TRANSITWAY WIDTH ASSESSMENT

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Research Report 339-3
Improving Mobility Through Application of High-Occupancy
Vehicle Priority Treatments
Research Study 2-10-84-339

Sponsored by
State Department of Highways and Public Transportation
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
Texas A&M University System
College Station, Texas 77843

November 1984

ABSTRACT

This report presents the results of bus operating tests performed on several simulated transitways at the Texas A&M University Research Annex. One vehicle was parked in the transitway to simulate a breakdown, and another was driven past the "stalled" vehicle at comfortable speeds. Parked, or "stalled", vehicles included a 40-foot transit bus and a passenger car. Passing vehicles included a 40-foot transit bus and a passenger van. The width and alignment of the barriers delineating the transitway were varied to simulate several one- and two-lane transitways and both tangent and curved sections. Simulated bus breakdowns were performed to determine the percentage of bus breakdowns that might close a transitway of a given width. The findings should allow better determination of transitway width in future planning and design efforts.

Key words: Transitways, high-occupancy vehicle lanes, busways, HOV facilities, highway design.

ACKNOWLEDGEMENTS

The funding for this research effort was supplied by the Metropolitan Transit Authority of Harris County (METRO), Texas State Department of Highways and Public Transportation (TSDHPT) (both HPR 2-10-84-339 and IAC 84-85-0820) and the Federal Highway Administration (FHWA). In addition to the funding, METRO supplied two regular route transit buses, two drivers, a supervisor and a mechanic. TSDHPT supplied the concrete barriers and paint barrels used to delineate the lane. In addition, this project could not have been conducted without the cooperation and hard work of the following individuals.

METRO --- Luther Gayle, Rudolph Becera, Clarence Gilner, Lloyd Eubanks and John Sedlak

TSDHPT -- Hunter Garrison, Walt Jones and W.V. Ward

DISCLAIMER

SUMMARY

The Metropolitan Transit Authority of Harris County (METRO) and the Texas State Department of Highways and Public Transportation (TSDHPT) along with the Federal Highway Administration (FHWA), sponsored a transitway evaluation test at the Texas A&M Research Annex. METRO, as of the publication date of this report, is evaluating three alternative transit plan proposals which call for 133 to 186 miles of transitways in freeway, railroad and major arterial street corridors. The three freeway median transitways under construction in Houston have been designed using several different design guideline documents, but without much information as to actual operating expectations. This report attempts to address two major design and operational questions.

- What percent of controlled (non-accident) bus breakdowns will result in a total blockage of a transitway?
- If a bus does breakdown in the lane, what passing speed may be expected from following buses?

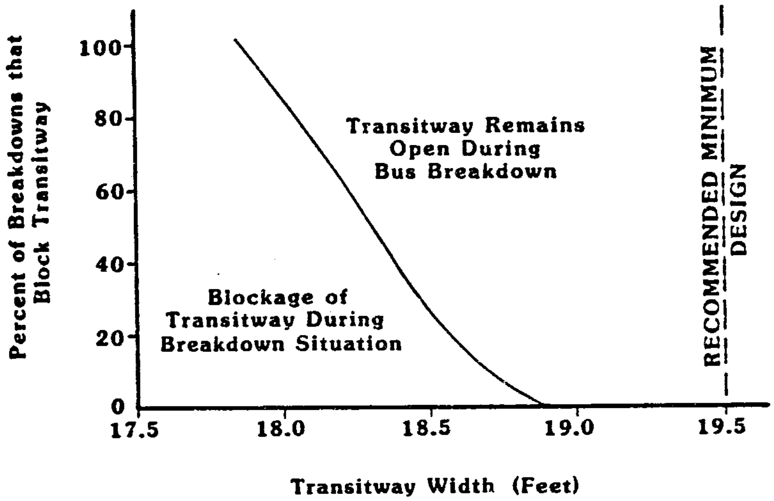
Both questions relate to the width of the transitway -- at some narrow width an unacceptably high number of breakdowns result in lane closure, and at some wide width no significant reduction in speed from the normal 50-55 mph operating speed will be necessary. Parking tests were conducted using regular 40-foot transit buses to answer the first question (Figure S-1). Several different transitway widths and alignments (curved or tangent sections) were simulated to answer the second question.

Minimum and desirable transitway widths were determined using passing speed information, delay estimates, and cost estimates of a bus breakdown for various transitway widths (Figure S-2). Table S-1 summarizes these quantities for the recommended minimum and desirable configurations. The widths

Table S-1. Recommended One-Lane Reversible Transitways

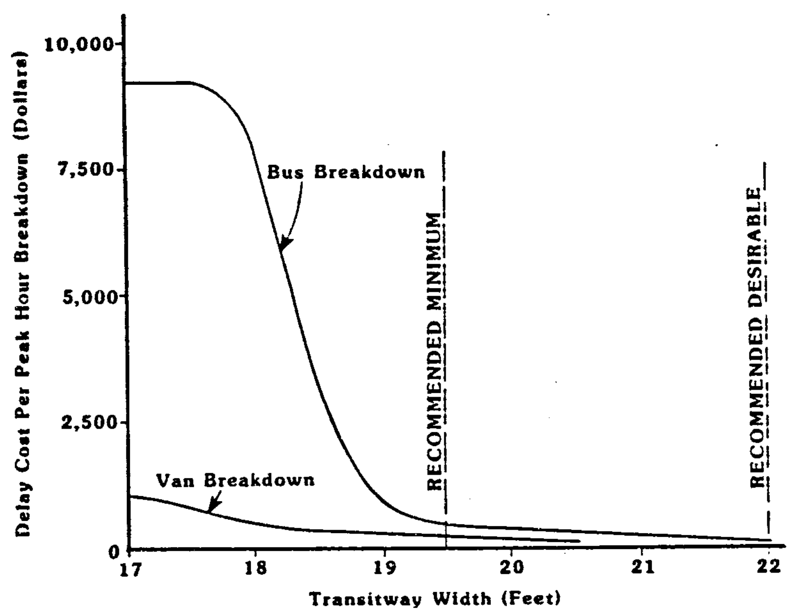
Transitway Width	Passing Speed (mph)	Delay[1] (sec)	Cost of Peak Hour Bus Breakdown[2]	% of Controlled Breakdowns That Will Block Lane[3]
Minimum				
19.5' Tangent	9	200	$460	0%
Desirable				
22.0' Tangent	38	55	$ 80	0%

[1]Relative to constant 50 mph transitway speed
[2]Assumes $50 per bus hour, $7 per passenger hour, 75 buses and 300 vans per peak hour 50 riders per bus, and 9 riders per van (Figure S-2).
[3]See Figure S-1.



Note: Assumes 9.5 feet of clear space necessary for bus to pass stalled vehicle.

Figure S-1. Bus Breakdowns That Block Transitway



Note: Assuming typical breakdown rates, 15 bus breakdowns and 75 van breakdowns can be expected per year. The delay cost is calculated by multiplying the probability of the event (lane closed or open) to the value associated with that event. Peak-hour volumes of 50 buses and 300 vanpools were combined with an incident time of 30 minutes. Values of $50 per bus operating hour and $7 per passenger hour were used to assess the cost of delay.

Figure S-2. Delay Cost of a Peak-Hour Breakdown on Tangent Transitway are clear distance (toe-to-toe of barrier) between two concrete barriers, with a 12-foot lane striped in the middle of the clear width and an equal shoulder area on each side.

The two-lane, two-direction cross section tested, consisted of a travel lane on each side of a center shoulder area. The minimum recommended cross-section for this type of lane is a 10-foot middle shoulder, with an 11-foot lane and 0.5-foot clearance between the travel lane and the barrier on each side of the shoulder. This results in a total clear width of 33 feet. The desirable cross section would widen the clear space to 36 feet with a 10-foot shoulder, 11.5-foot travel lanes and a 1.5-foot clearance area.

IMPLEMENTATION STATEMENT

Project 2-10-84-339, and its predecessor Project 2-10-74-205, is oriented toward assisting the Department in the planning, implementation, and evaluation of priority treatment projects. Transitway construction in Houston and possibly in several other major Texas cities, has been a major component of transportation improvement plans.

The Department is involved in the planning, design and funding of several transitway projects and this document should allow a more accurate determination of the transitway design features. A quantification of design values to help assure functional transitway design and operation has been developed through this research effort.

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INTRODUCTION

Transitway development in Houston began in 1973 with the Gulf Freeway reconstruction project. Computer simulation of future freeway demand indicated that it was not possible to serve that demand simply by only building more freeway lanes. A one-lane, reversible transitway designed to serve buses and vans, constructed in the median of the freeway, was found to be a cost effective alternative for serving the person movement demand. The design of the transitway was undertaken with the obvious constraints imposed by trying to retrofit an operating freeway within a constrained right-of-way. Compromises in freeway design could be made; the elimination of inside shoulders and narrowing of lane widths to 11 feet generally resulted in a clear median transitway space of 19.5 feet between the concrete barriers.

Planning for the Katy Freeway Transitway also began with a major freeway rehabilitation effort and concluded with a freeway configuration much the same as that of the Gulf -- no inside freeway shoulders, narrow lanes, and at least 19.5 feet of transitway clear space between the concrete barriers. The North Freeway Transitway, made necessary by the success of the Contraflow Lane project, is also being constructed in conjunction with a freeway widening and resurfacing project and will have similar geometric features.

In establishing acceptable widths for a transitway, little formal guidance was available. Due to the retrofit process and constrained right-of-way, trade-offs between freeway and transitway design standards were required. A literature review was undertaken in an attempt to determine transitway design standards. Table 1 presents a summary of relevant priority lane dimensions recommended by several design guideline documents. Transitway travel lane widths vary between a minimum of 11 to 12 feet to a desirable width of 11.5 to 13 feet. Shoulder specifications vary not only in width, but also degree of specificity. Seven different publications specify only "shoulder width" dimensions, with ranges of 2-to 8-foot minimum and 10-foot desirable shoulders. Left shoulder widths are detailed in three publications, varying between 2 and 8 feet, with right shoulders varying between 6 and 12 feet. These widths are contrary to those that will be required in Houston, as in all cases the buses will park on the left side of the lane in the event of a breakdown.

Table 1. Transitway Design Guidelines

Source	Lane Width		Shoulder Width			Total Pavement	
	Min.	Des.	Total	Left	Right	One-Way	Two-Way
AASHTO	11'	12'		4' des 2' min	12' des 6' min	23' des bus 20' min bus 28' des car 23' min car	28' bus 48' car
NCHRP 155	12'	13'	10' des 8' min			24-25'	36-44'
California		12'		2'	8'	26'	40'
Canada		11.5'	1.5'				
Minnesota		12'	10' des 5' min				
Houston MTA		12'	10' des 3' min			20' des 18' min	40' bus 52' des car 48' min car
Texas SDHPT	12'	13'	10' des 2' min bus 6' min car				44' des 28' min
Virginia		12'	12'				36'
Wisconsin		13'	10' des 8' min				50' des 26' min
Pennsylvania		12'		8' des 2' min	8'		

Sources: 1,2,3,4,5,6,7,8,9,10

The total width of a one-lane transitway is specified in four publications; the widths range from 20 to 26 feet for bus-only operations. Two-way transit operation for buses only would require a pavement width between 28 and 50 feet; if carpools are allowed to use the transitway, a clear width of 48 to 52 feet is suggested.

This range of transitway design specifications makes the design of transitways difficult in itself; the restricted right-of-way and need for complementary highway improvements further hinder design flexibility. Engineering judgments must be made as to compromises in both transitway and highway configurations. Clearance envelopes for transit buses must be balanced against the reality that only a minimum amount of roadway widening is possible at most locations. In many cases, widening may not even be a viable alternative. The Houston area, with over $400 million in currently committed transitways, certainly has a need to develop standards for use in the transitway design phase . Design standards that have been agreed upon will also simplify a multiple agency highway/transit undertaking.

The transitway design process in Houston recognized that sufficient width must exist to allow vehicles in the transitway to pass a stalled bus. Less importance was placed upon the need to pass the stalled vehicle at a high speed. It was felt that, with the passengers of a stalled bus possibly exiting the bus into the lane, high passing speeds were neither desirable nor safe, and sufficient space frequently could not be provided to permit a high speed pass. Potential collision damage to transit buses would also be minimized with slow passing speeds, especially in those cases where the disabled bus was unable to park directly against the barrier.

As a result, the issue became "how wide does a transitway need to be to permit passing of a stalled bus?" Since every extra foot required for the transitway forced additional compromises in freeway design, this was a critical issue that, to date, had not been conclusively addressed. Thus, a major objective of this study was to determine the percentage of controlled (non-accident) vehicle breakdowns that might be expected to block a transitway; the width of the transitway was varied during the tests. These tests were conducted with a typical transit bus parking against a New Jersey-type concrete barrier in both tangent and curved roadway sections. A second objective was also pursued; this involved testing the speed at which one bus could pass a parked ("stalled") bus within several different transitway width/layout configurations. Measurements of speed and distance were collected for each passing maneuver, and overhead photographs were taken to determine the relationship between buses and barriers. The intent was to identify the impact on potential passing speed of increasing the transitway width.

This report summarizes the operating experience on several significant transitway projects and briefly examines the various design guidelines published on this subject. The speed-distance curves for various transitway widths and alignments are included, along with data concerning the bus parking maneuver in a breakdown situation. Several acceleration curves obtained during the testing are also included and analyzed for their potential impact on transitway facility design.

PROBLEM STATEMENT

The typical buses to be used on the Houston transitway system are GMC RTS-04s. These buses are 8.5 feet wide with an additional 0.6 to 0.7 feet on each side for mirrors. These mirrors, however, are positioned at different heights (left side approximately 5 feet above the ground and right side approximately 7 feet) eliminating a mirror-to-mirror conflict when both buses are facing the same direction (Figure 1). Thus, for one bus to pass another on a one-way transitway, the outside dimension of the two buses together would be between 18.0 and 18.5 feet.

A 19.5-foot wide lane, when considering clearances between buses and barriers, would appear only marginally adequate for passing stalled vehicles,

Note: The distance between the buses is approximately equal to that experienced in the 19.5-foot transitway.

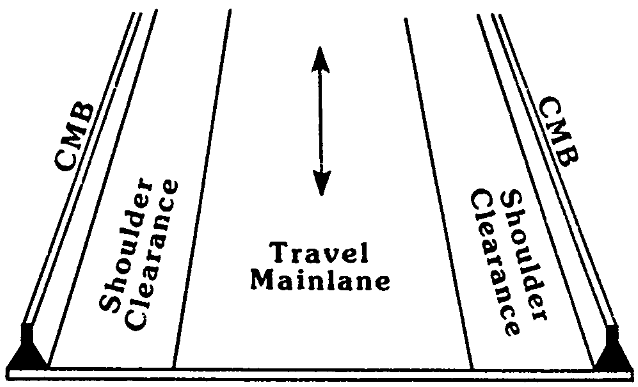
Figure 1. Relative Mirror Position During Bus Passing Maneuver

even at slow speeds. This was illustrated in May 1984 on a completed section of the Katy Transitway when a Metropolitan Transit Authority of Harris County (METRO) bus simulated a breakdown situation and another attempted a passing maneuver. Several passes were made, and, although none were at more than 5 mph, the bus drivers reported discomfort with this movement.

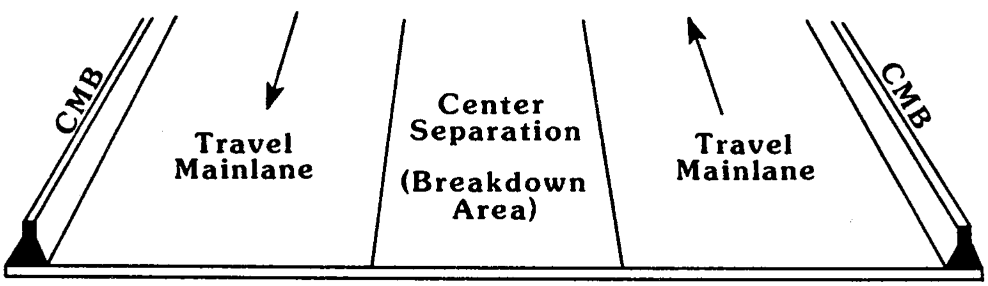
METRO, the Federal Highway Administration (FHWA) and the Texas State Department of Highways and Public Transportation (TSDHPT) recognized the problems presented by the possibility of a bus blocking the lane or severely reducing the passing speed. It is essential that the transitway provide a reliable level-of-service. Bus volumes on Houston transitways are expected to generally be in the range of 50 to 100 per peak hour, with vanpools comprising another 200 to 400 vehicles per hour. Very little documentation could be found for passing speeds on one or two-lane busways of the type that METRO and SDHPT plan to operate. The general configuration of these transitways is shown in Figure 2. The two-lane Shirley Highway Busway is operated with shoulders on each side of the travelled way instead of between the two-directional lanes. The Houston plans for a one-way transitway include a travel lane in the middle of the clear space instead of the more typical wider right-side shoulder. The 50-55 mph operating speed planned for these narrow transitways is also somewhat higher than that observed on some one-lane facilities around the country.

A METRO survey of several currently operating priority lane projects (11)* indicates that the revenue-miles between a transit vehicle breakdown

*Denotes number of reference at end of report.



ONE-LANE, ONE-WAY REVERSIBLE



TWO-LANE, TWO-WAY

Figure 2. Current Cross Sections Proposed for One-Way and Two-Way Transitways in Houston

vary from 1000 to 27,000 (Table 2). Applying a typical Houston priority lane trip length of 10 miles results in a forecast of at least one, and perhaps

Table 2. Survey of HOV Lane Operating Characteristics

Project Name	Vehicles Using HOV Lane	Transit Vehicle Breakdown Frequency on HOV Lane (Avg. revenue-miles between road calls)
El Monte Busway California	Buses Vanpools 3+ Carpools	4,300
I-10 Golden Gate Bridge HOV Lane California	Buses Vanpools 3+ Carpools	22,500
Gowanus Expressway Contraflow lane New York	Buses Taxis	1,200
Long Island Expressway Contraflow lane New York	Buses Taxis	3,400
Contraflow Bus Lane, Lincoln Tunnel Approach New Jersey	Buses	11,100
North Freeway Contraflow Lane, Houston	Buses Vanpools	27,000 (10,000 for vanpools)

Source: 11

five, bus breakdowns every week on each priority lane project. With a breakdown rate approximately equal to transit buses and volumes three to eight times larger, vanpools and carpools are also a key component of the breakdown problem. It is possible that at least one breakdown per peak period could become the normal operating condition rather than an abnormal occurrence. Safety problems resulting from frequent breakdowns are a concern in the development of an operating strategy. In addition, the possible complete blockage of a lane that is totally enclosed with concrete barrier walls and has infrequent access points (three to five miles apart) would result in severe bus service and traffic handling problems; the intent of providing reliable transitway service would be defeated. Adverse publicity and undesirable user experience resulting from congested operation on such a frequent basis could lead to diminished ridership or even the loss of public support for priority treatment projects.

TESTING PROCEDURES

The two major objectives of this research effort, as previously discussed, were the breakdown parking measurements and the determination of speed profiles of the passing maneuver for various different transitway widths. The data collection process for each of these operations is summarized below. All testing was performed by Texas Transportation Institute at the Texas A&M Research Annex located north of Bryan, Texas. The tests were conducted during the week of July 23, 1984. Weather was generally clear and very hot.

Bus Driver Selection

Two professional bus drivers were provided by METRO for the week of testing. One driver had approximately 3.5 years of experience and the other had 0.5 years of experience. Their driving skills were, according to an assessment by METRO supervisors, near average for the expected transitway route drivers. While two drivers do not qualify as a statistically valid sample of a fleet with 1000 drivers, the cost of providing a statistically significant number of drivers would have been prohibitive. Several passes were made for each test, and several different transitway widths were measured. Time constraints would not have allowed any more drivers to participate in the study. To eliminate the inevitable learning process that takes place over a week of doing the same type of test would have required several shifts of drivers; no available record for comparison of driving skills would have been available in advance of the tests. Two drivers, while not a desirable sample, were assumed to be adequate for the conduct of this research study.

