also may be provided in areas of heavy bus volumes and loading to facilitate passenger loading and to allow buses to overtake stopped vehicles. They may be developed as part of transit malls (such as Bank Street in Ottawa) where the roadway is narrowed and the sidewalk width is increased except at bus stops.

Typical examples of recessed bus bays are shown in Figure 90. Recessed bus bays may be provided (1) at mid-block, (2) on the near side of an intersection for joint use with right turns, (3) on the far side on an intersection, and (4) on the far side in conjunction with a near-side right turn.

The location of bays should be consistent with the pattern of bus stops along the same street. However, at signalized intersections where right turns exceed 250 in the peak hour the combination near-side right-turn bay and far-side bus stop bay is preferred.

Design Guidelines

Typical bus bay design guidelines are shown in Figure 91 for single-bus loading-unloading conditions. For each additional bus 45 ft should be added, consistent with the criteria given in Table 44. Bus turnouts should enable buses to decelerate, load, and accelerate with minimum effect on through traffic. Design factors to be considered include:

1. Bus bays should be at least 10 ft wide.

2. Near-side bus bays should be at least 50 ft long for a single bus, plus a 60- to 80-ft transition distance. The curves used should be of 100-ft radius, separated by a short tangent distance.

3. Far-side bus bays should provide a 50-ft loading area plus 40 to 60 ft of transition distance. A 25- to 50-ft radius curve should be used on the initial exit from the bus bay, followed by a short tangent and a 50 to 100-ft radius curve on entry to the main roadway.

4. Mid-block bus bays include a composite of transition requirements for near- and far-side bus bays. Total impacted area for a single-bus bay would range from about 150 to 200 ft, suggesting a minimum 400- to 600-ft block for application.

5. Ideally, bus bays should be constructed with contrasting pavement color and/or texture. They should be clearly delineated with a 6- to 8-in. solid white lane line.

Bus Stop Shelters

Bus shelters are an important component of improved bus marketing strategies and passenger amenity programs. They

TABLE 44
BUS STOP AND BAY CAPACITY REQUIREMENTS^a

PEAK-HOUR BUS FLOW	CAPACITY REQUIRED (BAYS) WHEN SERVICE TIME AT STOP IS				
	10 SEC	20 SEC	30 SEC	40 SEC	60 SEC
15	1	1	1	1	1
30	1	1	1	1	2
45	1	1	2	2	2
60	1	1	2	2	3
75	1	2	2	3	3
90	1	2	2	3	4
105	1	2	3	3	4
120	1	2	3	3	5
150	2	3	3	4	5
180	2	3	4	5	6

^a Random arrivals: 95 percent confidence level. Computed from the cumulative poisson distribution.

are an integral part of the modern transit system, yet their origin dates back to interurban and street railway operations (42). Their primary function is to provide

passenger protection from weather without compromising passenger safety or involving excessive installation and maintenance costs. Shelters provide a distinct identity to

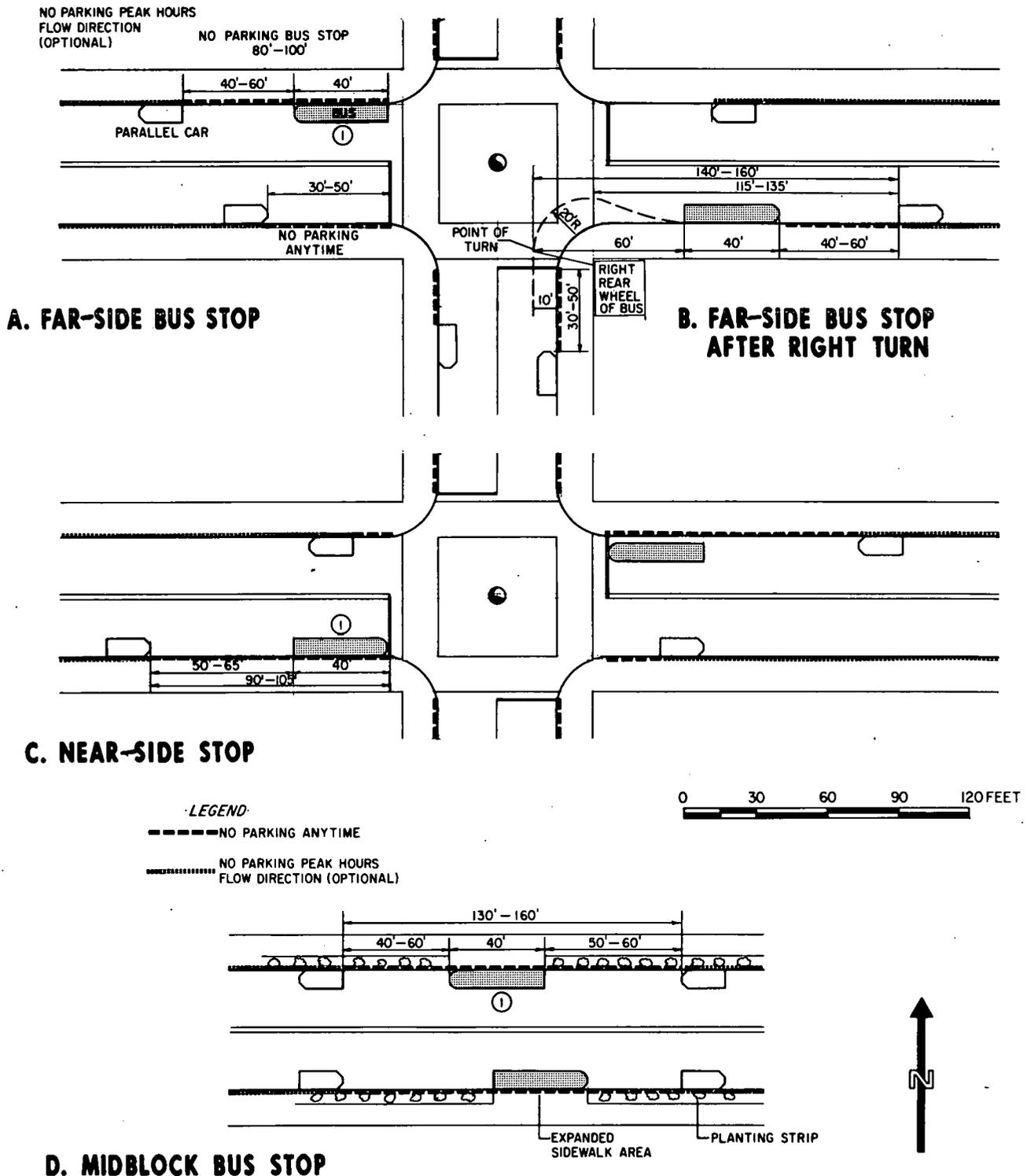


Figure 89. Bus stop design standards.

major bus stops and can enhance the public image of the bus system (43, 44).

Applicability

Bus shelters should be provided at major terminal or passenger interchange points, where bus boarding volumes are heavy, where "transit identity" should be reinforced, where waiting is likely to occur, and where physical site conditions allow their development. Shelters also should be provided at locations to serve the physically disadvantaged (near hospitals and residences for the aged).

Suggested priorities for bus shelter installation are given in Table 45. Locations with high passenger demands and low bus service frequency should be given priority. Shelters generally should be provided where there are 100 or more boarding or transferring passengers daily, and total daily passenger waiting times range from 500 to 1,000 min.

Economic analysis provides another means of evaluating bus shelter priorities. The person-minutes benefited per dollar of annual cost provides a useful index. This relationship can be stated as follows:

$$I = \frac{PT(D_1 + RD_2)}{K_i C_a + C_m} \quad (9)$$

in which:

- P = number of passengers;
- T = average waiting time per passenger, in minutes;
- D_1 = days of inclement weather;
- D_2 = days of noninclement weather;
- R = a discount factor (a factor that can be used to reflect the effect of waiting during normal weather; $0 < R < 1$);
- K_i = capital recovery factor;
- C_a = capital (installation) costs; and
- C_m = annual maintenance cost.

A benefit-cost ratio can be derived by imputing a value of time to the numerator in Eq. 9.

Design Guidelines

Bus shelters should be of contemporary design and constructed of highly durable weather- and vandal-resistant materials. They should afford a high degree of visibility, provide a pleasing appearance, and afford ample weather protection and passenger amenities. They should minimize installation and maintenance costs. Typical shelter designs that achieve these objectives are shown in Figures 92 and 93.

Bus shelter designs should have the following characteristics:

1. **Visibility.** Maximum visual exposure is essential for passenger safety. Shelter sides, where enclosed, should provide the maximum possible transparency. Shelters should not be hidden from view by placement behind other structures.

2. **Accessibility.** Bus shelters should provide two points of access. "Doubled sided" shelters, in which access is

provided from the sidewalk and the street, are generally desirable; they allow natural pedestrian flow from the sidewalk directly into the bus entrance, thereby maximizing protection from the weather. Each opening should be at least 2½ to 3 ft wide.

3. **Appearance.** Shelters should be of pleasing appearance and should blend with their surroundings. This is necessary to offer comfort and attractiveness to potential bus patrons. Moreover, placement and appearance adds significantly to "street furniture." Shelters should be clearly identified with "bus logo" symbols.

4. **Materials.** Shelters may be constructed from steel, anodized aluminum, wood, concrete and tile block, reinforced concrete, fiber glass, plastics, and/or glass. The choice of materials depends on availability and cost, past experience, climate, and local preferences. Materials should have a high life expectancy and should afford adequate design flexibility in size and the arrangement of enclosure walls. Sharp corners and edges should be avoided. Roofs should be opaque and heat reflecting.

5. **Modular construction.** Modular construction, including off-site prefabrication, is desirable to reduce interference with traffic, help achieve uniformity in shelter design throughout an area, and allow ready expansion of capacity.

6. **Capacity.** Shelter capacity should be based on the maximum daily passenger accumulation at the bus stop. Approximately 3 to 5 sq ft per person should be allowed in developing shelter size requirements. Shelter modules of 10 to 12 ft in length, 5 to 7 ft in width, and 7 to 8 ft in height (about 50 to 60 sq ft) will generally be appropriate.

7. **Amenities.** The facilities that are provided will vary among and within communities. Weather protection and benches are usually essential. Bus route maps and schedules, lighting, telephones, and, in some cases, trash receptacles may be appropriate. Interior shelter space generally should be free of clutter.

- (a) Benches should be provided in areas where waiting times are long, and/or in commercial areas where they provide rest areas for transit-oriented shoppers.
- (b) Lighting, wherever possible, should be by means of existing street and commercial illumination. Special lighting within shelters, where provided, should be kept in working order. Lighting should allow nighttime reading of information within shelters.
- (c) Heaters have applicability in shelters at busway stations, at locations where surveillance is possible, and in areas with extreme winters. Radiant heaters (perhaps radiant floor heating) should be considered for these conditions. Switches may be passenger-activated with automatic turnoff, and placed out of reach of children. Heaters, however, generally (1) increase installation costs (by about \$250 to \$300), (2) are subject to vandalism, and (3) may need special utility connections.
- (d) Bus schedules should be provided and kept up to date. Bus route maps should be provided

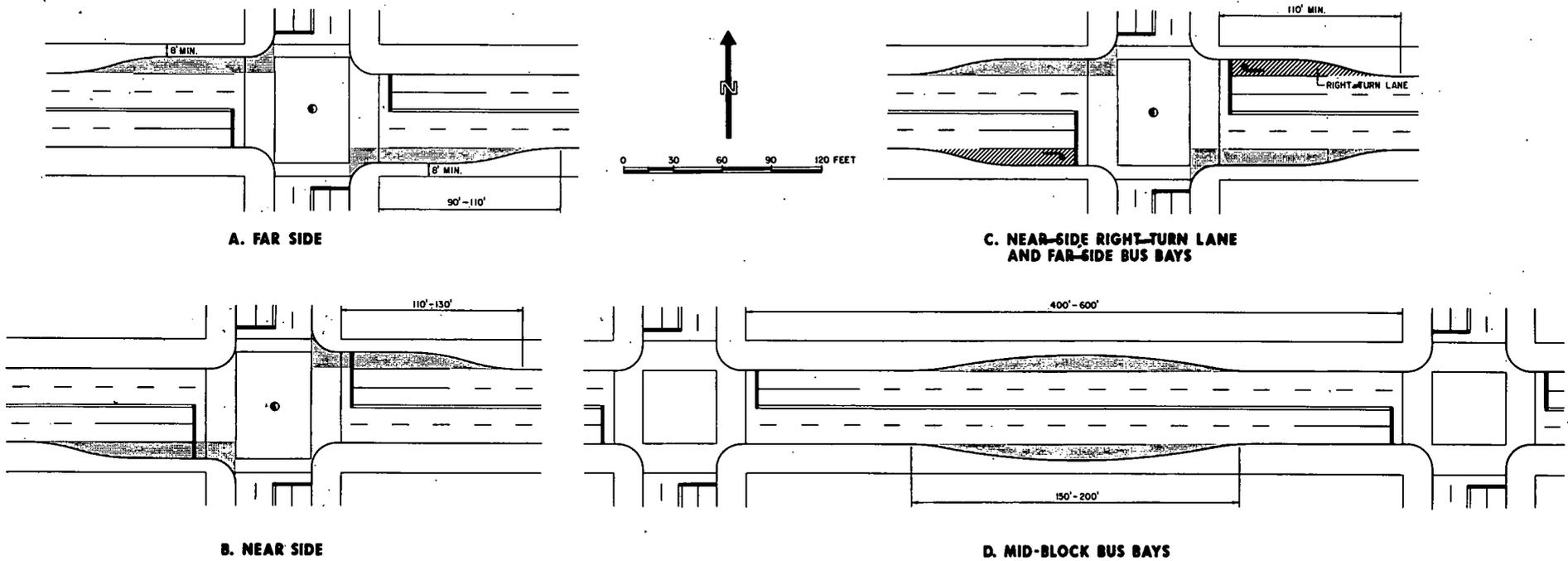


Figure 90. Arterial bus bay location options.

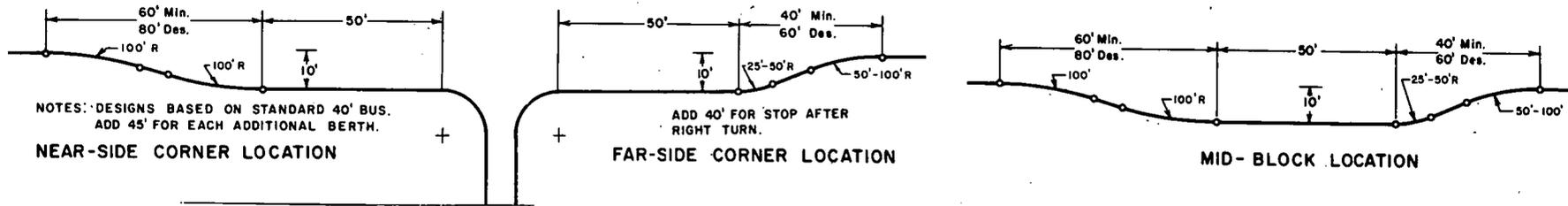
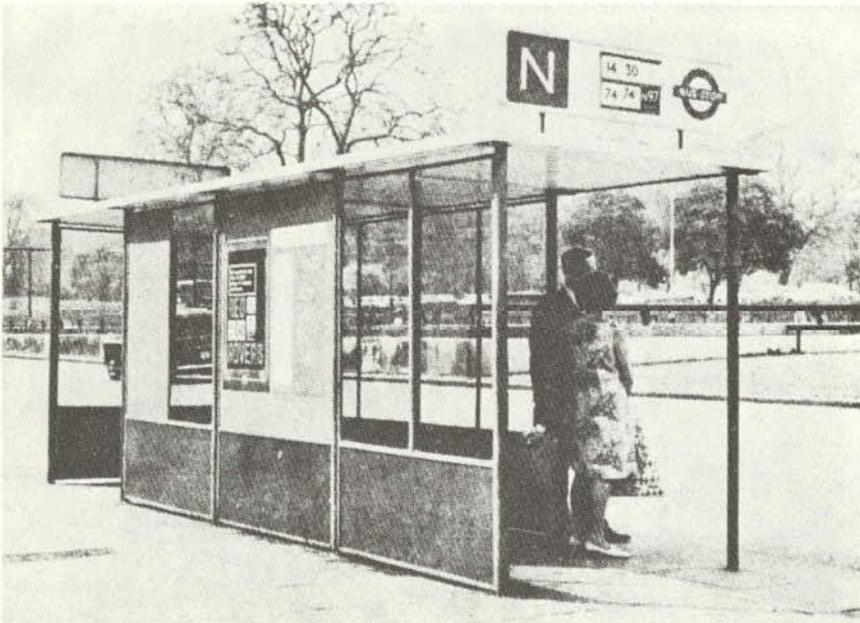


Figure 91. Bus stop turnouts, arterial streets.



