BUS PRIORITY SYSTEM

Prepared for
Dean J. G. McGuire
Texas A & M University
College Station, Texas 77843

by
Thomas A. Warner
August 9, 1974

4727 Homer, Apt. 201
Dallas, Texas 75201
August 9, 1974

Dean J. G. McGuire
College of Engineering
Texas A & M University
College Station, Texas 77840

Dear Dean McGuire:

The accompanying report entitled "Bus Priority System" is submitted with your instruction of May 31, 1974.

The primary purpose of this report is to present information about the "Bus Priority System". An effort has been made to cover the subject throughly, including background, methods of bus priority, planning and design, criteria, cost analysis of B.P.S. and estimated results. The sections on cost analysis and estimated results are with respect to the "Urban Corridor Demonstration Project" of the North Central Expressway of Dallas.

I wish to acknowledge the information and assistance given me by Mr. Jim Ansley, Mr. Karl Tipple and Mr. Tom Schlitt of the Department of Traffic Control, City of Dallas.

I sincerely hope that this report will meet with your approval.

Respectfully yours

Thomas A. Warner

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Abstract

The Bus Priority System is being constructed to relieve congestion on freeways and city streets and to reduce the travel time of Bus passengers. Thus, providing a new degree of traffic control flexibility and strategy evaluation.

Introduction

With traffic congestion on urban streets increasing, the need to develop and evaluate real-time traffic surveillance and control systems capable of counteracting this growing congestion has, likewise, increased. The Bus Priority System (BPS) is such an experimental system now being installed to provide a more efficient movement of people.

Bus Priority System

BACKGROUND

Buses serve a wide variety of transportation functions. They provide local and express bus service between downtown and residental neighborhoods. In larger cities, they provide for crosstown movements and serve as feeders to rapid transit lines. They operate on local streets, arterial streets and expressways. They provide a high degree of service availability and flexibility and they are an integral part of the modern multi-modal urban transport system. (Table 1, Page 4)

Freeways. The first and most obvious reason for affording preferential treatment to the bus is that it plays a crucial part in the balance of public and private transport, and as such, potentially holds the solution for peak-period congestion. A second reason for preferential treatment is that the bus is the only road vehicle which is an inter-related part of a time dependent system. A delay to a private car is experienced as time lost only to that vehicle. A delay to a bus creates a disturbance in time which is propagated throughout a route or network, ultimately affecting all the buses in a system. A third reason is to maintain user convenience. For services to remain attractive, access time must be kept to a minimum.

Arterials. The function of BPS is to provide extra green signal time to buses. The increased "go" condition for buses will be granted only if the time can be utilized by a bus and if the net delay to all people at the intersection can be reduced. Upon approaching an intersection the bus driver signals the bus' status as either "through" or "stop" depending whether he plans to continue through the intersection or stop and discharge or pick up passengers. Knowing the status of a bus, the computer can determine if an extension of the green interval will provide an advantage

Table 1

SUMMARY OF THE STATE OF THE ART OF BUS PRIORITY TREATMENTS

TYPE OF TREATMENT	TYPICAL EXAMPLE OF EXISTING TREATMENT
1. Freeway Related Treatments	
A. Busways	
1. Busway on Special right-of-way	Runcorn, England Busway
2. Busway on Freeway, median or right-of-way	Shirley Busway, Washington area
3. Busway in Railroad right-of-way	None
B. Reserved lanes and ramps	
1. Bus lanes on Freeways - Normal flow	None
2. Bus lanes on Freeways - Contra-flow	Southeast Expressway Boston
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
Arterial Related Treatments	
A. Reserved Lanes and Streets	
1. bus streets	Nicollet Mall, Minneapolis,
2. C.B.D. curb bus lanes-normal flow	Washington, D.C.
3. arterial curb bus lanes-normal flow	Hillside Avenue, Queens, New York City
4. C.B.D. median bus lanes-normal flow	Canal Street, Neutral Ground, New Orleans
5. arterial median bus lanes-normal flow	None
6. C.B.D. curb bus lanes-contra-flow	Alamo Plaza, San Antonio
7. arterial curb bus lanes-contra-flow	Ponce de Leon, Fernandoz Juncos, San Juan
B. Miscellaneous	
1. Bus signal pre-emption	Kent, Ohio
2. Special signalization	Cermak Road, Chicago
3. Special turn permission	"No Left Turn, Buses Excepted," Los Angeles
3. Terminals	
A. Central area bus terminals	Midtown Terminal, New York City
B. Outlying transfer terminals	Dan Ryan, 95th Street Bus, Bridge, Chicago
C. Outlying park-and-ride terminals	Lincoln Tunnel, Approach at I-495 contra flow bus lane

for its passengers. If the extension can be utilized, the computer next checks the vehicular and people volumes on the cross street and then determines if an extension of green would reduce the net people delay. Thus, the BPS emphasizes the importance of the movement of people not just vehicles.

METHODS OF BUS PRIORITY

With a rising volume of urban travel, transportation is becoming one of the biggest problems facing urban planners and engineers today. It is generally agreed that every urban region requires a balance between private automobile usage and public transportation, with the latter becoming increasingly important as traffic volume grows and streets and highways become overloaded. To maintain this balance, improvements in private and public transportation must continually be sought.

Freeways. Bus Lanes. The practice of reserving lanes exclusively for buses is one improvement which has been considered.* The idea has long been advocated by transit authorities. Such lanes have not achieved a broad level of acceptance because the lanes would be under-utilized in the present context of traffic. Although the capacity of a freeway lane varies, it is probably fair to state that a single freeway lane with an average occupancy of 1.2 persons per car should carry up to 2,400 persons per hour. Current demand for public transit lies far below this figure on almost all urban freeways. Therefore, a lane reserved exclusively for buses has not been shown to be the most efficient means for moving people on freeways. (Figures 1, 2, Page 6, 7)

*The concept of reserving a bus lane was first suggested by Mr. Nathan Cherniak in 1963.

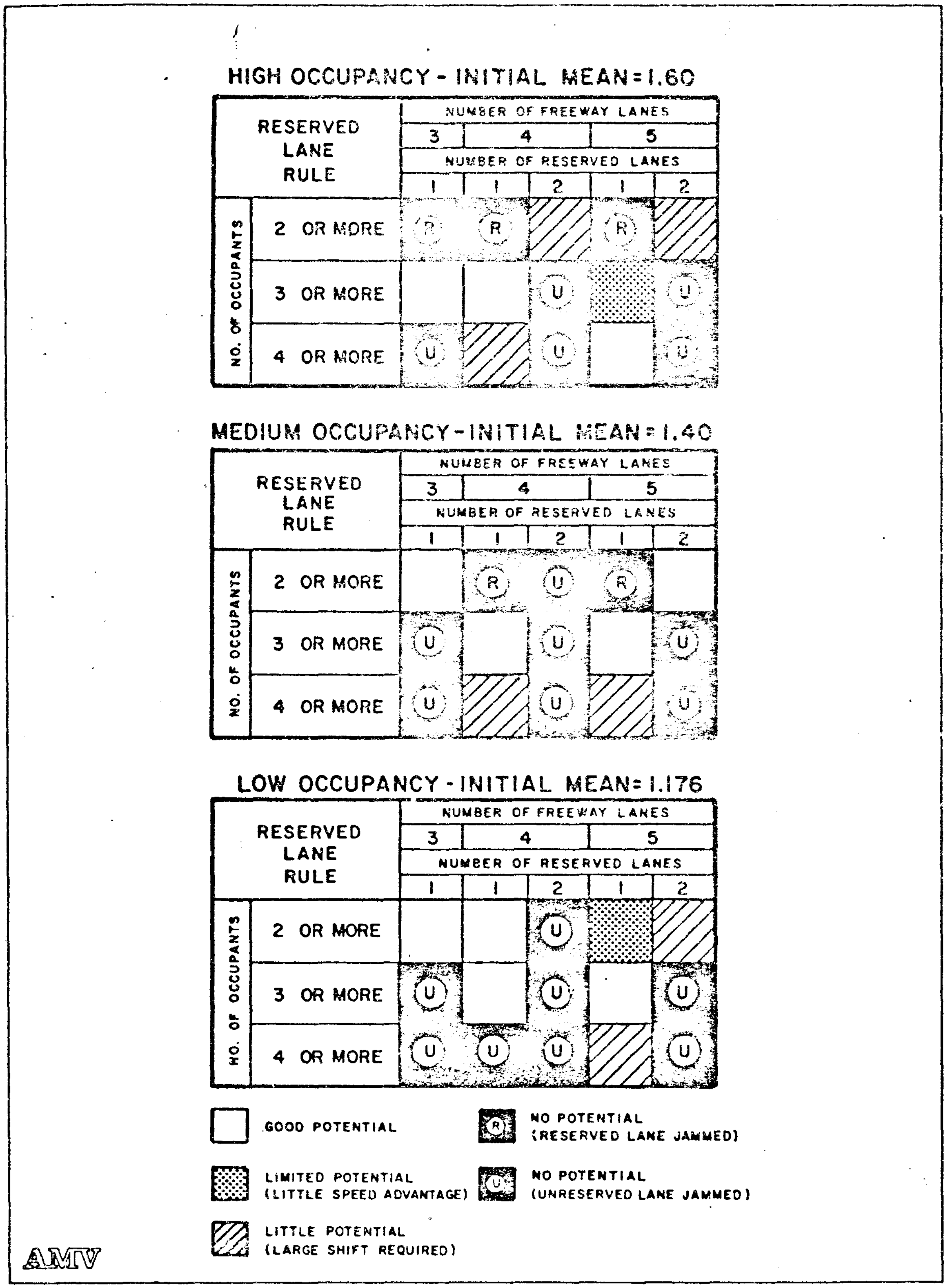
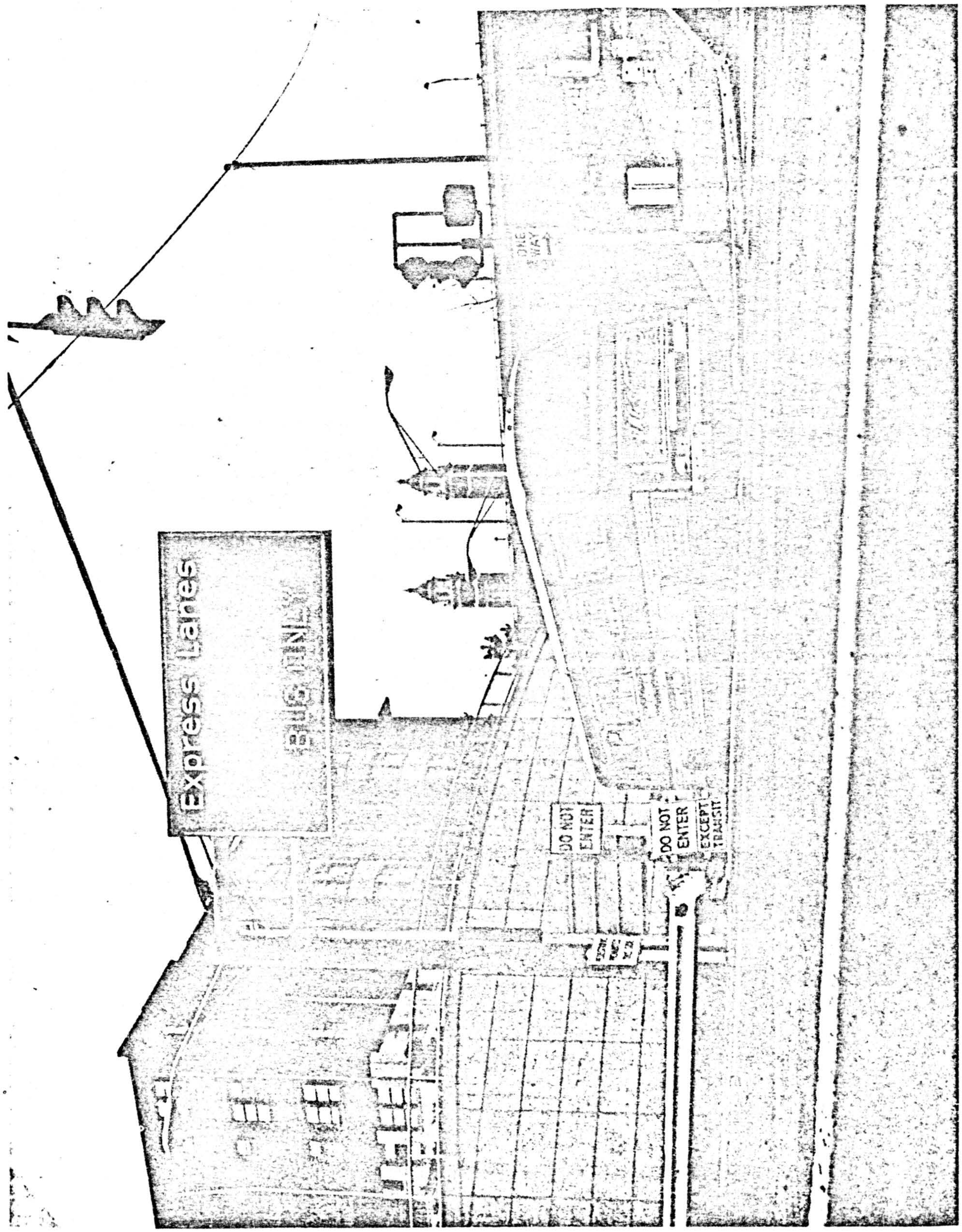


FIGURE 1. GENERAL FEASIBILITY OF RESERVED LANE CONCEPT

Figure 2



Blue Streak exclusive northbound bus ramp onto I-5, Seattle, Wash.