Bus Parking During Breakdown Situation

Perhaps the most important phase of the study was the initial determination of the bus-to-barrier relationship that would result should a transit vehicle be required to park in the lane. A 600-foot length of 10- to 15-foot precast concrete sections of "New Jersey" -type barrier was supplied by TSDHPT for the tangent and curve section parking tests. The sloping sides of this barrier shape (Figure 3) not only assist in redirection of impacting vehicles, but also provide a warning (tire scrubbing) to drivers before the body of vehicles impact the barrier.

The drivers were instructed to accelerate the bus to 35-40 mph and approach the line of barriers in the center of the transitway (Figure 4). They were to then move to the left side of the lane and position the bus as close to the barrier as was comfortable. This parking maneuver was performed with both the bus engine on and coasting with the engine off. The power steering was not deactivated when the power was switched off but, in this condition, less adjustment in parking location could be made due to the lack of available forward power. Parking the bus on the left side of the transitway allows the driver a clearer view of the bus/barrier distance and also facilitates the exit of passengers through the doors, which are located on the right side of the bus. The distance between the toe of the barrier and the edge of the far side of the bus was measured at the front and back of the bus. Several (4 to 8) attempts were made for both curve (Figure 5) and tangent transitway sections and with power and without bus power. The difference between the transitway width and this parking distance is referred to in this study as the clear width.

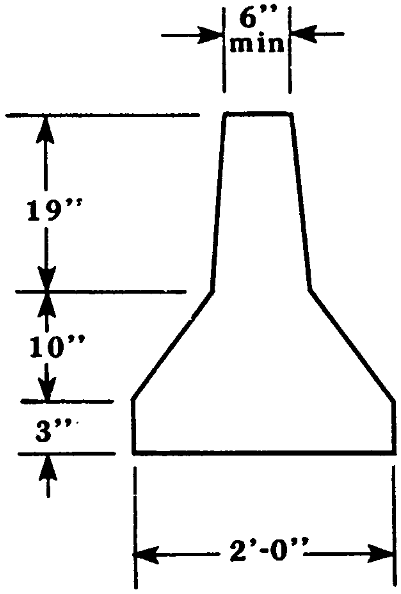
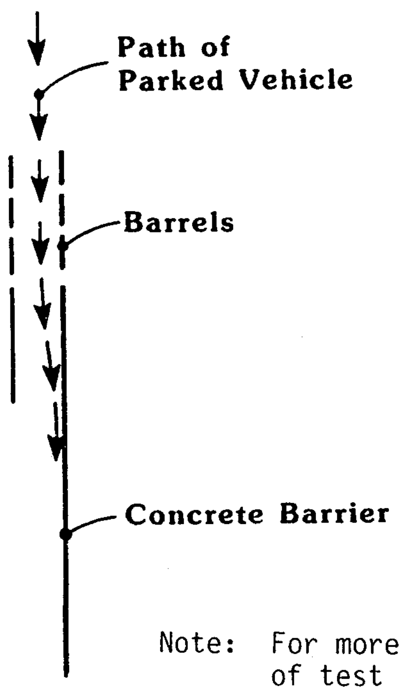
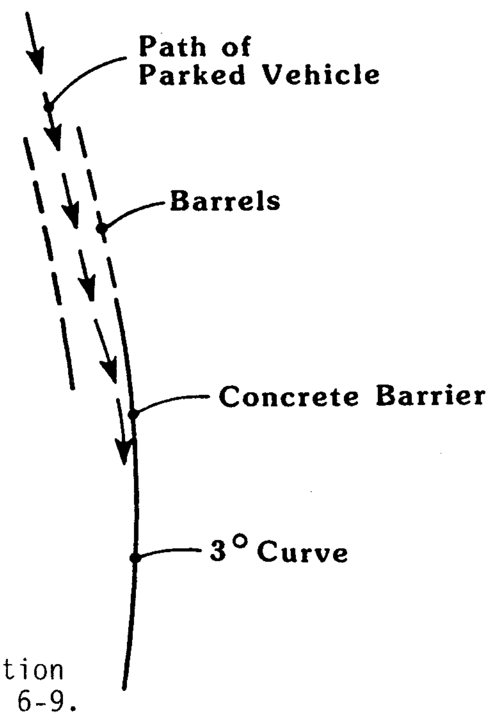


Figure 3. New Jersey-Type Concrete Barrier Used In Transitway Tests





Note: For more complete description of test site, see Figures 6-9.

Figure 4. Parking Test On Tangent Barrier Section

Figure 5. Parking Test On Curved Barrier Section

Passing Maneuver Simulation

The one-lane transitway test site consisted of barrels and concrete barrier arranged as shown in Figures 6 and 7. The short (100 feet) section of concrete barrier and barrels on the left side was moved to provide the appropriate transitway width for the test, while the long section remained stationary. Single lane transitway widths of 19.5, 20.5 and 22.0 feet were used. Also, for those widths, one or more different clear widths (derived from the parking tests) were used. Nighttime operation, with no luminaire lighting, was tested for 19.5- and 20.5-foot transitways.

The parked (stalled) bus was located on the left side of the simulated transitway, as will be the policy in operating the Houston system. The section shown in Figure 7 was a 3-degree curve with the buses approaching from the north. METRO advisors determined that this configuration (bus parked on inside of curve), rather than the bus parked on the outside of curve, represented the most difficult passing maneuver. Neither of these layouts had lane markings for the passing test; this provided less guidance to the driver than will actually be present during normal transitway operation.

The two-way transitway passing tests were configured as shown in Figures 8 and 9. Striping (lane markings) was provided for each of these tests, with 4-inch continuous white construction striping tape placed as shown in the figures. The short barrier section and barrels were 34.0 feet from the long section of barrier, with a 10-foot median shoulder striped in the center of the transitway.

A 35mm camera was positioned 50 feet above the parked vehicle for all tests to record (on slide film) the location of each bus during the passing maneuver. The camera was activitated by an air hose triggered by the passing bus. The parked to passing vehicle and passing vehicle to barrier clearances

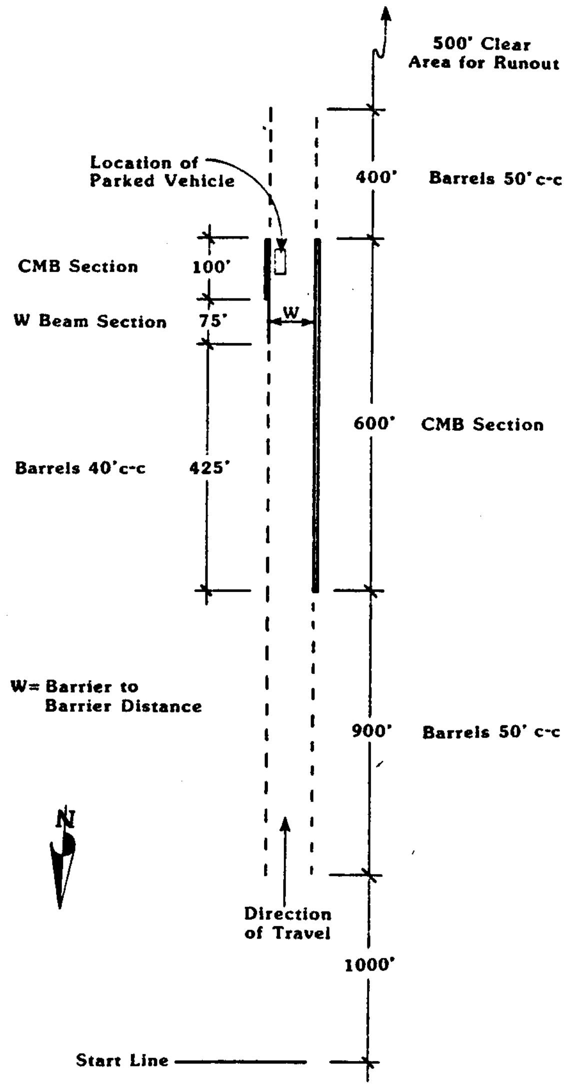


Figure 6. One-Lane Tangent Section Passing Test Site Configuration

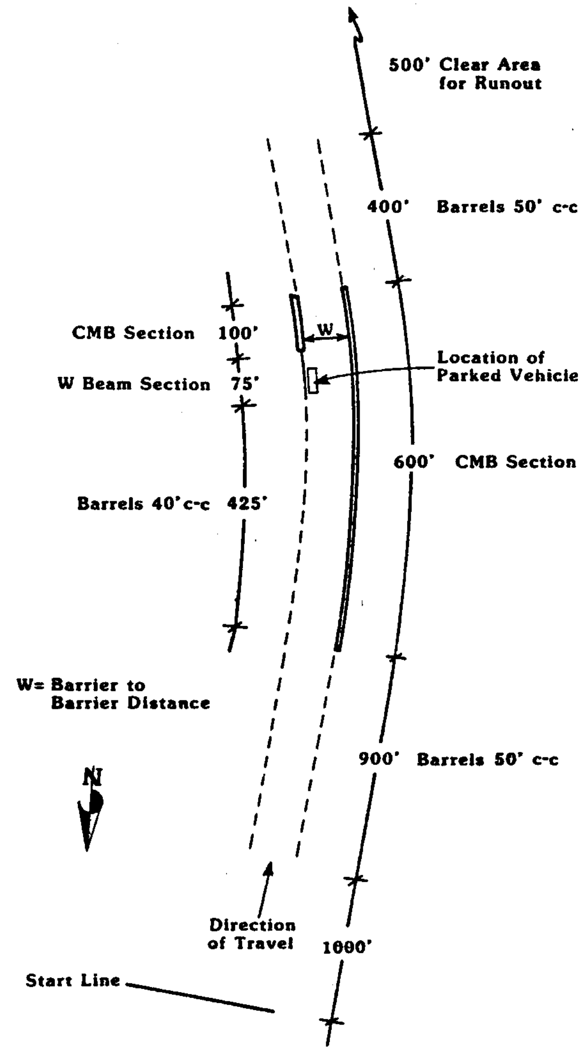


Figure 7. One-Lane Curve Section Passing Test Site Configuration

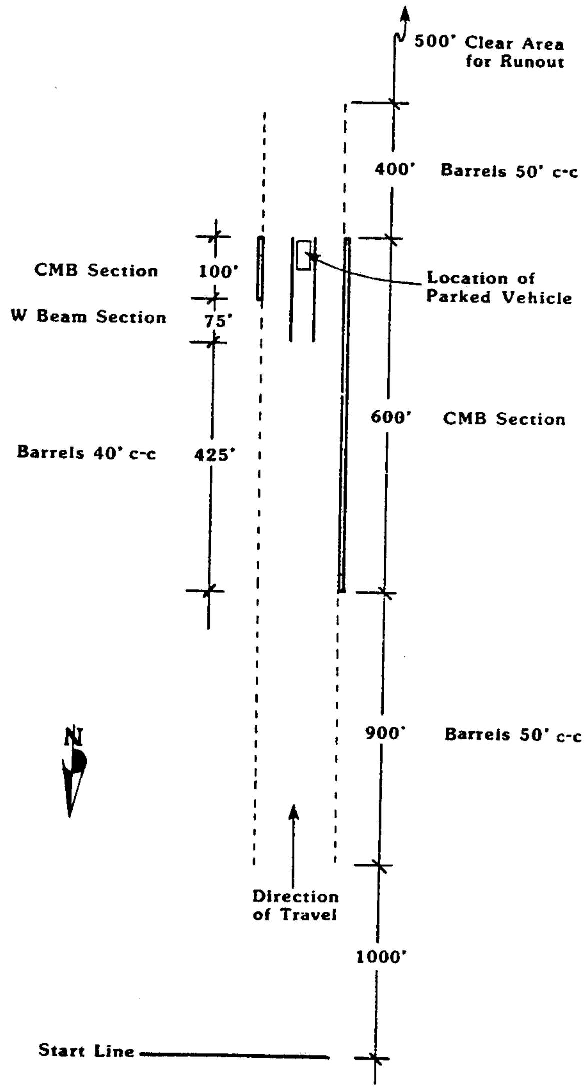


Figure 8. Two-Lane Tangent Section Passing Test Site Configuration

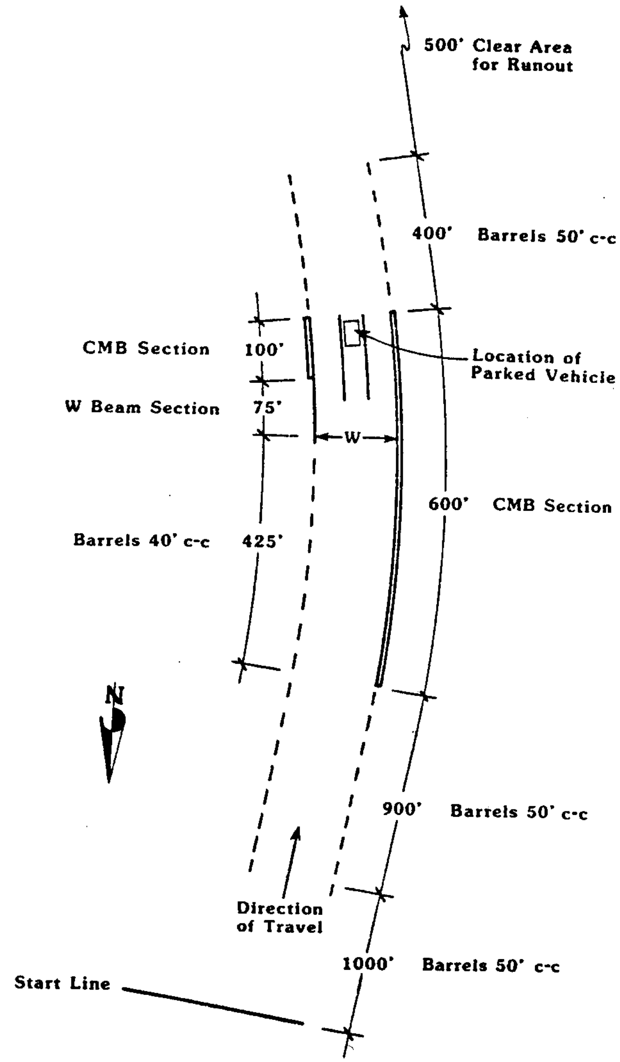


Figure 9. Two-Lane Curve Section Passing Test Site Configuration

were derived using stadia grids placed on the roof of all vehicles utilized for the test.

The speed versus distance data were collected using an instrumented fifth wheel attached to a bus and a van (the two types of passing vehicles). The 2400-foot length of roadway (Figures 6 through 9) was provided in advance of the test site for the drivers to accelerate from stop to 50 mph and then decelerate as they felt necessary to pass the "stalled" vehicle (bus or passenger car). A distance of more than 500 feet was provided after the test site to allow the driver to accelerate back to at least 30 mph.

The bus drivers were instructed to pass the stalled vehicle at speeds that were comfortable for them assuming they had a full load of passengers. They were to ignore the possibility, present during actual operation, that people might step out of the stalled vehicle into the path of the passing bus. This possibility would lead to slow (less than 10 mph) passing speeds for safety reasons at any one-lane transitway width below 25-30 feet. Ignoring potential passenger conflicts, then, allowed passing speed to vary with transitway width.

Bus Acceleration Tests

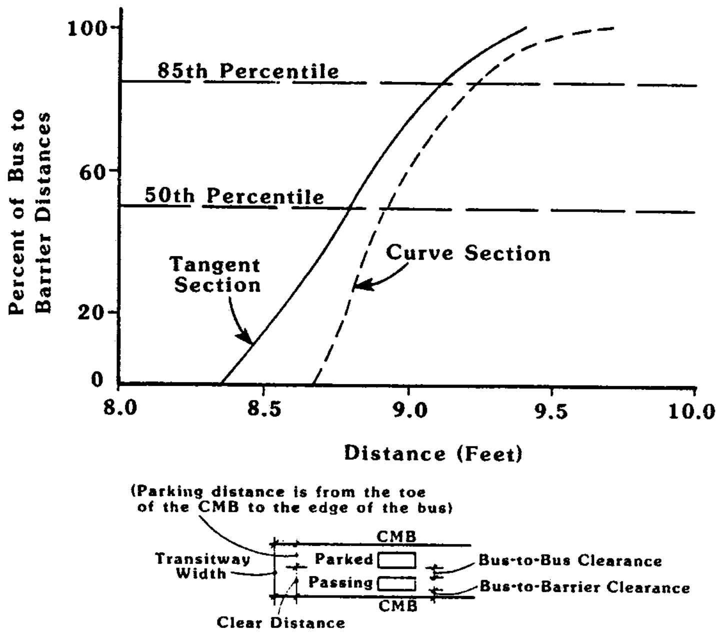
The time and expense involved in organizing the tests and the time involved in moving the barriers to new configurations made possible the collection of several different transit bus acceleration curves. These curves were used in the data analysis section of the report. Accelerations from 0-50, 10-50 and 20-50 were performed with and without the air-conditioning unit operating. The fifth wheel was used to measure acceleration over distance. All the passing tests were performed with the air conditioning on.

BUS AND VAN BREAKDOWN SIMULATION

A main concern of transitway operators is the possibility of a lane blockage. Limited access and continuous concrete barriers combine to make any breakdown a potentially hazardous situation with the possibility of total stoppage of flow on the priority lane. The breakdown situation parking tests were conducted to estimate both the frequency of total lane closure in relation to number of breakdowns and the distance between the barrier and the stalled bus that might be expected to occur for different transitway layouts.

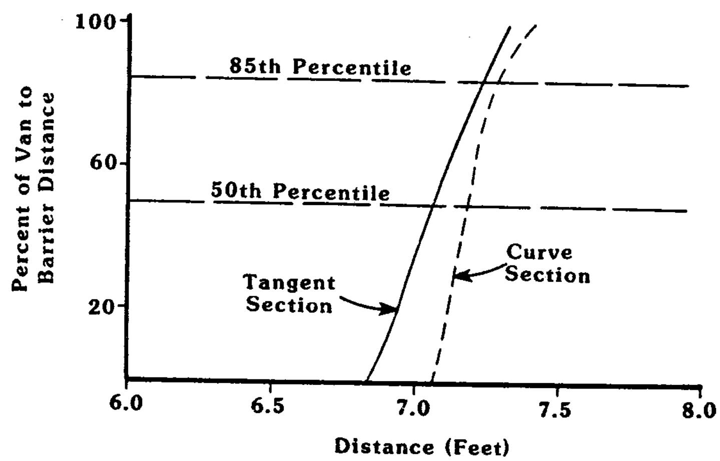
Figures 10 and 11 illustrate the unadjusted data obtained from the several parking tests that were conducted with buses and vans. The distance from the concrete barrier to the far side of the bus was measured at both the front and back of the parked vehicle. Figures 4 and 5 show the barrier layouts and approximate parking locations for the tangent and three-degree curve sections. The 85th percentile distance used in positioning the buses for the passing speed tests was 9.1 feet for a tangent section and 9.2 feet for a curved section.

These values, however, do not adequately illustrate the observed behavior. Tests were conducted with the engine both on and off and, as presented in Table 3, the engine operating conditions had an effect on the parking location. While the power steering did not shut off, as it does in a passenger car, the ability to maneuver and position the bus was limited by the absence of power. The 0.1 to 0.3-foot difference due to engine operating condition is equal to the difference attributed to "experience". "Experience" refers to the difference in average parking distance between the first set and last set (3-4 parks per set) of tests with the engine operating. The tangent section data were collected at the very beginning of the week. The curve section data were taken in the middle of the week, after many passing



Note: Due to the shape of the bus and the shape of the concrete barrier, it is possible for the measured distance to be less than the 8.5-foot bus width.

Figure 10. Summary of Transit Bus Breakdown Parking Test Data



Note: Refer to sketch and note in Figure 10.

Figure 11. Summary of Van Breakdown Parking Test Data

maneuvers had been performed, and, thus, represent a much more experienced driver than the tangent layout test data.

