ADEQUACY OF MINIMUM PASSING SIGHT DISTANCES FOR COMPLETING OR ABORTING THE PASSING MANEUVER

by

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Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Civil Engineering

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September 30, 1987

Blacksburg, Virginia

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(ABSTRACT)

Overtaking and passing maneuvers on two-lane rural roads is still one of the most complex situations drivers are faced with in everyday driving. In passing, drivers must judge the speed, acceleration and deceleration capabilities of their own vehicle, that of the impeding vehicle and the speed and rate of closure of the oncoming vehicle. They also have to make decisions on the adequacy of an acceptable gap and sight distance.

This report presents an investigation of the adequacy of the current "Manual on Uniform Traffic Control Devices" (MUTCD) for marking on two-lane, two-way roads. It examines the existing criteria, problems associated with it and its reasonableness. Passing sight distances which incorporates both the option of aborting or completing the passing maneuver is presented.

A model describing the kinematics of vehicle trajectories during the passing maneuver on two-lane roads is utilized for this purpose. The model is based on the presence of a delima zone during the passing maneuver. At this point, the decision to complete or abort the passing maneuver provides the same factor of safety. This critical position is located using the model. The parameters that strongly influence the required sight distance are investigated.

Thus passing sight distances that will provide reasonable margin of safety throughout the passing maneuver will be achieved. It is realized from the results that the current MUTCD passing sight distance is inadequate from a safety standpoint, except for high accelerations and high decelerations.

Acknowledgements

I would like to acknowledge with sincere thanks the help and contributions of my major advisor, S. A. Ardekani. His limitless patience and marvelous suggestions have proved invaluable.

I also wish to thank the other members of my thesis committee: A. G. Hobeika, for his continuos guidance and endless help, and R. D. Walker, for the valuable materials he covered in the courses I have taken with him. These materials have been and will continue to be of great help to me.

I am deeply grateful to my parents for making my education all these years possible. I am also grateful to my wife for her help, patience and encouragement. Lastly, I wish to express my appreciation to my friends, at the University of Toronto, Canada, and at Technion University, Israel for their suggestions.

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1.0 INTRODUCTION

On two-lane, two-way rural roads, the driver is faced with multiple decisions during an overtaking maneuver. Most motorists have been faced at one time or another, with a passing zone that seems too short for safe passing. Overtaking a slow vehicle on a two-lane road is among the most complex and potentially hazardous situations in daily driving (Ref. 6). The driver who is doing the overtaking, in a bid to cope with the situation, must be able to decipher and process the relevant information presented to him in a dynamically changing frame of reference. He must be able to make specific and quick judgements which would provide a good margin of safety should he decide to complete or abort the passing maneuver. In such situations poor judgement can result in a very undesirable incident.

About seventy-one percent of the highways are considered as two-lane, two-way highways on which vehicles frequently overtake slower moving vehicles. Passing in this case must be accomplished on the opposing traffic lane. If passing is to be done with safety the overtaking driver should have a sufficient sight distance ahead, clear of traffic, to execute the passing maneuver without cutting off the impeding vehicle in advance of meeting an opposing vehicle. Similarly, he must be able to abort the maneuver safely if he finds the opposing traffic too close when the maneuver is partially completed. At each passing section the length of roadway ahead of the overtaking driver should be equal to or greater than the minimum passing sight distance. Frequency and length of passing sections for highways depend principally on topography, roadway geometry (horizontal and vertical curvature) and cost. The minimum passing sight distance is sufficient for a single isolated passing only.

The importance of the overtaking maneuver, furthermore, has implications for overall-road safety. From the literature reviewed, it is seen that overtaking accidents on two-lane, two-way rural roads are the severest of all accidents on rural roads. Seveteen percent of accidents being head-on collisions.

In spite of the complexity of the overtaking maneuver, and despite the research done on this issue, the investigation of "aborting" the passing maneuver has not been extensively carried out. The Manual on Uniform Traffic Control Devices (MUTCD) specifies the minimum passing sight distances in connection with marking for demarcating passing and no-passing zones. Recent research points out the inadequacy of the MUTCD for completing the passing maneuver, but fails to address the issues of both completing and aborting the pass.