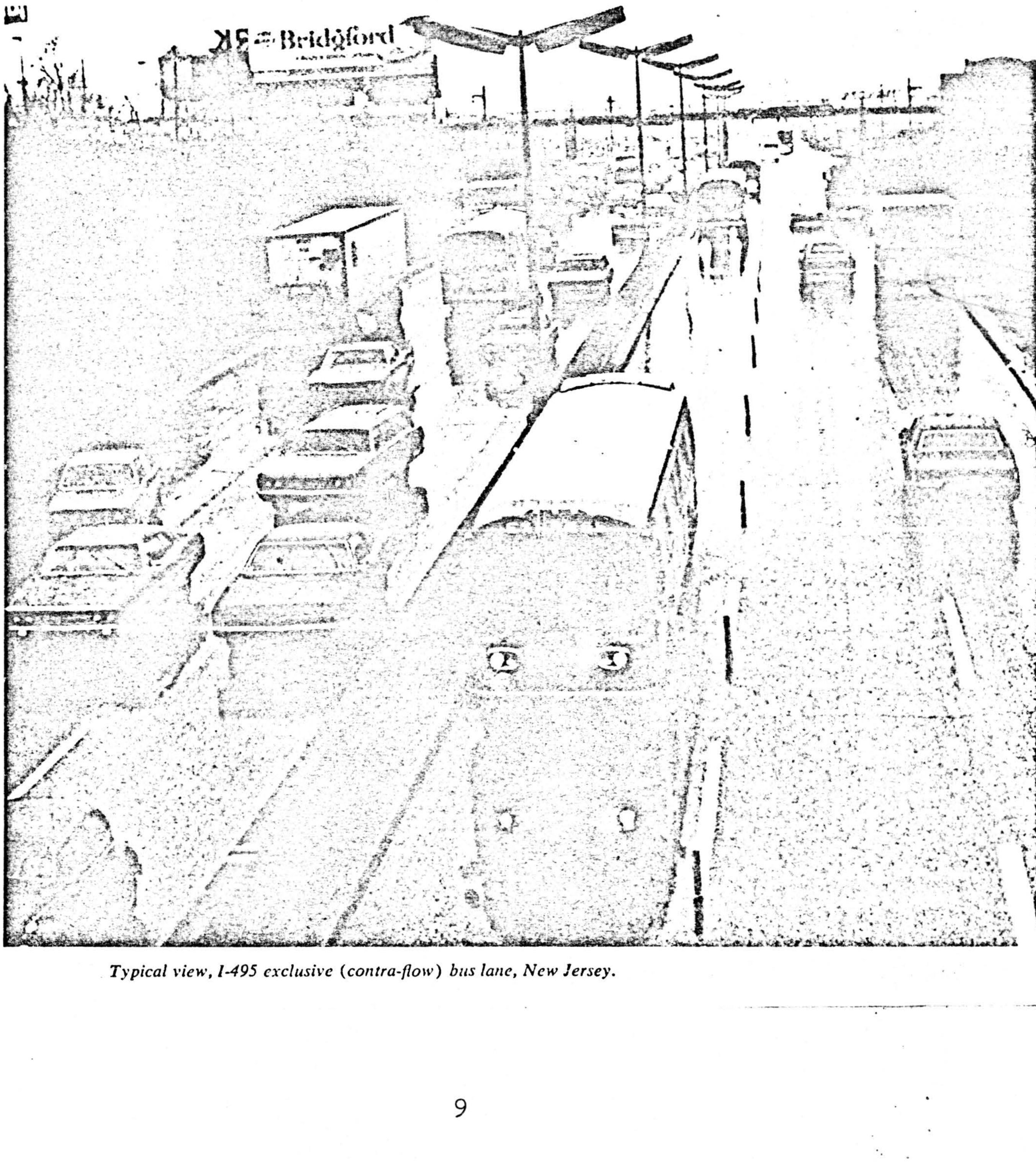
Contra-flow. Contra-flow Bus Lane is a bus lane using a portion of the roadway that serves relatively light opposing traffic flow and will not reduce peak directional highway capacity or efficiency. It is an adaption of the reversible-lane concept applied to urban freeways for more than three decades.

Potential problems include the need to remove median barriers at crossover or transition points, blocking of the lane by accidents or stalled buses, safety and possible congestion in the remaining off peak direction. Existing contra-flow bus lanes operate only in peak hours on freeways that are at least six lanes wide and provide at least two lanes for general traffic in the off peak direction. (Figures 3, 4, Page 9, 10)

Ramp Metering. Provision of special bus ramps to and from freeways, and metering of other ramps with special priority for buses, can expedite bus flow with minimum construction costs and minimum delay to other users. Bus ramps can bypass queues, reduce bus travel distances, and promote continuity in a system of bus priority treatments. Ramp metering is designed to keep main freeway lanes operating at reasonable speed levels.

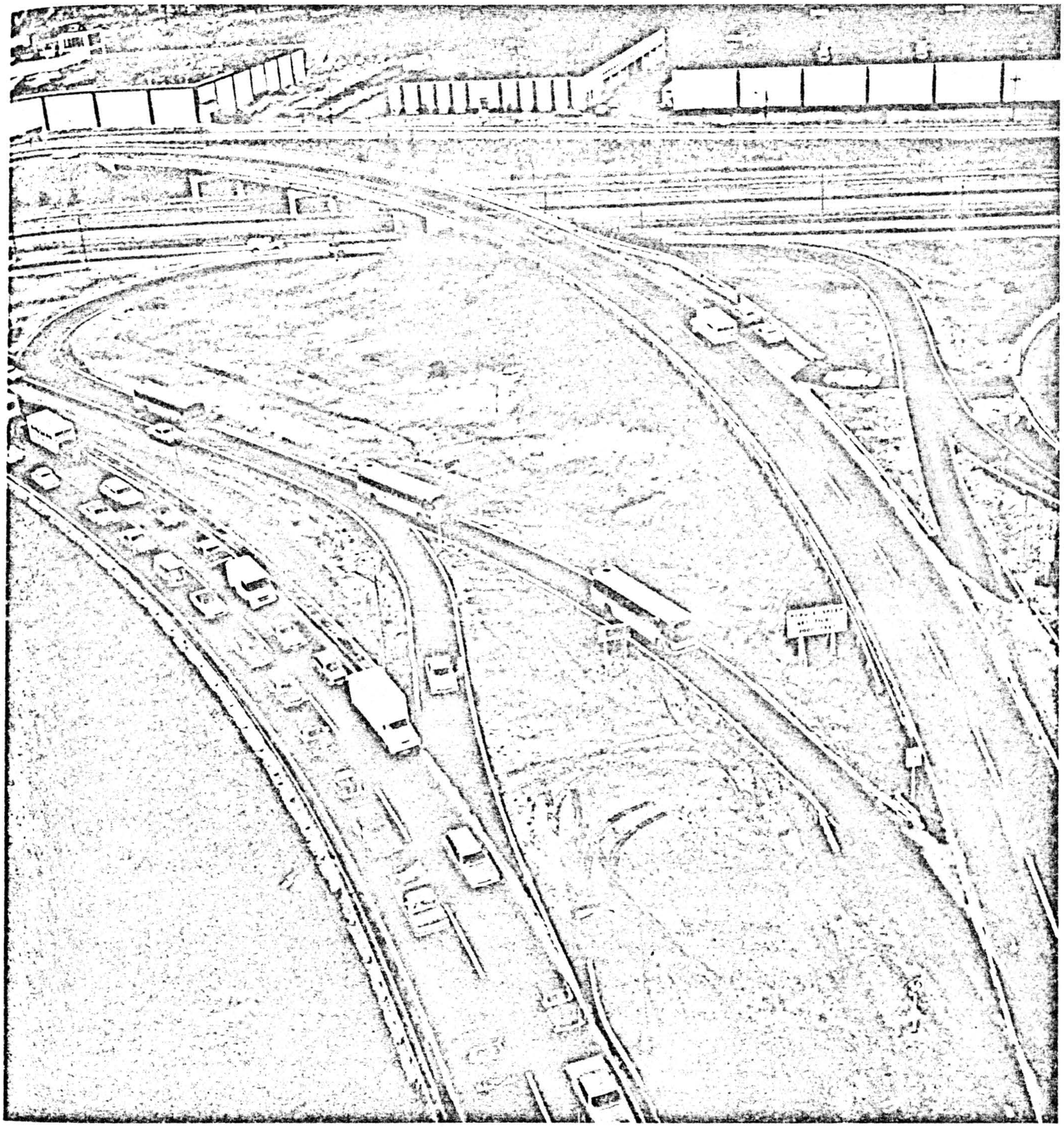
For preferential bus entry to freeways that are controlled by ramp metering, special traffic signals on entrance ramps allow only those vehicles to enter the freeway that can be accomodated without reducing main-lane speeds. Cars are required to wait a few moments at ramp signals, although those on short trips may divert to parallel routes to avoid waiting. Where ramp-metering is in effect, it is often possible to provide a bypass lane for buses so that they can bypass automobile queues, and can then achieve better speeds on the freeway. At metered locations, buses may enter and leave the freeway for passenger loading and unloading with minimum delay. Ramp

Figure 3



Typical view, I-495 exclusive (contra-flow) bus lane, New Jersey.

Figure 4



Special bus entry road, I-495 exclusive (contra-flow) bus lane, New Jersey.

Table 2

PEAK HOUR BUS VOLUMES ON URBAN ARTERIALS
RANKED BY PER CENT BUS PASSENGERS OF TOTAL PASSENGERS - DOMINANT DIRECTION OF FLOW
Current Conditions[1]

ARTERIAL LOCATION	CITY	VEHICLES PER HOUR		PASSENGERS CARRIED			PER CENT CARRIED BY BUS
		BUS	AUTO	BUS	AUTO	TOTAL	
Nicollet Mall	Minneapolis	64	0	2,900	0	2,900	100.0
Market Street (East of Broad)	Philadelphia	143 [2]	465	8,300	695	8,995	92.5
State Street @ Madison	Chicago	151 [2]	465	6,100	660	6,760	90.0
Hillside Avenue	New York	170 [2]	630	8,500	950	9,450	90.0
Pennsylvania Avenue @ Seventh	Washington, D.C.	120	600	6,000	900	6,900	87.0
Market Street @ Van Ness	San Francisco	155 [2]	1,200	9,900	1,550	11,450	86.5
Main Street @ Fourth Street	Los Angeles	115	720	5,850	1,100	6,950	84.0
Main Street @ Harwood Street	Dallas	100	635	4,400	900	5,300	83.0
Hill Street @ Seventh Street	Los Angeles	109	800	5,250	1,200	6,450	81.5
Broad Street @ Hunter Street	Atlanta	48	290	1,920	435	2,355	81.5
Seventh Street @ Main Street	Los Angeles	91	705	4,500	1,050	5,550	81.0
Forbes Avenue @ Wood Street	Pittsburgh	47	400	2,300	560	2,860	79.5
Fifth Avenue @ Smithfield	Pittsburgh	47	420	2,300	590	2,890	79.5
Liberty Street @ Sixth Avenue	Pittsburgh	66	650	3,250	910	4,160	78.2
"K" Street NW @ 13th Street	Washington, D.C.	130	1,300	6,500	1,950	8,450	77.0
Eye Street @ 13th Street	Washington, D.C.	104	1,100	5,200	1,600	6,800	76.5
Smithfield Street @ Fifth Avenue	Pittsburgh	50	550	2,450	770	3,220	76.0
Thirteenth Street @ "F" Street	Washington, D.C.	101	1,050	5,000	1,600	6,600	75.8
Broadway @ Sixth Street	Los Angeles	78	850	4,000	1,390	5,390	74.5
Adams Street Bridge	Chicago	107	785	3,425	1,220	4,645	73.7
Granville Street @ Georgia	Vancouver	70	900	3,150	1,200	4,350	72.5
Wisconsin Avenue	Milwaukee	78	935	3,100	1,200	4,300	72.0
Chestnut @ 12th Street	Philadelphia	67	890	3,350	1,350	4,700	71.5
State Street @ Roosevelt	Chicago	72	670	2,305	935	3,240	71.4
Washington Street @ Wacker	Chicago	108	1,100	3,800	1,540	5,340	71.4
Wood Street @ Forsyth Ave.	Pittsburgh	55	800	2,700	1,120	3,820	70.8
Seventh Street @ Pennsylvania Ave.	Washington, D.C.	80	1,150	4,000	1,720	5,720	70.0
Main Street @ Pratt	Hartford	75	625	1,875	815	2,690	70.0
Jackson Blvd. Bridge	Chicago	88	845	2,815	1,325	4,140	68.0
Sixth Avenue @ Smithfield	Pittsburgh	33	560	1,620	780	2,400	67.6
Eglington Avenue @ Bathurst	Toronto	80	1,200	3,300	1,700	5,000	66.0
Elm Street @ Harwood	Dallas	80	1,345	3,500	1,880	5,380	65.2
Sacramento Street	San Francisco	25	410	1,000	535	1,535	65.0
Constitution Avenue @ 15th	Washington, D.C.	120	2,200	6,000	3,300	9,300	64.5

Table 2, Cont.