Table 3. Summary of Bus Breakdown Simulation Parking Tests

Parking Condition	Barrier Layout	
	Tangent[1,2] (distance in feet)	3° Curve[1,2] (distance in feet)
All Conditions - Bus	8.9	9.0
With Engine Operating	8.8	8.9
Without Engine Operating	8.9	9.2
Without Experience	9.0	9.1
With Experience	8.7	8.9
All Conditions - Van	7.2	7.2
With Engine Operating	7.2	7.2
Without Engine Operating	7.2	7.2
Without Experience	7.3	7.2
With Experience	7.1	7.1

[1]All dimensions are 50th percentile values for each condition
[2]All dimensions are the distance between the toe of the barrier and and the outside edge (right side) of the bus (see diagram in Figure 10).

The values for passenger van parking maneuvers were obtained using an experienced van driver and show less variation than that shown by the bus drivers. This is possibly due to the relative ease of parking a van as opposed to a bus. The values also indicate that a stalled bus occupies nearly 2 more feet of lane area than does a van, leading to the conclusion that, during controlled (non-accident) breakdown situations, the transit bus breakdown will result in a much more severe constriction of clear space.

Table 4 summarizes the clear width utilized for the development of estimates of passing speeds. The parking distances of 9.1 and 9.2 feet for tangent and curve layouts are subtracted from the distance between concrete barriers to estimate the clear width that might be expected for at least 85 percent of controlled breakdowns. The impact of this variation in clear distance on passing speed and cost of transit operation during a vehicle breakdown is examined in a later section titled, "Delay In The Bus Passing Maneuver". The cost of breakdowns that close the lane, as well as those that only slow passing speed, is estimated and conclusions are made as to minimum and desirable transitway widths.

Table 4. Bus-to-Barrier Clear Distances

Transitway Width And Alignment	Clear Distance[1] (feet)
19.5' Tangent	10.4
20.5' Tangent	11.4
22.0' Tangent	12.9
34.0' Tangent	12.5
19.5' Curve	10.3
20.5' Curve	11.3
22.0' Curve	12.8

[1]See Figure 10.

BUS ACCELERATION AND BREAKDOWN PASSING TESTS

Most of the study effort was concentrated on obtaining speed versus distance data for several different transitway configurations. The previously referred to learning experience by the bus operators over the week of testing required several adjustments to be made in the actual data before the development of expected speed distance curves could begin. The actual data are, however, illustrative of the variation in passing speeds.

The graphs of actual and adjusted speeds begin at 1500 feet from the start line (the point where buses began accelerating from a stop, see Figures 6 through 9). Speeds from 0 to 1500 feet were very similar and are presented in the section below concerning bus acceleration characteristics. That section analyzes the speed versus distance and speed versus time curves for transit buses (with and without air-conditioning) under full acceleration and simulating a full passenger load.

Adjustments to actual data were made to estimate passing characteristics for novice and experienced transitway bus operators and are presented in the final part of this section. The novice condition refers to the average of the two professional bus drivers at the beginning of the week of testing. The "novice" label, then, applies to those bus operators who have bus driving experience, but little time driving on a transitway. The "experienced" label was derived from driver behavior after approximately 50 test runs (passing maneuvers). Suggested design speed versus distance curves for both categories of transit driver are presented in the final section.

Transit Bus Acceleration Curves

One side benefit of having the transit buses wired to a fifth wheel speed-distance recorder was the opportunity to collect information on the acceleration characteristics of regularly operated GMC RTS-04 buses. These buses, along with the Eagle (intercity) coaches, will comprise the majority of Houston's transitway operating fleet. Their acceleration characteristics have an impact on both the design and operation of the transitway. The bus passing tests, presented in following sections, were conducted using a standing start and an acceleration to 45-50 mph. For purposes of clarity, the acceleration portion of those tests is not presented in the other sections of this report.

The curves in Figure 12 indicate the relatively short distance required to accelerate a GMC RTS-04 bus to 30 mph. The impact of any bus breakdown on transitway operations is illustrated in the amount of distance required (up to 1/4 mile) to accelerate from 40 to 50 mph. The gearing ratios used on transit buses for on-street operations are not conducive to high speed or acceleration past normal arterial street speed limits. The Eagle coaches used to service many of METRO's park-and-ride lots may be geared differently, in that those routes operate on freeways for most of the trip and achieve a higher maximum speed than local route buses. The GMC buses chosen for this test, therefore, are the controlling vehicle in terms of acceleration characteristics relating to the breakdown passing maneuver.

The three curves in Figure 12 indicate that there is little difference in the distance required for a bus to achieve 40 mph whether accelerating from 0 or 20 mph. Based on this observation, it would seem that passing speed on a transitway would not significantly affect the design. If little time is lost accelerating from less than 5 mph, as opposed to 20 mph, the savings in transitway construction costs and other potential uses for that width may outweigh any benefits.

This cursory analysis, however, ignores several safety aspects of transitway operation that relate to lane width. A wider clear space allows more room for a disabled bus to park without blocking transitway flow. A higher

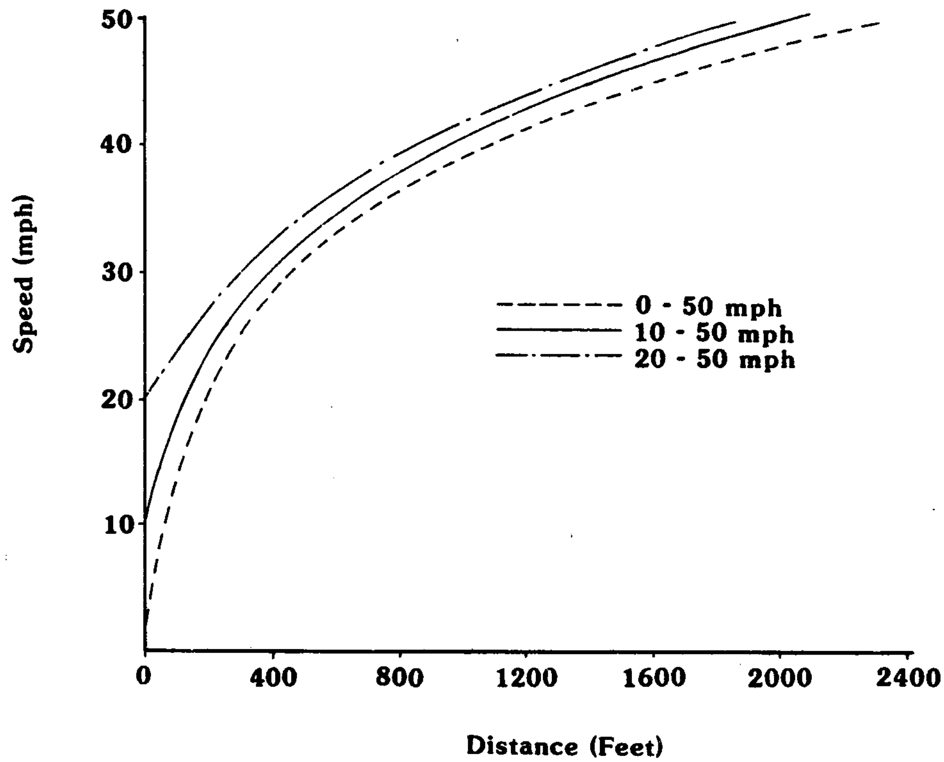


Figure 12. GMC RTS-04 Transit Bus Acceleration Characteristics Measured During TTI Tests, Level Terrain

passing speed at a breakdown location decreases the need for deceleration and, thus, enhances the continuity of bus speed. This is a safer operation than one in which bus operators are required to drastically slow their speeds at a constriction point due to the decreased possibility of rear-end collisions.

Figure 13 compares the observed time to accelerate from 0 to 50 mph observed at the Texas A&M Research Annex to the characteristics of a GMC transit coach reported in a 1968 study (9). Almost 10 seconds more is required to reach 50 mph in the newer, heavier GMC coaches. The acceleration time curve begins to climb noticeably after a speed of 30 mph is reached

(Figure 13). The newer bus only requires 22 seconds to reach 30 mph from a stopped start, but another 30 seconds to accelerate from 30 mph to 50 mph.

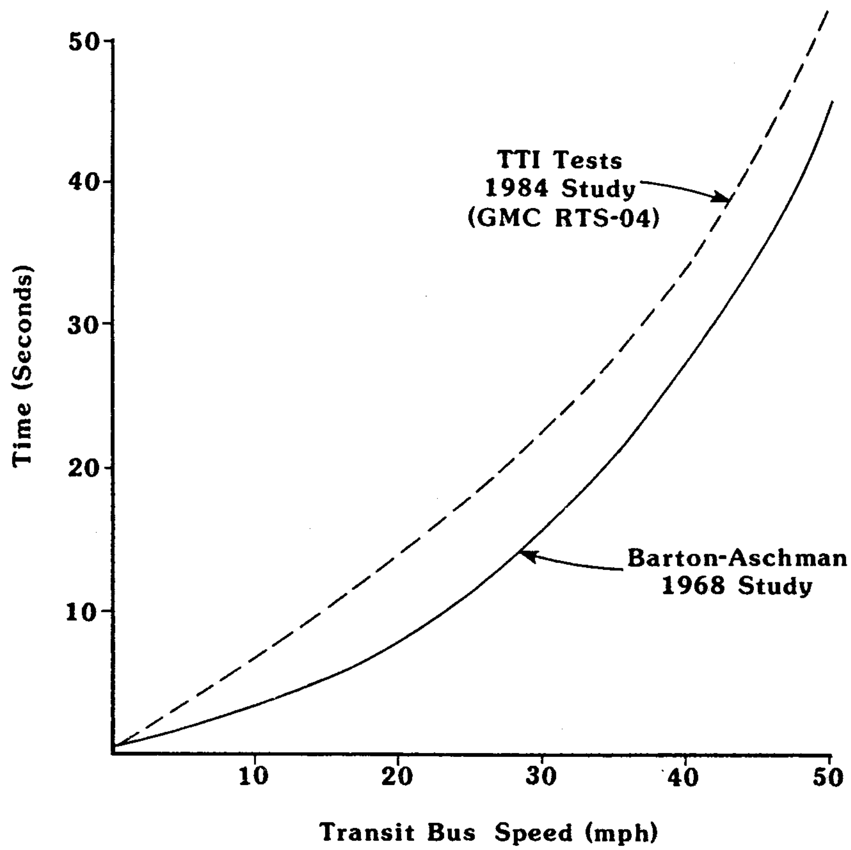


Figure 13. Comparison of Acceleration Characteristics of Old and New Transit Buses

Figure 14 illustrates the effect of air-conditioner operation on an empty bus at full acceleration. More than 300 feet less is required to reach 50 mph without air-conditioning, with the gap between curves widening noticeably at the upper end of the speed range.

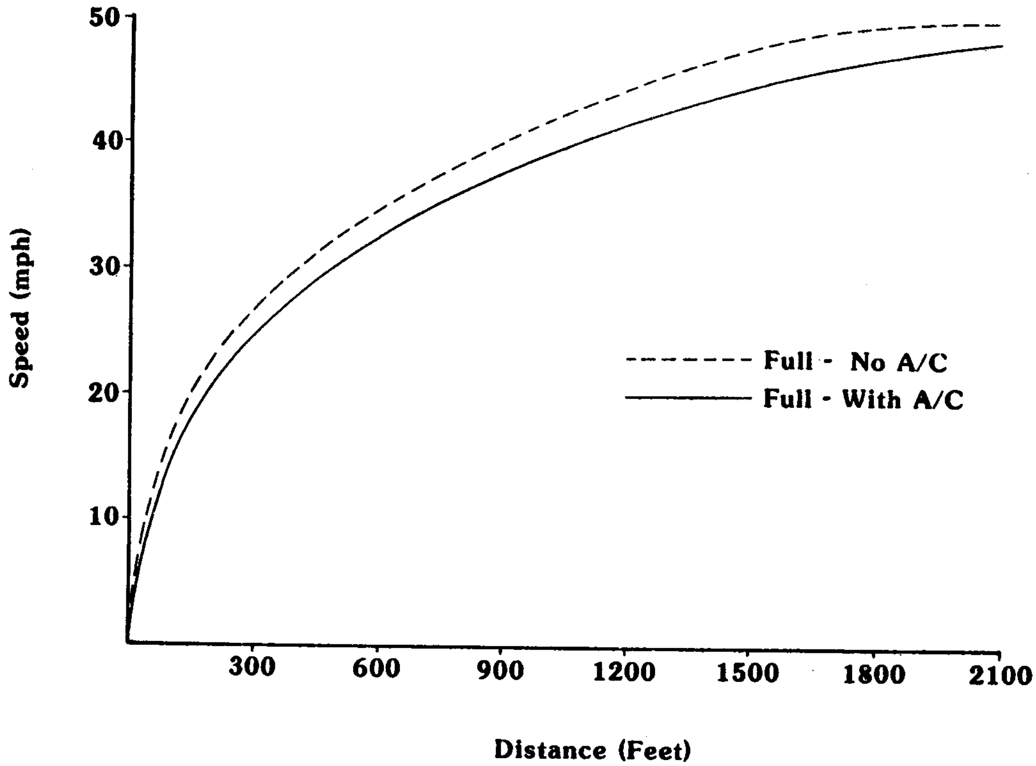


Figure 14. Effect of Air-Conditioner Operation on Transit Bus Acceleration

Actual Data Points -- Passing Tests

The data presented in Figures 15 through 21 represent the speed versus distance relationships observed during the actual testing period for each of the widths shown in Table 4. The acceleration portion of the data (from 0 to 1500 feet) is not present, but the section of curve from 1500 to 2000 feet does show some effect from the test conditions since the increase in speed would not actually be present during normal transitway operation as the buses would be traveling at 50-55 mph. The arrow at the bottom of each graph indicates the position of the parked (stalled) bus, and thus, the location of the constriction in the simulated transitway. The relatively close proximity of the two buses to barriers and each other for the 19.5-foot test is illustrated in Figure 22.

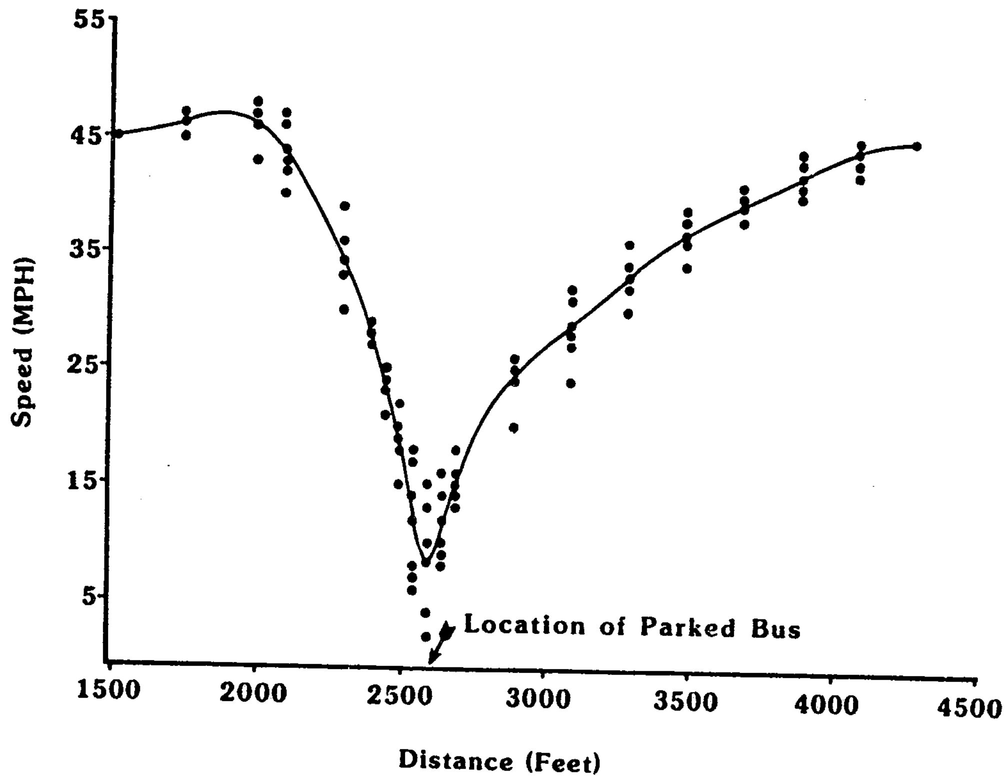


Figure 15. Passing Speed On 19.5-Foot One-Way Transitway--Tangent Section -- All Data Points

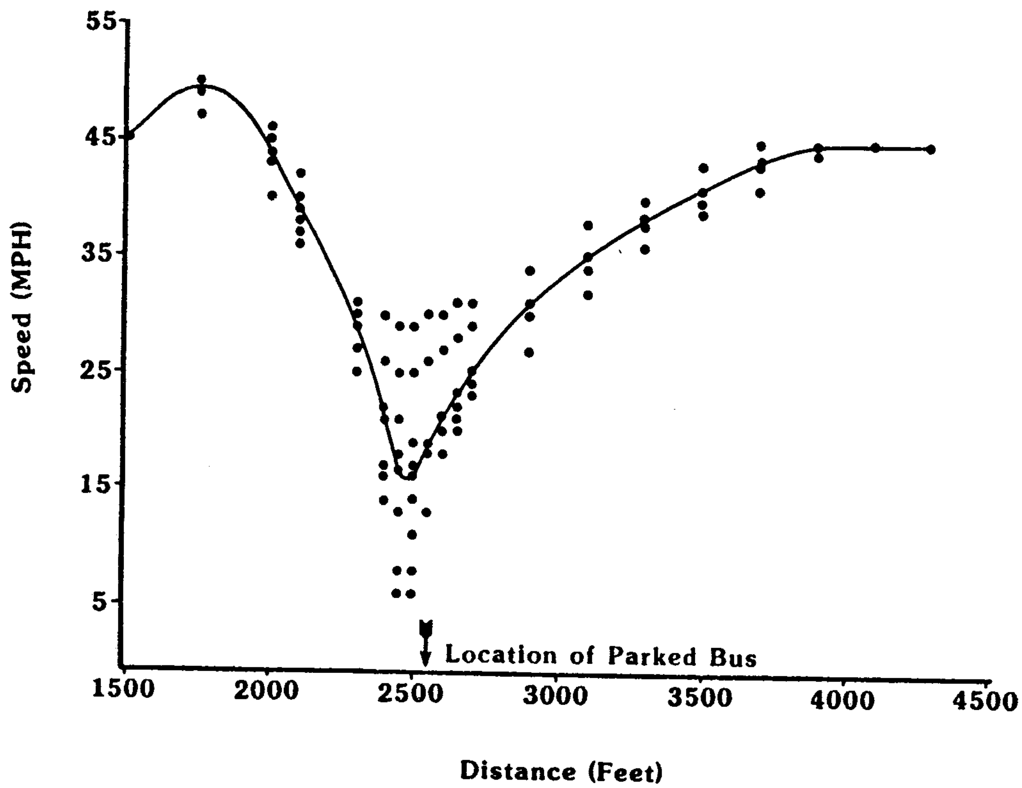


Figure 16. Passing Speed On 19.5-Foot One-Way Transitway -- 3° Curve Section -- All Data Points