**URBAN MASS TRANSIT ADMINISTRATION –
PROTOTYPE DESIGN**



LONDON TRANSPORT – DOUBLE-SIDED DESIGN

Figure 92. Typical bus shelter designs.

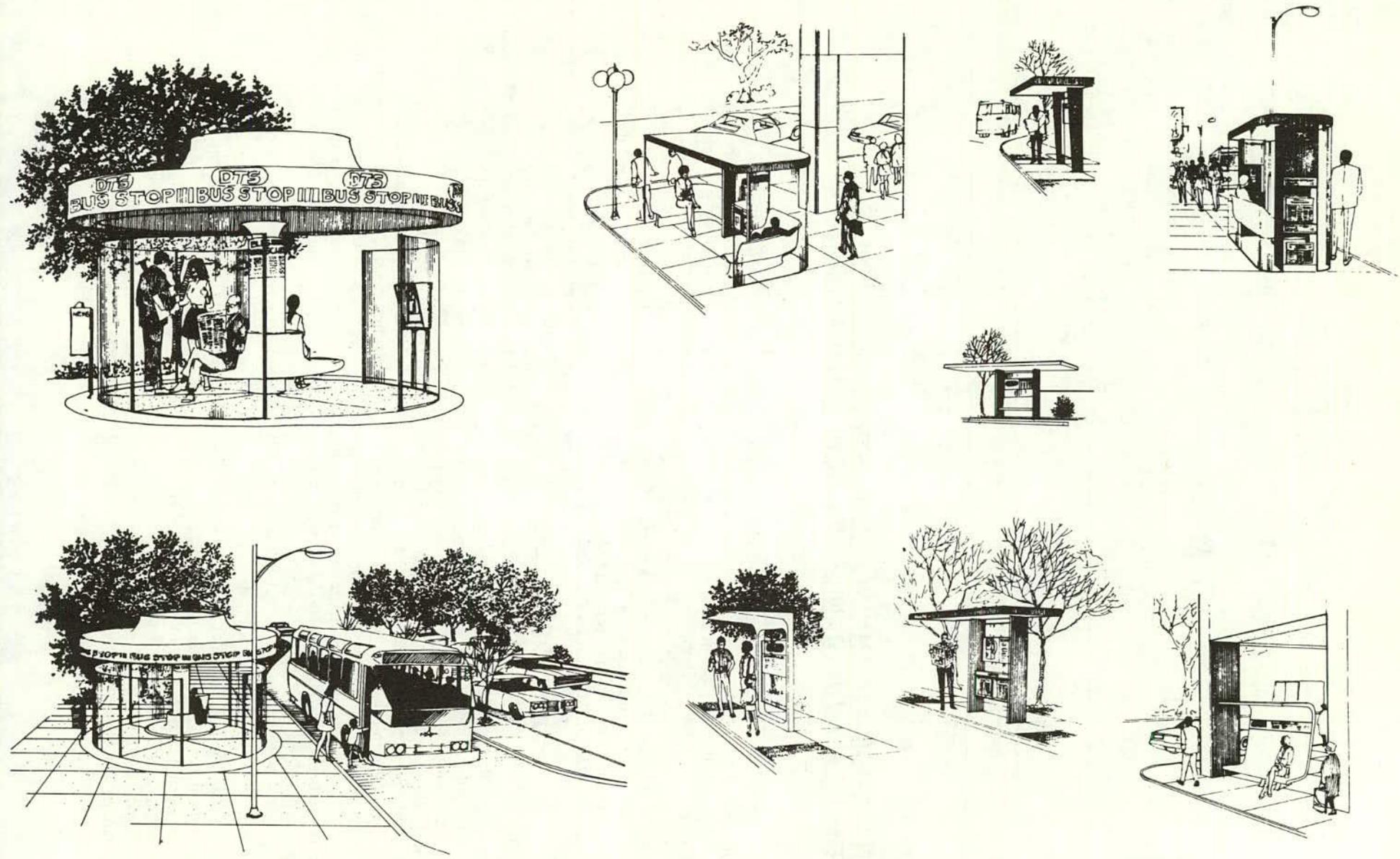


Figure 93. Bus shelter design concepts.

TABLE 45
SUGGESTED BUS SHELTER
INSTALLATION PRIORITIES

DAILY BOARDING OR ALIGHTING PASS.	INSTALLATION PRIORITY WHEN AVERAGE PEAK-PERIOD BUS SERVICE FREQUENCY IS		
	0-5 MIN	5-15 MIN	OVER 15 MIN
300 or more	1c	1b	1a
250-299	4a	2b	2a
200-249	4b	2a	2c
150-199	4c	3b	3a
100-149	4d	3d	3c

- where shelters serve several bus lines. Bus travel information when inserted between transparent panels is protected from weather and vandalism.
- (e) Telephones should be provided alongside or, in some cases, within shelters. However, their installation inside shelters should be discouraged where vandalism would be a problem.
- (f) Police, fire alarm, and mail boxes may be located on the outside of the bus shelters.

8. Costs. Shelters should have a minimum service life of 15 years. Construction and maintenance costs should be minimized. Typical units should have a cost range of \$20 to \$30 per square foot, or approximately \$1,500 to \$2,500 per shelter at 1973 price levels. Annual maintenance and repair costs should not exceed \$300 to \$400.

CHAPTER SIX

APPLICATION—PLANNING AND DESIGN GUIDELINES: TERMINALS AND TRANSPORTATION CENTERS

This chapter contains planning and design guidelines for terminal-related bus priority treatments, including (1) central area bus terminals, (2) outlying auto-bus-express transit interchange areas, and (3) outlying auto-bus (park-and-ride) transfer facilities. General planning implications are discussed first, followed by a detailed description of applicability, planning concepts, and design guidelines for each type of treatment. The materials represent a synthesis and extension of contemporary literature (5, 45, 46, 47, 48, 49, 50, 51) on parking and terminals.

GENERAL PLANNING OVERVIEW

Transportation terminal and interchange facilities serve at least two important functions: (1) They provide off-street downtown distribution for radial express bus operations; (2) they help intercept motorists and local buses in outlying areas and facilitate passenger transfer to express transit lines. In both cases they help achieve fast, dependable transit services to the core, with attendant reductions in vehicle-miles of auto travel and downtown parking space demands. In both cases, they complement the basic bus and highway systems.

Planning Guidelines

Terminal planning, location, and design embodies basic traffic circulation, transit operations, and site planning principles. Relevant factors include (1) line-haul transit routes (rail and bus); (2) passenger interchange needs; (3) passenger arrival and departure patterns; (4) bus distribution opportunities and constraints within the city center; and

(5) land requirements, availability, impacts, and costs. These factors, weighted with obvious economic and environmental considerations, determine when terminals should be developed, where they should be located, and how they should be designed and related to urban land-use and development patterns.

The following planning guidelines are significant:

1. Terminals should form an essential part of the overall transit operation by (a) simplifying route structure, (b) facilitating passenger interchange, and/or (c) penetrating major passenger-generating areas.
2. Terminals should achieve collateral land-development and environmental benefits (i.e., catalyzing joint multi-use developments). They should minimize adverse environmental impacts.
3. Terminals should achieve a more cost-effective and attractive means of distribution than achieved through bus tunnels, bus lanes, or proliferated local bus services.
4. Terminals should produce clearly identifiable benefits to bus passengers and bus operators. Passengers using terminal facilities should realize both time and cost savings to the city center over comparable trips wholly by local bus or car. Ideally, time savings should be at least 5 min per trip.

Design and operations should (1) provide bus priority access directly to and from express roads or busways by grade-separated approaches that eliminate street congestion; (2) maximize berth capacity by keeping bus layover and recovery times to a minimum; (3) separate urban from intercity bus services, and loading from unloading opera-

tions; (4) minimize the number of differing bus routes utilizing each loading berth; (5) minimize walking distances for transferring passengers, especially to and from local bus lines; and (6) use outlying automobile parking as an alternative to excessive local bus mileage in low-density residential areas.

Design and arrangement of bus loading areas calls for judicious application of the design standards and passenger loading criteria identified in Chapter Two. Where automobile parking facilities are provided, they should be designed on the basis of standard "design passenger vehicles."

Access to terminals should minimize conflicts with surrounding streets and should be sufficiently removed from major intersections. Designs should be kept simple, and key decision points should be minimized or spread. Traffic controls should be coordinated with those in adjacent areas.

Application Potentials

Terminal and other modal interchange facilities are most appropriate where large volumes of passengers board or transfer daily. This mass interchange is essential to achieve optimum integration of various transport modes as well as financial feasibility of terminal construction. The extent of construction should, therefore, be consistent with the number of passengers served.

Facilities generally should be provided in conjunction with rail rapid transit lines, busways, and contra-flow freeway bus lanes. Thus, they will have wide applicability where urban area population exceeds 750,000, and downtown employment exceeds 50,000, as follows:

1. Express bus or rail transit routes with high passenger concentrations and service frequency are desirable.
2. Route structure and land-use patterns make it feasible to break bus routes and/or provide crosstown and circumferential services. For example, modal interchange points at the perimeter of high-density development (69th Street Terminal in West Philadelphia).
3. Patrons rely on car and bus access to outlying express transit stations.
4. Downtown access and parking are inhibited by high costs, peak-hour congestion, and inadequate approach road capacity.

Terminals in medium-sized communities will usually be part of "transportation centers" in which intercity bus services and parking facilities are the principal components, or represent strategically located outlying parking lots serving express bus lines.

CENTRAL AREA BUS TERMINALS

Central area terminals consolidate bus operations at a single location, facilitate passenger interchange between bus lines, reduce bus journey times, and improve general traffic flow by reducing inefficient bus mileage on congested downtown streets. They provide a focus for intercity and express bus services; local bus service is more effectively accommodated on-street.

Terminals are essential to express bus operations where other bus priority measures are not feasible. They make

it possible to achieve high bus volumes on expressways, across bridges, and in tunnels by providing off-street loading for large concentrations of buses. In conjunction with special bus ramps and bus roadways, they attain grade-separated bus operations in congested centers, and provide an option to downtown busway development. However, one-point delivery in the downtown area usually requires secondary distribution by local bus or rapid transit.

Terminals can achieve substantial time savings for bus riders as compared with on-street distribution. Time savings should be sufficient to offset the time losses involved in transferring. The Port of New York and New Jersey Authority Midtown Bus Terminal saves passengers 20 minutes per trip; Philadelphia's proposed Market Street East Terminal will save passengers 15 minutes per trip. Central terminals underlie successful freeway bus service along I-495 in New Jersey and across the San Francisco-Oakland Bay Bridge.

Planning Criteria

Terminals vary in form, type, and size, depending on specific urban needs. They range from single-level facilities that serve intercity buses and offer minimum passenger amenities to large multi-level transportation centers that serve several modes and contain supporting land uses. The more elaborate transportation centers include (1) rail facilities, (2) commuter and intercity bus services, (3) ancillary parking, (4) car-rental, taxi, and air-limousine areas, (5) pedestrian waiting areas, (6) ticket offices, (7) retail stores, (8) offices, (9) community facilities, (10) concourses, and (11) vertical pedestrian circulation systems (52). High passenger concentrations at a single location are conducive to intense multi-use development.

Applicability

Downtown off-street bus terminals should be considered wherever the attendant service improvements and development potentials exceed the costs involved. They are appropriate where (1) downtown curb loading capacity is limited, (2) large volumes of express buses aggregate, and (3) on-street bus routing is slow, unattractive, unreliable, and cannot be improved through bus priority measures. In these cases, the terminal becomes necessary to maintain bus schedules, improve driver productivity, and realize the benefits of line-haul express services on busways or freeways. It becomes an option to downtown busway service.

Terminals should be considered when the following general conditions apply:

1. Land availability. Land and buildings are available from former railroad operations (the 37-berth Transbay Terminal in San Francisco) or will become available through urban development (proposed Market Street East Bus Terminal, Philadelphia). Land costs should be reasonable relative to the total passengers served and the site's proximity to major generation points. Land acquisition costs have traditionally limited major terminal developments to large urban centers with high bus concentrations (e.g., New York City's Midtown and George Washington Bridge Terminals).

2. Bus volume concentrations. Terminals should be provided wherever on-street operations of terminating buses disrupt general traffic. As a general guide, off-street terminals should be provided wherever there are 20 to 25 peak-hour terminating buses with more than 1,000 terminating passengers. This operation would require up to five loading positions and an equivalent holding area.

3. Destination accessibility. Terminals should be located within walking distance of most passenger destinations. Terminals with exclusive bus connections to freeways or busways are feasible where the CBD is compact or where high-capacity transit service is available for supplementary distribution. Transfer to local rapid transit, streetcars, and buses is an essential feature of many existing and proposed terminals. Direct rapid transit connections are available in New York City (Midtown Terminal), Chicago (Greyhound Terminal), and Philadelphia (proposed Market Street East Terminal). In San Francisco, five streetcar lines loop and layover at the Transbay Terminal.

Location Guidelines

Locations of existing and proposed CBD bus terminals provide important locational guidelines. The terminals (1) provide direct connections to expressways, (2) are located between the expressways and the CBD core, (3) are removed from points of peak land value, and (4) are within a few blocks of major employment centers (Fig. 94). Terminals usually incorporate air rights developments, and major water crossings on approaches are common.

These locational criteria are generalized in Figures 95 and 96. Downtown terminals should be located at points of "optimum efficiency" where express modes have just lost their essential freedom of high-speed movement, as follows:

1. They should be located within a short walking distance of major office concentrations in the city center (for example, a 5-min or ¼-mile walk for 50 percent of users).
2. They should connect with secondary public transport distribution systems.
3. They should minimize travel times to and from free-flowing approach roads or busways.
4. Special penetration bus roads, where provided, should traverse wholesale and other CBD fringe uses.

Planning Flexibility

Terminal planning should include detailed estimates of demand, capacity, revenues, and costs. Capacity should be based on realistic demand forecasts, with full recognition of annual, seasonal, daily, and peak-hour traffic characteristics. Space demands should consider individual carrier's operating needs, and should not be developed on an over-all average unit basis. The factors that create demands for carrier space must be clearly identified in order that future changes in operating space requirements are properly anticipated. Changes in route configuration, service frequency, and fare collection practices will influence future capacity. Accordingly, design should allow for expansion of capacity, including adaptability to new bus sizes, types, and technologies.

Revenues from ancillary land development are especially important in conjunction with terminal facilities that mainly provide downtown distribution for urban express bus services. These should be carefully assessed, especially where terminals constitute alternatives to busways or to on-street distribution.

Design and Operating Features

Bus terminal type, size, and design should reflect specific passenger, bus service, and traffic access requirements. Relevant factors include: (1) passenger traffic volumes, arrival modes, and peaking patterns; (2) bus volumes and operating practices including fare collection, service frequency, loading patterns, layover times, reservoir requirements, and (3) access linkages to surrounding roads and streets.

Capacity Ranges

Off-street bus terminals should provide at least five loading positions. Most cities will find 20 to 30 loading berths adequate to serve intercity and suburban requirements. Terminals that provide downtown distribution for busways or regional express bus services may require a greater number of positions, depending on specific local conditions and operating procedures. Thirty to 40 berths are suggested as a nominal terminal size for express bus service. (San Francisco's 37-berth Transbay Terminal, for example, serves 13,000 peak-hour passengers.)