The major purpose of this research is to investigate the MUTCD passing sight distance requirements for both completing and aborting the passing maneuver by the use of a kinematic model.

The research approach and scope of this study will be to evaluate the passing practices of drivers from data on prior research. Practices as determined from accident reports, current vehicle specifications and performance (acceleration, deceleration, stopping ability) and their effects on sight distance are examined.

2.0 LITERATURE REVIEW AND PROBLEM STATEMENT

2.1 Methods Used to Evaluate Passing Sight Distances

To properly outline the research and identify its objectives, it is first necessary to explain the various techniques that have been developed for evaluating sight distances on two-lane, two-way roads.

Over the years several studies have addressed the issue of sight distance and overtaking. The efforts have been mostly observational with only a few analytical or theoretical calculations. Much of the work in this area has mainly considered only completing the passing maneuver. Only a few like Lieberman (Ref. 15), Saito (Ref. 5) and Herman (6) have touched on the issue of aborting the passing maneuver as well.

Early attempts to assess the adequacy of sight distances dates back to the late 1930's and early 1940's. Studies by Norman (Ref. 12) perhaps constitute the first comprehensive research on overtaking maneuvers. It involved observation of 1635 overtakings using one hundred pneumatic tubes spaced at fifty feet intervals on the road surface. Norman's analysis gives details of acceptable gaps by drivers but not of gaps rejected. A similar study by Prisk (Ref. 17) and another by Norman (Ref. 16) indicated that the passing vehicle travelled to a point approximately abreast of the impeding vehicle at about one-third of the left lane occupancy distance by the passing vehicle.

Pretty and Miller (Ref. 14) also investigated gap acceptance by drivers wanting to overtake on two-lane rural roads. Observations were made from vehicles being driven on straight level roads at speeds of 30, 35 and 40 mph at two sites near Melbourne. They recorded both rejected and accepted gaps, unlike those of earlier studies. They used maximum likelihood estimate techniques and a log-probit analysis for their data. The authors noted that drivers make decisions whether or not to overtake based on available gap, sight distance, speed of their vehicles as well as that of the impeding vehicle and the estimated speed of the oncoming vehicle. They also found from a fit of a log-normal distribution to the accepted gaps that, the estimated mean critical gap increases with the increase in the speed of the overtaken vehicle. Their study however did not report the effect of the speed of the oncoming vehicle on the size and gap accepted.

In the early 1970's, a number of theoretical and experimental efforts were directed towards the improvement of the safety and efficiency of two-lane, two-way highways by improving no-passing zone regulation and procedures. In 1971, Valkenburg and Micheal (Ref. 22) conducted tests at three sites in Lafayette, involving 915 passing maneuvers, totaling 3000 miles of driving. Their test centered on measuring the lengths of the passing maneuvers and the time to complete a pass for test cars driven at speeds of 40, 50 and 65 mph. These speeds span a range of average traffic speed that is usually found on two-lane highways. The types of passing vehicles were separated into four groups, namely, automobiles, pickups, single unit trucks and semi-trailer trucks. The types of passes examined were categorized into accelerative pass, fly pass, voluntary return and force or hurried return. Their findings indicated that the mean length for the accelerative pass with a voluntary return by automobiles passing trucks was consistently longer at speeds of 38, 47 and 61 mph than for other types of passes.

Herman (Ref. 6) in 1972 made a theoretical analysis based on his earlier research with Gazis and others on the dilemma faced by drivers approaching an intersection during the green to amber phase transition. At a critical position the driver is in a fix as to whether to accelerate and go through the intersection or decelerate and stop. He related this problem to overtaking on two-lane roads and developed a model which takes into account both the option of aborting or completing a pass during the overtaking maneuver. The similarity between these two problems had been commented on by Valkenburg and Micheal in an earlier study.