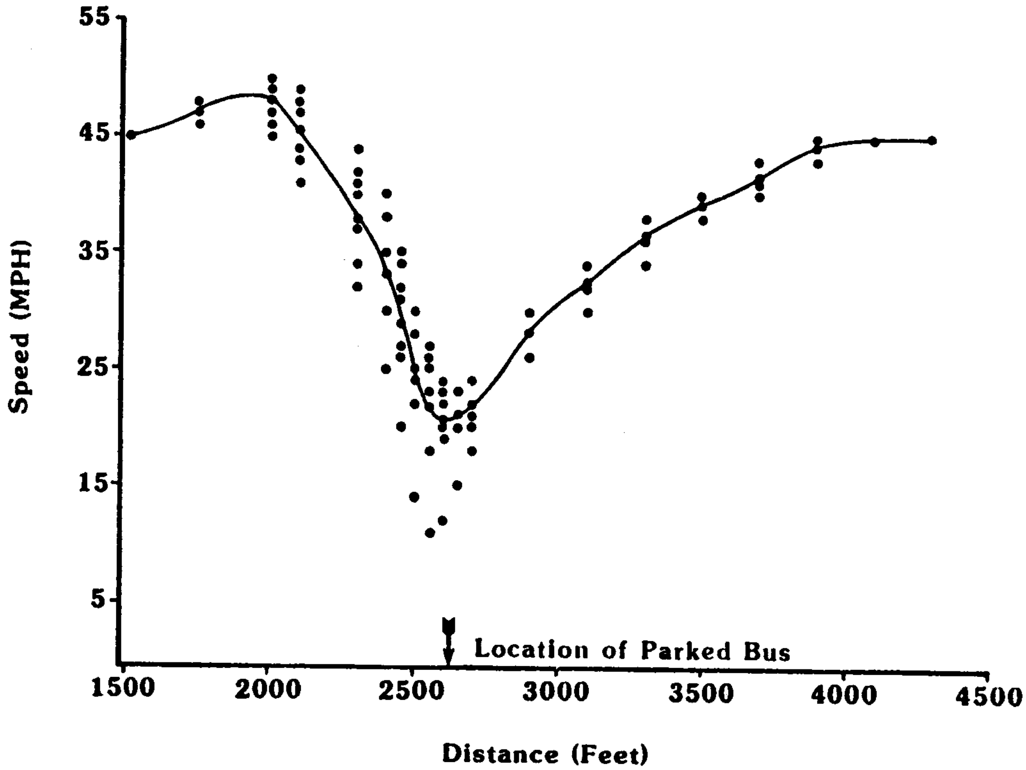


Figure 17. Passing Speed On 20.5-Foot One-Way Transitway -- Tangent Section -- All Data Points

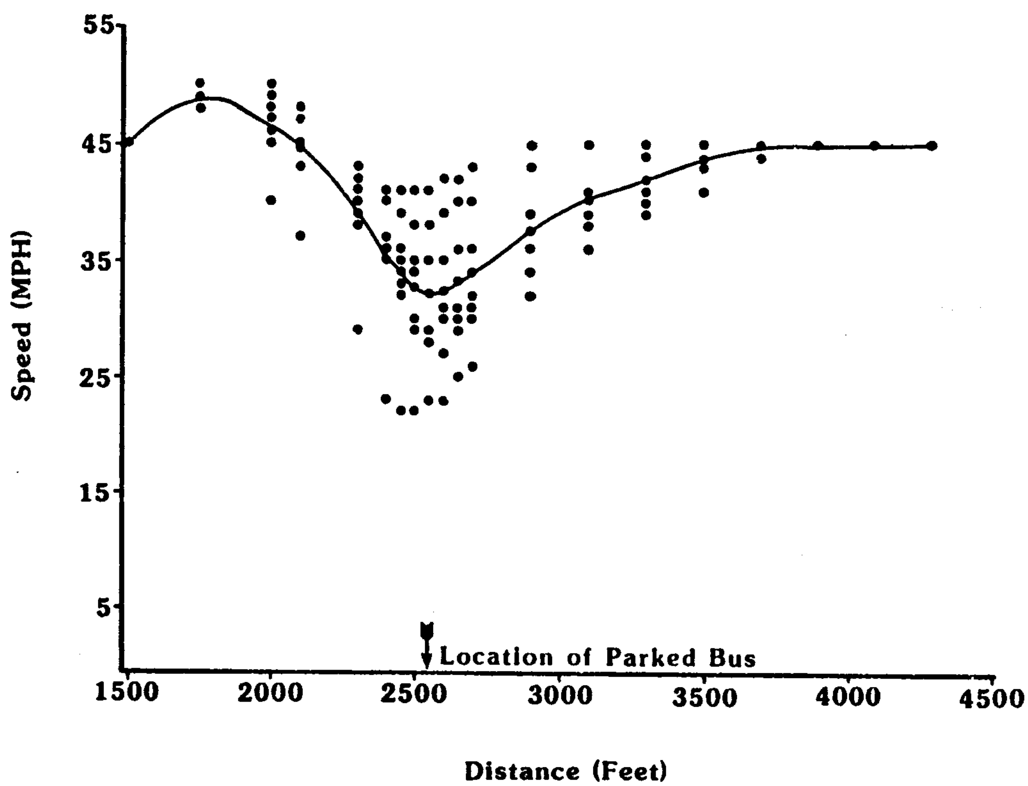


Figure 18. Passing Speed On 20.5-Foot One-Way Transitway -- Tangent Section -- All Data Points

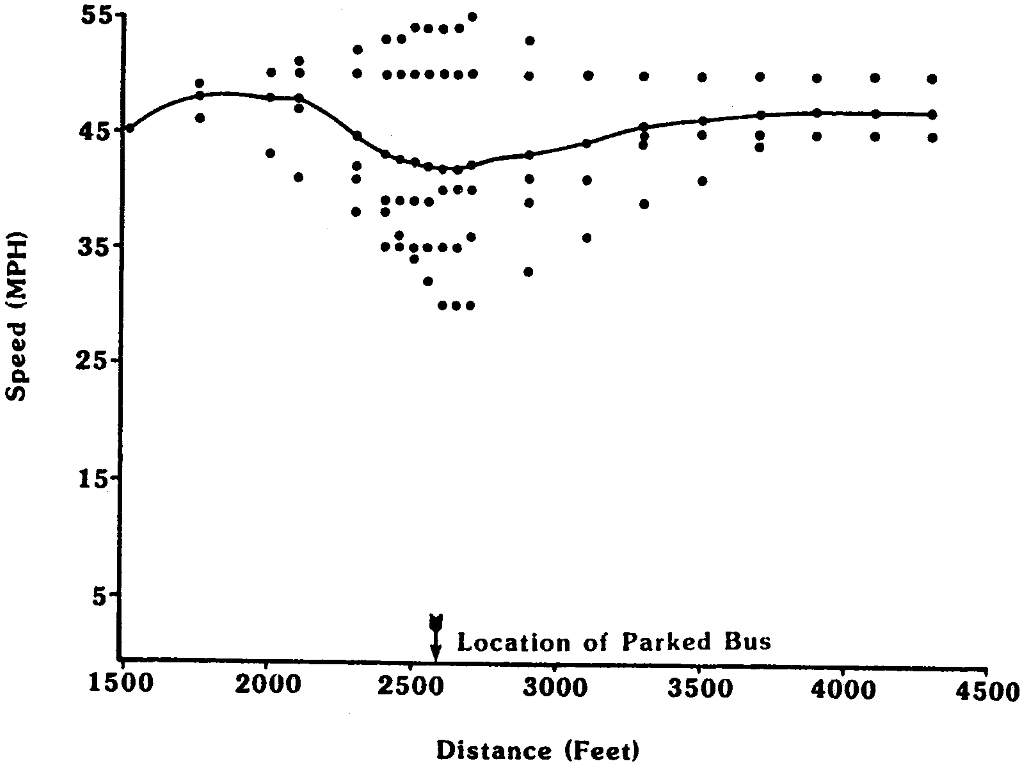


Figure 19. Passing Speed On 22.0-Foot, One-Way Transitway -- Tangent Section -- All Data Points

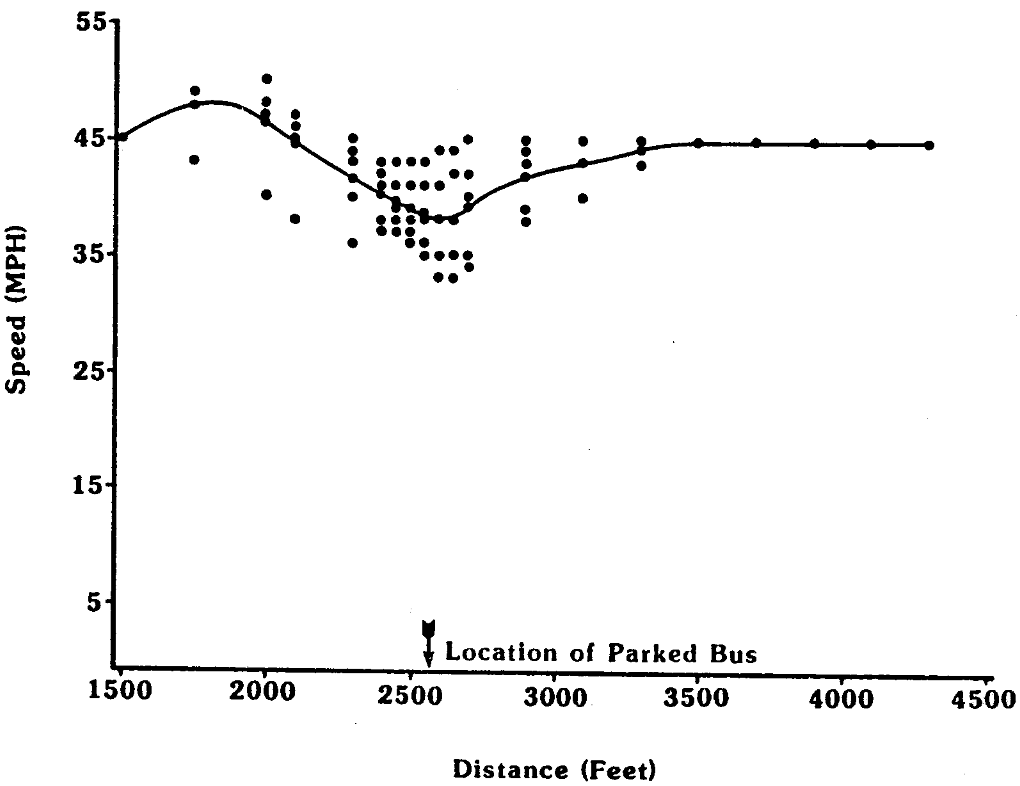


Figure 20. Passing Speed On 22.0-Foot, One-Way Transitway -- 3° Curve Section -- All Data Points

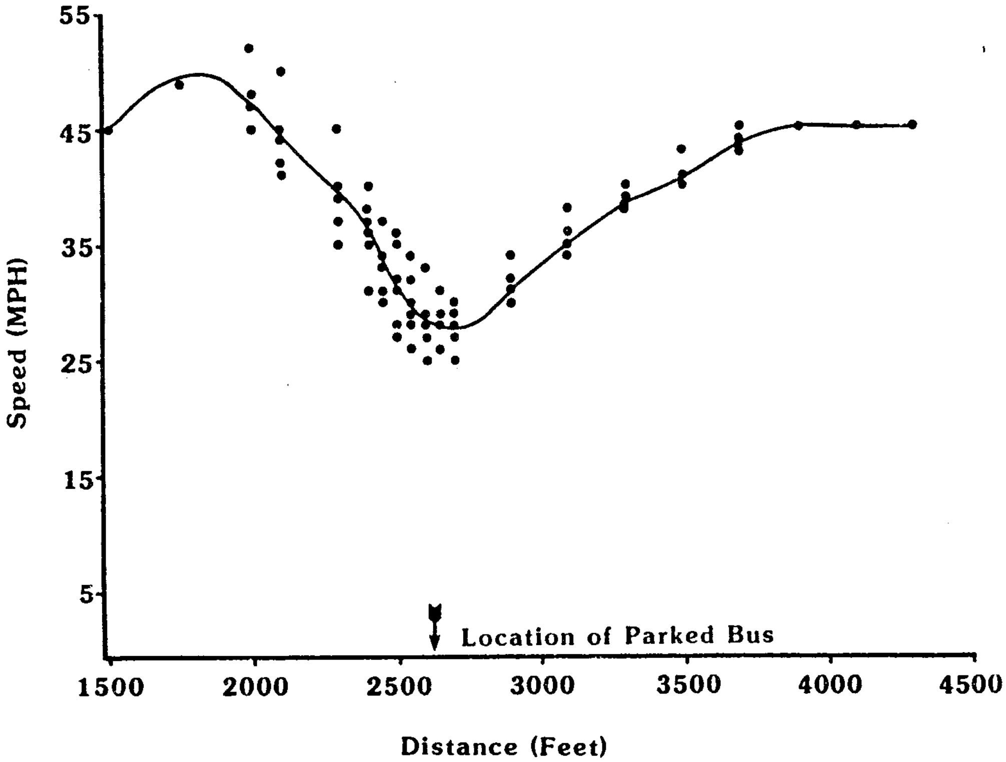


Figure 21. Passing Speed On 34.0-Foot, Two-Way Transitway -- Tangent Section -- All Data Points

Figure 22. Bus 2168 Passing Bus 2142 in a 19.5-Foot Tangent Transitway Test Section

The test number in Table 5 gives an indication of the amount of experience each driver had during that set of tests. Three to five runs per test

Table 5. Summary of Actual Data Points, Bus Passing Tests

Transitway Width and Alignment	Test Number	Mean Passing Speed (mph)	Standard Deviation (mph)	Standard Deviation as a Percent of Mean (percent)
19.5' Tangent	2	9	5	63%
20.5' Tangent	5	21	4	19
22.0' Tangent	6	42	10	24
34.0' Tangent	10	28	3	11
19.5' Curve	13	16	8	50
20.5' Curve	15	32	6	19
22.0' Curve	17	38	5	13

were conducted and, thus, over the week of testing each driver made approximately 60 passing maneuvers (17 tests). The standard deviation of the average passing speed quantifies the distribution in speeds evident in the figures. The values might be combined with the recommended curves presented later in this report to obtain an estimate of the range of passing speeds to be expected. The range of speeds seems to be more related to transitway width than it does to experience level. The narrow lane standard deviations are a very high percentage of the mean speeds with the other deviations representing half that percentage. Driver perception of the clear width is particularly important at narrow clear widths and, thus, more variability will be seen in the narrow lane passing speeds. The table and graphs also illustrate that both driver familiarity and slight changes in transitway width may result in dramatic improvements in passing speeds. This information is presented in the next section of this report.

The 34.0' curved alignment, initially proposed as one of the test sections, was eliminated from Table 5 due to the placement of the stalled vehicle at the end of the 3-degree curve. This section, in effect, operated more like a tangent alignment because the passing maneuver was accomplished in or close to a tangent area. Testing was completed and barriers moved before this deficiency was identified. This problem was corrected for the one-lane tests.

Figure 23 illustrates the relationship between the passing speeds for buses and vans on the narrow transitway simulation. The passing speed of a novice van driver in this constricted situation is significantly higher than professional bus drivers. This relationship (van to bus passing speeds) held throughout the testing period. A 50 mph van passing speed was attained in all but the narrowest transitway clearances. The condition of a van passing a bus will not control the operation of a transitway under breakdown conditions. The relationship between the passing van and parked bus is shown in Figure 24.

Passing Speed Adjusted For Driver Experience

Passing tests were conducted at the beginning and near the end of the week for a simulated transitway width of 20.0 feet. The difference resulting from experience gained in approximately 45 test runs, as illustrated in Figure 25, resulted in a doubling of passing speeds on a tangent alignment. The relationship in this figure is used in all of the following graphs to adjust the actually collected data to two conditions defined for this test. Only that portion of the graph below 45 mph is shown. The plot between 45 mph and 50 mph is, as has already been seen, long and almost identical among

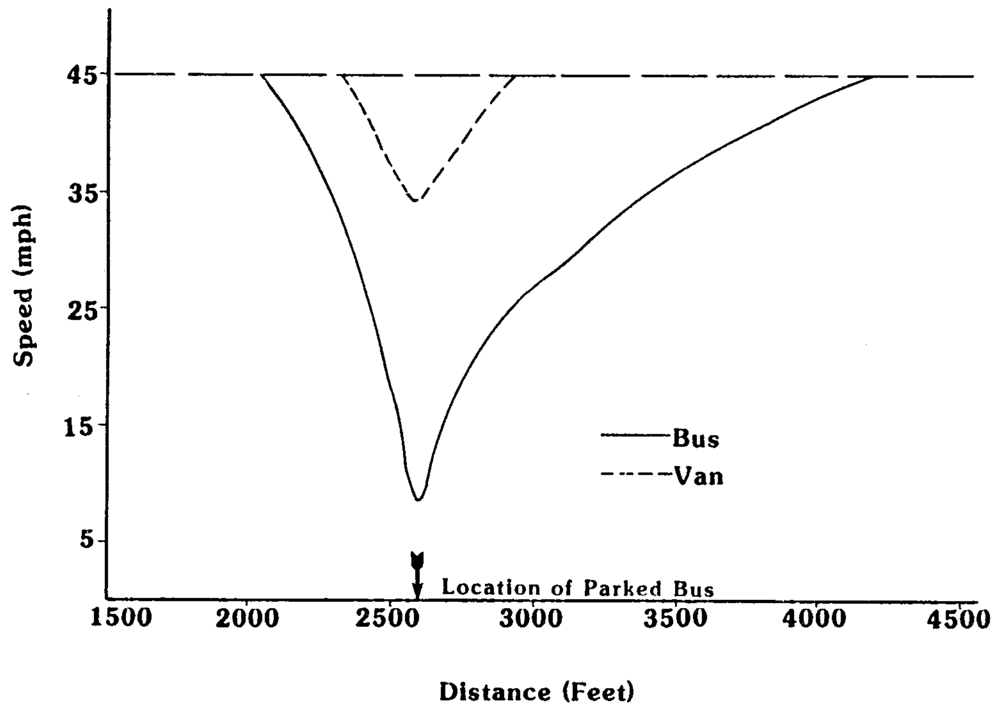


Figure 23. Comparison of Speed Profiles of Transit Bus and Van Passing a Parked Bus in a 19.5-Foot Tangent Transitway

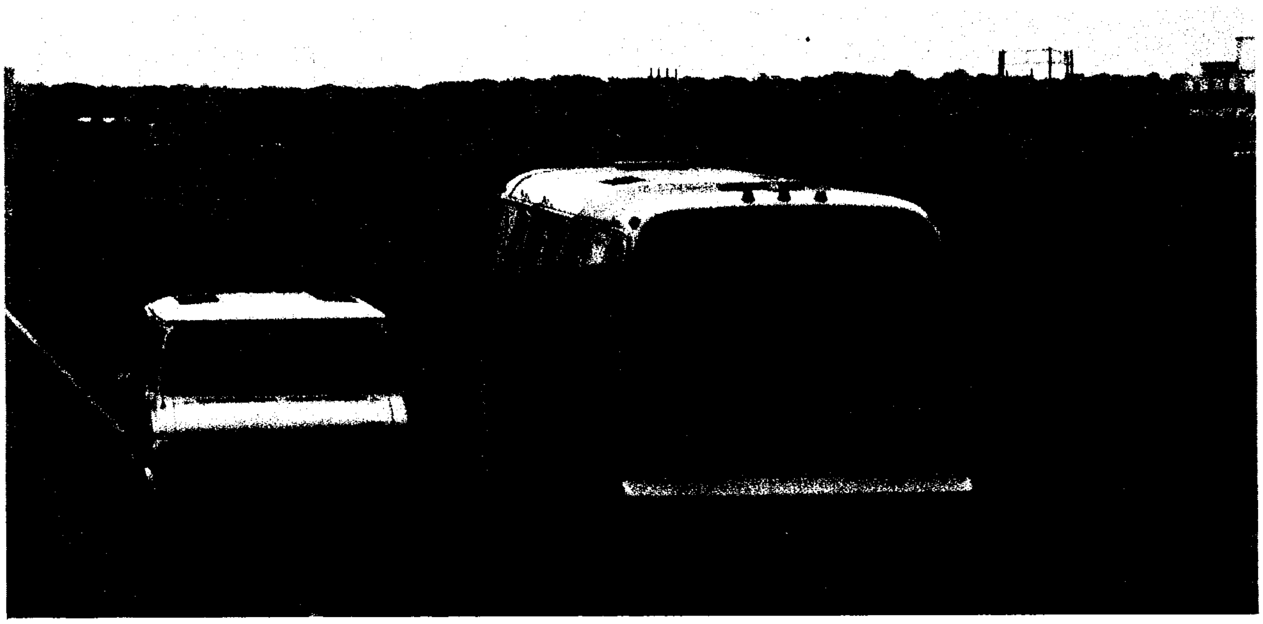


Figure 24. Picture of Van Passing Parked Bus in a 19.5-Foot Transitway

all the various transitway widths. Significant differences in amount of delay occur below 45 mph, however, and thus 45 mph is used as the base line for the bus passing speed curves in a later section.