Design Variables

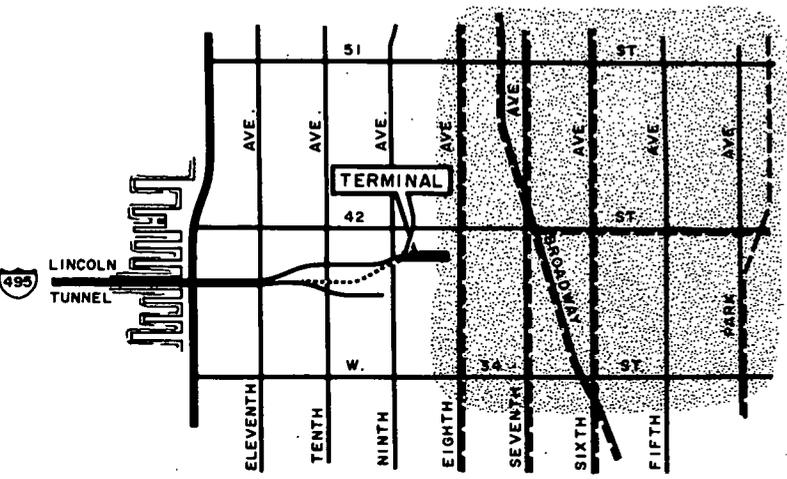
Internal terminal design of bus platforms and runways are influenced by (1) the general bus circulation scheme (i.e., straight through the area, in and out on a 90 deg turn, in and out on a 180-deg turn, clockwise or counterclockwise circulation); (2) the provision of holding area space for marshalling empty equipment for proper feed-in; (3) loading and unloading on the same or separate platforms; (4) use of single- or double-lane bus runways; and (5) use of (a) one-level design or (b) two-level designs that involve passenger access by stairway to and from the platforms. A basic design requirement is the need for buses to load and unload on the right side of the bus.

Functional Objectives

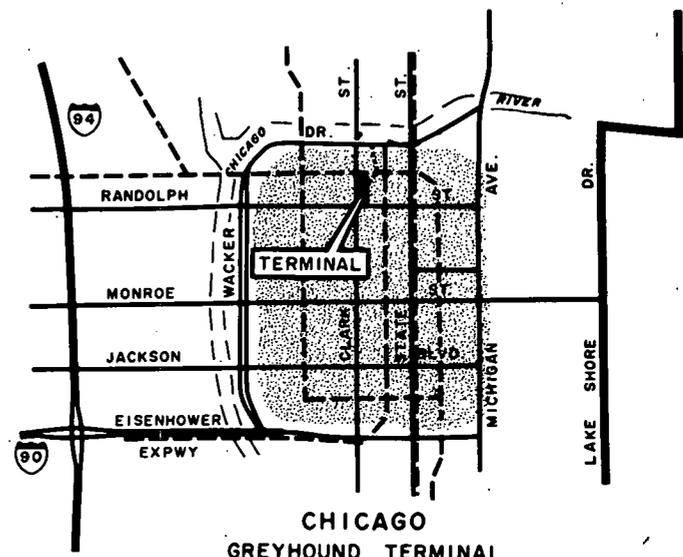
Terminal design should separate vehicle and passenger movements, and reflect their specialized circulation and geometric requirements. It should effectively interrelate bus, passenger, and baggage functions (Fig. 97). The bus arrival-unloading-layover-loading-departure sequence should form the heart of the terminal operation around which various other functions depend. Baggage and parcel functions should mainly serve intercity bus operations and can be minimized for conventional commuter bus services.

Desirable functional objectives are identified in Figure 98 for a "typical" central bus terminal. They include:

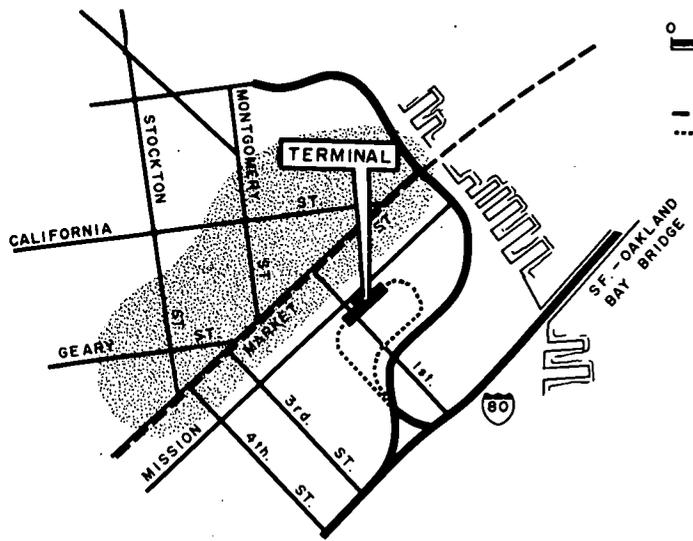
1. Grade separated bus entry and exit.
2. Direct pedestrian connections to other modes.



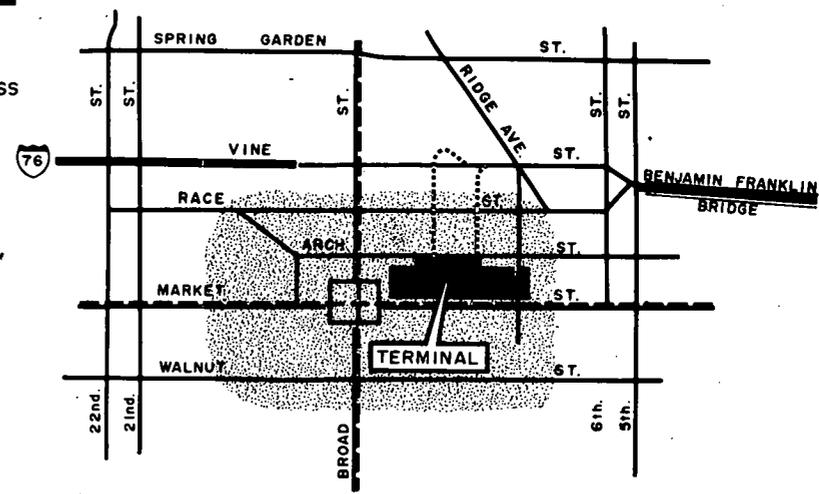
NEW YORK
PORT AUTHORITY BUS TERMINAL



CHICAGO
GREYHOUND TERMINAL



SAN FRANCISCO
TRANSBAY TERMINAL



PHILADELPHIA
MARKET ST. EAST COMPLEX



--- RAPID TRANSIT
..... TERMINAL ACCESS

Figure 94. Location of major CBD bus terminals.

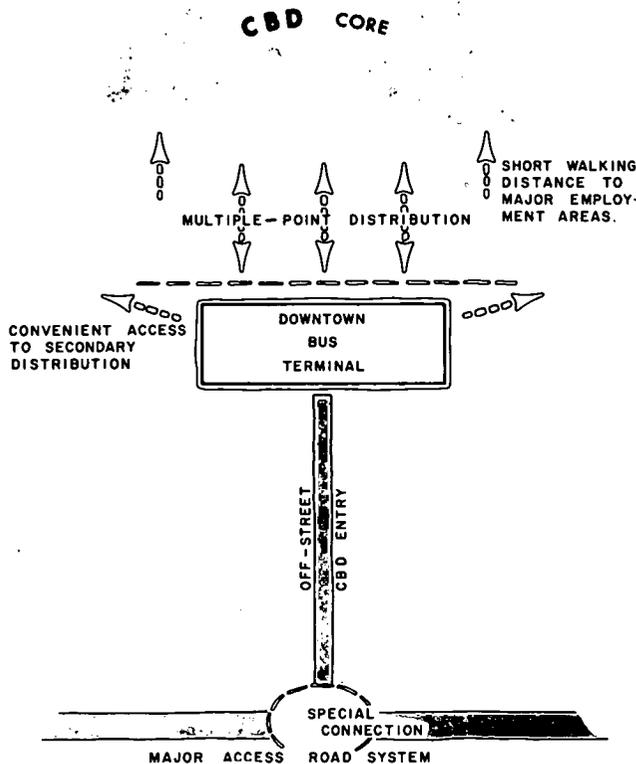


Figure 95. Generalized CBD terminal location concept.

3. Air-rights development of commercial uses (including accessory parking).
4. Separate commuter and intercity bus levels.
5. Separate commuter bus loading and unloading areas.
6. Parallel unloading areas with passing lanes for commuter buses.
7. Commuter bus loading areas in shallow sawtooth platforms.
8. Closely stacked sawtooth loading-unloading platforms with passing lanes for intercity service.

Bus Lanes and Runways

Bus dimensions and maneuverability influence roadway widths, platform shapes, column spacing, ceiling heights, and other design aspects, as follows:

1. Bus lane widths. Lanes 10 ft wide can be used for 8-ft-wide vehicles (9.5-ft lanes may be "forced" in some cases because of space restrictions or land values). Eleven-foot lanes are preferable where ample terminal space is available and are the minimum width for 8.5-ft-wide buses. Lane dimensions must be carefully developed where physical conditions fix their positions (e.g., concrete ceiling or columns).
2. Runway width. Double-width or two-lane runways should be provided wherever possible. They allow passing and overtaking of buses and provide temporary storage. This flexibility is important when (1) departure headways are short, (2) different bus companies or multiple bus

routes operate from a common platform, and (3) the terminal layout requires loading platforms to be relatively long.

Unloading bus roadways should be two lanes wide to enable empty or lightly loaded buses to proceed past a heavily loaded bus. This is essential where the unloading roadway is also the only terminal entrance road.

Double-lane roadways should be at least 20 ft wide for overtaking buses parked close to the curb; a 22-ft width is preferable, especially where bus maneuvering distances are limited.

3. Additional clearances and widths. Width and radii of driveway entrances and exits to runways should permit equipment to operate without extremely sharp turns. Actual swept-paths of equipment should be determined by careful tests, and additional clearance should be provided to allow for variations in driver performance and vehicle characteristics in daily operations. Reverse or compound curves should be avoided.

4. Ramping. Ramping to and from street roadways (or busway connections) should be sufficiently gentle to avoid rough treatment of equipment and passengers, particularly when buses are heavily loaded. Where this factor is involved, tests should be made with allowance for possible future vehicles with a longer wheelbase and overhang. Because of the longer wheelbase of buses, critical attention should be paid to vertical clearance where a sag curve exists, because required bus clearances will be greater.

5. Headroom and side clearance. Adequate headroom and side clearance must be provided where buses enter terminal buildings and other structures. Actual dimensions of current and possible future equipment should be checked before fixing critical dimensions. Side clearances should permit free movement of vehicles to avoid damage and delay. Minimum side clearance to all structures along the roadway should be at least 1 ft. Vertical clearance should be at least 12 ft for typical equipment. Special allowance should be made for use of terminals by deck-and-a-half or double-deck buses.

Loading and Unloading

Design and arrangement of bus loading platforms should be scaled to specific capacity and operational requirements, as follows:

1. Separate intercity and commuter services. Bus terminal design should separate commuter and intercity loading facilities. The two types of bus operation have differing service characteristics and platform design requirements, as follows:
 - (a) Intercity buses have long layover times to allow for passenger loading, unloading, baggage, and parcels. Berth capacity is low, typically about two buses per hour, and layover times of more than 30 min are common. Intercity bus services may operate twice the number of scheduled runs in peak periods, a factor that must be recognized in establishing loading platform capacities. Closely stacked sawtooth platforms should be provided. They allow greater passenger amenity because

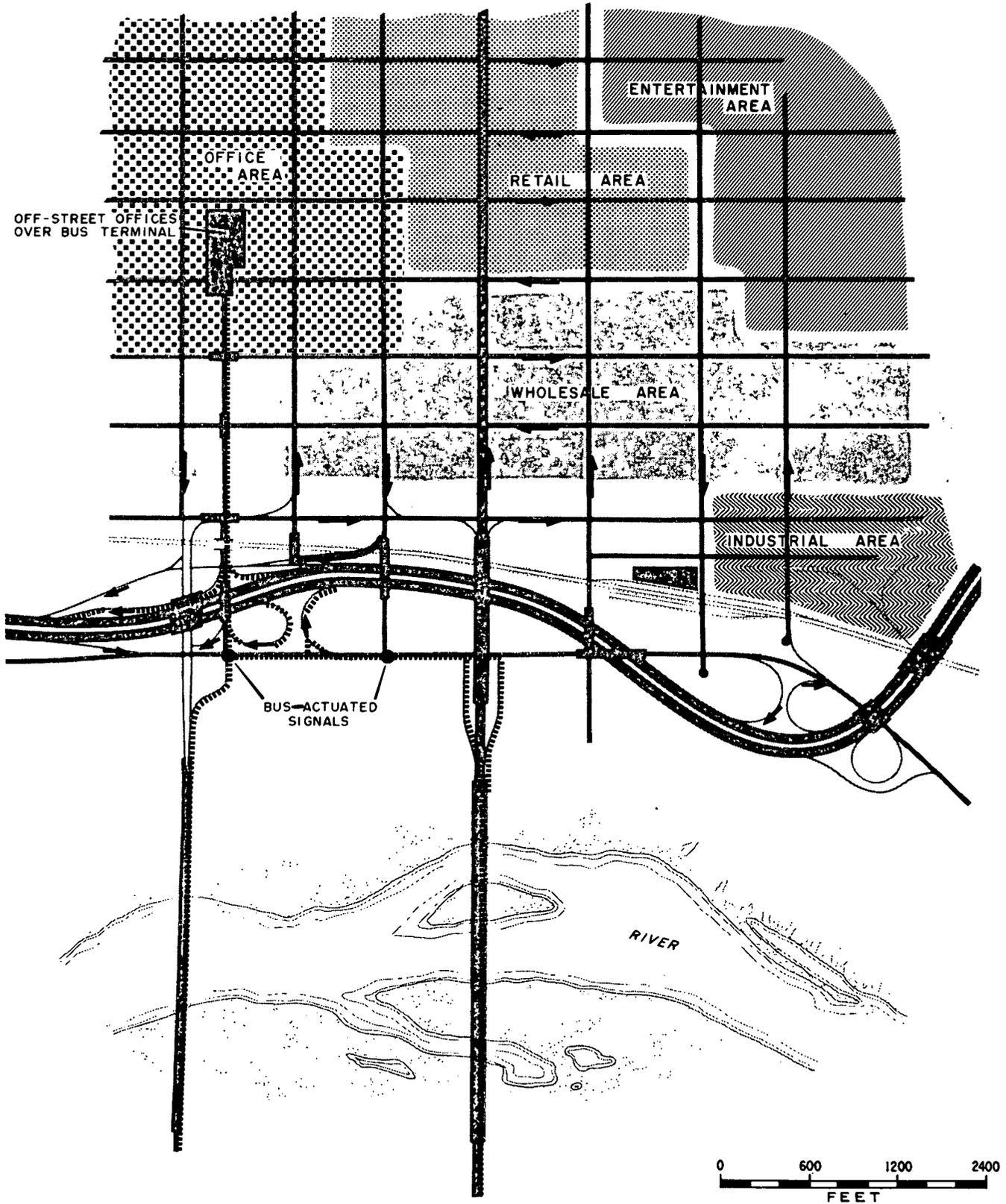


Figure 96. Illustrative CBD terminal location.