PEAK HOUR BUS VOLUMES ON URBAN ARTERIALS
RANKED BY PER CENT BUS PASSENGERS OF TOTAL PASSENGERS - DOMINANT DIRECTION OF FLOW
Current Conditions[1]
(Cont)

ARTERIAL LOCATION	CITY	VEHICLES PER HOUR BUS	VEHICLES PER HOUR AUTO	PASSENGERS CARRIED BUS	PASSENGERS CARRIED AUTO	PASSENGERS CARRIED TOTAL	PER CENT CARRIED BY BUS
Spring Street @ Seventh Street	Los Angeles	111	1,500	4,450	2,500	6,950	64.0
Sixteenth Street @ Florida Ave.	Washington, D.C.	80	1,500	4,000	2,250	6,250	64.0
Fourteenth Street @ Constitution Ave.	Washington, D.C.	80	1,550	4,000	2,350	6,350	63.0
Connecticut Avenue @ Cathedral Ave.	Washington, D.C.	90	1,800	4,500	2,700	7,200	62.5
Walnut @ 15th Street	Philadelphia	48	960	2,400	1,450	3,850	62.5
Commerce Street @ St. Paul	Dallas	72	1,415	3,300	2,120	5,420	61.0
Sheridan @ Hollywood	Chicago	32	500	1,100	700	1,800	61.0
Michigan Avenue @ Roosevelt Rd.	Chicago	77	770	1,815	1,210	3,025	60.0
Asylum @ Main Street	Hartford	35	450	875	585	1,460	60.0
Michigan Avenue Bridge (Upper Level)	Chicago	116	1,590	3,580	2,390	5,970	60.0
Sutter Street	San Francisco	63	1,300	2,500	1,700	4,200	59.5
Madison Avenue @ 42nd Street	New York	96	2,400	4,800	3,600	8,400	57.1
Second Avenue @ 42nd Street	New York	110	2,800	5,500	4,200	9,700	56.8
First Avenue @ 44th Street	New York	110	2,800	5,500	4,200	9,700	56.8
Sixth Street @ Figueroa	Los Angeles	29	965	1,875	1,430	3,305	56.7
Georgia Avenue @ Granville	Vancouver	45	1,200	2,000	1,600	3,600	55.5
Clay Street	San Francisco	26	650	1,050	850	1,900	55.3
Ninth Street @ Market Street	Philadelphia	22	600	1,100	900	2,000	55.0
Second Avenue North	Birmingham, Ala.	44	1,400	2,300	1,950	4,250	54.0
Grand Avenue @ Temple Street	Los Angeles	24	855	1,400	1,215	2,615	53.5
Geary Street	San Francisco	43	1,250	1,720	1,630	3,350	51.4
Howard Street @ Fayette Street	Baltimore	30	470	790	755	1,545	51.0
Marietta @ Spring Street	Atlanta	35	1,050	1,400	1,580	2,980	47.0
Peachtree @ Ellis	Atlanta	55	1,700	2,200	2,550	4,750	46.5
Tryon Street	Charlotte, N.C.	40	1,150	1,200	1,700	2,900	41.4
Eighth Street @ Los Angeles St.	Los Angeles	30	1,155	1,290	1,835	3,130	41.3
O'Farrell Street	San Francisco	27	1,200	1,080	1,550	2,630	41.2
Trade Street	Charlotte, N.C.	30	1,000	1,000	1,500	2,500	40.0
Pratt Street @ Paca St.	Baltimore	64	2,390	2,215	3,825	6,040	36.7
Charles Street @ Madison St.	Baltimore	33	1,915	1,480	3,060	4,540	32.6
Lombard Street @ Greene St.	Baltimore	42	1,750	1,335	2,800	4,135	32.0
Eleventh Street Bridge	Washington, D.C.	54	4,120	2,870	7,735	10,605	27.1
Cathedral Street @ Eager	Baltimore	36	1,545	880	2,470	3,350	26.3
St. Paul Street @ Preston	Baltimore	45	2,815	1,375	4,505	5,880	23.4
Calvert Street @ Lexington	Baltimore	39	2,645	1,185	4,230	5,415	21.9

(1) Data compiled by Wilbur Smith and Associates involves assumptions in some cases as to car or bus occupancy.
(2) Buses operate in more than one lane.

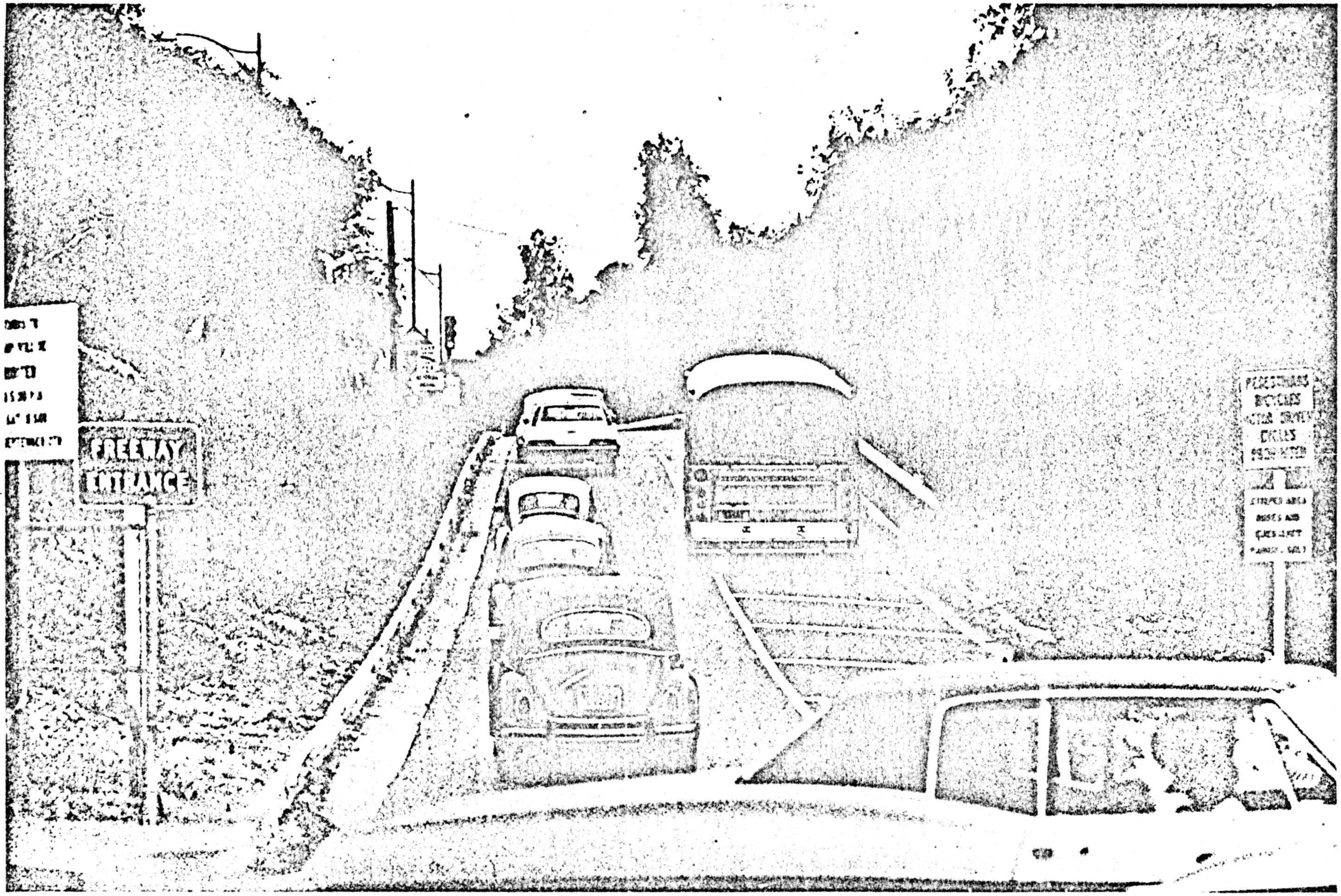
metering is especially suitable for application in corridors with low peak-hour bus passenger demands and with frequent peak-hour congestion. (Figure 5, Page 12)

Arterial. Most urban bus service will continue to operate on arterial streets. Bus ways and reserved bus lanes on freeways mainly will be limited to larger cities (population usually over 1,000,000) where freeways provide direct service to downtown areas. All cities, however, will benefit from effective coordination of transit and traffic improvements. Radial bus routes generally cover a few downtown streets where bus priority treatments can expedite flow. Bus headways frequently range from 30 sec to 3 min.

Buses carry more than one-half of all peak-hour travelers on arterial streets leading to and within the downtown area. The relative use of buses - and in many cases the actual number of bus passengers - exceeds those on freeways. Typical peak-hour bus and passenger characteristics, summarized in Table 2, underscore the importance of bus use on arterial streets and the need for bus priority treatments to maintain and increase patronage.

Bus priority treatments on arterial streets include:
(1) measures designed to separate car and bus movements and (2) general traffic engineering improvements designed to expedite over-all traffic flow.

Bus Lanes. Bus lanes comprise the treatment mostly used. These lanes either are used exclusively by buses or are shared with taxis and right turning vehicles. They are located along curbs, or in street medians and they operate in or counter to automobile traffic flow. Bus lanes generally involve removing a travel lane from automobile use and giving it to buses. They are sometimes implemented in conjunction with one-way street routings and curb parking prohibitions; in these cases, there is gure 5



Example of bus priority treatment at metered freeway ramps, Los Angeles, Calif.

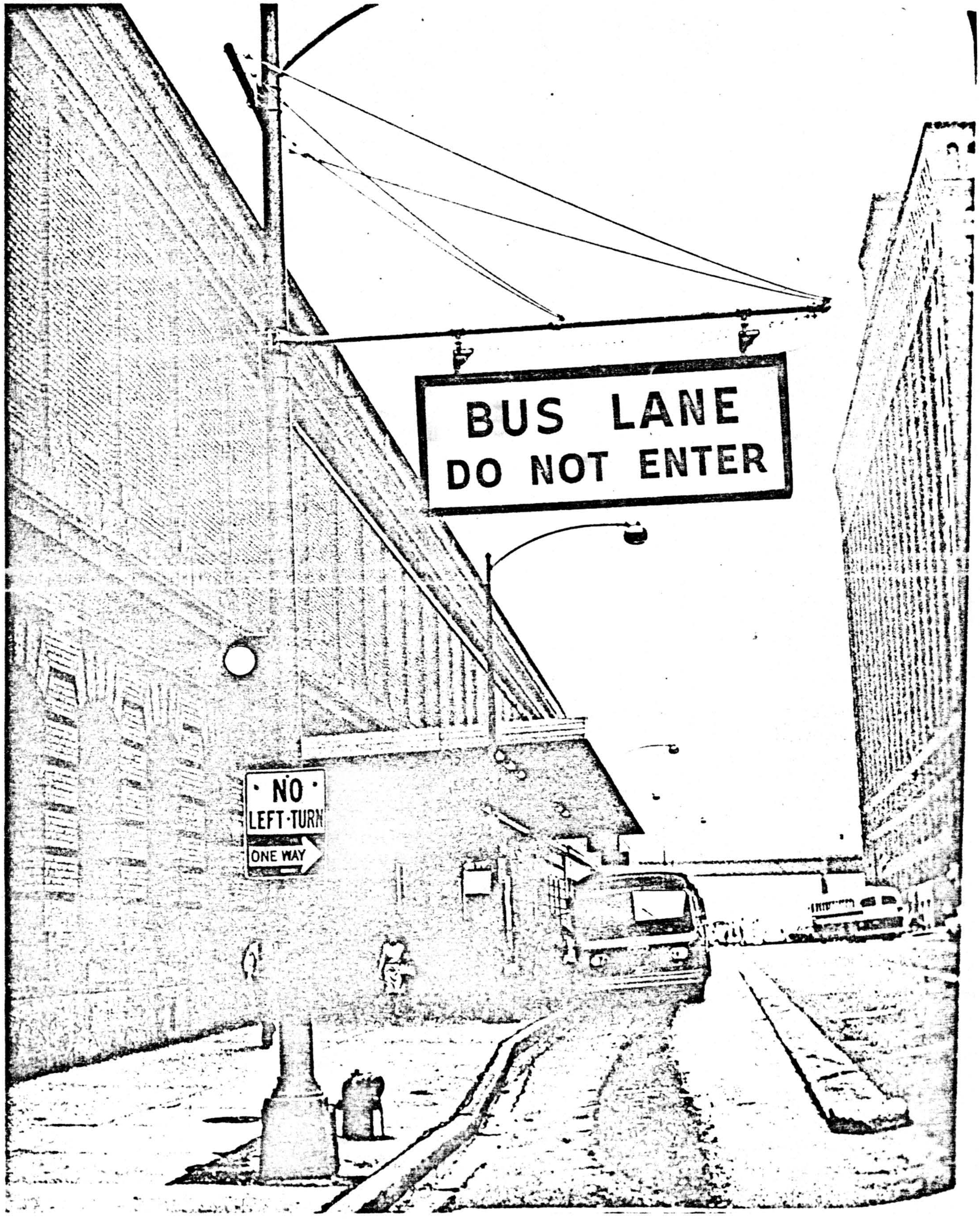
usually no net loss in street capacity. In other cases, buses normally dominate the lanes used and the designation of bus priority lanes causes no appreciable change in automobile capacity. (Figure 6, Page 14)

Curb Bus Lanes, Normal Traffic Flow. Curb bus lanes in the normal direction of flow are most common. These lanes are usually in effect during peak periods, although some operate continuously. They are easy to implement and involve minimum street routing change at little cost. However, they are often difficult to enforce and may produce only marginal benefits to bus flow. Right-turning vehicles either conflict with buses or must be prohibited. (Figure 7, Page 15)

Median Bus Lanes. Median Bus Lanes are an outgrowth of streetcar operations. The lanes are in effect throughout the day. They are removed from traffic conflicts along the curb, and they allow other traffic to make right turns without conflicting with buses. However, they require wide streets with provisions for service stops and pedestrian refuge in the median. Passengers are required to cross active traffic lanes to reach bus stops. Left turns must be prohibited or controlled to minimize interference with buses. (Figure 8, Page 16)

Contra-Flow Bus Lanes. Contra-flow bus lanes are lanes in which buses operate opposite to the normal traffic flow. Contra-flow bus lanes operate on one-way streets, usually throughout the day; however, they can be provided in conjuction with peak-hour bus service. Buses using the lanes are separated from traffic flow and are therefore not affected by peak-hour congestion at signalized intersections. They are largely "self enforcing" and are subject to less infringement by taxis. They frequently are located to permit more direct bus routing. The lanes may complicate loading and access to adjoining properties. They increase left-turn conflicts, with

Figure 6



Canal Street contra-flow bus lane at Northwestern Station, Chicago, Ill.