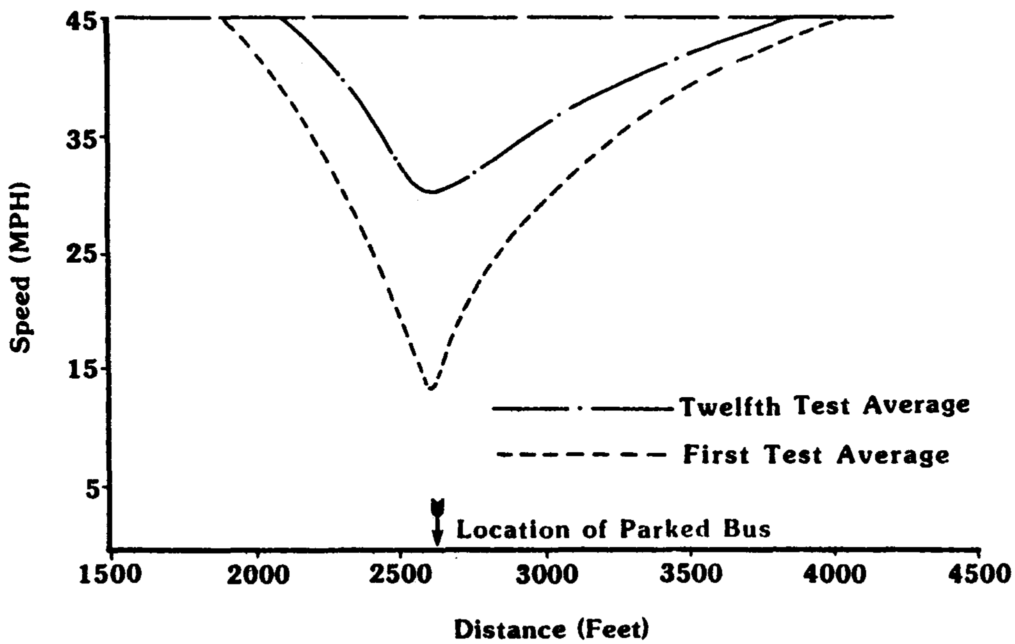


Figure 25. Impact of Approximately 45 Test Passes on Speed Profile of Transit Bus on 20.0-Foot Tangent Transitway

The "novice" category refers to the average of the two professional bus drivers at the beginning of the week of testing. Novice, then, refers to driver familiarity with transitway operations rather than overall bus driving experience. The "experienced" driver is derived from driver behavior near the end of the week of testing.

With operational safety being a very important factor in the design of a narrow transitway, the recommendations made in this report are derived from novice driver behavior. This should be remembered when analyzing the graphs in this section. Curves on the following pages attempt to show all relevant comparisons between driver experience, transitway width, transitway alignment (curved vs. tangent) and lighting conditions (day vs. night) with no suggestion concerning recommended widths. These curves only present the operating behavior that might be expected under several different operating conditions. Not all comparisons are available due to the shortage of time for the testing procedure, but major design features and operational expectations can be ascertained.

Tangent versus Curve--One Lane Transitway

The adjusted comparisons for tangent and curved layouts are illustrated in Figures 26 and 27. The expected passing speeds for 19.5-foot lanes are below 10 mph for both layouts and are not significantly different. The medium width transitway (20.5 feet) passing speeds increase to 20 mph for tangent sections and 15 mph for the 3-degree curve. The increasing speed differential culminates in speeds of 38 mph and 25 mph for the wide transitway (22.0 feet).

Passing speeds of 5 to 10 mph, as observed in the tests, are possible on narrow clearances with relatively experienced drivers. Due to the driver's ability to perceive the clear space, the speed differential between tangent and curve grows as the transitway widens. With a narrow width the driver has to slow down to comfortably get through the gap; as the width on a tangent increases, the bus operator can adjust his speed to the wider gap. The passing maneuver on a curve, however, does not allow such an immediate judgment to be made. The observed behavior during the curved tests consisted of the first run being fairly slow as the driver determined the clear width; and successive runs increased in passing speed as the driver gained confidence.

Figures 28, 29 and 30 present the same information as the two previous graphs with a more direct comparison of speed profile available. With each transitway width graphed separately, the differences in the deceleration

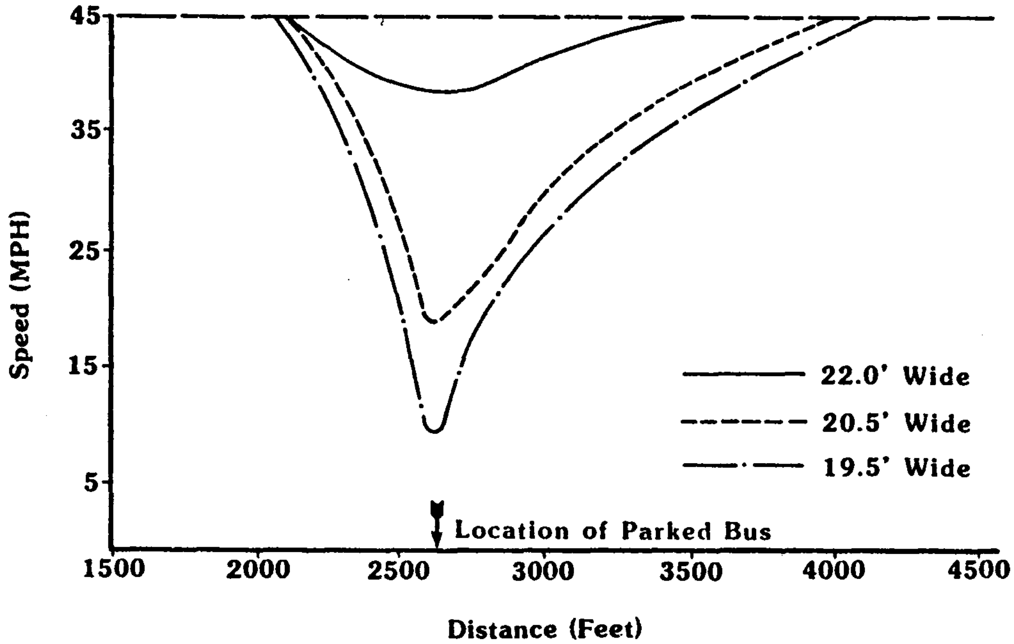


Figure 26. Novice Driver Speed Profiles On Tangent Sections of Transitways

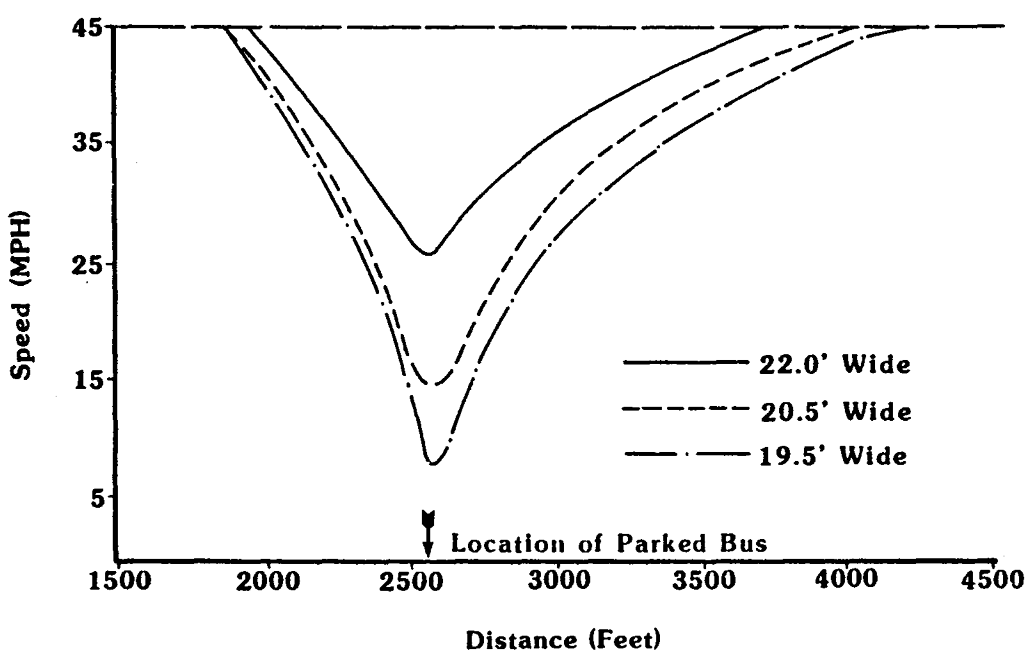


Figure 27. Novice Driver Speed Profiles On 3° Curve Sections of Transitways

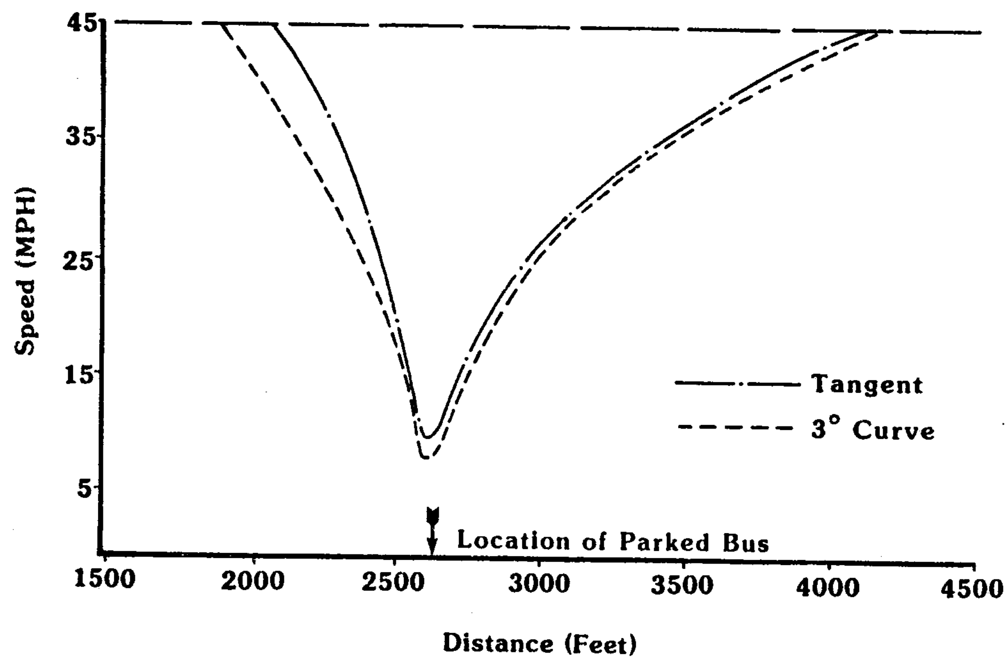


Figure 28. Speed Profile Comparison For Novice Drivers -- Tangent vs. 3° Curve on 19.5-Foot Transitway

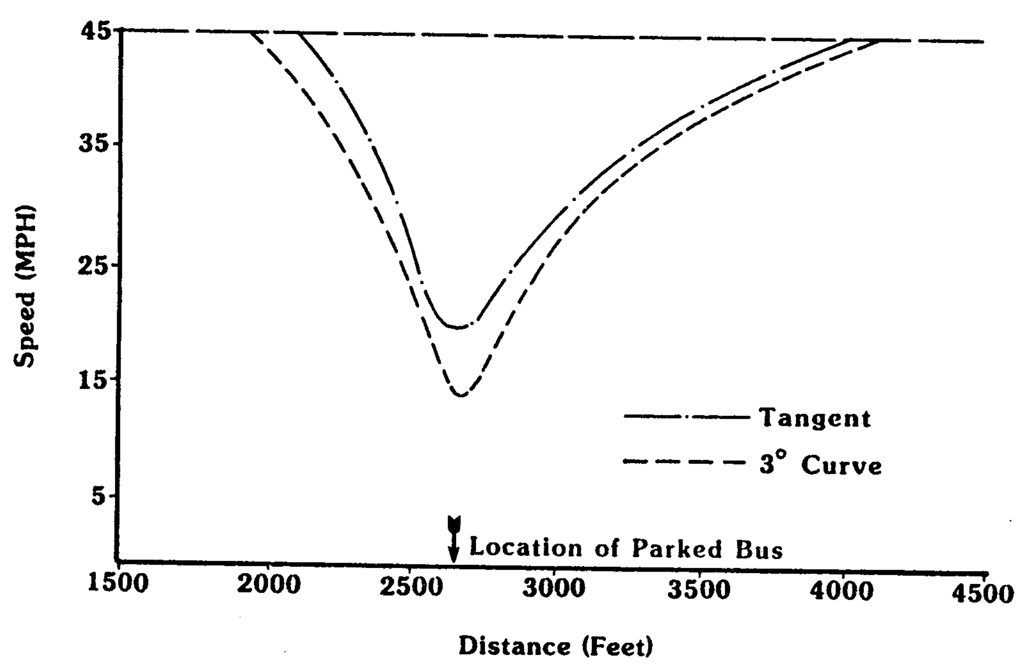


Figure 29. Speed Profile Comparison for Novice Drivers -- Tangent vs. 3° Curve on 20.5-Foot Transitway

pattern are clearly evident. The inability of drivers to instantly perceive the clear space on a curve section results in the slow down maneuver beginning sooner than on the tangent section. The passing speeds on a 19.5-foot lane are almost identical, but the driver decelerates in a more gradual fashion on the curve. This behavior is also evident on the medium width (20.5 ft) and wide transitways (22.0 ft).

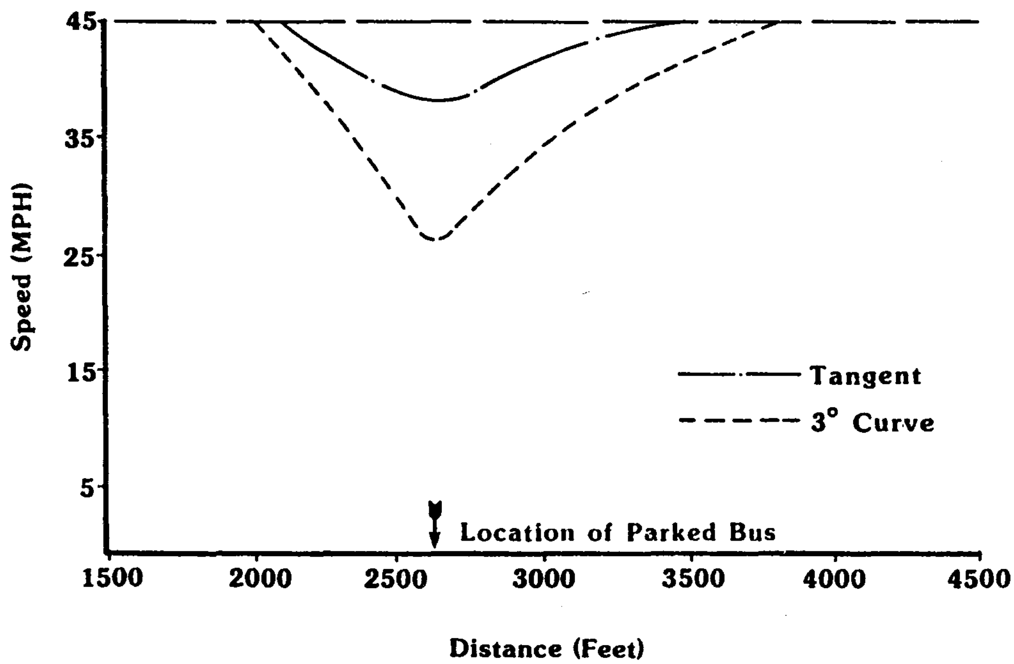


Figure 30: Speed Profile Comparison For Novice Drivers -- Tangent vs. 3^{o} Curve on 22.0-Foot Transitway

Day versus Night--One Lane Transitway

Two different widths were tested at night Figures 31 and 32 depict the comparisons. The conditions during the night test consisted of no moon, no

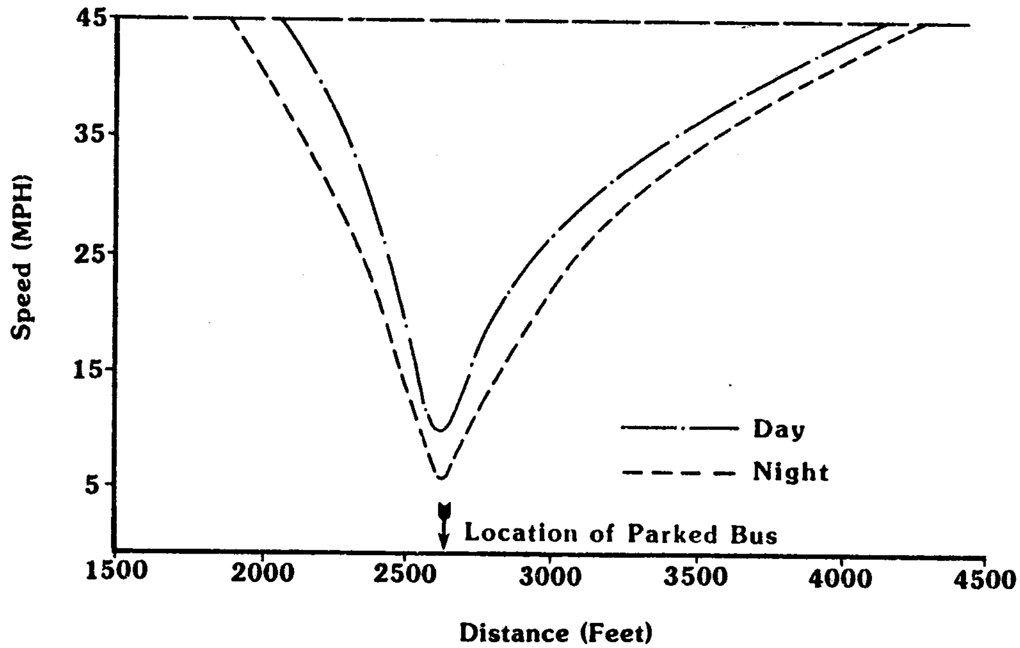


Figure 31. Speed Profile Comparison For Novice Drivers -- Day vs. Night Operation on a 19.5-Foot Transitway

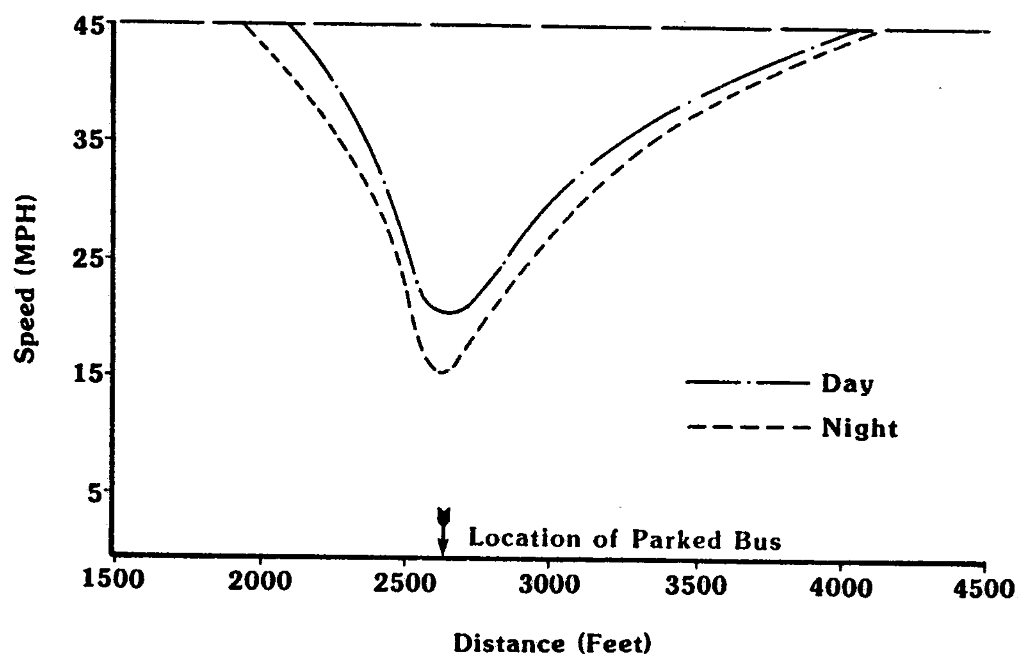


Figure 32. Speed Profile Comparison For Novice Drivers -- Day vs. Night Operation on a 20.5-Foot Transitway

illumination other than passing vehicle headlights and parked vehicle flashers, and no reflectors on the barriers. These are, with the exception of rain or fog, probably the worst visibility conditions that will be experienced. The approximate 5 mph decrease in passing speed is about the same as that estimated in the tangent versus curve graphs. The more gradual slowdown seen on the curved sections is also evident in the night passing maneuver.