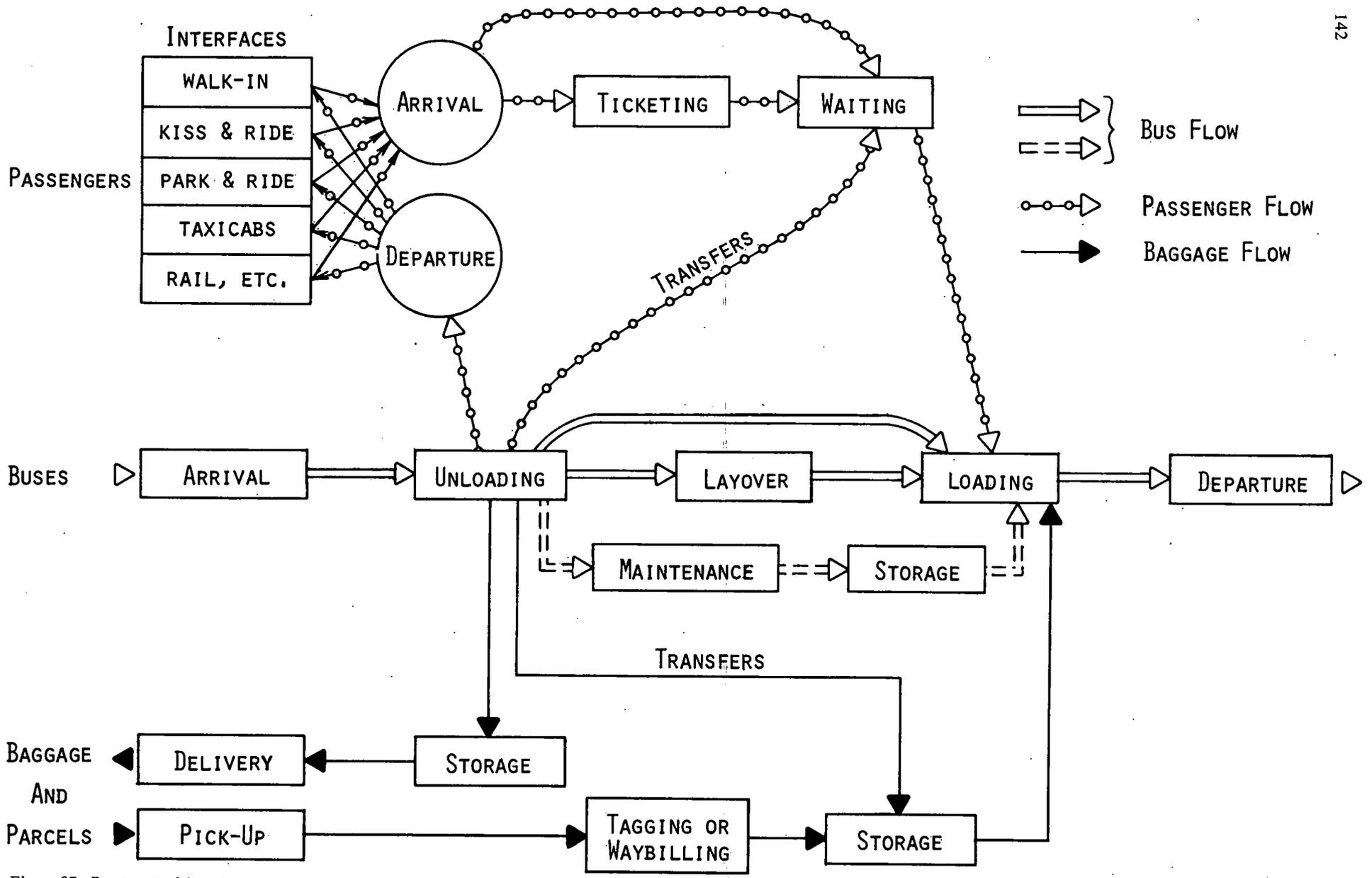
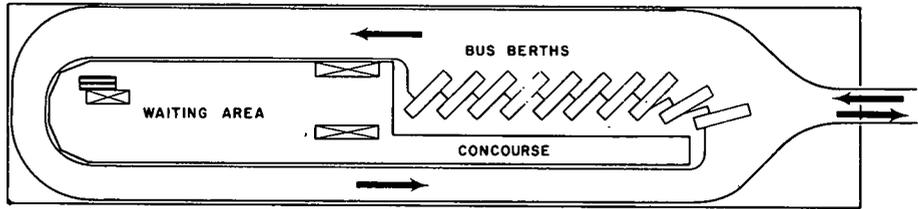
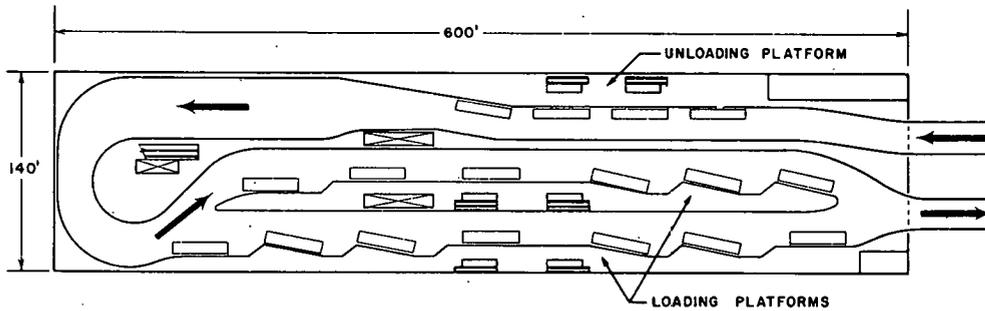


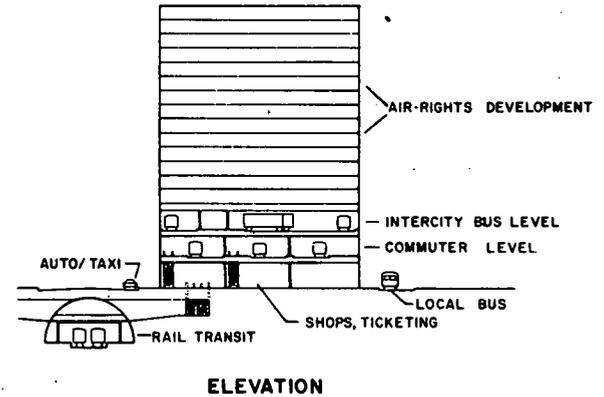
Figure 97. Bus terminal functions.



INTERCITY BUS LEVEL

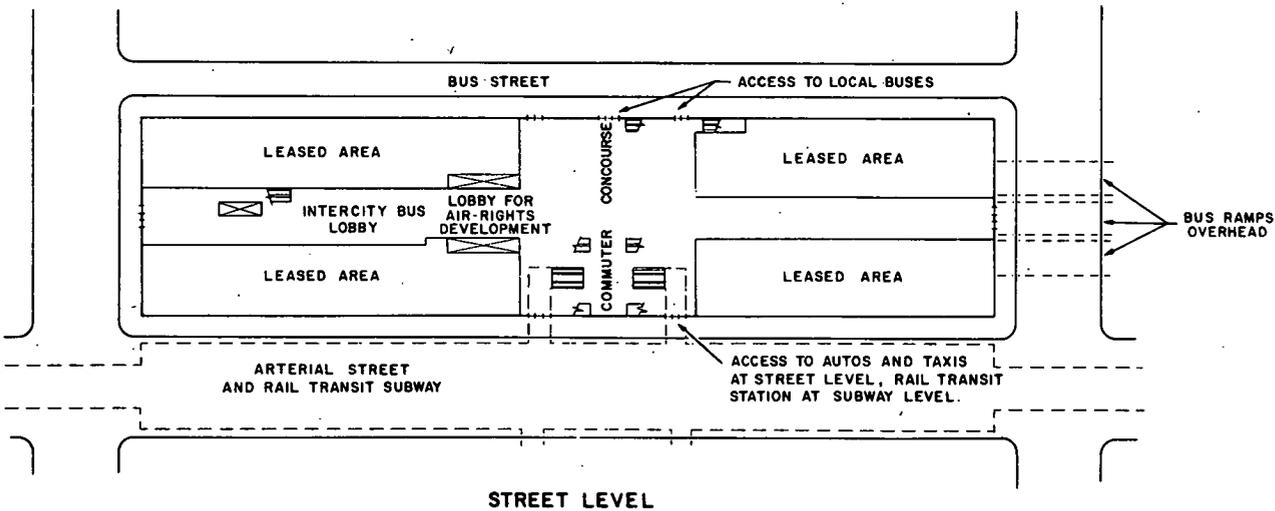


COMMUTER BUS LEVEL



ELEVATION

NOTE: BUILDING ENVELOPE DIMENSIONS MAY BE EXPANDED AS APPROPRIATE.



STREET LEVEL

Figure 98. Typical CBD bus terminal design, large city.

they can be readily enclosed and climate controlled.

- (b) Commuter buses need higher peak-hour capacities; however, their baggage and parcel requirements are rare. Passenger unloading and loading areas should be clearly separated to minimize passenger conflicts and reduce dwell times. This separation takes advantage of the ability to unload passengers at a faster rate (40 to 60 per door per minute) than the rate at which they generally can board (30 per door per minute or less). Accordingly, terminals should use linear or shallow sawtooth loading platforms that allow several buses to queue at the same platform and also allow pull-through bus movements. Berth capacities average from 8 to 10 buses per hour at both the New York and San Francisco terminals.

2. Berth requirements. Berth space requirements should give careful consideration to peak-period bus arrivals and departures (scheduled and actual) and passenger service times. Operating policies should be designed to maximize berth turnover, especially where a terminal serves a single carrier (viz., downtown busway distribution for a metropolitan transit authority).

The following factors will influence bus turnover:

- (a) Type of carrier. Long distance (baggage) vs short haul (no baggage).
- (b) Fare collection. Pay enter vs pay leave, cash vs tokens, prepaid tickets, etc.
- (c) Terminal type. Line terminal, partial load pickup and dropoff vs stub end terminal, full-load pickup and dropoff.
- (d) Berth configuration. Long multi-berth platforms (departure controlled by slowest loader) or bypass and sawtooth (departure on demand).
- (e) Type and volume of passenger arrivals. Batch, intermittent, continuous.
- (f) Route density characteristics. Light-density suburban (slow) vs heavy-density urban (fast).
- (g) Company operating policy. Wait for full bus (payload) or depart according to schedule regardless of passengers in bus.
- (h) Approach road reliability. Variability of traffic, capacity restraints.
- (i) Passenger service times and berth capacities. Values identified in Chapter Two reflect these factors. These service times can be used to estimate or simulate berth requirements for specific demand levels and operating practices.

A load of 50 passengers leaving a bus on a 2-sec headway would require less than 2 min to unload. Thus, if similar bus loads arrived on a 2-min headway, theoretically one berth would be adequate. In practice, however, schedule or running time variations would make two berths necessary, even under good operating conditions.

3. Unloading platforms. Unloading platform length should reflect (a) the number of berths required to accommodate peak unloading passenger volume and (b) bus pull-in, pull-out, and tail-out characteristics. Where a con-

siderable number of empty buses enter a terminal with need to stop at the unloading platform, a separate lane protected from the unloading runway maneuvers by a physical divider should be provided.

Another important factor is whether or not buses are allowed to stand or layover empty at the unloading platform as a holding area in lieu of proceeding to (a) the loading platform, (b) a separate holding area, or (c) directly out of the terminal. Such layovers generally should not be permitted except for small-scale operations.

4. Loading platforms. Loading platform space and arrangement is generally the most critical feature in terminal operation where rush-hour conditions predominate. Separate loading spaces for different main routes or destinations should be provided. Ideally, each commuter (or express bus) route should have its own loading area.

For a simple one-route operation, all bus berths generally can be located on one platform. However, where several bus routes are involved the number of routes or different-type services assigned to one platform should be held to the *lowest possible minimum*—preferably not more than two or three. (For example, if eight berths are required for a terminal accommodating eight different routes, four two-berth platforms handling two routes each can be operated more efficiently than two four-berth platforms handling four routes each.) Loading platform widths for simple operations may be as narrow as 8 ft; however, platforms requiring substantial queuing of accumulated passengers and involving considerable circulation should be at least 12 ft wide. Obstructions on the platform may require greater platform width.

For sawtooth positions, loading platforms parallel to the bus door should be at least 5 ft wide.

5. Loading queues. Queuing is necessary for most rush-hour conditions to (1) avoid crowding and disorder and (2) minimize use of available space. Queue layout and control should be based on careful study. Queue positioning should be clearly denoted by signs and by chain or pipe-rail barriers (stanchions).

On high-capacity multi-berth platforms, signing should help eliminate confusion by marking the starting point for a given queue (usually the bus loading point) and by indicating to approaching patrons the correct way to a given loading point or queue. Overhead-mounted signs are advisable wherever their installation is possible, thereby minimizing the number of posts and stanchions on the platform and providing increased visibility.

Where several queues must form for various bus routes on one platform, space utilization efficiency can be achieved by "folding" certain queues into a U rather than letting them extend in one long continuous line. Platform obstructions may necessitate variations in queue shapes. (It is important to allow circulation space for the platform starter or supervisor, preferably along the front edge of the platform.)

Patrons standing in a queue occupy an average of approximately 1.67 ft of lineal space each (a queue of 50 patrons will be about 83 ft long). A single queue can be confined within a space 2 to 2½ ft wide. A double queue

will require approximately 3½ to 4 ft between barriers. Nonrigid barriers (chains or ropes on stanchions) may be placed closer together than rigid railings.

6. Passenger platforms. Loading and unloading spaces and bus lanes may form one continuous flat surface for low-cost or temporary terminal layouts. Minimum control and guidance will require marked areas for passengers, preferably with stanchions and chains or railings.

For permanent installations, passenger loading platforms should be raised to (1) better define passenger and vehicle spaces; (2) provide drier, cleaner surfaces on which to stand; and (3) provide greater convenience and safety in stepping into or out of vehicles.

Platform elevations and curb heights of 5 to 8 in. are satisfactory. Door step heights on the vehicles that would use a terminal should be checked where higher platforms are considered. Passenger access at the ends of raised platforms (in one-level terminals) should be ramped on an approximate 12-to-1 slope rather than by an abrupt change.

Platform space designed exclusively for unloading should adequately accommodate passengers as they walk away from the bus; storage for passenger accumulation is not necessary. Width should be sufficient to permit free circulation past the exit door of unloading buses where the momentary accumulation of a few passengers may take place. Exit locations in a high-capacity terminal should be balanced to minimize walking distance and conflicting movements under peak-hour conditions.

Passengers should be protected from buses in multi-lane terminals by means of a guard railing or fencing along the back edge adjacent to the next vehicle lane. This barrier should have a minimum clearance of 12 in. from the runway. The bottom portion of the fence or railing should be equipped with a continuous shield to protect patrons' clothing from exhaust blast and, in the case of outdoor terminals, from roadway splash.

7. Platform shelters. Canopy-type shelters over loading areas on open lots are important for patron convenience and protection. They should provide vertical clearance equal to that for terminal doorways, thereby allowing canopies to extend a foot or more over the roof of vehicles for increased protection against rain. Supporting columns should be designed to minimize platform interference.

8. Vertical access. Vertical access should be provided by stairways, ramps, and/or escalators in multi-level terminals. Location at one end of a platform usually minimizes obstruction, particularly if the platform is relatively narrow. These locations result in a smoother one-way flow of patrons toward the various loading queues or loading points. Moreover, a stairway location at the forward end (bus exit end) of the platform enables arriving patrons to see bus destination signs readily.

Ancillary Facilities

Intercity bus terminals and large commuter terminals should provide ancillary pedestrian and bus service facilities. Passenger concourses should be enclosed, well lighted, and climate controlled. Restaurants, newsstands, stores, dispatchers' offices, and rest rooms should be provided. Design values include the following:

1. Waiting room. Space allowances range from 15 to 35 sq ft per person; 20 to 24 sq ft per person represents a satisfactory standard.

2. Ticket office. Each selling position should be allotted 50 sq ft. Although one position may be provided for each 25 to 30 waiting room seats, the number of positions usually should be based on personnel normally required plus anticipated extra personnel for peak periods.

Counters should be 42 in. high; cages or windows are not desirable.

Where urban express services dominate, fare collection may be via turnstiles, thereby simplifying cashier booth and ticket office requirements.

3. Baggage room. Baggage rooms, where provided, should comprise 10 percent of the total building area or contain 50 sq ft for each bus loading dock, whichever is higher.

OUTLYING TRANSFER TERMINALS

Outlying mode-transfer terminals form the interface between line-haul transit and neighborhood collection functions. They are usually found (1) along outlying rapid transit stations, (2) at ends of rapid transit lines, (3) at interchange points between major highway and rail lines, and, (4) along express bus lines. They recognize the need for auto and local bus distribution to express transit from areas where population densities are too low to rely on walk-in patronage.

Transfer points make it possible to reduce local transit services into the city center. This allows higher productivity of transit personnel and equipment and simplifies routing.

Transfer points permit wider station spacings on express transit routes, thereby improving line-haul operating speeds and efficiency.