Figure 7

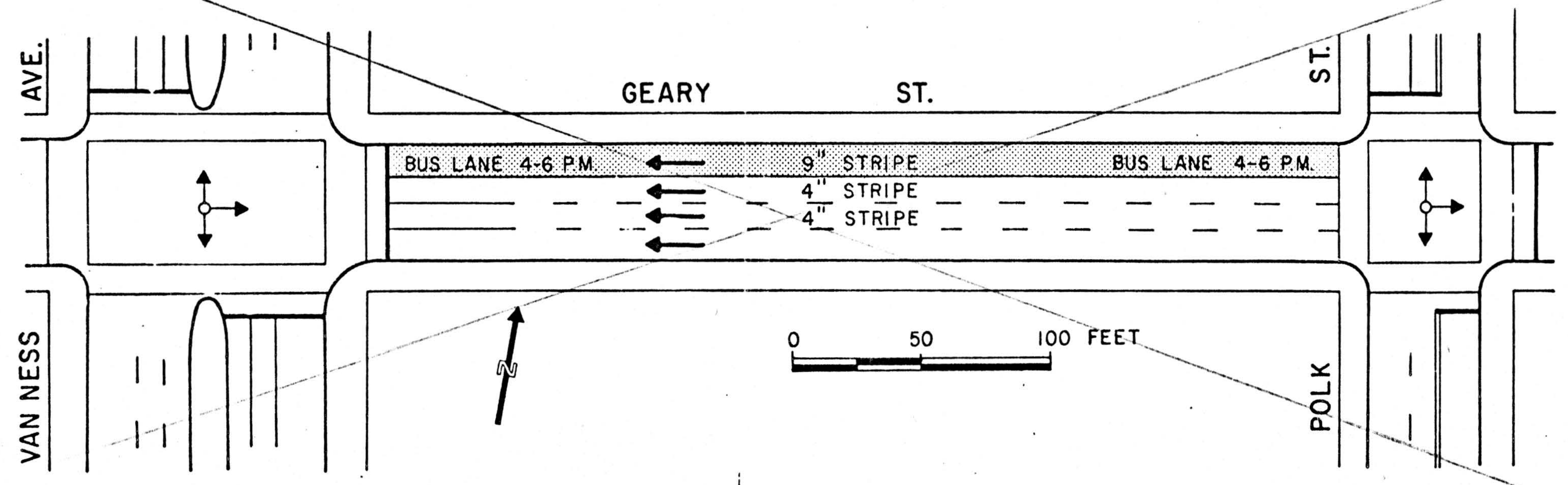
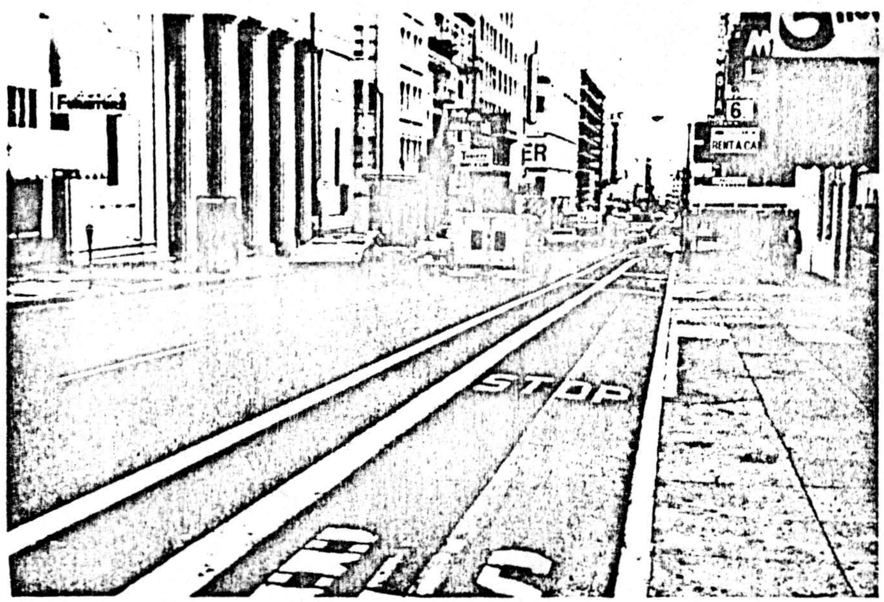
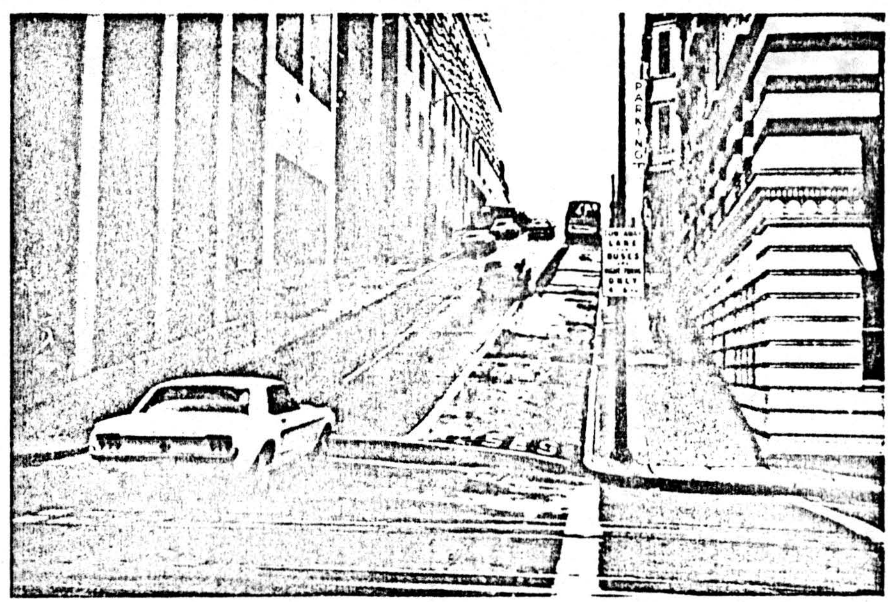


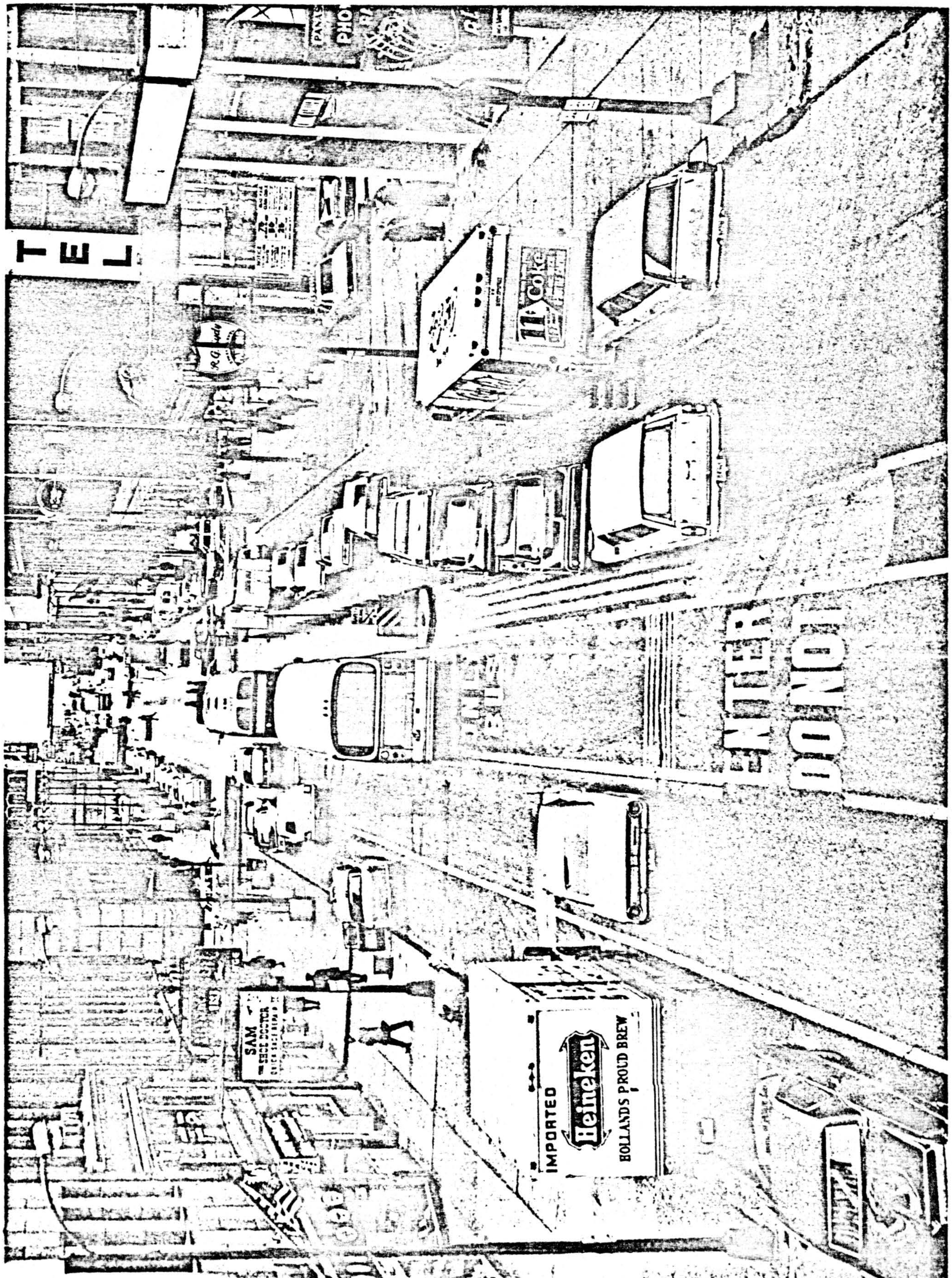
Figure C-45.–Typical lane markings, Geary Street bus lane, San Francisco, Calif.





Typical views of bus lanes, San Francisco, Calif.; O'Farrell Street (left) and Sacramento Street (right).

Figure 8



Typical view, Washington Street bus lane, Chicago, Ill.

opposing traffic. On one-way streets with frequent signals, buses may have to operate against the signal progression. (Figure 9, Page 18)

PLANNING AND DESIGN

Bus priority treatments vary widely in their planning philosophies; their design concepts; their 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 new are viewed differently than those that optimize existing facilities. Variabilities in design standard affect ranges in operating speeds, characteristics of existing freeways and local design process.

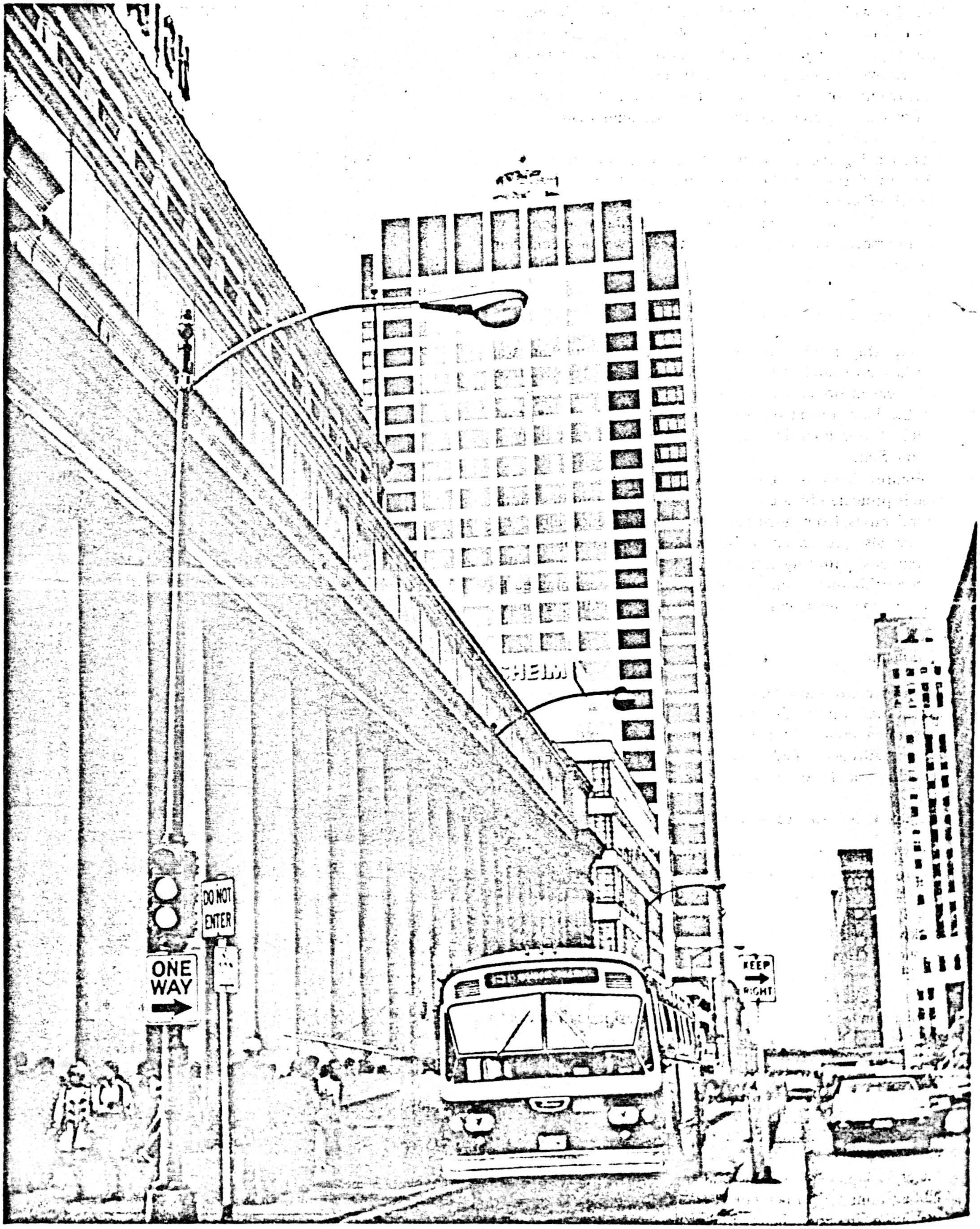
Freeways. Planning and design of bus services in relation to urban freeways suggests the following broad guidelines:*

1. Existing bus volumes in freeway corridors are not necessarily a true measure of potentials. It is not likely that the existing or the proposed busways, would be justified if existing bus volumes on the freeways or in their service corridors were used as the only basis for their justification. Consideration also should be given to the potential induced and diverted bus riders. A realistic appraisal of both existing and projected bus demands is essential.

2. Identification of major overland 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 forecast highway loads are realistic.

*Levinson, Herbert S., Hoey, William F., Sanders, David B., Wynn, Houston F., Bus Use of Highways. Report 143, National Co-operative Highway Research Program. pp 78-80

Figure 9



Canal Street contra-flow bus lane at Union Station, Chicago, Ill.

3. It is not feasible to remove existing freeway lanes from autos in 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.

4. 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. A bus free-flowing in mixed traffic on level grades (0 to 4 percent) occupies space equivalent to 1.6 automobiles. Optimum use of bus lanes in freeways or busways might be achieved by allowing buses and other vehicles to share the exclusive lane or lanes up to the point where bus service is needed. It would give buses a time advantage via a reserved lane that might otherwise not be available. This approach, however calls for a very high level of control and enforcement; it would be unlikely to maximize the benefits of bus travel over auto travel, nor would it give buses a sufficient time advantage over all cars.

5. Right-hand freeway lanes are not usually desirable for exclusive bus use, because of frequent conflicts with entering and existing cars, which would have to weave across the bus lane on their way to and from ramps.