In addition, Troutbeck (Ref. 4) in Australia investigated sight distances for overtaking maneuvers. Similar to the studies by Miller and Pretty, he used maximum likelihood techniques to estimate his parameters. The study was rather comprehensive and involved a total of 3150 overtakings, with 1537 of these relating to long vehicles (10-16 meter trucks) travelling at speeds between 55 and 85 km/h (34 and 53 mph). The duration of an event in this study could be determined to a greater degree of accuracy than could the distances travelled by vehicles. The analysis, therefore, gave more emephasis on time measures. The research vehicles were fitted with video equipment, together with speedo-odometer and radar speed meters. Video cameras were fixed to the front and rear of the test vehicle and by affixing mirrors near the lenses, the video system could record in four directions simultaneously. A large coefficient of skewness of many parameters was noticed and it was found that most overtaking parameters (especially overtaking times and distances) could be better represented by a log-normal distribution rather than a normal distribution. He found among other things that, in establishing the effect of the length of the overtaken vehicle on overtaking times, the most important period is the time the passing vehicle spends along side the overtaken vehicle. This time and length of vehicle was bound to be strongly correlated. If the length of the overtaken vehicle was increased from 5 to 10 meters the mean overtaking times increased by 17 percent and 19 percent for accelerative overtakings by cars and flying overtakings by cars respectively. Similarly, for the same increase in overtaken vehicle length, they mean overtaken distances increased by 17 percent and 21 percent. Also it was indicated that, at the end of the overtaking maneuver, drivers tend to cut in on trucks more than when overtaking cars. The 85th percentile critical gap was reported to increase as the speed of vehicle increases. Furthermore, the overtaking times were significantly correlated at the 5 percent significance level, with the size of the accepted gap. The accepted gaps were found to be highly correlated with safety margin. Also the 85th percentile critical gaps for cars overtaking cars at V km/hr was equal to the 85th percentiles critical gaps for cars overtaking trucks travelling at a speed of (V - 13.5) km/hr.

Weaver and Woods (Ref. 9) and Weber (Ref. 10) have also briefly discussed the concept of aborting the passing maneuver. Weber, however, discusses the issue much more and compares the difference between some of the principles behind design and marking of no-passing zones.

Somewhat more recently, in the 1980's, Lieberman (Ref. 15) and Saito (Ref. 5) investigated the issue of both completing and aborting the passing maneuver on two-lane, two-way highways. Saito's derivations are a modification of Lieberman's model. The model is a kinematic one. In their derivations they fix such parameters as length of the impeding vehicle, space headway between aborting and impeding vehicles and the gap between the rear bumper of the impeding vehicle and the front bumper of the aborting vehicle. It is also assumed for analysis that the speed of the oncoming vehicle and speed of the passing vehicle are the same. With these, they develop equations on acceleration and deceleration (Saito) times and rates, as well as clearance distances. Saito used the model to investigate the adequacy of the MUTCD passing sight distances for *aborting* the passing maneuver only. He also centered his investigation mainly on passenger cars passing passenger cars. His study found the MUTCD distances inadequate. Unfrotunately, he did not consider both the option of completing and aborting the passing maneuver together. It is also important to note that Saito's model and that of Herman are rather different. Donaldson (Ref. 8) discusses Saito's findings and comments that he should have investigated the issue of cars passing trucks in more detail. Saito, however, did investigate for passenger cars passing trucks 55 feet long. His computations and graphical representation imply that a significant increase in the collision-zone is affected by the attempt of passenger cars to pass trucks. Nevertheless, his own consideration of this conclusion is very brief.

Recently, Polus and Tomecki (Ref. 3) have conducted experimental studies at sites near Pretoria in South Africa. Data were collected at two sites on level two-lane, two-way rural road sections. The volume of the first site was 100 vph and 200 vph on the second road. Instrumented vehicles were driven simultaneously along each section at speeds of 37.5, 43.8, 50.0 and 56.3 mph (60, 70, 80, 90 km/hr). The vehicles were equipped with multi-purpose data acquisition and processing system called Traffic Engineering Loggers (TEL). The data extracted from the TEL were divided into accelerative and flying overtakings.