Secondary distribution by automobile helps (a) increase the transit market, (b) reduce the extent of express transit lines, and (c) reduce downtown parking requirements. Parking at outlying express transit stations allows automobiles to serve areas where it is not economical to operate local bus service.

Terminal size and location should reflect (1) land costs and availability, (2) bus and street patterns, (3) traffic conditions, and (4) passenger interchange volumes, peaking characteristics, origins, and modes. Terminals should be located where substantial changes in population density form logical break-points for express service to the city center. Terminals located relatively near the city center in medium-density areas should emphasize rail-bus transfer. As population densities decline, parking becomes increasingly important. The proportions of park-and-ride and kiss-and-ride passengers increase with distance from the city center. Consequently, most existing rail-bus interchange takes place within 4 to 10 miles from the city center, whereas parking is emphasized at greater distances.

The transfer from car to bus, or from local to express transit, is a journey break-point that involves penalties in travel time and convenience. Thus, terminal planning, design, and operations should make transfers quick and easy.

Bus and passengers should have priority access to express transit station entry areas. Pedestrian routes to and from express transit lines should be direct and involve a minimum of stair climbing and vehicle conflicts. Terminal areas should be well ventilated, illuminated, and designed for easy surveillance; adequate passenger shelters should be provided. Facility location and design should be compatible with adjacent land uses. Bus routes and stops should be clearly identified. Approach road signing should be clear and consistent.

Local-Express Transit Interchange

Outlying transfer facilities between local and express transit should be developed at a smaller scale than downtown terminals. Designs should be simple, ancillary facilities should be kept to a minimum, and a relatively few bus bays should serve heavy peak-hour loads. Direct pedestrian access should be provided to major nearby generators such as office buildings, shops, and apartments.

Planning Criteria

Transfer between local and express transit lines is most applicable in medium-density areas. It is also essential at the outermost express transit terminals. Transfers generally should be limited to those areas where the practice is well established or where it can be achieved without reducing patronage.

Interchange facilities should be provided where the following general conditions apply:

1. Express transit and local lines intersect (i.e., a radial rail rapid transit route and a circumferential bus line).
2. There is a natural convergence of bus routes on approaches to the express transit station.
3. The transfer point is located at an outlying activity center generating its own traffic.
4. The transfer simplifies service scheduling and dependability over a direct bus routing. (For example, the breaking of one long route into two shorter routes).
5. Local bus routes can be rerouted to serve (or currently serve) express transit services.

The transfer between local and express transit services should save at least 5 min to the city center as compared with a single local service. It is essential to provide adequate bus access to the transfer point, including bus priority treatments.

Design and Operating Features

Interchange design should encourage direct convenient pedestrian access between local and express transit. Passenger interchange should be accomplished with minimum interruption to vehicle traffic and with minimum deviation of buses from their normal routes. Terminals should allow rapid passenger interchange and facilitate quick bus entry and exit. Increases in bus mileage should be avoided. Provision should be made for kiss-and-ride and park-and-ride where appropriate. Factors to be considered are:

1. Bus route options. Bus routes may operate through

or adjacent to a station or they may terminate there. Through routing of buses is common at interchange points and usually is better served by on-street stops with recessed loading areas. Outlying terminals provide convenient points for breaking up longer routes, especially where terminals are break-points in urban density patterns. Common practice is to reroute buses into the line-haul transit stations to encourage longer trips by rapid transit.

2. Special bus facilities. Off-street bus loading areas or loops should be provided when there are more than 12 to 15 buses per peak hour terminating at a single stop and where the stop serves as a staging area for buses.

There is no "typical" bus terminal layout. The amount of bus traffic, possible points of street access, site configuration and frontage area, freeway interchange design, and topographic relationships dictate the layout of specific bus facilities. Loading arrangements may be compressed or elongated, and may involve loading parallel or perpendicular to the express transit alignment.

Designs should enable terminating buses to (1) unload without delay, (2) pass through a holding area where they can wait if their normal berth is occupied, and (3) proceed to a loading berth for normal layover and boarding. Unloading passengers should have short, direct access to the station lobby. Buses should unload and load at the same point only where bus volumes are relatively light or where buses run through the station.

3. Terminal capacity. The number of bus berth positions should be based on the maximum number of buses in the terminal at any given time. Berthing requirements will depend on peak-hour passenger volumes and berth turnover. Current experience indicates 10 to 15 loading positions (20 to 30 bus berths) as an upper limit for most urban conditions.

Chicago's 95th Street (Dan Ryan) Terminal has 22 berths, of which 14 are normally used for loading; its Jefferson Park Terminal has 14 loading positions in addition to curbside unloading areas. The most intensively used transfer station, the Eglinton Terminal of the Yonge Street Subway in Toronto, has 13 loading berths accommodating two to four buses each. Philadelphia's 69th Street Terminal has 10 loading berths and 6 unloading berths, some of which are shared with suburban streetcars.

4. Terminal orientation. Local bus service in off-street loading areas generally should circulate counterclockwise. This will bring bus passengers to major station access points without requiring pedestrians to cross bus routes. Maximum separation of pedestrian and vehicle paths should be provided.

5. Berth capacity. Bus layover times should be minimized during peak periods with 5-min (loading) dwell times a desirable maximum. This allows a peak berth turnover of about 10 buses per hour.

Berth capacity can be increased by "covered transfers," which eliminate fare collection upon boarding local or express transit services. Under these free transfer conditions, loading berth capacity can approach 20 buses per hour (as at the Eglinton Terminal in Toronto).

6. Berth design. A specific loading area should be designated for each bus route. Heavily used bus routes may

need two berths, whereas low-headway lines may double-up at a single berth. Bus platforms may be either of the parallel pull-through type or of modified sawtooth design. A primary design requisite is the need for buses to load parallel to curbs or walkways.

7. Street access. Access should be directly from arterial streets. Street widenings, reserved bus lanes, special bus turn lanes and signals, or even bus grade separations, may be provided to expedite bus flow and minimize conflicts. (Reserved bus lanes are provided on approaches to Toronto's Eglinton Station; a special left-turn bus lane and traffic signal is provided at Chicago's Jefferson Park Terminal; and a trumpet interchange is provided at Toronto's Warden Terminal.)

Space between expressway lanes and service roads can be used for bus interchanges where express transit is located in the freeway median. The initial freeway design should provide for such facilities. (Chicago's 69th and 95th Street Bus Bridge Terminals incorporated bus facilities in the basic freeway design as a result of advanced planning and right-of-way reservation.)

8. Cost minimization. Costs will vary with specific urban conditions. However, every attempt should be made to minimize costs. Costs equivalent to \$75,000 to \$100,000 per loading berth at 1973 price levels represent a desirable objective.

Design Examples

Typical interchange designs illustrate these guidelines:

1. Arterial street bus-rail interchange (Fig. 99). The most common type of modal interchange involves bus turnouts on arterial streets that cross express transit lines. Turnout length should be based on application of the criteria set forth in Chapter Five. Turnouts are located adjacent to station entrance and exit points. The station entrance is located on the side of the street that allows direct pedestrian entry from the major direction of approach. An auxiliary exit can be provided on the other side of the street to minimize midblock pedestrian crossings. A median island with fence may be desirable to preclude midblock pedestrian crossings.

2. Busway-local bus interchange (Fig. 100). Local buses circulate in a clockwise pattern crossing the busway at a signalized intersection. Direct platform access is provided to and from the major travel direction. The at-grade bus intersection provides opportunity for entry into the busway and direct express service to downtown. Considerable length is required to negotiate grade changes and simultaneously allow buses to stop in level areas.

3. Typical bus terminal within freeway interchange (Fig. 101). A single bus bridge in conjunction with a pair of new bus runways adjacent to frontage roads alongside a depressed freeway provides direct access for arterial and freeway buses. Buses circulate clockwise around a central express transit station. Special bus-actuated traffic signals allow bus entry and exit from adjacent arterial streets. Where a secondary street bridge across the freeway is located within 500 ft of the arterial overcrossing, it may be used in lieu of the special bus bridge.

Park-and-Ride Facilities

Park-and-ride facilities are part of a strategy designed to intercept automobiles at outlying locations along express transit lines. They are essential at all express transit stations in outlying areas, especially where population densities are too low to support suburban bus services.

They involve the transfer of parking from the city center to outlying areas, thereby reducing CBD commuter parking and land requirements, and reducing core-bound peak-hour highway travel with its attendant air quality and environmental implications. They permit principal portions of downtown trips to be made by public transport without reducing passenger convenience or increasing walking distances. They often attain more attractive time-distance relationships to the urban core than those afforded by parking facilities on the fringes of downtown. They can substantially expand the catchment areas of the express bus service.

They also can simplify bus routing patterns, reduce bus mileage in low-density areas, and improve express service reliability by enabling the automobile to provide neighborhood collection and distribution. Express buses can operate predominantly in line-haul services with increased trunk-line frequency, and simplified downtown distribution.

Outlying parking facilities are provided in major cities with rail transit (Boston, Chicago, Cleveland, New York, Philadelphia, Toronto, San Francisco); individual facilities range upward from 200 spaces in Chicago to 2,000 in Cleveland. Parking is provided along express bus routes in many cities (notably, Milwaukee, New York, St. Louis, Seattle, and Washington, D.C.); individual facilities range upward to 1,500 spaces with lots in the 100- to 300-space range common. Express service to most of these lots has been restricted to peak demands in contrast to rail-oriented lots, which usually have transit service throughout the day.

Planning Criteria

Many opportunities exist for bus-oriented change-of-mode parking where free spaces are available near suburban bus stops, both on- and off-street. Provision of off-street parking can increase assurance of parking spaces, make possible extra security protection, increase convenience by reducing walking distance, and achieve patron concentrations that can help sustain express bus service, including line-haul bus priority treatments. Environmental quality and energy conservation objectives, coupled with community support of commuter bus services, have increased the potentials for outlying bus transit parking facilities.

The decision to park-and-ride is largely determined by the weight commuters place on the inconvenience and time lost in change-of-mode parking versus the higher parking costs and the strain of driving in highly congested traffic. Outlying bus-oriented parking has generally failed to attract bus passengers in medium-size communities where downtown parking is relatively inexpensive, and in larger cities when the park-and-ride trips do not compete with other modes from a cost-and-time standpoint.

Outlying change-of-mode parking facilities have greatest potential applicability in urban areas where car travel to the

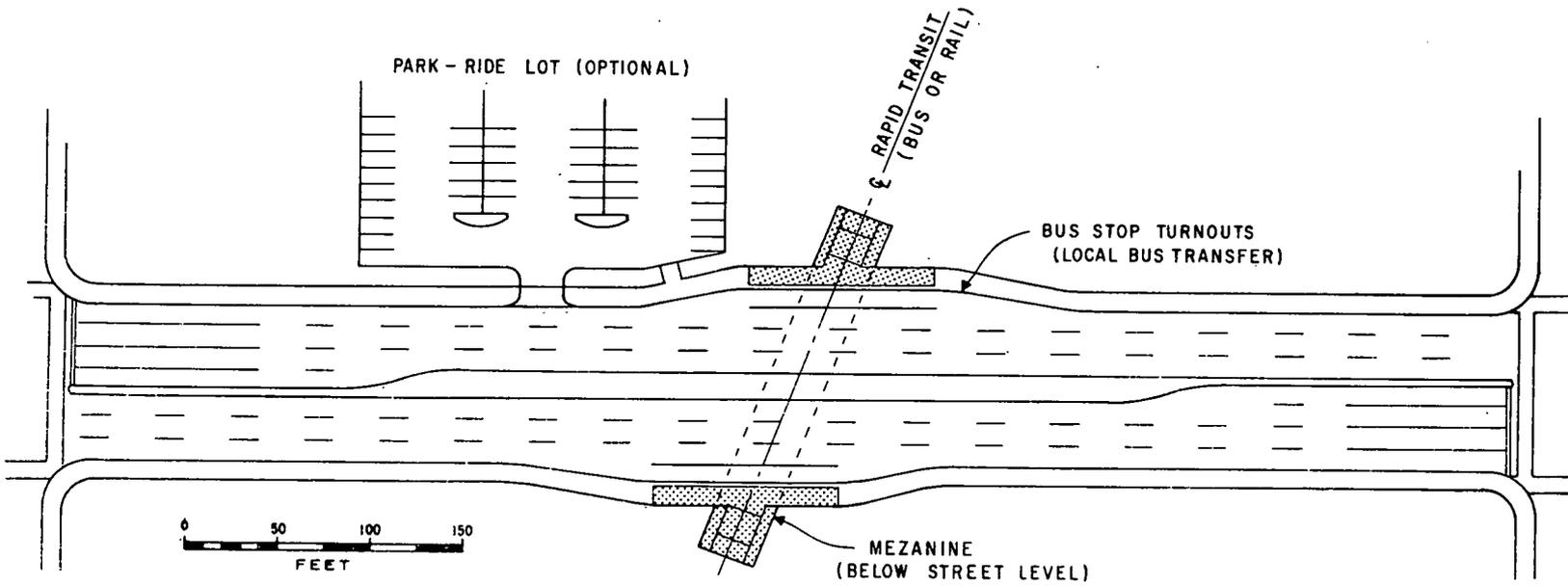


Figure 99. Typical arterial street bus-rail interchange.

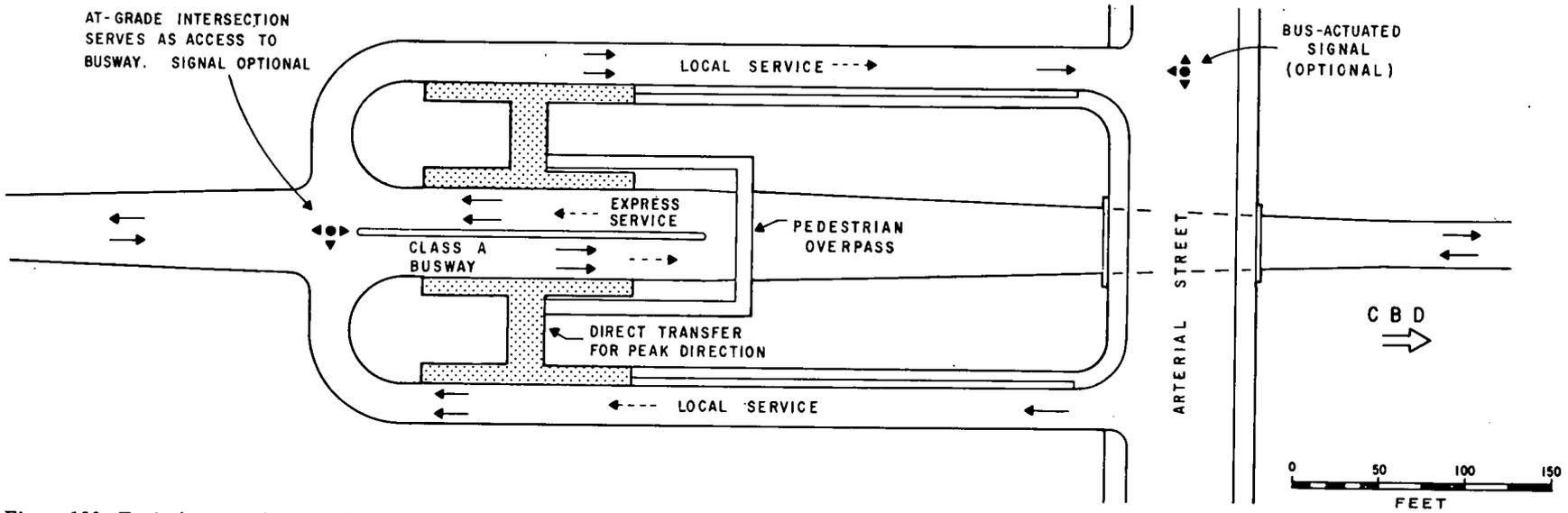


Figure 100. Typical express-local bus interchange.