6. 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-flow operations. Special bus entry and exit to and from the median lanes can be provided in many cases without interfering with normal auto traffic on the right hand ramps.

7. Effective downtown passenger distribution facilities are an essential complement to regional bus rapid transit services. The cost/service implication of off street distribution should be effectively explored.

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

9. Busways should be designed to allow for possible future conversion to rail or fixed guideway transit with built-in features that will permit service to be maintained during the transition period. A 40 to 60 foot right-of-way would generally provide sufficient width for stations and permit continuity of service during the conversion period.

10. There may be merit in redirecting "busway emphasis" to developing facilities within the Central Business District (CBD), and on the close-in miles of radial corridors adjacent to it. This would allow buses to serve the areas of heaviest demand, a subject largely avoided in busway proposals. The heaviest transit demands in most cities are within a 4 to 5 mile radius of the center.

11. Metering of freeway ramps with bus bypass lanes should be introduced only where the technique will improve mainline through-flow. Metering usually requires available alternate arterial street routes.

12. Street level bus stops are generally preferable to turnouts from freeway lanes. Most bus stops along existing freeways are lightly patronized. Street-level stops, where buses leave the freeway for passenger pick-up and delivery, can provide added convenience to passengers at minimum cost. Use of bus bypass lanes on metered

ramp entering freeways will result in minimum delay to buses.

13. Current operating experiences indicate that exclusive bus lanes can effectively carry up to 120 buses per hour with stops in the lane. Higher line-haul capacities can be achieved by using larger vehicles and removing bus stop areas from the through travel lanes, provided downtown distribution capacity is adequate to absorb the additional loads.

14. There is a pressing need to increase peak-hour driver productivity, as most existing expressway bus services operate in only peak-hour periods. This suggests larger, higher-capacity vehicles, perhaps articulated buses, provided this would not result in unacceptable arrangements that allow drivers to work elsewhere during off-peak hours.

15. Bus technology should be directed to improving propulsion systems that minimize or eliminate the need for costly ventilation systems on tunnels. Improvement in bus loading capabilities (additional or wider doors, etc.) are also desirable.

Arterials. Most urban bus services operate along city streets. Even in cities with extensive freeway mileage, express bus patronage usually represents about 10 to 15 percent of the peak-hour bus travel. Moreover, many freeway configurations bypass rather than penetrate the city center and thereby offer little opportunity for use by the CBD-destined bus users.*

1. Effective enforcement of arterial bus lanes is essential. Many cities report major problems of curb lane availability. These sometimes can be solved by

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* Levinson, Herbert S.; Hoey, William F.; Sanders, David B.; Wynn, Houston F.; Bus Use of Highways. Report 143, National Co-operative Highway Research Program. pp 80

contra-flow bus lanes, which are not only self-enforcing, but also produce a sense of transit identity.

2. A much wider application of bus lanes is necessary before schedule speeds can increase sufficiently to produce operating economics and/or encourage additional riding. Although bus lanes can improve speed and reduce delays, they are often comparatively short segments of over-all bus routes.

3. Extended bus lanes on radial arterial streets could produce important benefits in service dependability. The lanes could often be provided without reducing lanes for cars in the heavy travel direction. On six lane streets, four lanes could be designated in the heavy travel direction, with the curb lane giving priority to buses.

4. Right-turns by non bus 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 turn or alternately in the 250 feet approaching the intersection.

5. The high proportions of peak-hour urban travelers using buses in downtown areas suggest that increased consideration be given to (a) bus streets and (b) bus priorities in auto-free zones. Where land conditions permit, the extent and time-limits of these treatments should be adjusted to allow for essential services.

6. Segregation of bus and auto traffic should be actively pursued in new town developments, as well as in existing urban areas.

CRITERIA

Existing criteria for bus priority treatments should be re-evaluated in relation to the role that buses play in meeting peak-hour demands, in reducing congestion and in reflecting specified urban design or environmental objectives. The underlying principle should be whether an exclusive bus lane or busway will carry more people than when it is used by cars during peak-travel periods. The number of bus riders in the exclusive lane should at least equal the number of auto occupants in the adjacent lane. Criteria for removing lanes from auto use in the heavy-travel direction must be more stringent than those for adding bus lanes or creating new bus facilities. (Table 3, 4, 5, Page 24, 25, 26, 27)

Freeway Criteria. Criteria should differentiate among (1) busway development (2) provision of an additional (contra-flow) lane for buses in the heavy-flow direction on freeways (3) reserving an existing lane exclusively for buses, and (4) ramp metering.

1. Volumes of 120 to 180 buses per hour (6,400 to 9,600 bus seats) - once suggested as conditions for designating a freeway lane as an exclusive busway - are rarely found in cities without rail transit. This volume exceeds the total bus fleet in many medium to large urban areas.

2. From the standpoint of person capacity, 50 to 60 buses per hour (2,500 to 3,000 bus seats) can generally accomodate the number of persons carried in cars in a freeway lane (2,250 to 2,700 persons). This level of corridor volume also occurs mainly in larger cities. If a minimum warrant of at least 3,000 existing and divertable bus passengers per hour were rigidly applied, several existing bus priority treatments would not have been implemented.

3. A somewhat lower volume may be appropriate to achieve wider application of freeway bus priority treatments, especially where low-cost measures (such as queue bypass lanes or preferential ramp metering)are involved. A special ramp used by 10 to 15 buses in the peak hour may be justified by transit user time savings,

Table 3

SUGGESTED BUSWAY DESIGN CRITERIA

	CLASS A	CLASS B
Design Speed	Desirable - 70 mph Minimum - 50 mph	Desirable - 50 mph Minimum - 30 mph
Lane Width, With Paved Shoulders	12 ft. (1)	11-12 ft. (1)
Lane Width, Without Paved Shoulders	13 ft. (1)	12 ft. (1)
Paved Shoulder Width (2) (When Provided)	8 ft. - 10 ft.	6 ft. - 8 ft.
Total Paved Width		
Normal Flow Busway	26 - 44 ft.	24 - 40 ft.
Special Flow Busway	30 - 36 ft.	
Contra-Flow Busway	30 - 36 ft.	
Minimum Viaduct Width (Curb-to-curb)	28 ft.	26 ft.
Minimum Tunnel Width	31 - 32 ft.	29 - 30 ft.
Ramps:		
Design Speed	30 - 35 mph	15 - 25 mph
Lane Width, With Paved Shoulders	12 ft. (3)	12 ft. (3)
Lane Width, Without Paved Shoulders	14 ft. (3)	13 ft. (3)
Paved Shoulder Width	8 ft.	8 ft.
Total Paved Width	14 - 22 ft.	13 - 20 ft.

(1) Increase lane width one foot when non-mountable type curbs are utilized adjacent to travel lane.
(2) Applies only to normal flow busways
(3) Refer to Table 1-B for minimum ramp width on curves. Increase lane width one foot when non-mountable type curbs are utilized adjacent to travel lane.

Table 3, Cont.

	CLASS A	CLASS B
Maximum Superelevation	.08 ft./ft.[4]	.08 ft./ft.[4]
Horizontal Curves Minimum Radius	70 mph - 1,600 ft. 60 - 1,150 50 - 750 40 - 450 30 - 250	
Absolute Minimum Radius (inner lane edge) Convertible to Rail Non-Convertible	 250 ft. 30 ft.	
Vertical Curve "K" Values[5]		

Design Speed	Crest K	Sag. K
70 mph	255	145
60	160	105
50	85	75
40	55	55
30	28	35

	CLASS A	CLASS B
Maximum Gradient: Convertability to Rail Convertible Ramps	 3 - 4 per cent 5 per cent 6 per cent up 7 per cent down	 6 per cent 7 per cent up 8 per cent down
Minimum Vertical Clearance:	14.5 - 18 ft.[6]	Desirable - 14.5 ft. Absolute Min. - 12.5 ft.
Minimum lateral distance to Fixed Obstructions[7] Left Right	 3.5 ft. 6 ft.	 2 ft. 3 ft.

(4) May be reduced to 0.6 ft./ft. in regions where roadway icing is a consideration.

(5) Length of vertical curve = K x algebraic difference in grades. The "K" values given above conform to current AASHO policy.

(6) Minimum vertical clearances vary according to the requirements of the selected rail system.

(7) Distance from the edge of the traveled lane to the vertical face of a non-continuous obstruction, such as a bridge pier or abutment.

Table 4

PAVEMENT WIDENING ON 2-WAY, 2-LANE BUSWAY CURVES

	24 FT.					22 FT.	
	DESIGN SPEED, MPH					DESIGN SPEED, MPH	
RADIUS	30	40	50	60	70	30	40
500 ft.	1.5	2.0				2.5	3.0
750 ft.	1.0	1.0	1.5			2.0	2.0
1000 ft.	0.5	1.0	1.0	1.5		1.5	2.0
2000 ft.	0.0	0.0	0.5	0.5	1.0	1.0	1.0
3000 ft.	0.0	0.0	0.0	0.0	0.5	0.5	1.0
4000 ft.	0.0	0.0	0.0	0.0	0.0	0.5	0.5

OTE: Values less than 2.0 may be disregarded.

Table 5

WIDTHS OF PAVEMENTS FOR RAMPS

RADIUS OF INNER EDGE OF PAVEMENT, FEET	PAVEMENT WIDTH IN FEET FOR: CASE I 1-lane, one-way no passing	CASE II 1-lane, one-way, with provision for passing stalled vehicle	CASE III 2-lane, one-way or two-way
50	22	39	45
75	19	31	37
100	17	28	34
150	16	25	31
200	16	24	30
300	15	23	29
500	15	22	28
1000	14	22	27
Tangent	12	20	24

especially where it improves bus service and driver productivity. Moreover, warrants should also consider (1) projected bus flows (2) downtown employment intensity and (3) downtown parking space costs.

Federal Highway Administration policies should be appraised in this context. In adapting these policies, it should be clearly recognized that express transit is essentially a peak-hour service. The policies suggest:

> ... that the general warrant for an exclusive bus lane is whether such a lane will accomodate more people than when used by general traffic. For an exclusive bus highway (as against a lane reserved for peak-period use), the analysis should consider not only the peak period, but the off-peak period as well. Analysis should examine the alternative of exclusive bus use in the peak period and mixed use in other hours.
>
> For preferential treatment of buses, the warrant should be applied when the number of persons served would be insufficient to consider exclusive bus use. Such treatment includes freeway metering with bus bypass ramps, closing certain ramps to all vehicles except buses and emergency vehicles, reserving curb lanes for buses, right-turning vehicles, and bus actuated traffic signals.*

Arterial Criteria. Warrants for reserved bus lanes in city streets, as developed by the Institute of Traffic Engineers, provide some general guidance.** They specify that:

1. A curb transit lane is practical, under normal circumstances, only during peak traffic periods, when curb parking and stopping regulations can be implemented.

2. A minimum of 60 transit vehicles per peak hour should use the transit lane to justify the lane's exclusive use.

---

* Marple, G.E., "Warrants for Exclusive Bus Facilities". Instr. Memo., FHWA (July 17, 1970)

** "Reserved Transit Lanes". Traffic Eng., Vol 29, No. 10 (July 1959) pp 37, 39, 40

3. The width of roadway must be sufficient for at least 2 lanes of travel in addition to the transit lane in the direction of travel of the transit lane.

4. The number of transit patrons using the transit vehicle in the subject street should equal or exceed 1.5 times the number of drivers plus passengers carried by other vehicles during the peak hour.

Contemporary practice suggests that warrants should be broadened. The number of buses per hour necessary to justify arterial bus priority treatments should be influenced by planning, as well as traffic consideration.

Bus priority lanes on main shopping streets should be installed to improve transit visibility and might be justified by a lower number of buses per hour than median bus lanes or bus lanes on other streets.

A bus mall that penetrates the heart of a commercial area may be desirable for lower volumes of peak bus flow than are normally considered for arterial bus lanes.

Accordingly, it appears desirable to establish specific criteria for: (a) main street bus malls, (b) main street curb bus lanes, (c) curb bus lanes, (d) median bus lanes, and (e) contra-flow bus lanes. The following factors should be considered in refining warrants:

From the standpoint of person capacity, 20 to 30 buses per hour (1,000 to 1,500 seats) can accomodate more people than are carried in cars in an equivalent arterial street lane (600 to 750 person per hour).

From the standpoint of enforceability, volumes of 40 to 60 buses per hour (resulting in approximately one bus in each block at any time) are desirable. At, or above these volumes, buses will tend to preempt the curb lane when "no stopping" controls are implemented.

When bus volumes are less than 60 in peak hour, taxis may be allowed in bus lanes.

COST ANALYSIS

A system of proposed freeway and arterial improvements was designed to improve bus as well as auto flow. The estimated costs and benefits are summarized in Table 6 and 7, Page 31.

Restriction of certain ramps to buses, metering of other ramps and provisions for bus bypass lanes around ramps, would cost $102,000. This compares with $245,000 to $619,000 in annual benefits, depending on the specific option that is implemented. Bus preemption of traffic signals at 37 intersections on 14 bus routes would cost nearly $1 million but would produce an estimated $3.5 million in annual benefits.

Bus turnouts at arterials at about 20 locations, increased radii at 45 locations, and reversal of STOP signs to favor buses would cost $365,000.

ESTIMATED RESULTS

Present busway patronage and forecasts for 1975 are summarized in Table 8 and 9, Page 32. If downtown employment growth continues, daily patronage might reach 20,000 riders. There would be about 8,000 one-way peak-period work trips, of which 4,000 would occur in peak hour. This is substantially more than 1,200 persons currently carried in buses on the North Central Expressway during the morning peak hour.