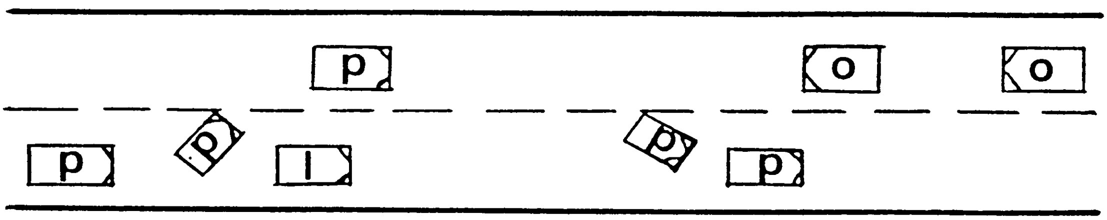
Their findings indicated that a negative correlation existed between the maximum speed difference and the speed of the overtaken vehicle. Analysis of speed variability of the passing vehicle during the process, revealed that for accelerative maneuvers, when the initial speed was low the final speed was higher and vice versa. Furthermore, for all maneuvers, the speed of the overtaking vehicle was almost constant throughout the overtaking process. This is in agreement with findings of Saito, Lieberman, Weaver and Woods.

2.2 Problems with Existing Design and Marking Principles

2.2.1 Present Criteria for Passing on Two-Lane, Two-Way Roads

Before discussing the present criteria used for marking, it is essential at this time to define the minimum passing sight distance. The "Minimum Passing Sight Distance" represents the minimum sight distance at which a passing driver must first be able to perceive an opposing vehicle from a critical position to permit execution of the pass with sufficient and safe clearance (Ref. 2, 5, 9, 10, 22). When available sight distance is less than the minimum sight distance a no-passing zone is warranted. Figure 1 shows the various positions of the passed vehicle, overtaking vehicle and the oncoming vehicle as defined by the minimum passing sight distance.

The Manual on Uniform Traffic Control Devices (MUTCD) (Ref. 1) is used by most states for marking passing and no-passing zones. Markings have definite and important functions to perform in the proper scheme of traffic control. In some cases they are used to supplement the regulations or warnings of other devices such as traffic signs and signals. In other cases they are



Notes: P - Passing Vehicle

I - Impeding Vehicle

O - Oncoming Vehicle

Figure 1. Relative Positons of Passing, Impeding and Opposing Vehicles in a Passing Maneuver

used to convey information to motorists which cannot be obtained from other devices (Ref. 1). Thus they serve as effective regulatory warnings which could not otherwise be made understandable by other devices. In brief, road markings can be said to have the advantage of conveying warnings or information to the driver without diverting his attention from the roadway.

The present pavement markings used by the MUTCD to delineate traffic flow and no-passing zone on two-lane, two-way highways consist of broken yellow line and solid lines. A double line consisting of two normal solid yellow lines delineates the separation between travel paths in opposite directions where overtaking is prohibited in both directions (Section 3A-6, 3B-1, Ref. 1). A double line consisting of a normal broken yellow line and a normal solid yellow line delineats a separation between travel paths in opposite directions where overtaking and passing is permitted with care for traffic adjacent to the broken line. It is prohibited for traffic adjacent to the solid line. This is a one-direction, no-passing marking. Figure 2 shows typical longitudinal marking applications for two-lane, two-way roads.

According to the MUTCD, centerline markings are desirable on paved highways in rural districts on two-lane, two-way pavements 16 feet or more in width, with prevailing speeds greater than 35 mph. It requires that "where center lines are installed, no-passing zones shall be established at vertical and horizontl curves and elsewhere on two and three lane highways, where an engineering study indicates passing must be prohibited because of inadequate sight distances. Furthermore, the present criteria demands that the no-passing zone for a two-lane, two-way shall be parallel and extended along the centerline throughout the no-passing zone.