Novice versus Experienced--One Lane Transitway

Figures 33 through 38 present the estimated improvement in passing speed that might be expected as a result of increased driver familiarity with transitway operations. The novice lines for the tangent layouts and experienced lines for the curves are similar to the plots of actual data points presented in Figures 15 through 21. The other lines were estimated using the relationship in Figure 25.

All three transitway widths, for both tangent and curved alignments, are estimated to have significant improvements in operation due to experienced drivers. The narrow transitway speeds more than double. Passing speeds on 19.5- and 20.5-foot transitways improve by 15 mph, and the passing operation on wide transitways is estimated to occur at 40 mph or more.

Two-Way Transitway

Figure 39 illustrates the estimate of novice driver behavior for two different widths of two lane transitways. The 34.0-foot graph was developed from the only actual two-way test conducted during the week. One transit bus was parked in the middle of the 10-foot breakdown shoulder. The passing vehicle used one of the 12-foot lanes (Figure 8) to simulate a passing maneuver. The parked vehicle was facing the passing bus so that mirrors were, as discussed in the problem statement, at the same height rather than

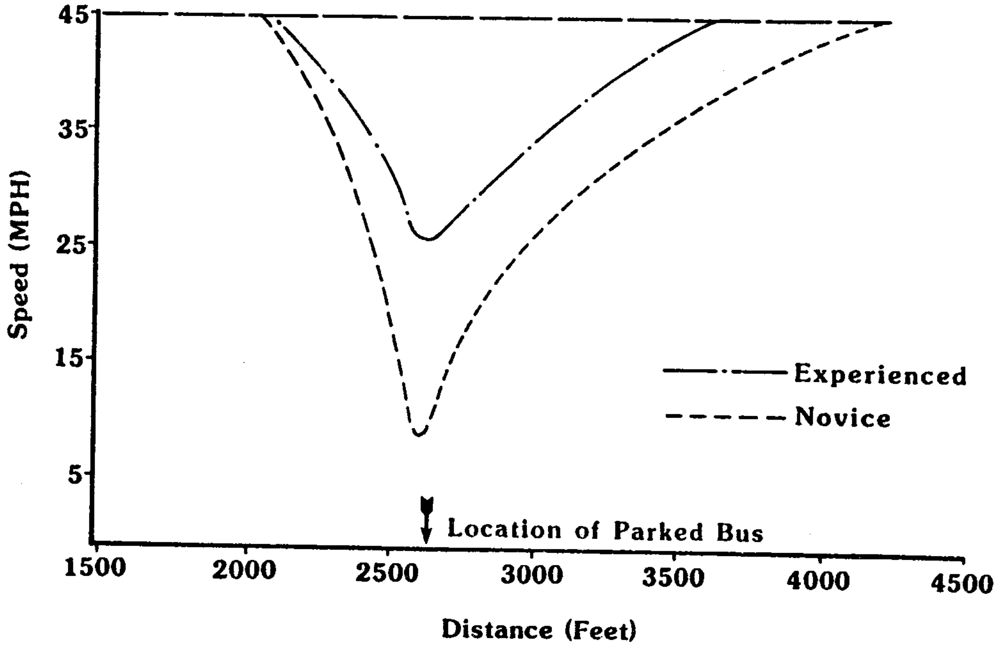


Figure 33. Speed Profile Comparison On 19.5-Foot Tangent Transitway -- Novice vs. Experienced Driver

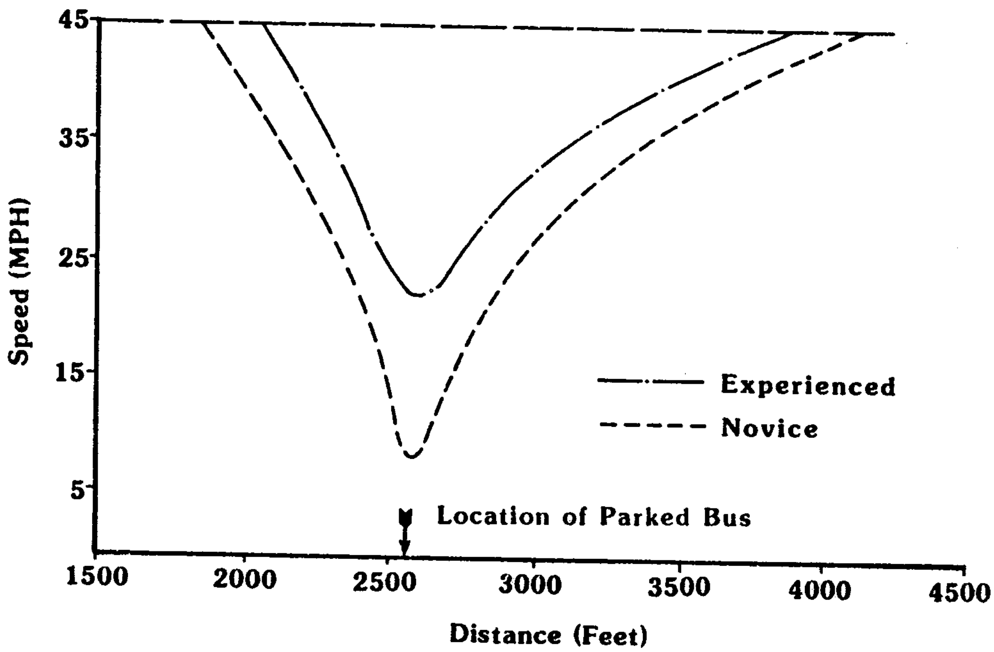


Figure 34. Speed Profile Comparison On 19.5-Foot 3° Curve Transitway -- Novice vs. Experienced Driver

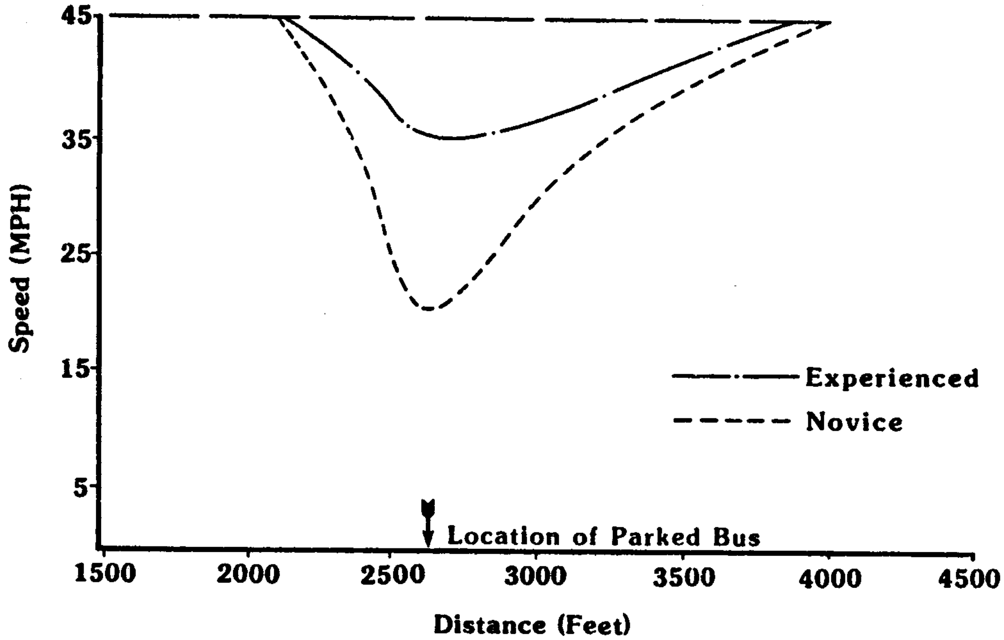


Figure 35. Speed Profile Comparison On 20.5-Foot Tangent Transitway -- Novice vs. Experienced Driver

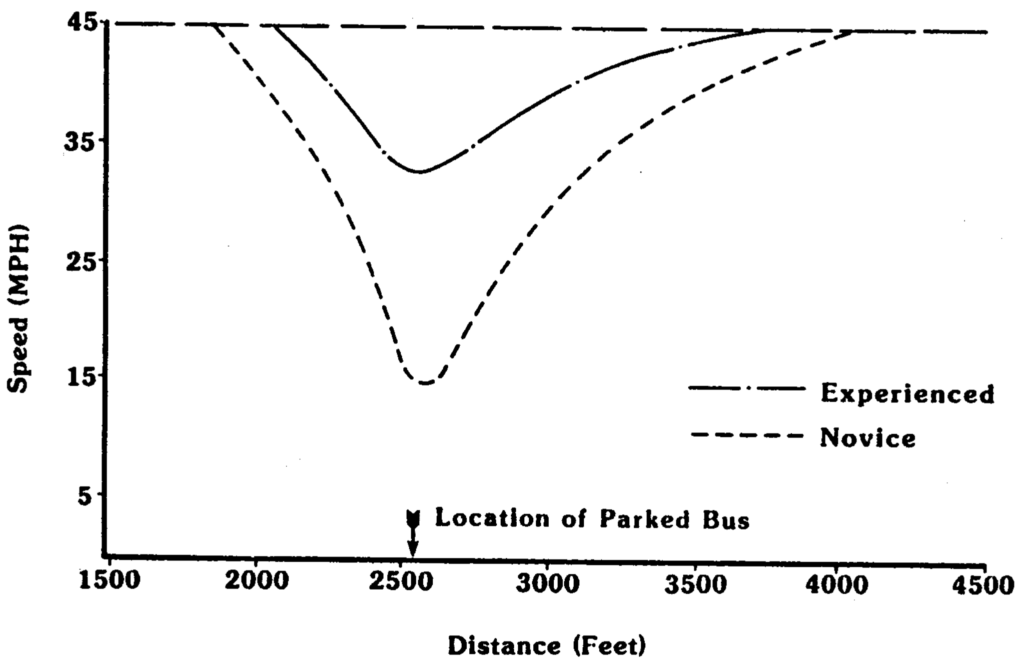


Figure 36. Speed Profile Comparison On 20.5-Foot 3° Curve Transitway -- Novice vs. Experienced Driver

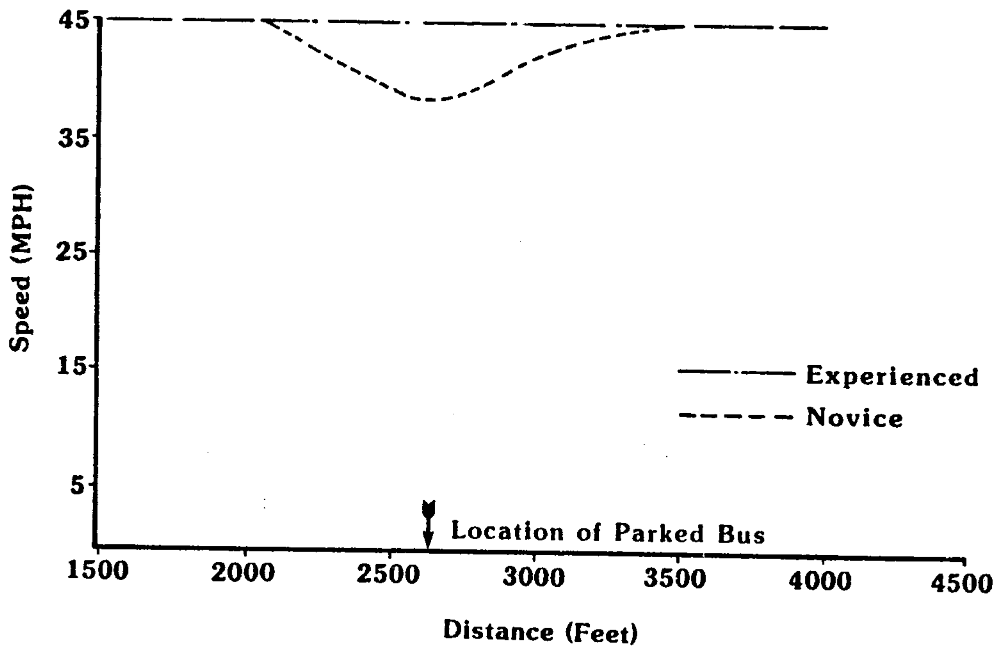


Figure 37. Speed Profile Comparison On 22.0-Foot Tangent Transitway -- Novice vs. Experienced Driver

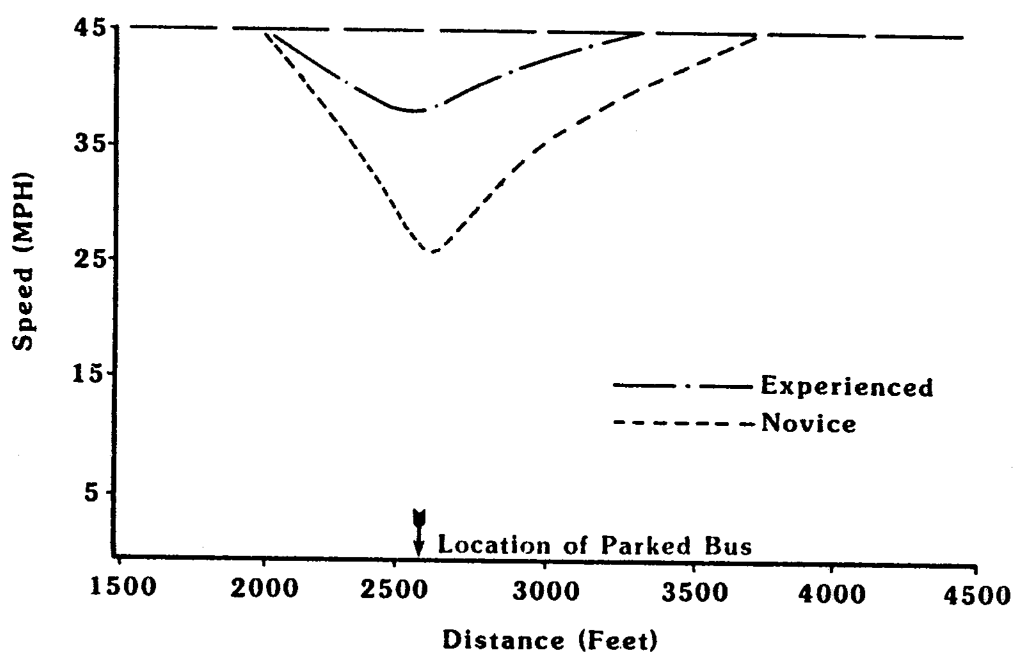


Figure 38. Speed Profile Comparison On 22.0-Foot 3° Curve Transitway -- Novice vs. Experienced Driver

the situation on one-lane transitways where the mirrors are not in danger of hitting each other. The 30.0-foot situation was derived from a test conducted on the 19.5-foot lane with the buses facing each other. The mirror heights at the point of passing were, thus, at the same height. The 30.0-foot dimension is obtained by adding the 10.4-foot clear space (Table 4) to the 19.5-foot lane width to obtain another "lane". This simulated two-way transitway results in a passing speed half that of the 34.0-foot lane.

The passing speed for the 34.0-foot transitway is approximately equal to that of the 20.5-foot single lane. The clearances on these two transitways, however, are 11.4 feet for the medium width lane and 12.5 feet for the 34.0-foot lane. This 1-foot difference should result in a substantial increase in passing speed, but the observed behavior provides some explanation of this

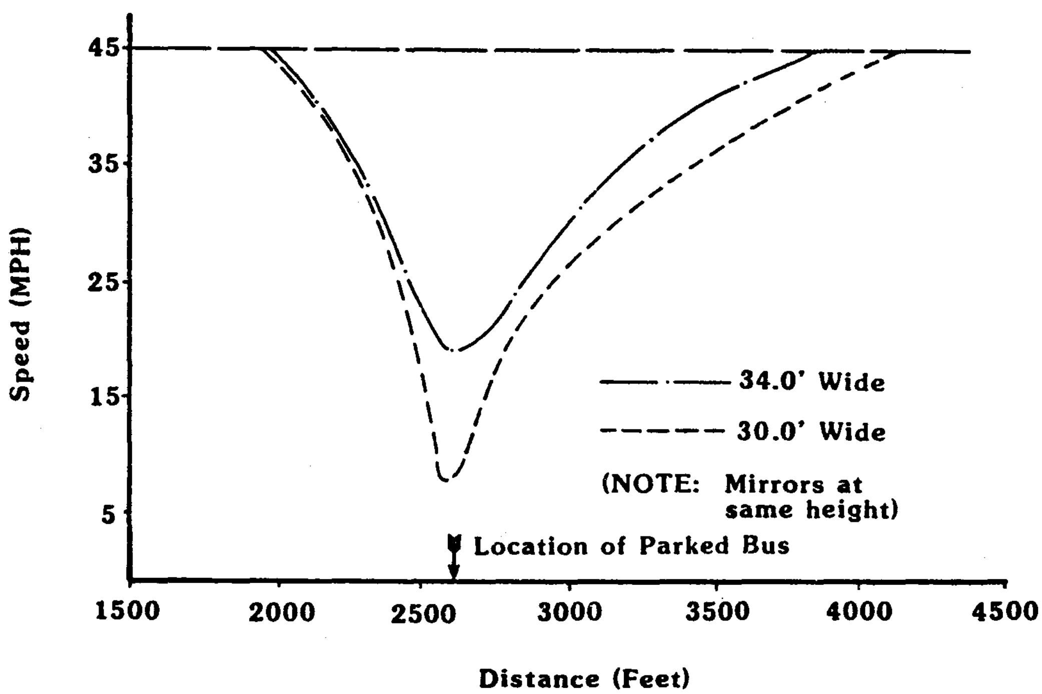


Figure 39: Speed Profile Comparison For Novice Driver on Two-Way Transitway -- 34.0 Feet vs. 30.0 Feet

result. The passing vehicle was driven alongside the barrier up to the parked bus and pulled closer to the barrier than in comparable one lane tests. The drivers reported that the constriction seemed narrower than it measured, possibly due to the comparatively wide nature of the barrier-to-barrier distance.

Figure 40 indicates that, for the narrow (10.4 foot) clear space, there does not seem to be any difference in passing speeds depending on mirror position. This is despite the fact that this results in a 0.7 foot decrease in an already constrained clear space.

Figure 41 illustrates the improvement in passing speed that might be expected on a 34.0-foot tangent two-way transitway section as driver experience levels increase.

<u>Delay in the Bus Passing Maneuver</u>

While passing speed during a breakdown situation is important, an economic estimate of the impact that lower speeds have on transit operation may be obtained through the use of delay estimates. Delay may be defined for transitway traffic as the difference in travel time between unconstrained operation and a situation in which there exists a "stalled" vehicle in the transitway. The additional time required to make a trip on the transitway may be estimated by measuring the area between the passing speed curve and a horizontal line at 50 mph. As discussed previously, the 45 mph value was chosen for use in the graphs due to the relative consistency of all curves between 45 mph and 50 mph. All transitway widths tested would incur approximately 20 seconds of delay between 45 mph and the normal 50 mph operating speed.