SUMMARY

This overview of bus priority treatments provides important insights into the problems, and the prospects associated with effective utilization of highways by buses. The effectiveness of these treatments can be measured in many ways -- for example, the reductions in the mean and variance of bus travel times. The annual person-minutes

Table 6

SUMMARY OF URBAN CORRIDOR PROPOSALS, DALLAS

PROPOSAL	DEVELOPMENT COSTS ($)	ANNUAL OPERATING COSTS ($)	ANNUAL BENEFITS ($)
Freeway bus priority (Bus priority ramps; metered ramps; coordinated frontage road signals)	101,900	16,000	245,000–619,000
Bus preferential treatment at 57 signalized intersections (Signals, 11 bus routes)	93,800	35,100	3,450,310
Bus turnouts on arterials (20 potential locations; increased turning radii, 45 locations; reversal of STOP signs to favor buses, 15 locations)	364,550	—	—

Table 7

DEVELOPMENT COSTS, NORTH CENTRAL BUSWAY, DALLAS

ITEM	COSTS ($1,000)		
	PHASE 1	PHASE 2	TOTAL
Parking terminal:			
Land purchase	1,500	—	1,500
Construction	500	—	500
Engineering design	15	—	15
Busway construction, right-of-way and air rights	—	300	300
Roads and lighting (9.5 mi)	—	25,118	25,118
Ramps and passenger loading areas	—	1,843	1,843
Passenger stations	—	1,050	1,050
Engineering design	—	1,870	1,870
Subtotal, development costs	2,015	30,181	32,196
Purchase of 40 buses	—	1,920	1,920
Project administration	10	370	380
Operating subsidy (12 mo) until busway is completed	150	—	150
Evaluation of busway	—	40	40
Total	2,175	32,511	34,686

Table 8

DAILY CAR AND BUS TRIPS INTO DALLAS CBD FROM NORTH CENTRAL CORRIDOR

PERIOD	VEH. TYPE	ALL TRIPS INTO CBD PERSONS	ALL TRIPS INTO CBD VEHICLES	CORRIDOR INTO CBD PERSONS	CORRIDOR INTO CBD VEHICLES
6:30 AM-6:30 PM	Auto	179,329	123,882	78,487	54,136
	Bus	52,535	2,162	22,383	921
	All	231,864	126,044	100,870	55,057
7:30 AM-8:30 AM [a]	Auto	33,569	23,633	14,703	10,328
	Bus	11,846	269	5,046	115
	All	45,415	23,902	19,749	10,443
24-hr	Auto	217,632	157,410	95,323	68,788
	Bus	63,756	2,747	27,160	1,170
	All	281,388	160,157	122,483	69,958

Table 9

PROJECTED 1975 PERSON-TRIPS TO DALLAS, ON NORTH CENTRAL BUSWAY

ITEM	PERSON TRIPS
1. Work trips to CBD [a]	175,900
2. Corridor-to-CBD work trips [b]	70,400
3. Corridor-to-CBD work trips between 7 and 9 AM [c]	42,200
4. Nondivertible peak-period corridor-to-CBD work trips [d]	3,700
5. Divertible peak-period trips [e]	38,500
6. Percentage of peak-period work trips diverted to busway [f]	(20)
7. Peak-period person-trips diverted to busway [g]	7,700
8. Estimated total 24-hr person-trips on busway [h]	19,300

[a] CBD employment projections for 1975 from Ref. (*B-8*).
[b] 40 percent of CBD work trips from corridor.
[c] 60 percent of CBD work trips in AM peak period.
[d] 60 percent of (a) 3,700 CBD work trips by auto from locations within 3 miles north of CBD, and (b) 2,500 "captive" bus rider CBD work trips in corridor. No future increase in these trips is anticipated, with CBD work trip growth offset by rising per capita auto ownership.
[e] Item 3 minus Item 4.
[f] Based on Ref. (*B-9*).
[g] Item 6 percentage applied to Item 5.
[h] Item 7 doubled to cover two-way peak-period trips (7 to 9 AM and 4 to 6 PM), based on Ref. (*B-6*). Total peak-period trips estimated at 80 percent of 24-hr trips to and from CBD, based on commuter-type transit system experience in New York City, Chicago, and Philadelphia.

saved per dollar of investment provides another quantifiable benchmark. Equally as significant is the recognition of public transport as important urban resources, and an essential public service.

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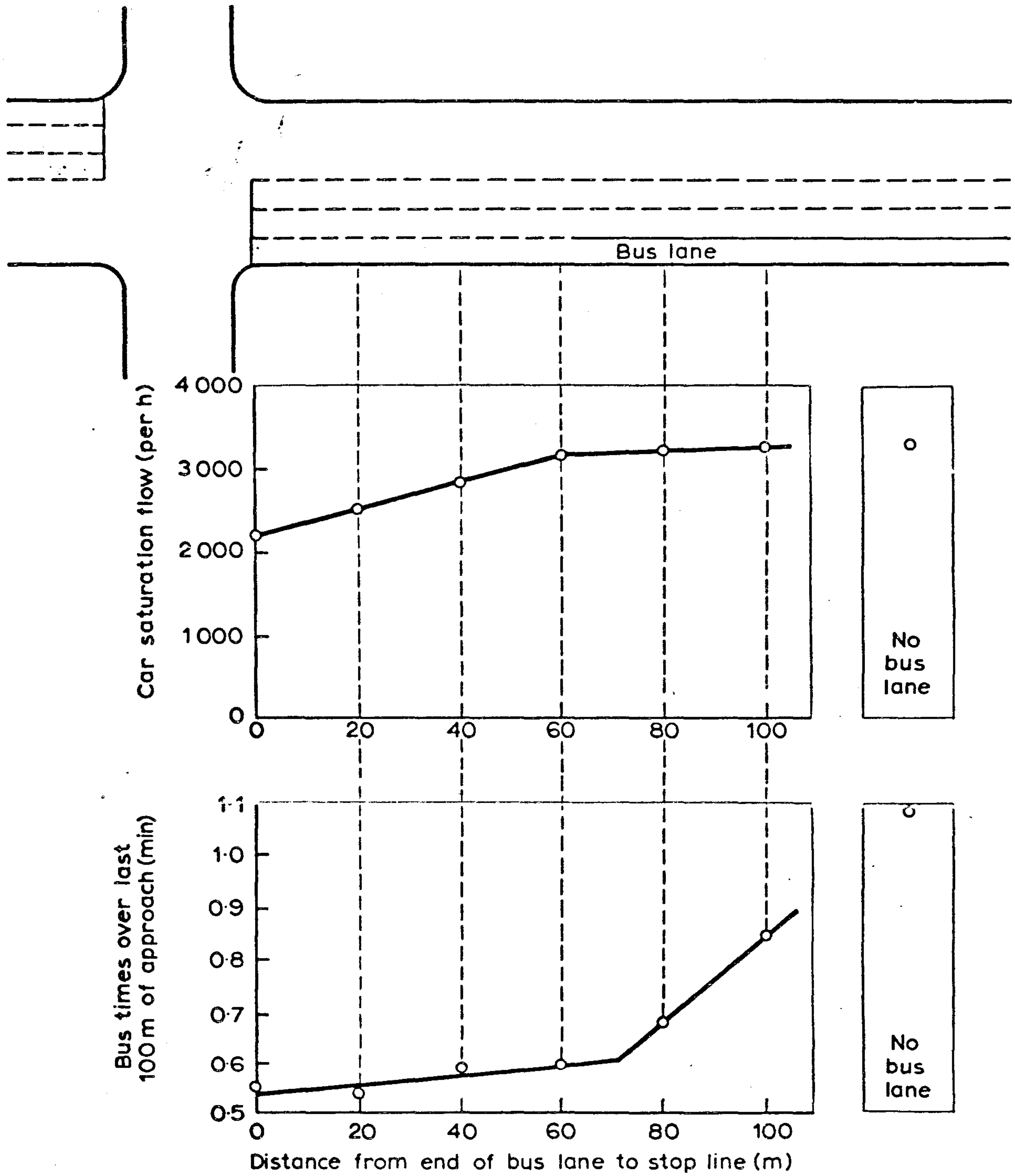
APPENDIX

Addendum

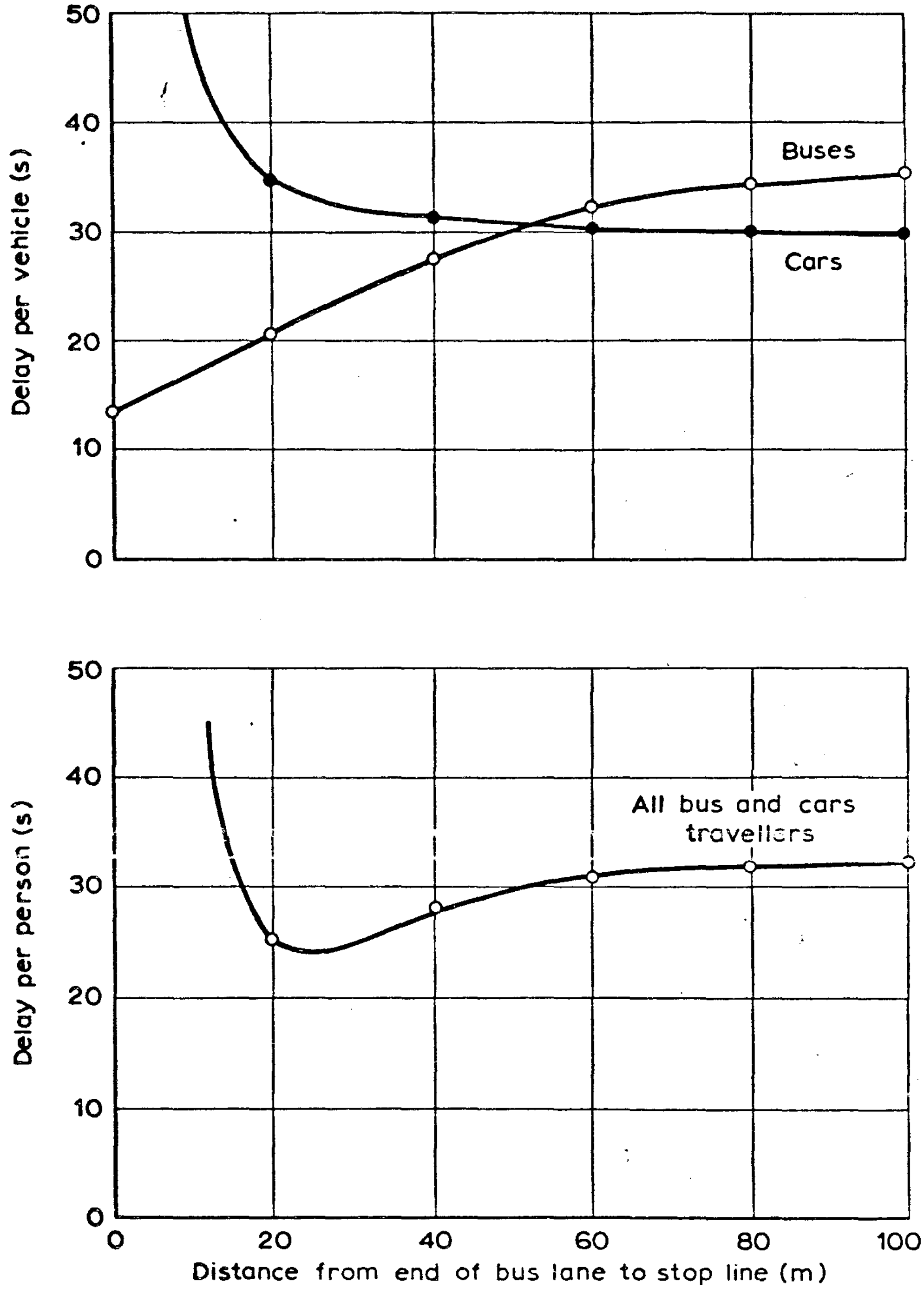
My Coop job for this period has mostly consisted of drafting on the three phases of the Urban Corridor Demonstration Project of the City of Dallas. A minute amount of field work was done since most of the preliminary field work had been completed before I arrived.

The drafting consisted of drawing the intersection and placing control cabinets, conduit, splice cans, etc., where needed or desired. The field work was mostly checking to see where existing structures (e.g. signals, conduit etc.) were and to see if additional wire, conduit, control cabinets, etc., were needed.



VALUES OF PARAMETERS	
Degree of saturation	100 per cent
Bus flow	120 per hour
Turning proportions	10% left, 10% right
Green time	30s
Cycle time	70s

Fig. 1. TEST-TRACK EXPERIMENT WITH BUS LANE: CAR SATURATION FLOWS AND BUS TRAVEL TIMES



VALUES OF PARAMETERS (3-lane approach)

Degree of saturation with no bus lane .... 90 per cent
Bus flow .... 130 per hour
Car flow .... 1 400 per hour
Bus occupancy 35
Car occupancy .... 1·4
Bus and car turning movements .... 10% left, 10% right
Green time .... 30 s
Cycle time .... 70 s