The sight distance used for marking no-passing zones are based on the 85th percentile speed. The object height and drivers eye height are both 3.5 feet. The criteria for delineating no-passing zone on a vertical curve is based on the distance at which an object 3.5 feet above the pavement surface can just be seen from a point 3.5 feet above the pavement. Figure 3 is an illustration of how this is determined. Similarly, passing sight distance on a horizontal curve is the distance measured along the centerline between two points, 3.5 feet above the pavement on a line tangent to an embankment or other obstruction that cuts off the view on the inside of the curve. The method is illustrated by Figure 4. A summary of the MUTCD minimum passing sight distance

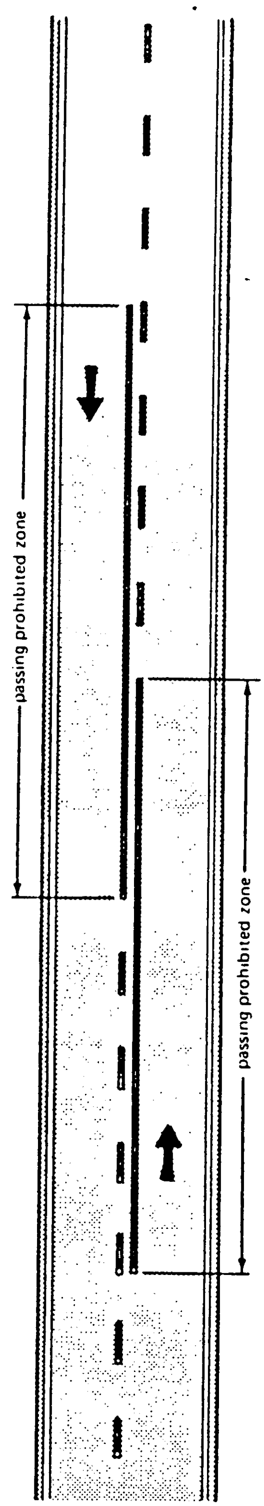


Figure 2. Typical Longitudinal Marking Applications for Two-Lane Two-way Roads

requirement for various speeds is given in Table 1. The beginning of a no-passing zone is that point at which the sight distance becomes less than specified in Table 1, while the end is the point where the available sight distance becomes greater than those specified.

In comparison, the AASHTO (Ref. 2) passing sight distances are somewhat higher than those of the MUTCD. The reason is due to design philosophy. It is the principle of AASHTO that, if total sight distance is provided at the beginning of a passing opportunity, a driver may sequentially execute each element of a passing maneuver comfortably with full visual knowledge throughout the overtaking. The idea is to allow adequate separation distance between the two opposing vehicles at the completion of the maneuver. This view is shared by Weber (Ref. 10) and Weaver and Woods (Ref. 9).

The amount of available sight distance can be decreased below this total distance value until a point at which sight distance ahead becomes the smallest necessary to perceive an opposing vehicle in time to safely complete a passing maneuver once the driver is committed to the execution of the maneuver. This in essence predicates minimum passing sight distances and forms the basis of the marking sight distance definition.

Even though the MUTCD sight distnces are being investigated, it is pertinent as a matter of comparison to describe AASHTO's criteria as well. The AASHTO policy divides the passing sight distance (see Figure 5) into two phases, which are subdivided into:

- Distance traversed during premaneuver time, d_1,
- Distance traveled in the left lane by passing vehicle, d_2,
- Clearance distance between the passing and on-coming vehicle, d_3,
- Distance travelled by the opposing vehicle, while the overtaking vehicle occupies the left lane, d_4.