The values shown in Table 6 indicate that a breakdown on the narrow transitway will result in more than 3 minutes of delay for every bus driven

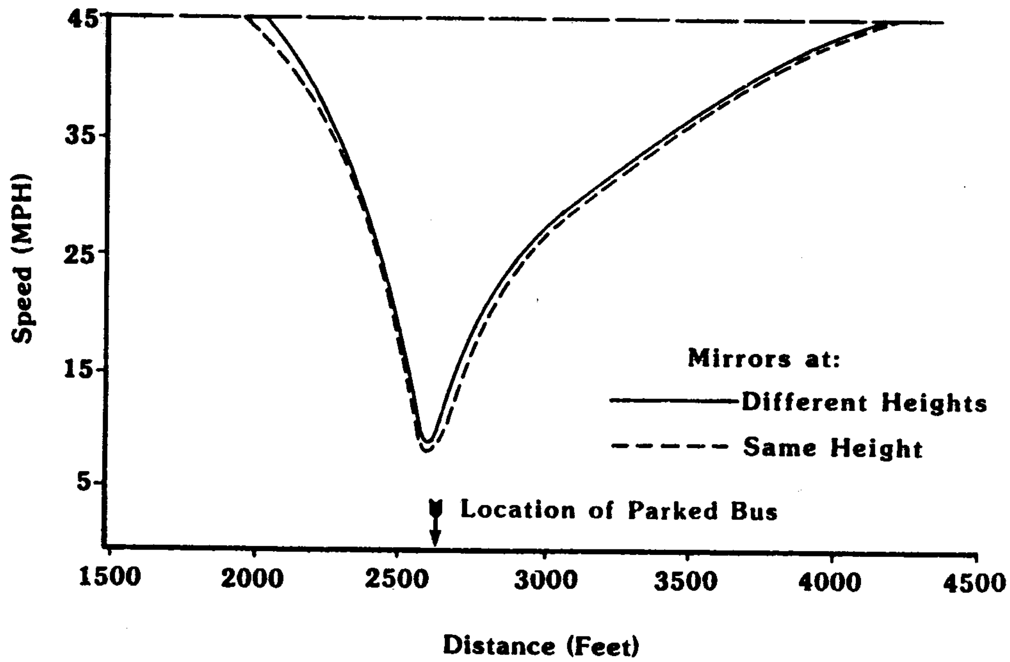


Figure 40. Effect of Mirror Position on Speed Profile of Novice Driver On 30.0-Foot Tangent Transitway

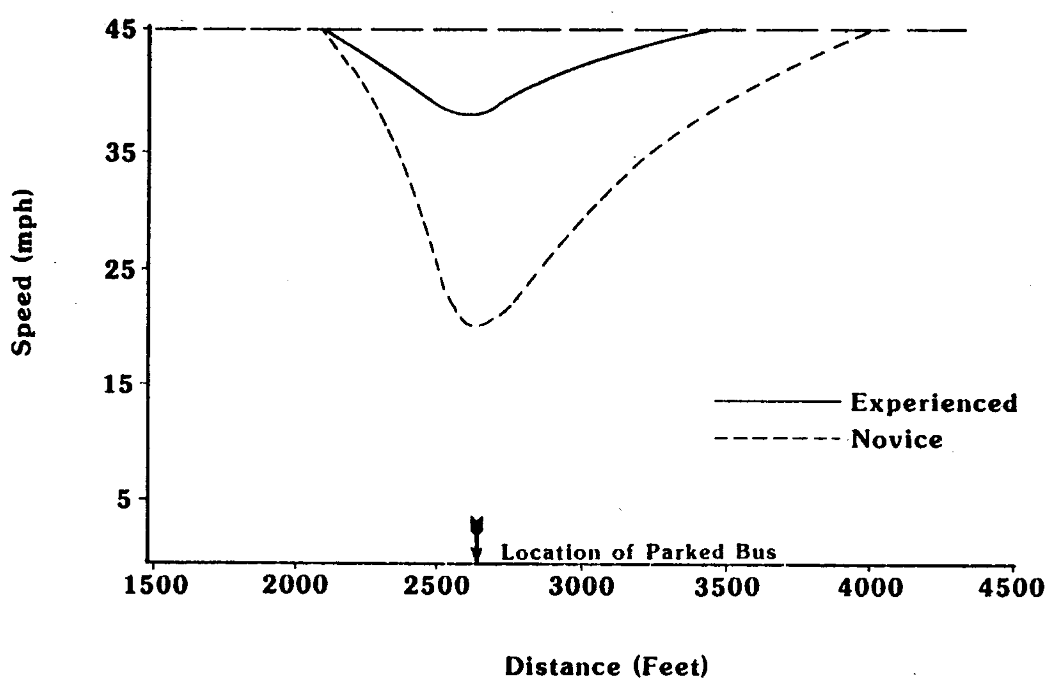


Figure 41. Speed Profile Comparison on 34.0-Foot Tangent Transitway -- Novice vs. Experienced Driver

Table 6. Summary of Estimated Bus Passing Speed and Delay

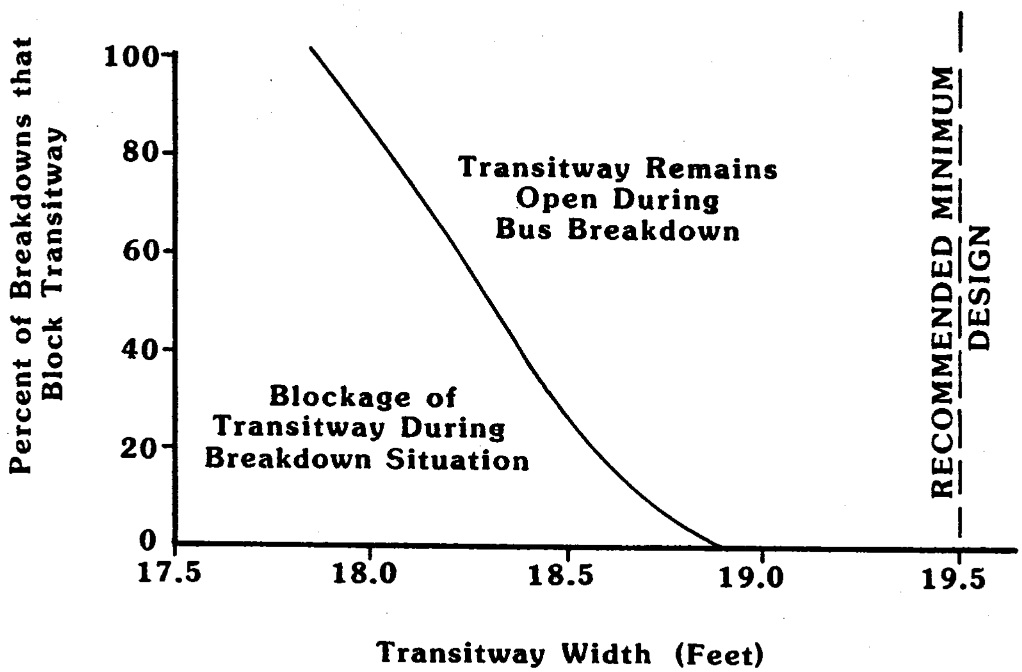
Transitway Width	Bus Passing Speed and Delay			
	Novice Driver		Experienced Driver	
	Passing Speed (mph)	Delay (sec)	Passing Speed (mph)	Delay (sec)
One-Way				
19.5' Tangent	9	200	26	110
20.5' Tangent	20	155	35	80
22.0' Tangent	38	55	45+	20
19.5' Curve	7	215	23	135
20.5' Curve	15	180	32	95
22.0' Curve	25	120	38	50
Two-Way				
30.0' Tangent	8	210	25	115
34.0' Tangent	20	150	38	50

Note: Novice refers to professional bus driver at the beginning of the test. Experienced refers to professional bus driver with approximately 50 test runs. Delay is the difference between a constant 50 mph speed and each estimated speed profile.

by a novice driver. Experienced drivers would reduce the delay approximately one-half and increase the passing speed by a factor of three. The medium and wide one-way transitways exhibit similar reductions from novice to experienced conditions; the delay also decreases as the lane widens. Passing a stalled vehicle on a tangent section of 22-foot transitway is not estimated to result in any more delay than the 20 seconds between 45 mph and 50 mph. Novice drivers on a wide (22.0 foot) curve section, however, may still encounter 2 minutes of delay due to a bus breakdown.

The graph in Figure 39 indicates a doubling of passing speed for the four feet of widening. Delay estimates from these two curves, presented in Table 6, indicate that a reduction of one minute in delay might result from this speed increase. Experienced drivers will reduce delay by one-third to one-half compared to novice drivers. The decrease in delay for the 34.0-foot transitway between novice and experienced drivers is due, in part, to the previously referred to ability to better gauge the gap between the parked bus and the barrier.

Figure 42 utilizes the parking distances on tangent transitway sections illustrated in Figure 10 to estimate the percentage of controlled bus breakdowns that might block narrow transitways. According to the collected data, any transitway wider than 19.0 feet would never be blocked due to a non-



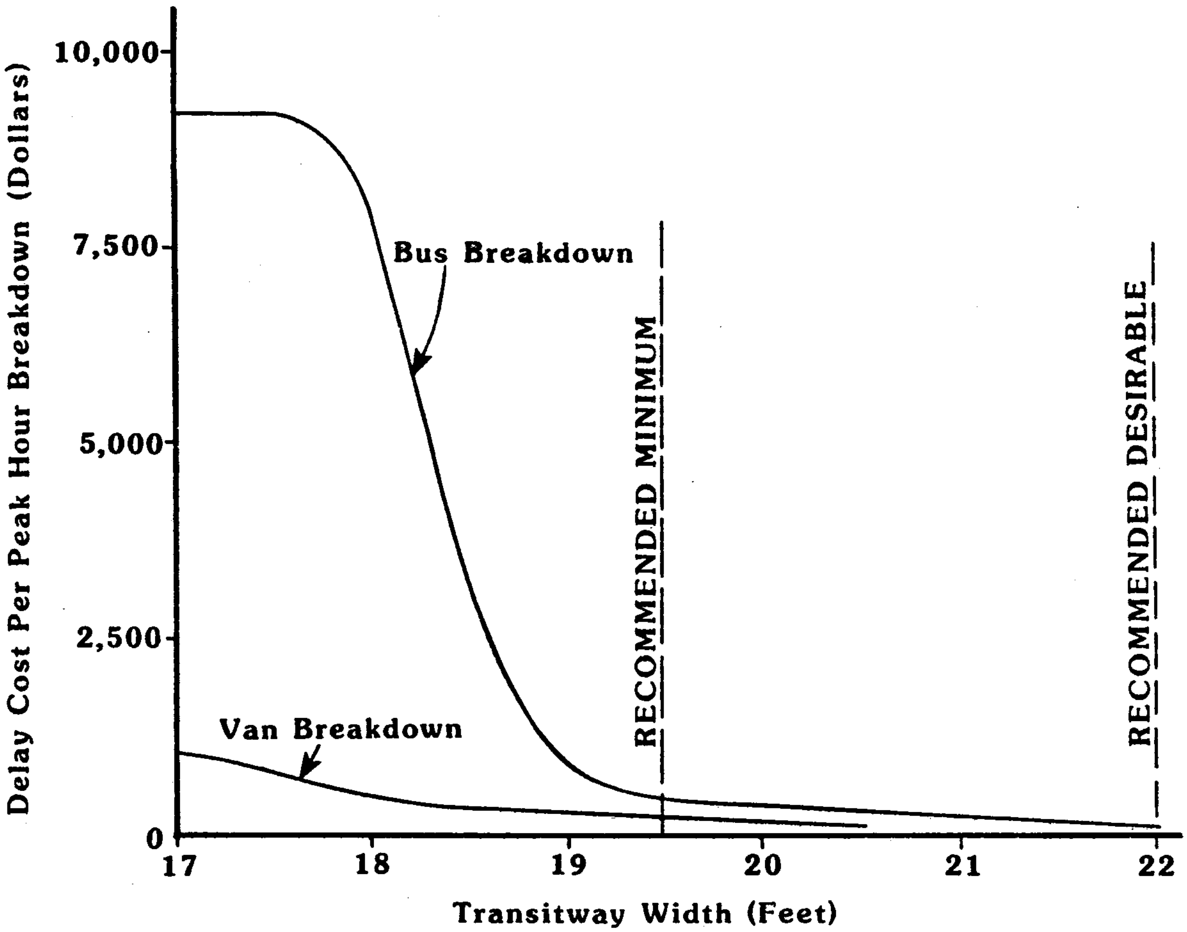
Note: Assumes 9.5 feet of clear space necessary for bus to pass stalled vehicle.

Figure 42. Percent of Controlled Bus Breakdown That Block Transitway

accident bus breakdown, but a 1-foot decrease in barrier-to-barrier width would increase the blockage rate above 80 percent. In addition, the 9.5 feet used as the required clear distance results in extremely slow passing speeds due to the 8.5-foot bus with a 0.7-foot wide driver's side mirror leaving only 0.3 feet of total clear space. The percent of blockage would decrease somewhat over time as drivers became more familiar with the parking maneuver, but any width less than 18.5 feet will almost certainly result in transitway closure due to bus breakdowns.

Estimates of the cost of delay to transitway users per peak-hour breakdown may be obtained using Figure 42 and the values for delay in Table 6. Bus operations are valued at $50 per hour, and bus and vanpool passenger delay are valued at $7 per hour. The stalled vehicle, whether lane-blocking or not, was estimated to be present for 30 minutes which reflects time for detection, dispatching a tow truck, passenger transfer and towing the disabled vehicle. Figure 43 reflects these estimates and average Houston peak-hour transitway volumes of 75 buses and 300 vanpools. A curve similar to Figure 42 was used to develop the van breakdown curve.

The sharp curve at 19.0 feet in the bus breakdown line in Figure 43 reflects the increasing probability that the transitway will be blocked as the width decreases. The lane blocking incident simulation estimated 70 vehicle-hours of delay and a queue in excess of 1 miles for each transitway closure. The probability of this occurrence was multiplied by the value of that delay ($9250) and added to the remaining probability and an estimated passing delay if the lane were not blocked (see note in Figure 43). The estimated increase in delay cost from less than $500 per incident on a 19.5-foot lane to $3000 for an 18.5-foot lane and to more than $7500 on an 18.0-foot transitway illustrates the importance in maintaining sufficient width on all sections of the transitway for stalled bus parking. This curve is utilized in the determination of minimum and desirable transitway widths.



Note: Assuming typical breakdown rates, 15 bus breakdowns and 75 van breakdowns can be expected per year. The delay cost is calculated by multiplying the probability of the event (lane closed or open) to the value associated with that event. Peak-hour volumes of 50 buses and 300 vanpools were combined with an incident time of 30 minutes. Values of $50 per bus operating hour and $7 per passenger hour were used to assess the cost of delay.

Figure 43. Delay Cost of a Peak-Hour Breakdown on Tangent Transitway

Position of Buses During Passing Maneuver

The overhead photos of the relative position of the two buses were useful in analyzing driver behavior in reacting to the lane constriction. Table 7 summarizes the observed driver behavior, and, thus, has some of the same problems attributable to the graphs of acutal data points. The trend that is evident, though, is the tendency to leave more bus-to-bus clear space on curved sections than on tangent sections. Similar width lanes result in much smaller right-side clearances, especially for the curved 22.0-foot transitway. Figures 44 and 45 allow comparison of the bus-to-bus distance for 19.5-and 22.0-foot transitways as viewed from the overhead camera.

Table 7. Transit Bus Postion At Point of Passing Maneuver

Transitway Width and Alignment	Actual Mean Passing Speed (mph)	Bus-to-Bus[1] Clearance (feet)	Bus-to-Barrier[1] Clearance (feet)
One-Way			
19.5' Tangent	9	1.6	0.3
20.5' Tangent	20	2.1	0.8
22.0' Tangent	42	2.7	1.7
19.5' Curve	16	1.7	0.2
20.5' Curve	32	2.4	0.5
22.0' Curve	38	3.6	0.8
Two-Way			
34.0' Tangent	28	3.4	0.6
19.5' Tangent			
Buses in same direction[2]	9	1.6	0.3
Buses in opposite[3] direction	7	1.7	0.2

[1]See Figure 10
[2]Adjacent mirrors are at different heights
[3]Adjacent mirrors are at same height

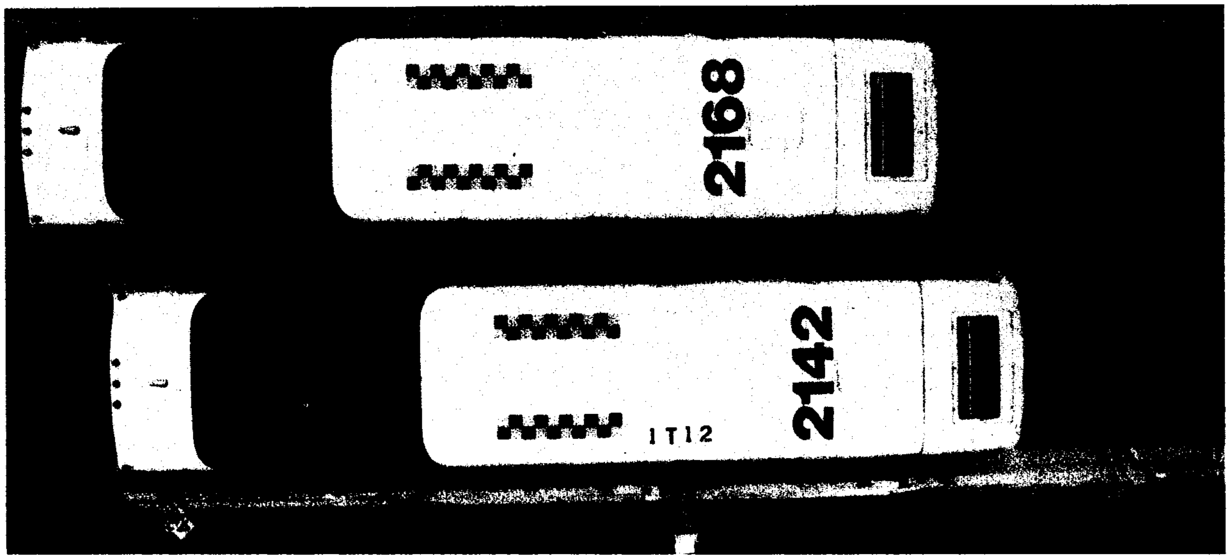


Figure 44. Overhead Picture of Bus 2168 Passing Parked Bus 2142 in a 19.5-Foot Tangent Transitway Test Section

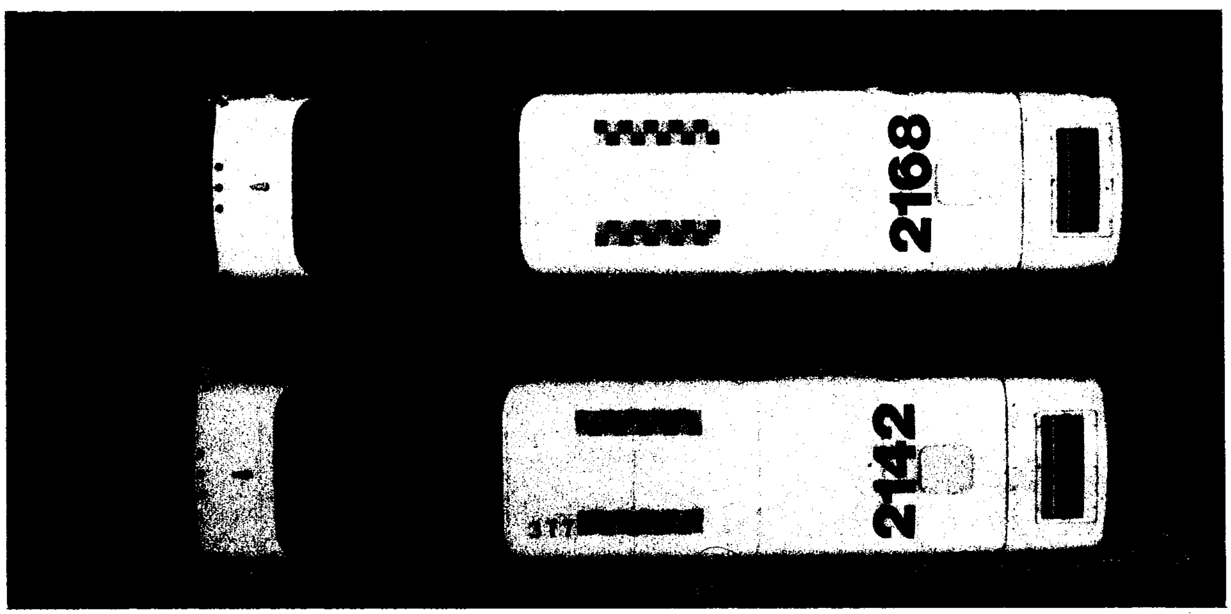


Figure 45. Overhead Picture of Bus 2168 Passing Parked Bus 2142 in a 22.0-Foot Tangent Transitway Test Section

Just as the mirror position had very little effect on passing speed, it also does not seem to effect the positioning between the bus and the barrier. This is despite the fact that each driver's side mirror protrudes approximately 0.7 feet from the edge of the bus. This leaves only 0.3 feet (1.7 - 2 (0.7)) between the two mirrors when the buses are facing opposite directions in the 19.5-foot transitway.