Fig. 2. COMPUTER SIMULATION OF BUS LANE: VEHICLE AND PERSON DELAYS

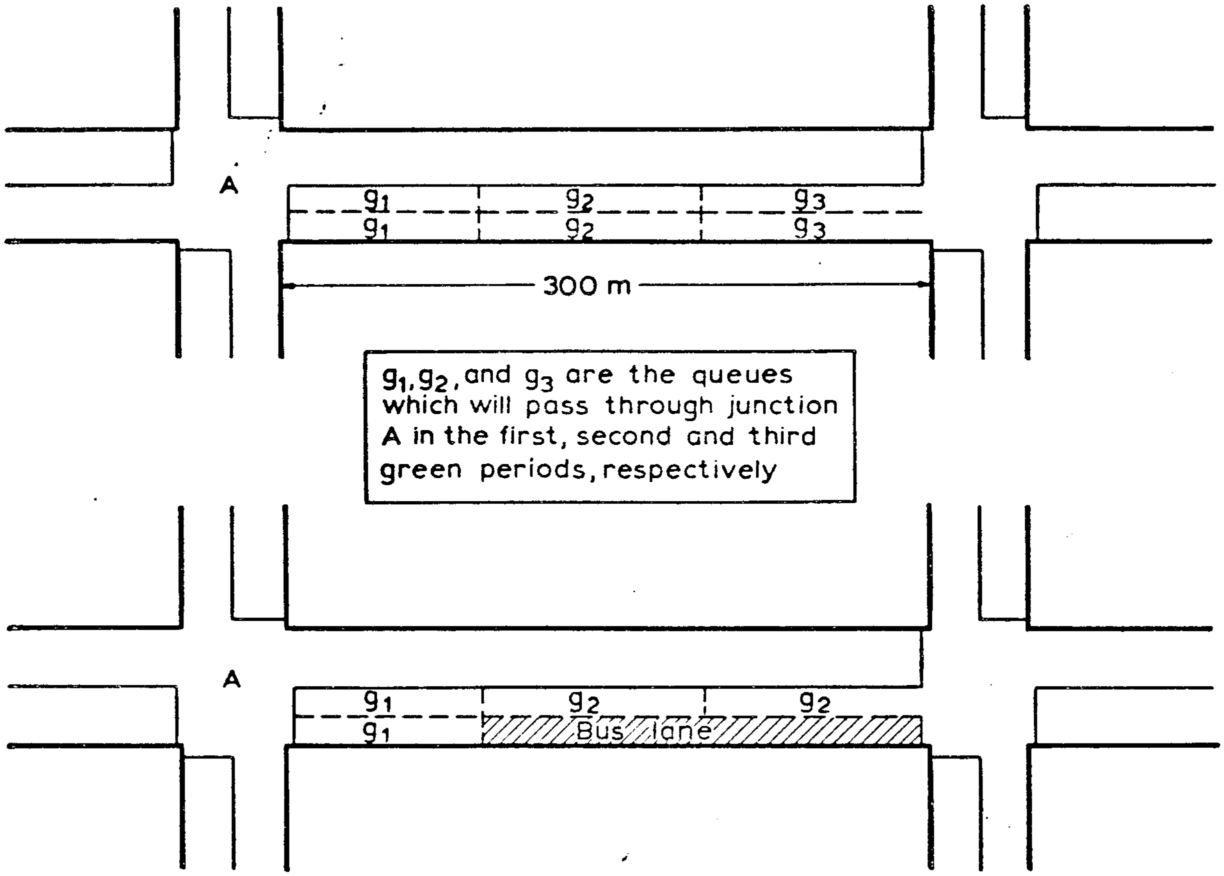


Fig. 3. QUEUEING VEHICLES ON AN IDEALIZED LINK

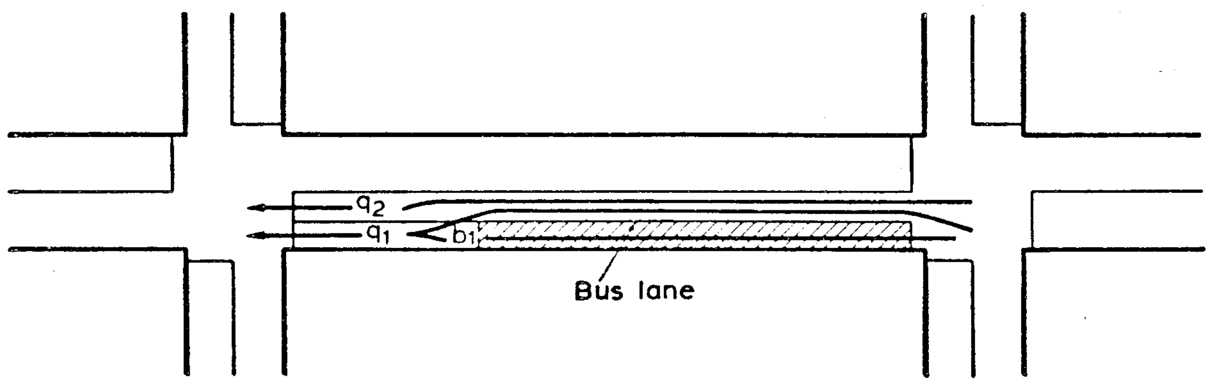


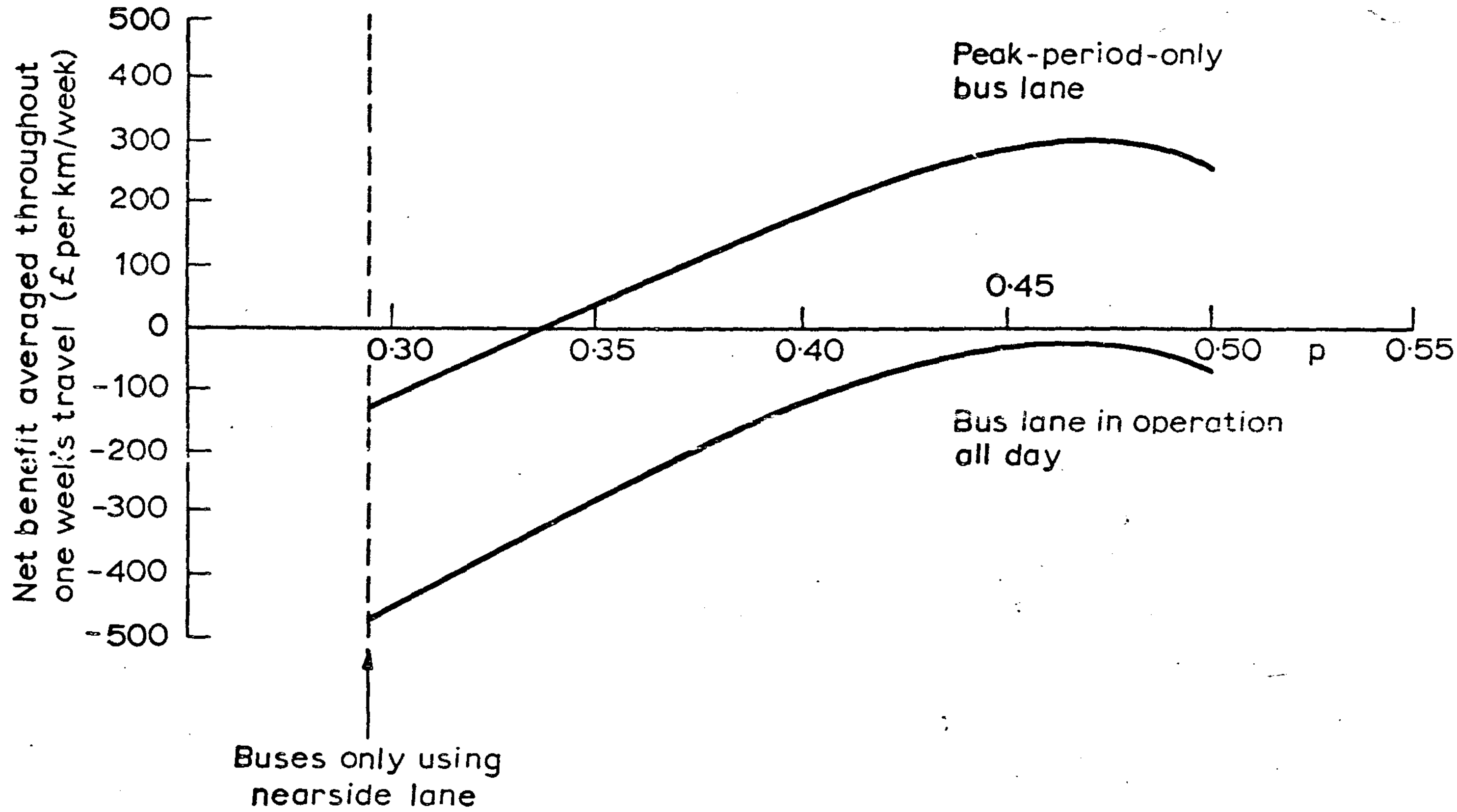
Fig. 4. BUS FLOWS AND OTHER TRAFFIC FLOWS ALONG LINK IN BUS-LANE MODEL

TRANSPORT AND ROAD RESEARCH LABORATORY

ERRATUM TO LR 448

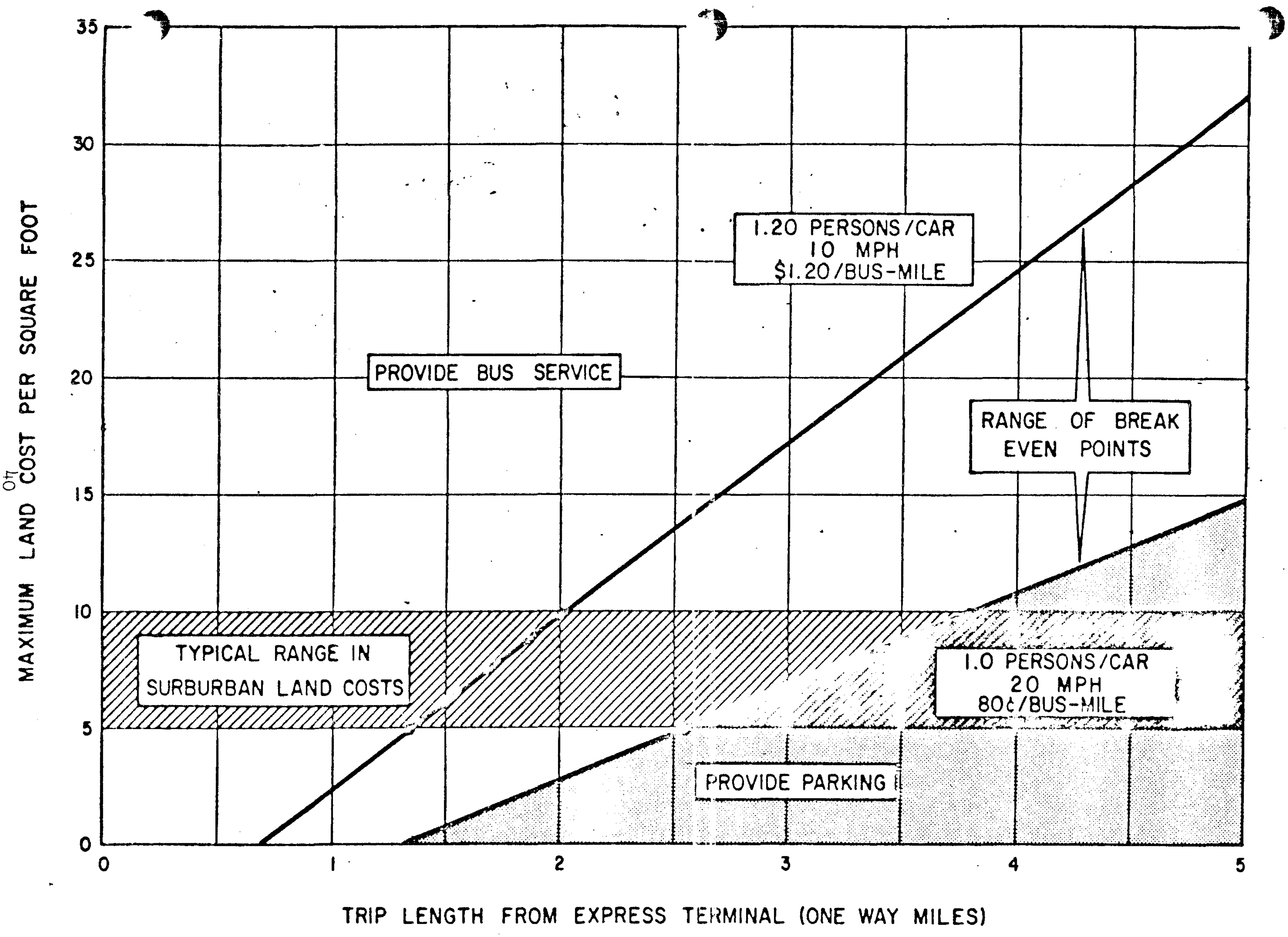
PRIORITY TO BUSES AS PART OF TRAFFIC MANAGEMENT BY Dr. F. V. WEBSTER

(This figure replaces existing figure 5)

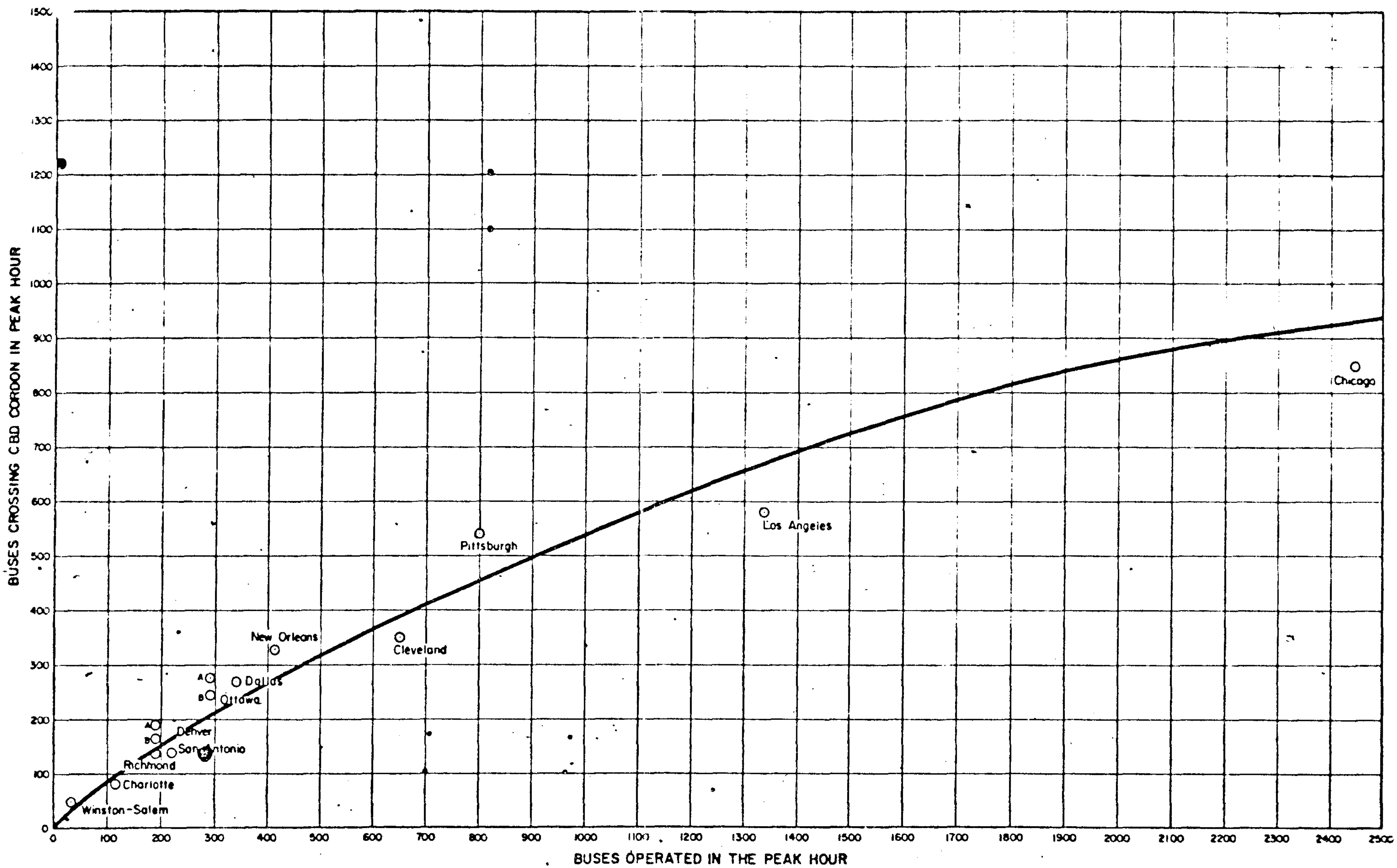


$p = \frac{q_1}{q_1 + q_2}$	is the proportion of pcu's in the nearside lane during peak periods