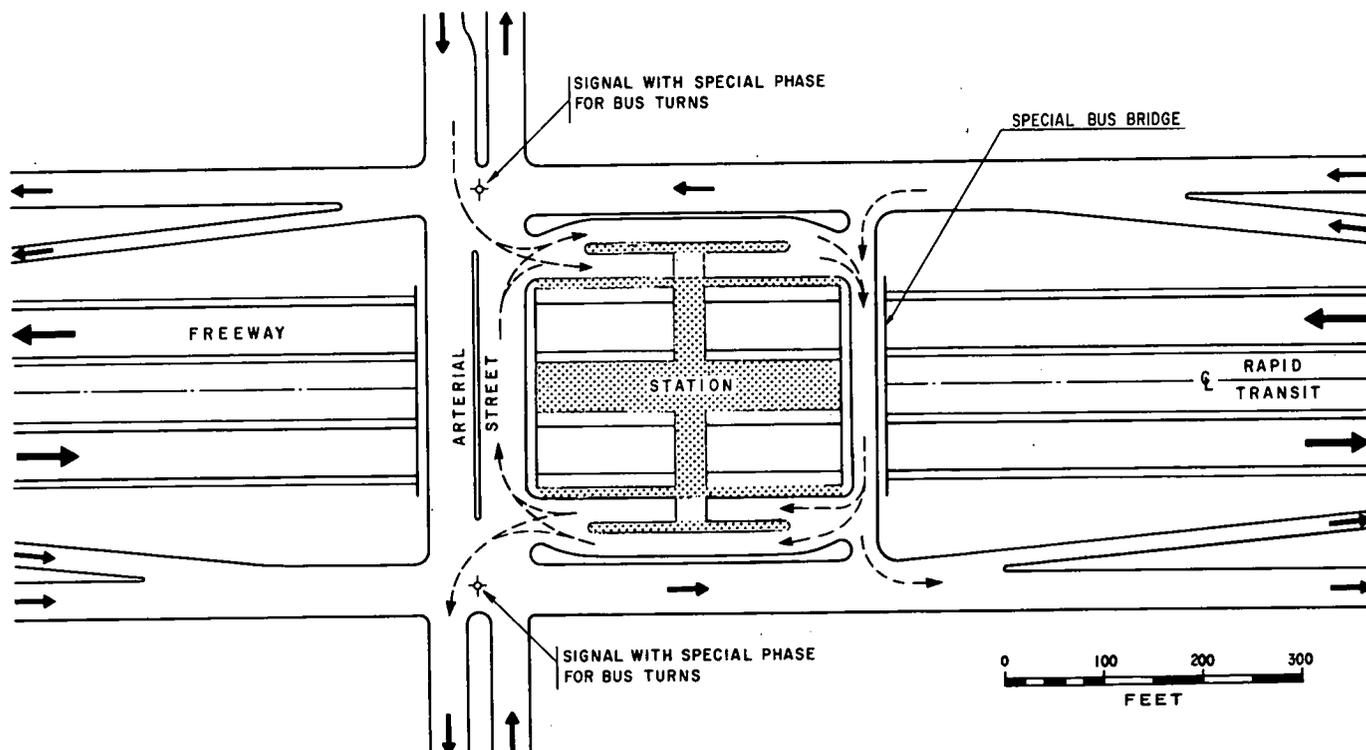


Figure 101. Typical outlying bus terminal within freeway right-of-way.

city center is inhibited and where daily parking costs average \$2.00 or more. Successful outlying parking requires fast and frequent line-haul express transit service to the city center, short walking distances between parking lots and transit stops, easy access to and from major roads, and ample free or low-cost parking.

Outlying parking should be provided wherever the multimodal trip to the city center is cheaper and faster than the trip by car. Fast and frequent express bus service to the CBD, competitive with car travel times and accelerated by bus priorities wherever possible, is essential for successful outlying parking. Other factors to be considered are:

1. Transit fares and parking fees should be competitive with the cost of auto commuting. They should be cheaper than driving to the CBD for at least two occupants in an auto based on \$0.05 per mile variable costs plus tolls and typical all-day parking costs within the CBD.

2. Travel times should be less than the corresponding time to drive to and park within the CBD. Time savings should exceed 5 min to overcome normal passenger reluctance to change modes.

3. Bus service from park-and-ride lots should operate at frequencies of at least six per hour during peak periods. Headways of 30 min or less are desirable during midday hours. Although 10-min peak-hour frequency represents a desirable minimum service standard, other factors (such as low fares; fast, direct service; and a convenient lot) might allow frequency to be reduced.

4. Change-of-mode parking facilities should be devel-

oped where land is relatively inexpensive, where environmental impacts are minimal, and where the rest of the journey by car is congested.

Meeting these broad criteria suggests that outlying park-and-ride facilities generally should be located at least 5 to 8 miles from the downtown area.

Outlying parking provides a viable alternative to suburban feeder bus service. The break-even points between commuter bus service and open-lot parking are shown in Figure 102 for various land costs and passenger trip lengths. This tradeoff model is based on the comparative annual operating and capital costs. It assumes four one-way bus trips per inbound passenger served; no off-peak utilization of buses; and 12-year debt service periods for buses and parking lots (see Appendix B for detailed assumptions).

The break-even points vary, depending on car occupancy, land costs, and bus operating costs. Thus, for land costs of \$5 per square foot, bus service is more economical for distances under 1.5 miles, and more costly for distances over 2.5 miles, depending on the specific cost parameters involved.

Outlying parking appears more economical than local bus service when land costs are low and travel distances to line-haul bus service are long. Conversely, in highly urbanized environments with high land cost; (as in mid-Chicago, Philadelphia) feeder bus service is more economical. The model indicates that parking along bus lines is preferable to extensive feeder bus service or diffuse express-local bus operations in low-density areas.

Access and Location Principles

Selection of sites should promote the larger community transportation objectives of (a) improving mobility and convenience for travelers, (b) promoting desirable land-use development, (c) minimizing direct public expenditures for transportation, and (d) minimizing adverse impact on local communities and neighborhoods.

The optimum distance of intercept parking points from the city center depends on (1) locations of major topographic barriers as they relate to the center city, (2) street convergence patterns, (3) line-haul express transit system configuration, (4) land development intensities, (5) land availability and costs, and (6) parking costs. Other factors to be considered include:

1. Road access. Park-and-ride facilities should have good highway access. They should intercept motorists prior to points of major route convergence and congestion. Locations near junctions of major radial and circumferential routes will increase accessibility from tributary areas.

Access to park-and-ride areas should be upstream from points of freeway convergence or interchange where peak-hour congestion is typical. Where there is no existing or

anticipated congestion, facilities may be located downstream of the junction to directly serve approaching inbound motorists.

Facilities should be located as far from downtown as practical to remove the maximum number of vehicle-miles of travel (VMT) during the peak traffic period. Eliminating the last mile of a 6- to 8-mile auto trip to the city center does not appreciably reduce radial highway capacity requirements. Moreover, increasing the parking supply on the fringes of downtown in conjunction with improved access to the core area might divert passengers from parallel line-haul transit routes.

Facilities should be clearly visible from major approach roads. Ideally, sites should border radial or circumferential freeways.

Access ramps and roadways should lead directly to parking areas without excessive interruptions from traffic signals, curb parking interferences, or frequent commercial curb cuts.

Facilities should have direct or nearly direct access from major streets. Park-and-ride traffic should not filter through residential neighborhoods. Access points should minimize

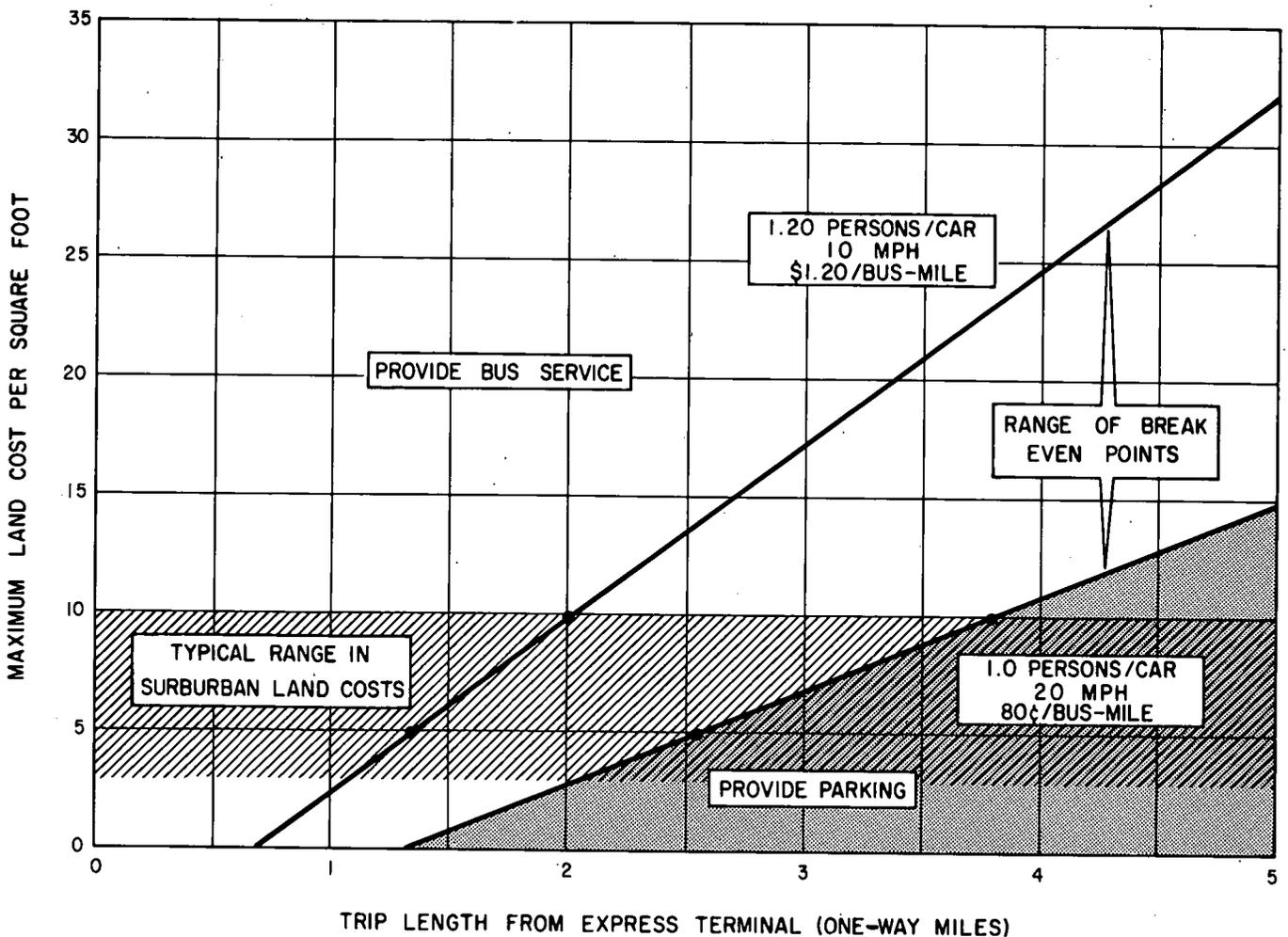


Figure 102. Parking and local feeder bus service costs in relation to trip length and land costs.

interferences to arterial street traffic; uninterrupted or steady-flow entrance traffic is desirable.

Access routes should be related to principal patron directions of approach. Park-and-ride traffic should be equitably distributed over boundary routes and should not be unduly concentrated in a single approach direction.

Circulation patterns should be clear and consistent. Patrons should arrive and depart via the same basic route. This will simplify trip orientation and encourage kiss-and-ride patronage.

2. Bus service. High bus speeds are necessary to attract patrons, reduce bus-hours of travel, and allow more than one round trip by each bus driver within the peak period.

Express bus travel from the park-and-ride station to the CBD must be free-flowing—either in mixed traffic, in an exclusive lane, or on an exclusive bus roadway.

Park-and-ride facilities should be located at major express bus stations. The last stop of an express bus route inbound toward the CBD is usually a desirable location.

Express shuttle bus services to the city center are desirable. Efficiency in bus operations is obtained by filling buses at the parking facility and running them nonstop to the terminal. At the same time, commuter travel times are minimized by eliminating intermediate stops.

Bus schedules should be based on a maximum load factor of 85 percent. Commuters should have bus seats available within 5 min of their arrival at a bus stop.

3. Land availability and use. Outlying bus parking sites should have adequate land for existing and future needs. Sites should be compatible with adjacent land uses, should not adversely impact nearby environments, and should achieve a reasonable level of use relative to development costs. Site selection should give priority (in order of importance), to (1) land currently in parking use, (2) undeveloped or unused land now in public ownership, (3) undeveloped private land, and (4) developed private land. Site selection should include an environmental impact assessment.

Acquisition and construction costs should be kept to a minimum consistent with other sites. Total development costs of \$2,500 per space are reasonable, where it is infeasible to provide additional radial freeway capacity.

Parking lot development is generally preferable and should allow for provision of future decks. Parking garage construction, however, may be appropriate where land supply is limited, demands are high, and multi-use developments are contemplated.

Development costs and environmental impacts sometimes can be minimized by jointly using existing parking facilities in shopping or recreation centers, because peak use at these centers normally does not coincide with commuter peaks. Commuters may use remote shopping center parking spaces that are used by shoppers only during evenings and Saturdays.

Land-use attractions at outer intercept terminals could help balance patronage and stimulate reverse riding. They may not, however, be applicable in conjunction with large-scale rapid transit parking developments.

Potential sites should be reasonably flat and well drained so that grading, paving, and drainage can be provided at

minimum expense. Ideally, the site should have adjacent land available to allow for future expansion.

To enhance acceptance of parking lots near residential neighborhoods, provision may be made for recreational use during weekends and evenings. Some lots may also be located to serve nearby recreational parking needs.

Parking Demands and Capacities

The amount of parking at any given location depends on its traffic potentials, street system capabilities, and the location of reasonably priced land. More parking space is generally needed in low-density suburban areas where walk-in and feeder bus traffic is minimal. Where space is limited, priority should be given to kiss-and-ride patrons.

Outlying parking potentials should clearly recognize (1) CBD growth patterns, (2) constraints to increasing CBD parking supply, and (3) extension of express transit services into auto-oriented areas. Some factors requiring attention are:

1. Demand estimates. Future CBD parking demands should be based on trend projections and the proportion of these demands that can (or will) be accommodated in the CBD should be clearly identified. The remaining demands should be transferred to outlying locations along express transit extensions, or to existing transit stations where perceptible parking deficiencies exist. The spaces should further be allocated based on the relative future CBD trips from each suburban sector.

A complementary, alternative approach involves estimating the patronage of express transit extensions (or service improvements). One parking space can be provided for every two to four inbound passengers in suburban areas (the Lindenwold and Cleveland experiences).

Stochastic multi-modal choice models can be used to estimate parking demands, in conjunction with major express transit services.

Studies of existing outlying modal-transfer parking show average daily turnover of 1.1 cars per space, and about 1.2 transit trips generated per parked car. Kiss-and-ride (pick up and drop off) may represent 20 to 40 percent of total peak-hour station arrivals. Median distances of 3 to 4 miles for park-and-ride passengers and 1 to 2 miles for kiss-and-ride patrons are common at existing park-ride locations.

2. Facility size. Parking capacities should be scaled to approach roadway capacities as well as to parking demands and bus service potentials.

Major rail-oriented park-and-ride facilities should approximate 1,000 spaces; 2,000 spaces represents a realistic maximum. These facilities can support all-day transit service and draw patrons from a large catchment area. Larger car parks usually require costly structures, create peak-hour access problems, and involve excessively long walking distances.

An optimum size range for bus-oriented lots is 400 to 700 spaces; 1,200 spaces is a realistic maximum.

A lot should provide about 400 cars to justify 10-min bus service during the peak hour. This relationship assumes that (a) bus service is provided exclusively for the lot,

(b) typical peak-period loadings of 45 persons per bus will transport 270 passengers (200 auto drivers and 70 passengers), and (c) 50 to 60 percent of the daily arrivals are in the peak hour.

3. Parking availability. The design load factor at each park-and-ride facility (i.e., the number of autos simultaneously parked divided by the number of spaces) should not exceed 80 to 90 percent. This will assure commuters a reasonable chance of finding parking space. If there is no available "back-up" space on nearby local streets, the design load factor should not exceed 70 to 80 percent.