Even when the buses face the same direction, the passing bus was nearer the barrier on the two-way lane than when on the one-way lane. Two-way operation is illustrated in Figures 46 and 47 with an 8-foot wide bus parked in the shoulder area. These pictures are for demonstration purposes only and all two-way tests were conducted with a standard 8.5-foot wide bus in the shoulder area (Figure 48).

Considering that local route buses operate next to street curbs along most of their routes, the close operation to the concrete barrier should not be unexpected. The two drivers at the test also indicated that the flared bottom on the barrier gave them a warning before any part of the bus body scraped the barrier wall. This also gave them added confidence to drive very near the barrier at fairly high speeds.

Figure 46. Ground-Level View of 34-Foot Two-Way Transitway Demonstration

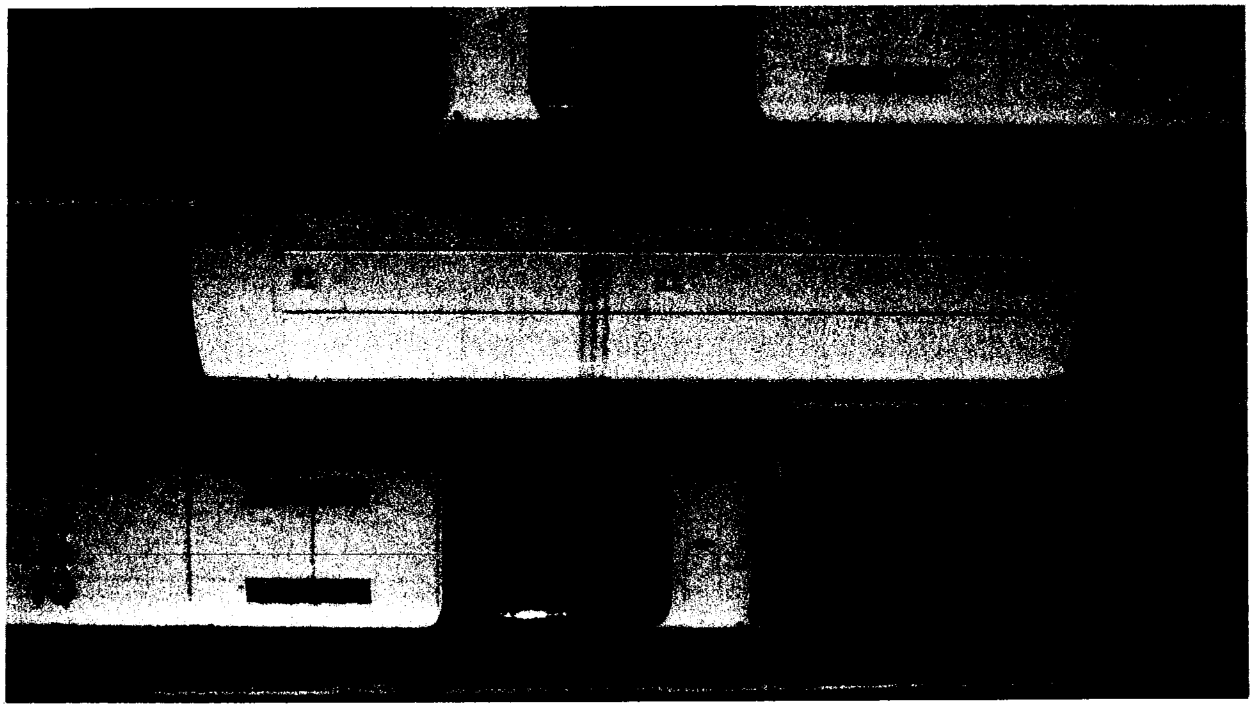


Figure 47. Overhead View of 34-Foot Two-Way Transitway Demonstration

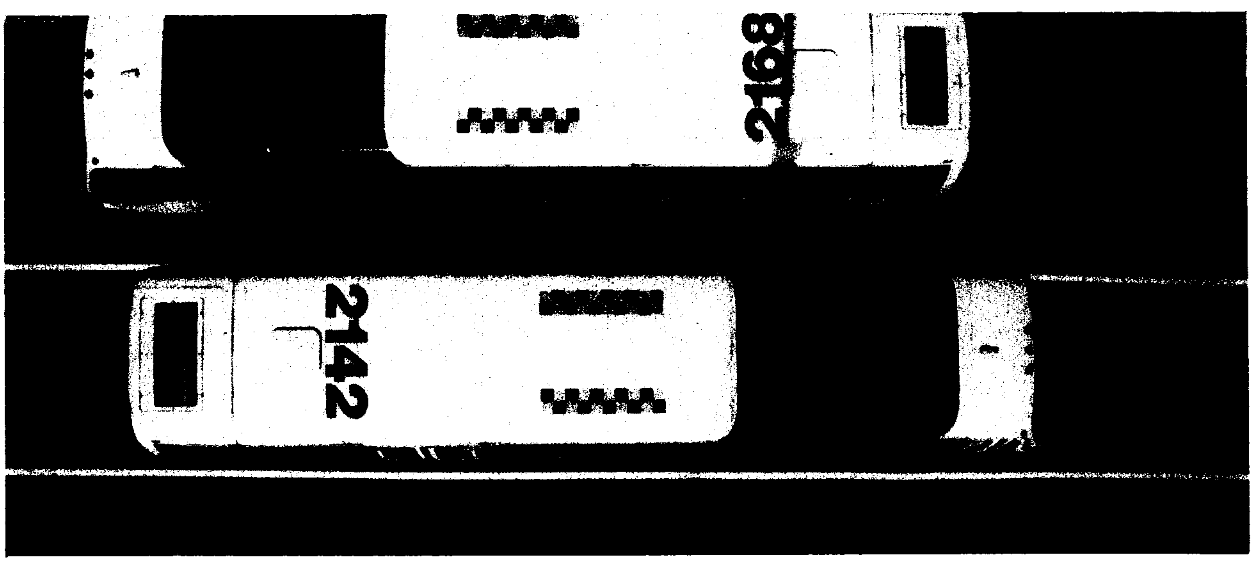


Figure 48. Overhead View of 34-Foot Two-Way Transitway Test

MAJOR FINDINGS CONCERNING DESIGN AND OPERATION OF TRANSITWAY

This report presents data that can be used to develop guidelines applicable to both the design and operation of a transitway facility enclosed by barrier walls. Safety considerations, as well as passing speed and delay time, are used to develop the suggested guidelines.

Design

Both bus drivers and METRO supervisory personnel felt very strongly that the standard New Jersey-type concrete barrier with the flared bottoms was a preferred barrier shape. This is important since consideration was being given to using barriers with vertical walls in order to increase space in the transitway. Experience with the parking tests and passing maneuvers in tight clearance sections also suggests that the drivers used the wide bottom of the barrier as a guide to positioning their vehicle. As they gained confidence that the tire could be rubbed on the bottom of the barrier with no damage to the body of the bus, the drivers were able to park the bus much closer to the concrete barrier. The photograph in Figure 49 shows the GMC bus parked next to the New Jersey barrier.

The travel speed and delay values summarized in Table 6 and the delay cost curve in Figure 43 are used to develop the minimum and desirable widths for reversible and two-direction transitways. The widths presented in Table 8 for tangent sections are between the toes of two concrete median barriers. The 19.5-foot dimension allows one bus to park on the left side of the transitway and another bus to pass on the right. Parking test data indicate that, under controlled breakdown (non-accident) situations, the clearance between the right side of the parked bus and the barrier will allow a slow passing maneuver to be accomplished by transitway drivers. The extra 2.5

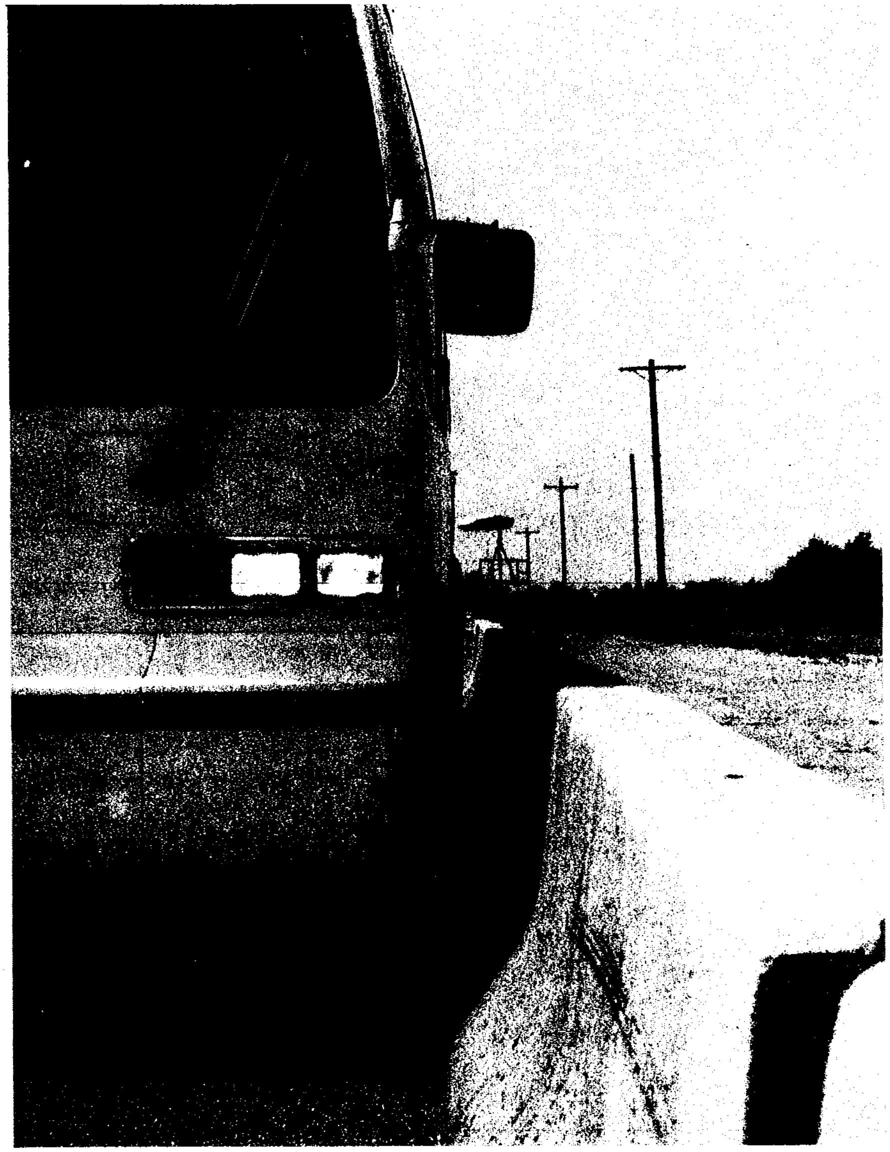


Figure 49: GMC RTS-04 Transit Bus Parked Next to New Jersey Barrier

feet of width in the desirable transitway section allows the passing speed to increase to almost 40 mph, resulting in very little delay to passing vehicles. That wider section also provides additional flexibility in the parking location for disabled vehicles and, thus, greater assurance that the transitway will remain open under vehicle breakdown conditions.

Table 8. Summary of Recommended Transitway Widths

Transitway Section	Minimum Width (ft)	Desirable Width (ft)
Reversible, tangent	19.5	22.0
Two-lane, two-direction	33.0	36.0
Widening on curves (≥2 degrees)	0.5	1.0

Widening on curve sections of more than 2 degrees should be a minimum of 0.5 feet and, desirably, 1.0 feet. These widenings will allow passing speeds to remain consistent with the passing speeds that occur on tangent sections.

Pavement markings for the reversible transitway should delineate a 12-foot lane in the center of the transitway. A solid, white, 4-inch paint stripe should be used to delineate the lane (Figure 50). A disabled bus would use the left side of the transitway for parking. Striping the lane in a manner that would provide a single wide shoulder on one side of the transitway, thereby forcing the bus operators to drive near one barrier, may lower operating speeds relative to a center lane operation. Also, since the lane is reversible, a stalled or parked vehicle has to park on the left side of the transitway or the door will be next to the concrete barrier and it will not be possible for passengers to exit.

The two-lane, two-direction transitway with a center shoulder should be a minimum of 33.0 feet wide and, desirably, be 36.0 feet wide. As was the case with the one-lane facility, widening on curved sections is recommended. The pavement markings, however, differ. The ten-foot shoulder in the middle should be delineated in the same manner as a two-way left-turn lane (Figure 51). This constant shoulder requires vehicles to operate in lanes near the barrier. To give these vehicles further guidance as to position relative to the barrier and to encourage 50-55 mph operating speed, a continuous 4-inch

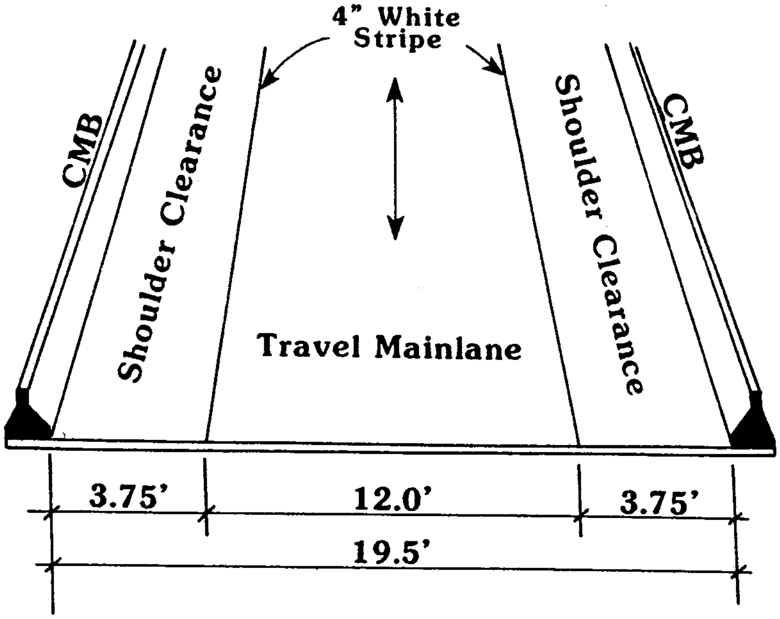


Figure 50. Typical Transitway Striping -- Minimum Width One-Lane Reversible

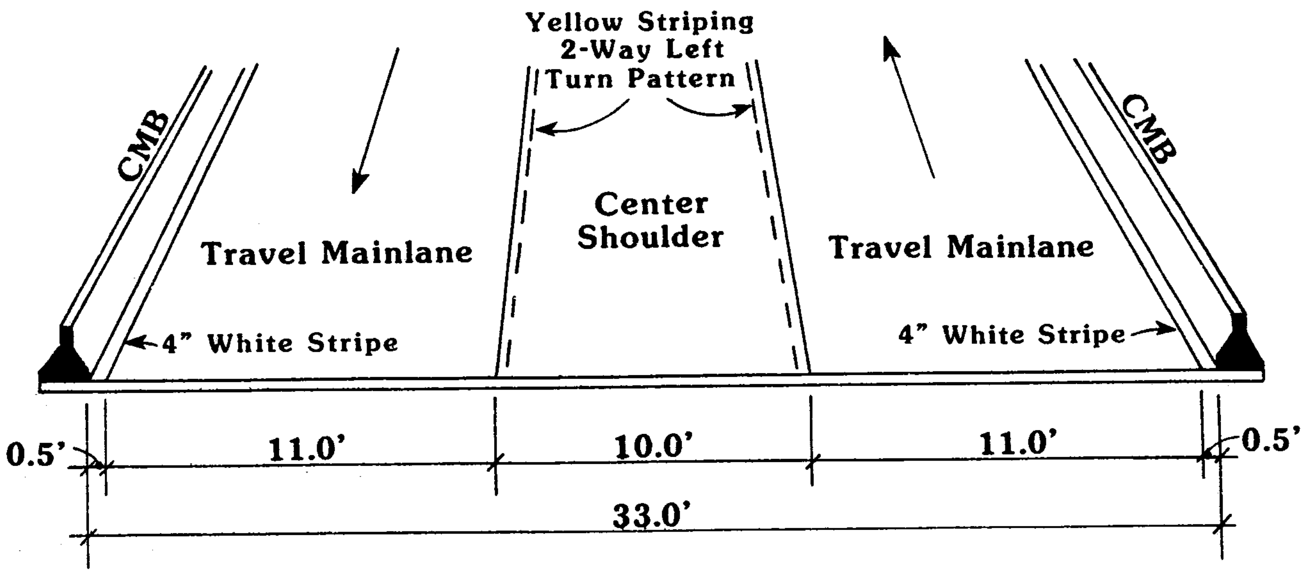


Figure 51. Typical Transitway Striping -- Minimum Width Two-Lane, Two-Way

white stripe should be placed approximately 0.5 feet from the toe to each line of barriers. The result is 11.0-foot travel lanes for the minimum width transitway.

Operation

This report dealt primarily with a bus passing another bus, as this was the maneuver which had the greatest impact on passing speed. Other passing tests conducted indicate that very little slowdown in speeds (less than 15 mph) might be expected in the van passing a bus maneuver. In all cases, a stalled van should not narrow the clear lane as much as a stalled bus. This, obviously permits higher passing speeds.

The two bus drivers for these tests were told to ignore the possibility that passengers may disembark from the stalled vehicle into the path of the passing vehicle. This allowed passing speed to vary according to width of the clear space. In actual operation, this concern for passenger safety would lead to slow (less than 10 mph) passing speeds for lane widths up to 25-30 feet. These safety considerations must be resolved before transitway operating speeds can achieve the "experienced" level as indicated in this report. The driver of a stalled vehicle may be instructed to keep all passengers inside until another vehicle (relief bus, van, etc.) arrives on the scene and blocks other vehicles from passing. Passengers from the stalled vehicle would then transfer to the "blocking" vehicle and resume their trip.

One of the most important results of this study is the realization of how vital previous driver training is to the successful operation of a transitway. Curves have been derived showing the improvement in passing speed from the "novice" to the "experienced" driver. This speed increase reduces delay, but, more importantly, reduces accident potential by allowing a more constant speed to be maintained. Training in the parking maneuver also provides greater assurance that breakdown situations will not result in a total blockage of the transitway. The cost of a lane closure incident is illustrated in Figure 43.

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