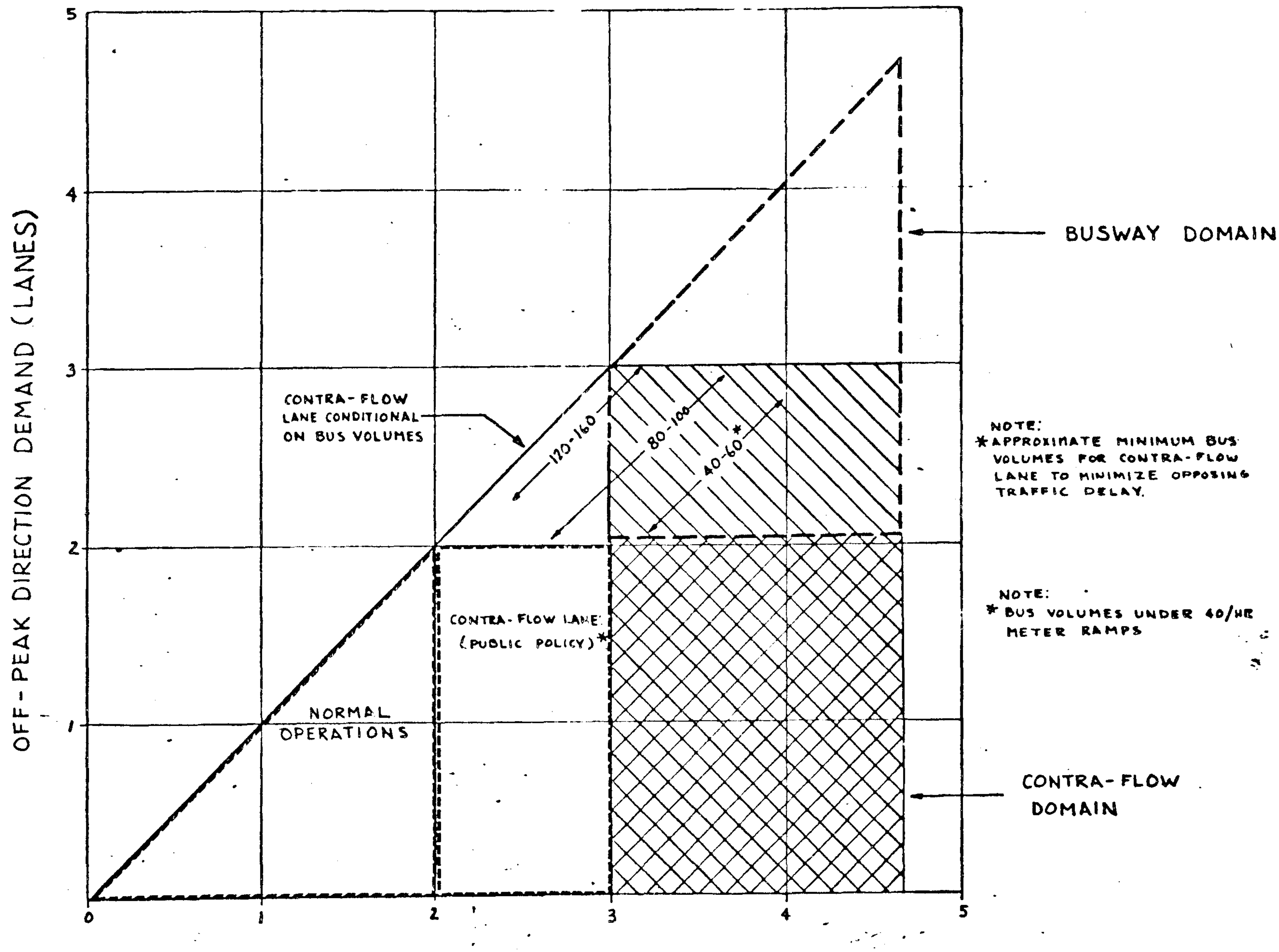
Fig. 5. RELATIONSHIP BETWEEN NET BENEFIT AND PROPORTION OF TRAFFIC (pcu's) IN THE NEARSIDE LANE DURING PEAK PERIODS



LOCAL BUS SERVICE AND LAND COST



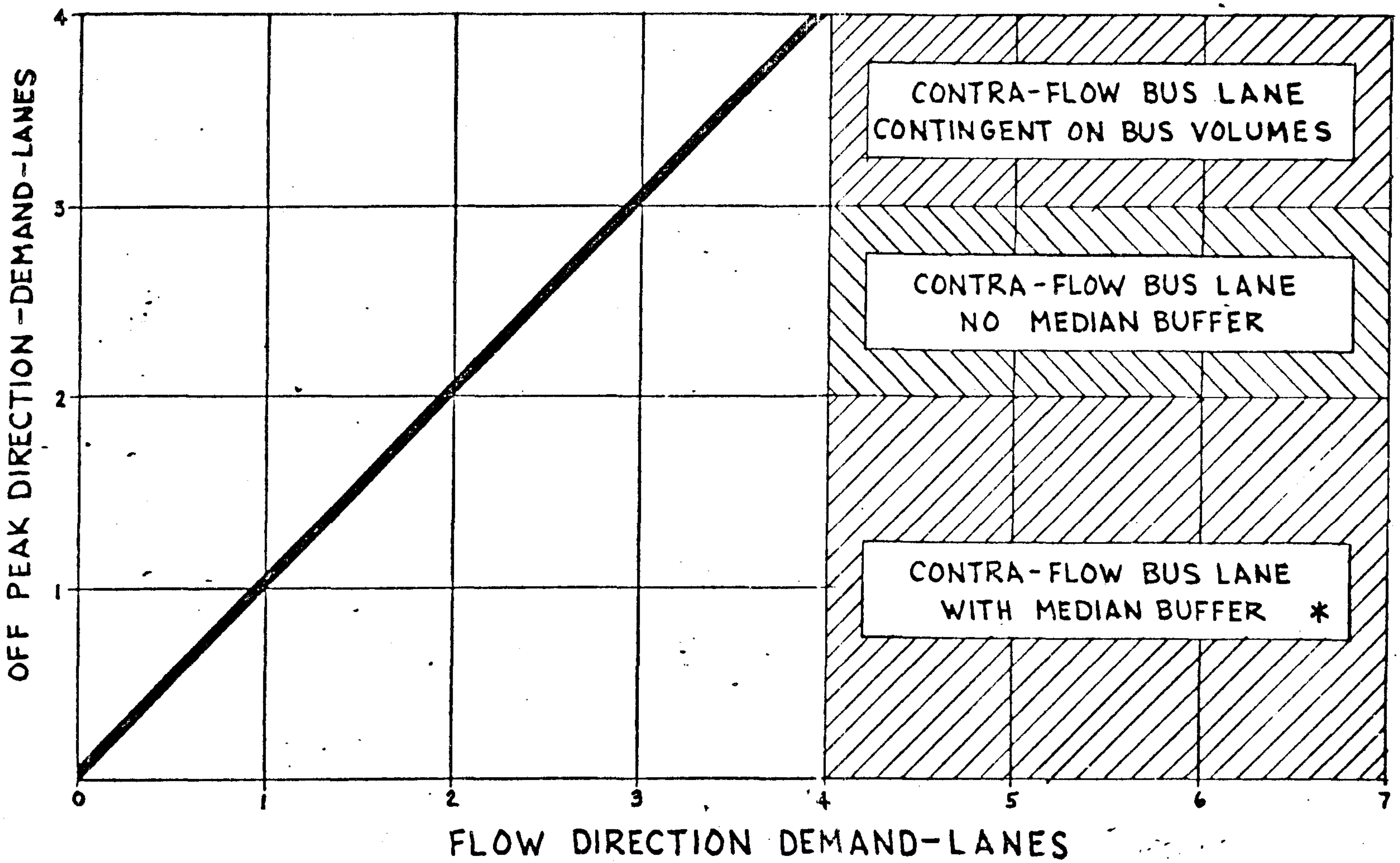
NUMBER OF BUSES ENTERING C.B.D. IN PEAK HOUR



BUS PRIORITY CONCEPT

SIX LANE FREEWAY

CONTRA-FLOW BUS LANE CONCEPT
EIGHT LANE FREEWAY



NOTE: *
WHEN BUS VOLUMES
ARE LESS THAN 40
REVERSIBLE CAR LANES
MAY APPLY.

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Table 7

TENTATIVE RANGES IN PEAK-HOUR BUS VOLUMES FOR BUS PRIORITY FACILITIES (ONE-WAY)

TYPE OF TREATMENT	DESIGN YEAR BUSES [1]
Freeway Related	
Busway	40-60
Contra-Flow Bus Lane	40-60
Bus Bypass Lane at Metered Ramp	10-15
Arterial Related [2]	
Bus Streets [3]	20-30
CBD Curb Lanes - Main Street [3]	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

(1) Existing conditions should meet 75 per cent of these volumes.
(2) Where arterial bus volumes are under 60 per hour, taxis may utilize bus lanes.
(3) Environmental considerations may influence bus lane and bus street installation.

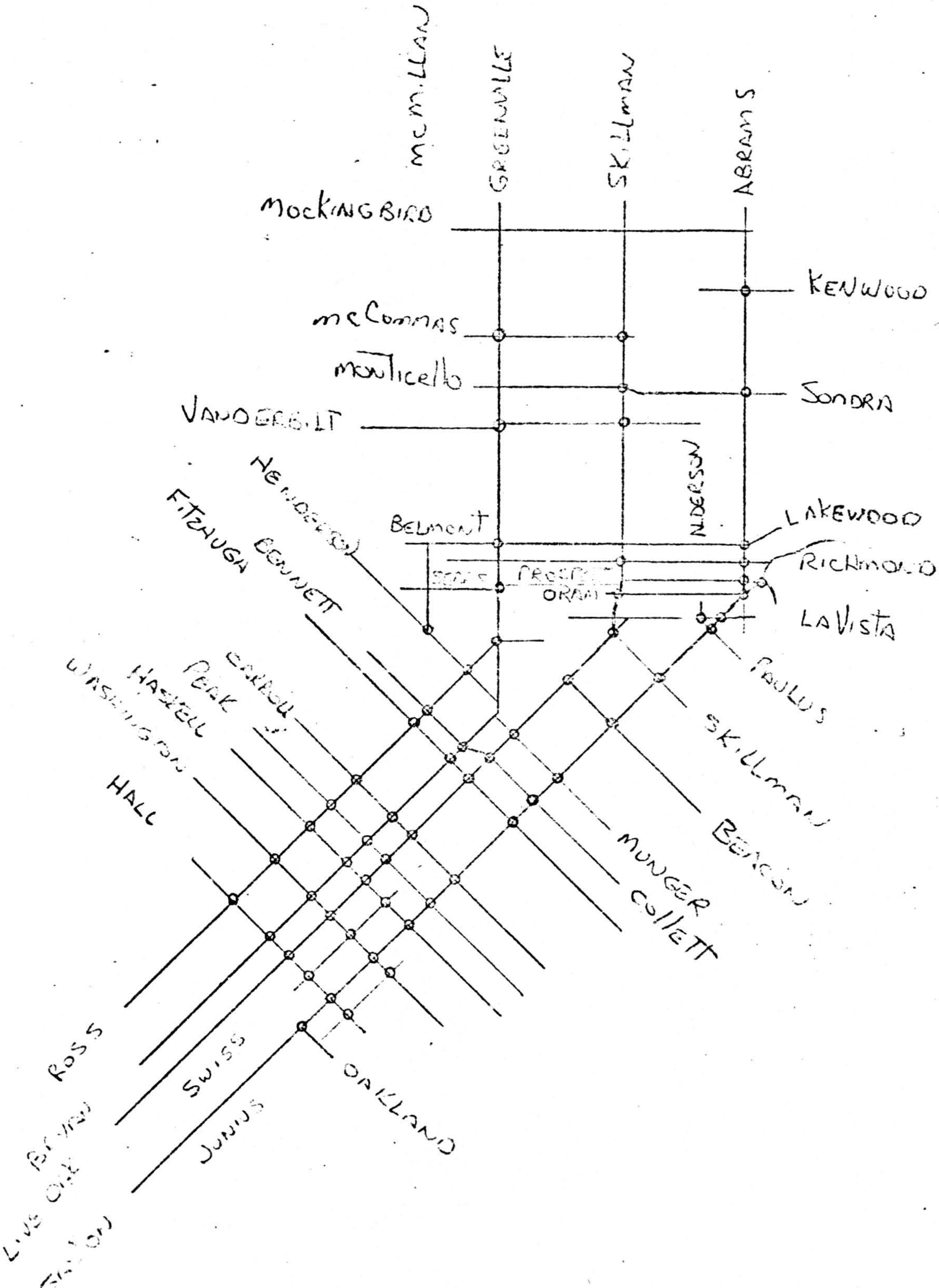
Table 6

GENERAL CONDITIONS CONDUCIVE TO URBAN RAPID TRANSIT DEVELOPMENT

PRIMARY DETERMINANTS	RAIL Desired Conditions For Rail System Development	RAIL OR BUS	BUSWAY (Minimum)
1. Urban area population	2,000,000	1,000,000	750,000
2. Central city population[a]	700,000	500,000	409,000
3. Central city population[a] density, in people per square mile	14,000[c]	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, in square feet	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)	100,000	70,000	35,000

a - "Effective Central City"--central city and contiguously developed areas of comparable population density.
c - Depends on land use assumption.
SOURCE: Adapted from Urban Transportation Concepts, Wilbur Smith and Associates, 1970.

Dallas Urban Corridor Demonstration Project



FIELD PROJECT AREA DETAIL (Arterial)