Design and Operating Features

Bus parking facilities should reflect the following design guidelines:

1. Site orientation priorities. Internal site design should minimize pedestrian travel and give priority to interchanging transit passengers. The following location priorities are suggested: (a) bus loading-unloading, (b) taxi loading-unloading (may intermix with buses or with cars), (c) passenger car unloading (drop-off), (d) passenger car loading (pickup) (kiss-and-ride), (e) bicycle parking, (f) short-term parking, and (g) long-term parking. Pedestrian-vehicle conflicts should be minimized within the more active areas (i.e., a, b, c).

2. Movement separation. Separation of car and bus movements is desirable. Exclusive bus access ramps should be provided where conditions warrant; however, in all cases buses should be able to enter, load, unload, and exit with minimum delay. At stations with low traffic volumes (less than 12 to 15 terminating buses per peak hour) buses may share parking area roadways with the kiss-and-ride and park-and-ride traffic.* For greater volumes, buses should use special lanes or roadways for unloading, waiting, and loading. All bus roads should permit passing of standing buses, and buses never should be required to back up into station areas.

3. Kiss-and-ride. Kiss-and-ride facilities should be provided at each outlying parking area. Twenty to 60 spaces represent a reasonable range. The area should involve drop-off close to the station entrance, plus a holding or short-term parking area for passenger pick-up. It should be clearly separated from commuter parking areas, but it may be used for midday parking if properly controlled.

4. Parking lot design. Park-and-ride requirements should be based on approximately 400 to 500 sq ft per parking space. These values account for parking stalls, pedestrian paths, circulation roads, and landscaping; they should be increased where irregularly shaped land parcels or unusual circulation patterns are involved.

Facilities should be designed for self-parking. Right-angle parking is preferable, although angle parking may be used where space is restricted. Ninety-degree parking spaces should be 9 ft wide and use a unit parking dimension of 62 to 65 ft.

Parking aisles should be oriented normal to the bus boarding areas, thereby allowing their use by pedestrians and minimizing the need for special walkways.

Where facilities exceed 500 spaces, parking roads should be clearly separated from bus and kiss-and-ride drop-off areas. One access lane should be provided for every 400 to 600 spaces.

Barriers should be provided between car rows only where it is desirable to introduce landscaping or to break up the scale of (compartmentalize) large lots.

Landscaping should be massed rather than scattered throughout the lot. This yields a better visual effect and makes snow removal and maintenance easier. Landscaped barriers at least 10 ft wide should separate the parking area from adjacent streets, although special cases, particularly in residential areas, may require greater width. Vertical screens or fences may be needed to protect the privacy of neighboring parcels. Landscape spaces and materials should be designed with snow removal, maintenance costs, and vandalism in mind.

Parking areas should be fenced, well lighted, clearly marked, and appropriately signed. They should be operational during all weather conditions.

Illumination should approximate 0.5 footcandles at the ground level.

Ideally, parking facilities related to bus operation should be free. However, where the modal-interchange point is near a commercial center, a small number of pay (preferably metered) spaces should be provided closest to boarding areas.

5. Pedestrian circulation. Pedestrian walking distances from car to bus stop generally should be less than 400 ft. Walking distances that exceed 1,000 ft from station entrance points (the absolute maximum) tend to discourage use.

Principal loading areas should be sheltered, and a covered walkway should be provided for the remaining distance to bus (or train) boarding areas. Protection against rain, with a 14-ft clearance over the bus roadway, should be provided. In northern climates transparent shelters are desirable. Walks across busways and major roads should be clearly marked.

Collector lanes in parking lots should provide direct pedestrian routes. The coefficient of directness (the length of path divided by the aerial distance) should not exceed 1.4, and preferably be kept to 1.2 or 1. Sidewalks should be at least 5 ft wide for traffic up to 70 persons per minute, plus 2½ ft for each additional 35 persons per minute. A minimum walkway width of 12 ft should be provided next to bus loading zones.

6. Approach signing. Large, clear, distinctively identifiable signing is essential on each major approach to bus parking facilities. Advance signing should call drivers' attention to the site and should be consistent with traffic safety and environmental standards. A special color scheme (such as gold on blue) may be appropriate.

Signing should include (a) site location, (b) parking costs, (c) type and destination of transit service afforded, (d) periods of operation, (e) transit headways (optional), and (f) expressway exit number. Trail blazers could lead the traveler to the parking facility entrance. Internal signing should delineate park-and-ride, kiss-and-ride, and bus routing.

* Source: Massachusetts Bay Transportation Authority.

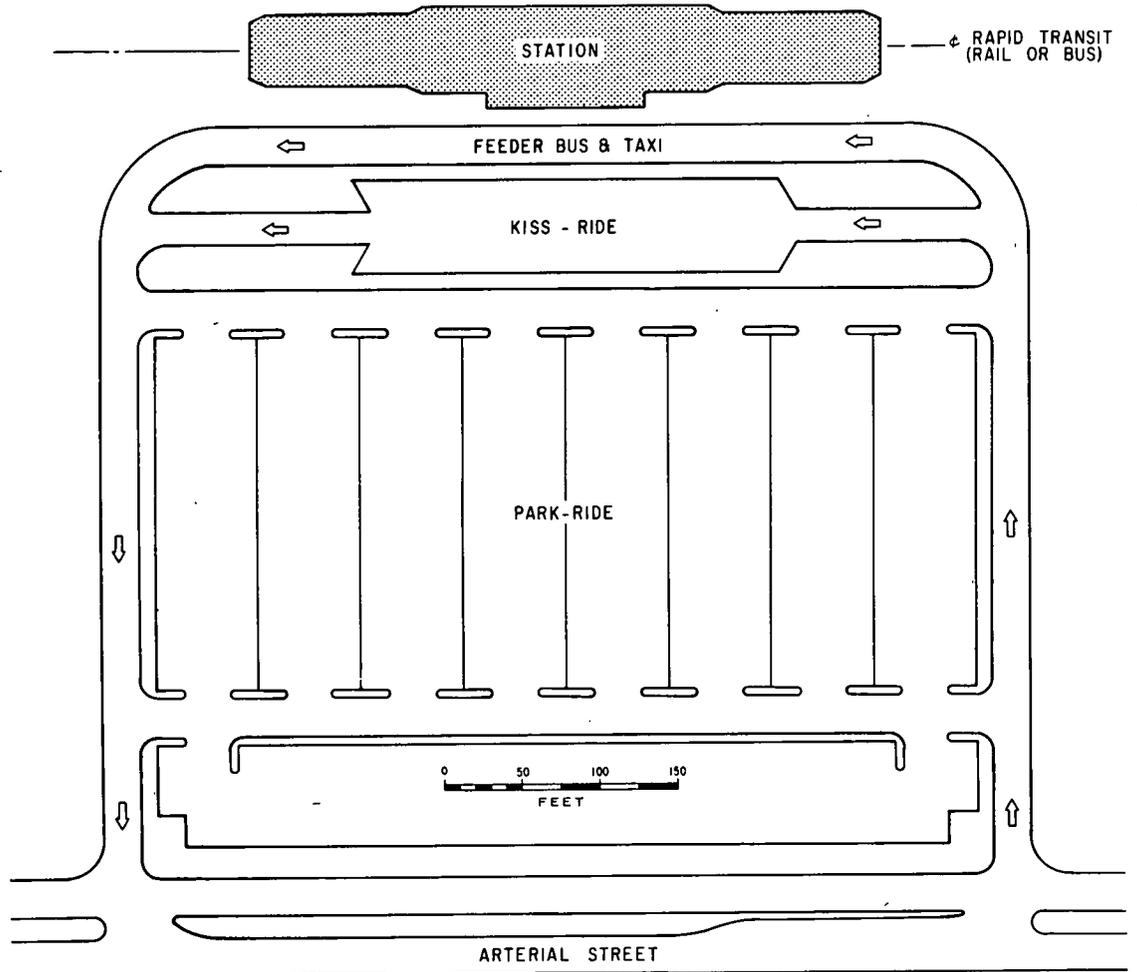


Figure 103. Typical park-and-ride lot.

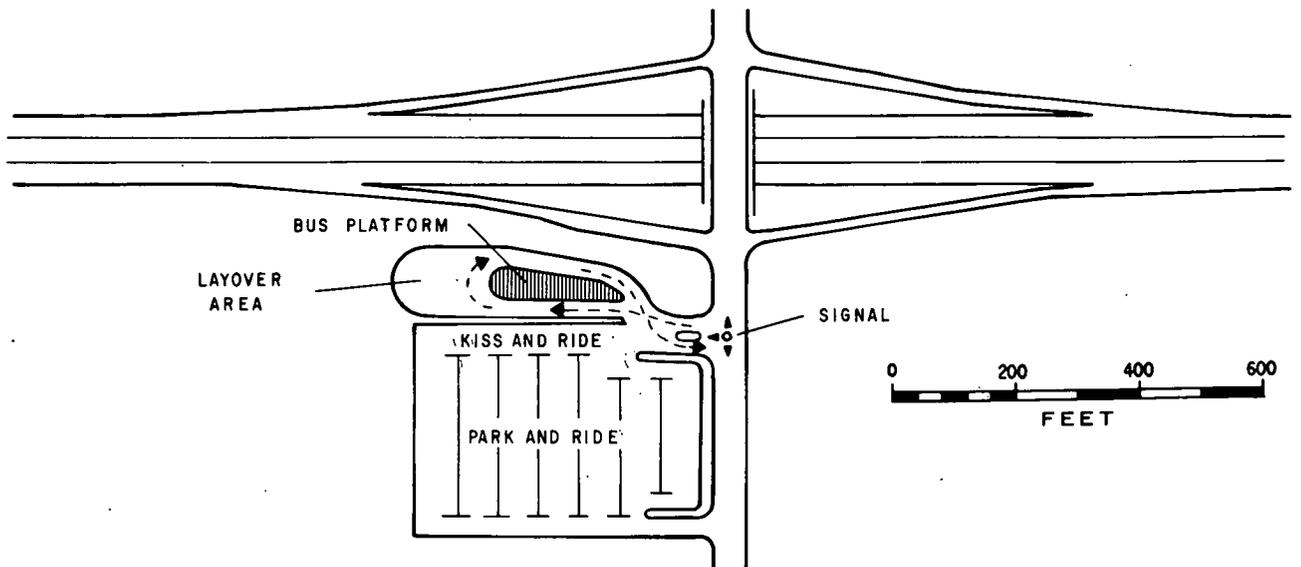


Figure 104. Typical freeway park-and-ride lot at diamond interchange.

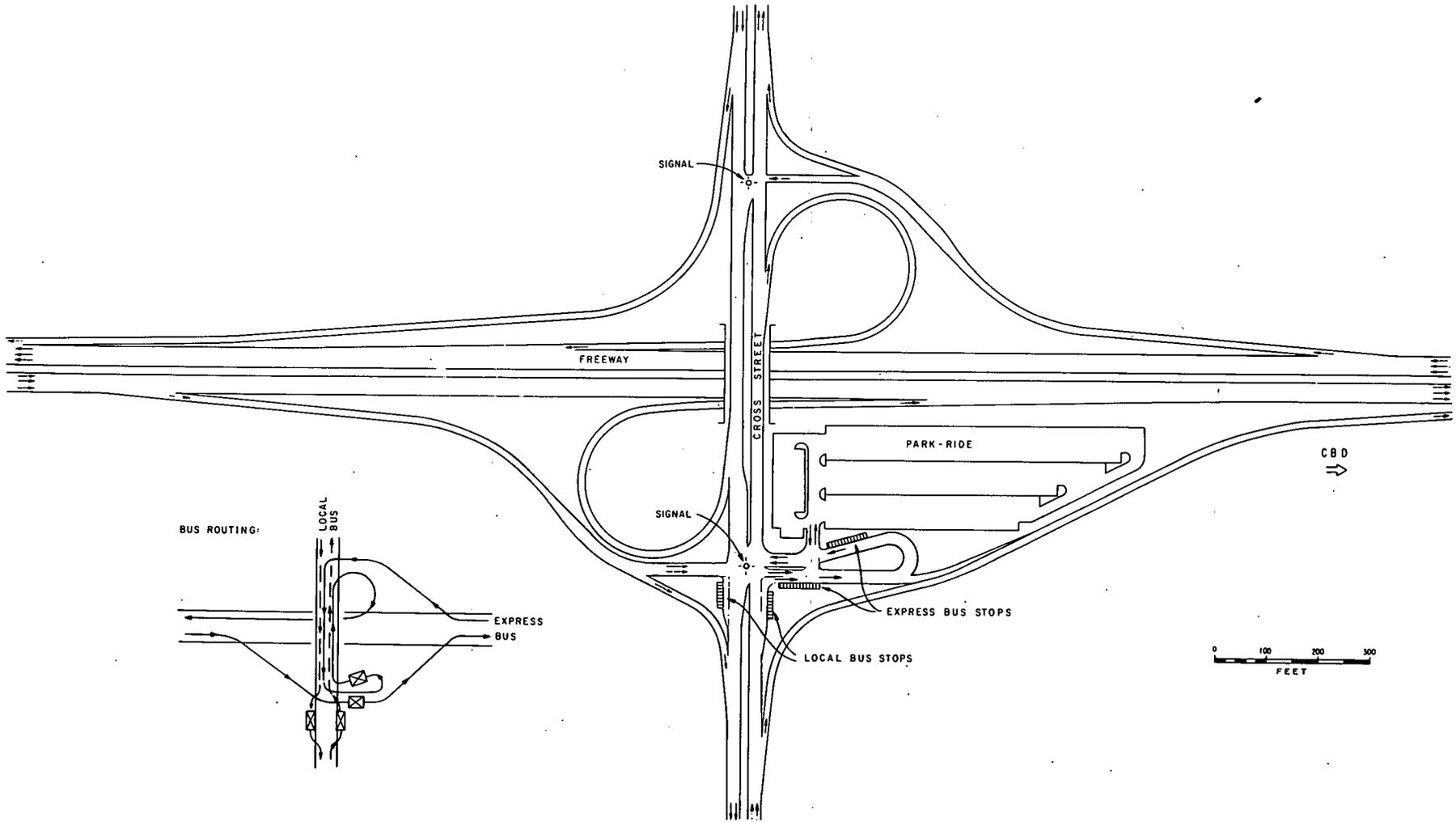


Figure 105. Typical freeway park-and-ride lot at partial cloverleaf interchange.

Design Examples

Typical designs illustrate the preceding principles, as follows:

1. Typical park-and-ride lot. Figure 103 shows how bus priority arrangements and parking lot orientation relate to line-haul busway or rapid transit services. Priority access is provided to buses, taxis, and kiss-and-ride patrons. Entrances and exit points are separated to simplify traffic controls and vehicle routings.
2. Typical freeway park-and-ride lot, diamond interchange. The plan of Figure 104 minimizes extra travel by line-haul freeway buses that must leave freeways to reach parking areas. It provides a single signal-controlled bus entrance plus an auxiliary access point for the parking area.
3. Typical freeway park-and-ride lot, partial cloverleaf

interchange. The treatment shown in Figure 105 develops parking facilities within a partial cloverleaf interchange. A quadrant opposite a loop ramp is used for parking facilities that are served by express buses. A special bus loop facilitates passenger interchange. Adjacent transfer is provided for local buses to further reinforce express bus riding. Express buses leave the freeway by means of signal-controlled ramps. They return to the freeway via diamond or loop entry ramps; minimal route deviations are required.

This design provides desirable freeway ramp arrangements plus special express bus and parking facilities without requiring excessive rights-of-way or complicated traffic controls. There are no weaving movements on the freeway and no extensive areal requirements for parking. The park-and-ride lot is contained within an area equivalent to that which would be occupied by an additional cloverleaf loop. Simple two-phase signal controls can be provided.

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APPENDIX A

ILLUSTRATIVE PLANNING AND DESIGN PROCEDURES

1. IDENTIFY NEED

- 1-1 Identify CBD demand in base and design year.
 - (a) Total employment.
 - (b) Peak-hour one-way design movement (across cordon). Where cordon count is unavailable, use 50 to 75 percent of CBD employment.
- 1-2 Identify corridor (quadrant) capacity requirements.
 - (a) Peak-hour one-way.
 - 1. Use 33 percent of cordon count where data are unavailable for symmetrical city.
 - 2. Use $(0.33) \times (360) / D$ of cordon count where data are unavailable and CBD serves a sector of D deg.
 - (b) Estimate modal split range. Where data are unavailable, assume 40 to 60 percent transit with about one-half of this amount potential to express bus service.
- 1-3 Identify highway transit service deficiencies, opportunities, and options.
 - (a) Ability to provide additional highway capacity.
 - (b) Locations of major capacity constraints.
 - (c) Locations where transit priorities can be provided.
 - (d) Locations of major transit flows and route convergence.
 - (e) Identify corridor bus priority potentials.
 - 1. Line-haul.
 - 2. Queue bypass.
 - 3. Local circulation.
 - 4. Terminals.
 - 5. Other.

2. SELECT AND EVALUATE POTENTIAL TREATMENTS

- 2-1 Denote conformity to CBD planning objectives relative to transit, highways, and parking, and to environmental goals.
- 2-2 Applicability of contra-flow freeway lanes.
 - (a) Freeway more than six lanes wide.
 - (b) High imbalance in volumes.
 - (c) Right-hand ramp access patterns.
 - (d) Minimum number of buses per hour.
- 2-3 Applicability of busways.
 - (a) Meets warrants for CBD employment intensity, cordon volumes, and urban population.
 - (b) Stops are required in express service area.
 - (c) Freeway is not available nor suited to bus priority operations.
 - (d) Minimum buses per hour.
- 2-4 Applicability of arterial bus lanes and streets.
 - (a) Minimum buses per hour.
 - (b) Transit image requirements.
 - (c) CBD development objectives.
 - (d) Provisions for service and alternate traffic routes are available.
- 2-5 Establish traffic-transit feasibility for other priority movements (metering, turn controls, bus stops, signal preemption).
- 2-6 Applicability of terminals.
 - (a) Existence of express transit.
 - (b) Constrained or high-cost CBD parking.
 - (c) Minimum identifiable time savings to passengers and buses.
 - (d) Cost-effective alternates to bus tunnels or bus lanes for downtown distribution.
 - (e) Patron reliance on bus and car access to line-haul express transit.
 - (f) Bus route structure conducive to breakpoints or land use.

3. BUSWAY PLANNING (Steps may be iterative)

- 3-1 Identify bus route structure, service types, and frequencies.
- 3-2 Identify ranges in peak-hour demand.
- 3-3 Prepare busway length and configuration options.
- 3-4 Identify intermediate access points, end points, station locations, and complementary park-ride facilities.
- 3-5 Establish downtown distribution patterns.
 - (a) Bus street (where no garages front on street).
 - (b) Contra-flow bus lanes (where continuous one-way streets exist).
 - (c) Median bus lanes (where street width permits).
 - (d) Off-street terminal.
 - (e) Off-street busway may be preferable where cost-service conditions permit or where conversion to rail is envisaged.
- 3-6 Establish station berth requirements and design.
 - (a) Estimate CBD requirements based on hourly volume at maximum-load station (increase 20 percent to reflect peak 20 min).
 - (b) Estimate outlying stations based on anticipated specific loadings.
 - (c) Establish type of vehicle, fare collection procedures, and basic loading-unloading service patterns.
 - (d) Develop station configuration-design concept.
 - (e) Compute berths by formula; alternatively, simulate bus arrivals, dwell times, and station occupancy; provide at least one spare position.
 - (f) Develop pedestrian access requirements.

- 3-7 Apply basic busway design standards.
- (a) Establish desirable and minimum design speeds.
 - (b) Establish mode of busway operation (i.e., contra-flow where stations are frequent relative to intermediate bus access points).
 - (c) Establish basic design controls and physical, economic, environmental constraints (above, below, at-grade; cross-section; curvature). Identify critical points and tradeoffs.
 - (d) Apply design criteria for curvature, super-elevation, gradients, pavement widening, ramps, illumination.
 - (e) Prepare preliminary functional plans, including busway alternatives, and joint-use potentials.
 - (f) Estimate capital costs, vehicle requirements, and operating costs associated with each option.
 - (g) Evaluate alternatives and select preferred options.

4. EVALUATE IMPACTS AND EFFECTIVENESS

- 4-1 Estimate capital and operating costs of bus priority treatments.
- 4-2 Estimate community dislocations and associated impacts.
- 4-3 Estimate time savings accruing to users.
 - (a) Estimate annual person-minutes saved per dollar of annual investment.
 - (b) Estimate person-miles \times speed for key segments.
- 4-4 Estimate annual impacts on bus services.
 - (a) Improved schedule dependability.
 - (b) Time savings and driver runs reduced.
 - (c) Local services that are eliminated or become marginal.
- 4-5 Estimate savings in additional highway capacity that may be required.
 - (a) Net savings in capacity.
 - (b) Community impacts obviated.

APPENDIX B

ECONOMIC IMPLICATIONS OF DEVELOPING FRINGE PARKING VERSUS PROVIDING LOCAL FEEDER BUS SERVICE

Building, operating, or planning busways and/or rail rapid transit must respond to travel needs of potential users. The ease with which people can proceed from home to work will significantly affect patronage levels and modal choice. If personal vehicles are involved, parking space must be provided at both trip ends. If buses are used to attract the same market, the service must be adequate and at a competitive price.

Feeder service to express transit can be provided (1) as pedestrians, (2) by bus, or (3) by car. Accordingly, a cost model was developed to investigate the economic tradeoffs between providing local feeder buses or having a park-and-ride facility.

ASSUMPTIONS IN MODEL FORMULATION

The following assumptions underlie the model:

1. It only deals with peak-hour trips.
2. Trips are a constant length between express bus stations and point of boarding the local bus; i.e., all local buses must travel the entire distance.
3. Vehicles park only in the parking facility provided.
4. Buses return empty to the residential area after delivering their initial load.

5. No user or social impacts are considered; only operational costs are examined.

6. Buses operate at full passenger loads.

7. Automobile occupancy ranges from 1.0 to 1.2 persons per vehicle.

8. Costs of providing standby bus service or additional parking spaces are not included.

Model components are developed—one describes each system. The bus cost model is discussed first, followed by the parking cost model. Both develop capital and operating costs on an annual basis.

BUS COST MODEL

The variables for the bus cost model are as follows:

- P = passengers per hour;
 C = capacity (passenger seats) per bus;
 D = number of days per year the system is in operation;
 C_b = capital cost per bus;
 N = number of buses required to fulfill demand;
 L = trip length, in miles;
 V = speed, in mph;
 K = layover time per bus per trip, in minutes;

K_1 = capital recovery factor; and
 C_o = operating cost, including equipment, per bus per mile.

Bus costs can further be assumed to consist of two elements: (1) equipment costs and (2) operating costs.

Equipment Costs (C_1)

Equipment costs represent the cost per bus amortized over its service life multiplied by the number of buses needed to serve the indicated demand; that is,

$$C_1 = K_1 C_b N \\ = K_1 C_b \left[\frac{P}{C} \left(\frac{2L}{V} + \frac{K}{60} \right) \right] \quad (\text{B-1})$$

Operating Costs (C_2)

Operating costs are assumed to be a function of the line mileage required to transport passengers multiplied by the unit operating cost per bus-mile, as follows:

$$C_2 = C_o \frac{P 2L D}{C} \quad (\text{one-way trips}) \quad (\text{B-2})$$

Therefore, total bus cost (C_t) becomes

$$C_t = \frac{P}{C} \left[K_1 C_b \left(\frac{2L}{V} + \frac{K}{60} \right) + 4C_o L D \right] \quad (\text{B-3})$$

when the expression is adjusted to reflect round-trip bus mileage.

PARKING COST MODEL

The variables for the parking cost model are as follows:

A = land cost per square foot;
 A_1 = land cost per space;
 B = construction cost per parking space;
 M = annual maintenance cost per parking space;
 K_2 = capital recovery factor;
 P = passengers arriving by automobile; and
 O = average occupancy per automobile.

Parking costs (C_p) can then be shown to be a function of automobile occupancy and number of cars, as well as land, development, and maintenance costs; that is,

$$C_p = \frac{P}{O} (K_2 A_1 + K_2 B + M) \quad (\text{B-4})$$

The variable A_1 equals $350A$; it assumes approximately 350 sq ft per car for parking requirements, including aisle, circulation, etc.

COMBINING THE MODELS

If parking facilities are provided only where costs are equal to or less than the costs for local bus service, comparing Eqs. B-3 and B-4 gives

$$(K_2 A_1 + K_2 B + M) \leq$$

$$\frac{1}{C} \left[K_1 C_b \left(\frac{2L}{V} + \frac{K}{60} \right) + 4C_o L D \right] \quad (\text{B-5})$$

This model can be solved in terms of any pair of variables by holding the others constant and then graphing two-dimensionally. For example, one may want to find the relationship between maintenance cost and bus trip length.

Because land development and maintenance costs are essentially constant, parking costs become sensitive to land costs. These costs were equated to bus trip length for the range of values given in Table B-1.

RESULTS AND CONCLUSIONS

The results of the tradeoff are shown in Figure 102, which indicates that if a bus is to provide a 3-mile feeder service (one-way) to a residential area, a parking facility could be provided at the same cost as the bus service for land priced up to \$17 per square foot. Under the most favorable bus operating conditions this is reduced to land priced up to \$6.50 per square foot.

There are, of course, certain limitations that influence the effectiveness of this model and call for care in interpreting its results. Inclusion of off-peak parkers would reduce parking costs if automobile turnover is increased and more vehicles share costs for the parking facility. Also, if buses return with passengers instead of traveling empty, bus costs would be reduced. Time costs and other user costs of driving and parking are not included in the model.

The model implies that in low-density areas parking along bus lines may be preferable to extensive feeder bus service or to nonstop, diffuse express operations. It suggests simplified line-haul express bus services with expanded parking in suburban areas. The simplified route structure can produce increased trunk-line service frequency, promote better route identity, and reduce downtown distribution complexity and requirements.

TABLE B-1

RANGE OF VALUES USED IN EQUATING LAND COSTS TO PARKING COSTS

VARIABLE	RANGE OF VALUES
C_b	\$40,000
$K_1=K_2$	$i=6$ percent; $n=12$ years
D	250 days per year
K	6 minutes
C	50 passengers
L	1, 2, 3, . . . , 15 miles
V	10, 15, 20 miles per hour
C_o	\$0.80, \$1.00, \$1.20 per mile
O	1.0, 1.2 persons per automobile
B	\$1,500 per space
M	\$50 per space per year

APPENDIX C

LEGAL ASPECTS—TYPICAL CITY ORDINANCES

1. EXTRACT FROM "JOURNAL OF THE PROCEEDINGS OF THE CITY COUNCIL OF THE CITY OF CHICAGO, ILL."

Regular Meeting—Wednesday, May 9, 1956 (Page 2582)
 "Mass Transportation Lane" and "Mass Transportation Vehicle" Defined; Regulations Prescribed for Use of Such Lanes.

The Committee on Traffic and Public Safety submitted a report recommending that the City Council pass a proposed ordinance transmitted therewith reading as follows:

**BE IT ORDAINED BY THE
 CITY COUNCIL OF
 THE CITY OF CHICAGO:**

SECTION 1. Section 27-1 of the Municipal Code of Chicago is amended by inserting in alphabetical sequence the following:

Mass transportation lane. That portion of a roadway indicated for use by mass transportation vehicles.

Mass transportation vehicle. A public passenger vehicle having seating capacity for 35 or more passengers.

SECTION 2. Section 27-39 of said Code is amended by adding thereto the following paragraph:

Where, in the opinion of the said commissioner, a separation of traffic is necessary to expedite the flow of traffic in a particular area, he may designate portions of roadways as mass transportation lanes, and when such lanes are so marked upon the roadways or otherwise so indicated by appropriate signs, it shall be unlawful for the driver of any mass transportation vehicle to use any other portion of such roadway, and it shall be unlawful for the driver of vehicles other than a mass transportation vehicle to enter or use any such mass transportation lane.

SECTION 3. This ordinance shall become effective upon its passage and due publication.

On motion of Alderman . . . the committee's recommendation was concurred in and said proposed ordinance was passed. . . .

2. BALTIMORE, MD., BUS LANES (1957)

SECTION 1. Pursuant to the power and authority contained in Article 28, Section 2J and 2X of the Baltimore City Code (1950 Edition) as amended by Ordinance No. 1006, approved by the Mayor on June 18, 1957, the Commissioner of Transit and Traffic hereby enacts an Administrative Regulation designating portions of the following streets as transit lanes and prohibiting the use of said lanes by vehicles other than those used for mass transit.

SECTION 2. It is hereby ordered and directed by the Commissioner of Transit and Traffic of the City of Baltimore that the following lanes of the following streets and thoroughfares within the City of Baltimore are hereby

designated transit lanes to be used solely by buses during the periods specified, and it is further ordered and directed that when the said lanes have been designated as transit lanes that during the hours that said lanes are so designated for the exclusive use of buses, it shall be illegal for any vehicle other than a bus to use said lanes, except that vehicles other than buses shall be allowed to use said lanes one block prior to executing right-hand turns.

3. WASHINGTON, D.C., BUS LANES (JULY 1969)

The marked traffic lane closest to the curb on the following streets or parts of streets shall, during the time set forth beside each below, except on Saturdays, Sundays, and holidays, be reserved for the exclusive use of vehicles not confined to rails or tracks and used for the transportation of passengers for hire over a defined route or routes in the District of Columbia (hereinafter referred to as mass transit vehicles); provided, however, that taxicabs, i.e., vehicles licensed under the provisions of Paragraph 31(d) of the Act approved July 1, 1902 as amended (License Act of 1932) may enter and leave such lane for the sole purpose of taking on or discharging a passenger or passengers, but the operator thereof shall, for such purpose, enter and leave such lane at the nearest point to such loading or unloading point and shall remain within such lane only long enough to so load or unload, and provided further that any vehicle may enter such lane within 100 ft of the approach to an intersection for the sole purpose of making a right turn at such intersection unless such turn is prohibited and so indicated by an official traffic control device: and provided further that no mass transit vehicle, except those engaged in express service, shall leave such reserved lane, except to make a turn or to pass a vehicle which is disabled or illegally blocking passage of such mass transit vehicle:

The burden of proof shall be upon the driver of a vehicle other than a mass transit vehicle entering such lane to show that he entered such lane for the purpose of taking on or discharging a passenger or passengers or of making a right turn, as the case may be, and the burden of proof shall be upon the driver of a mass transit vehicle leaving such lane, except one engaged in express service, to show that he left such lane for the purpose of making a turn or of passing a vehicle which was disabled or illegally blocking passage of his vehicle.

By order of the Board of Commissioners, D.C.

4. SYRACUSE, N.Y., BUS LANES (1970)

The marked traffic lane closest to the curb shall during the time set forth on appropriate signs and for the days indicated be reserved for the exclusive use of vehicles not confined to rails or tracks and used for the transportation of passengers for hire over a defined route or routes in the

City of Syracuse (hereinafter referred to as mass transit vehicles); provided, however, passenger cars and taxicabs may enter and leave such lane for the sole purpose of taking on or discharging a passenger or passengers, but the operator thereof shall, for such purpose, enter and leave such lane at the nearest point to such loading or unloading point and shall remain within such lane only long enough to so load or unload, and provided further that any vehicle may enter such lane within 100 ft of the approach to an intersection for the sole purpose of making a right turn at such intersection unless such turn is prohibited and so indicated by an official traffic control device: and provided further that no mass transit vehicle, except those engaged

in express service, shall leave such reserved lane, except to make a turn or to pass a vehicle which is disabled or illegally blocking passage of such mass transit vehicle:

The burden of proof shall be upon the driver of a vehicle other than a mass transit vehicle entering such lane to show that he entered such lane for the purpose of taking on or discharging a passenger or passengers or of making a right turn, as the case may be, and the burden of proof shall be upon the driver of a mass transit vehicle leaving such lane, except one engaged in express service, to show that he left such lane for the purpose of making a turn or of passing a vehicle which was disabled or illegally blocking passage of his vehicle.

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