The passing sight distance given for design purposes is the summation of d_1, d_2, d_3 and d_4 It is important to note that AASHTO's sight distance requirements are obtained from plan and profile drawings, by the use of a straight edge which is marked for height of drivers eye and height of object

Table 1. MUTCD Passing Sight Distance Requirements

85th Percentile Speed (mph)	Sight Distance (feet)
30	500
40	600
50	800
60	1000
70	1200

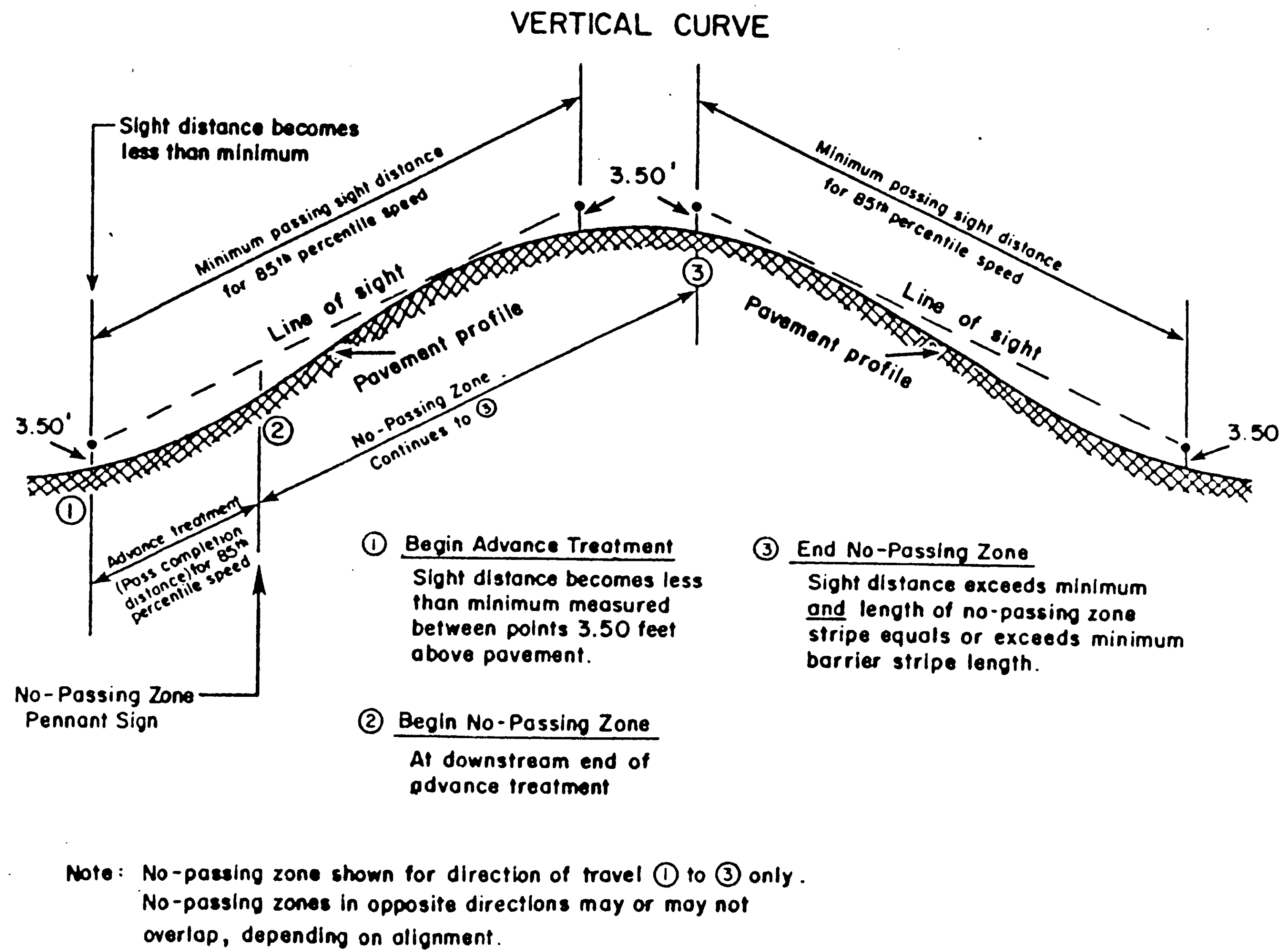


Figure 3. Method of Locating and Determining Limits of No-Passing Zones on Vertical Curves

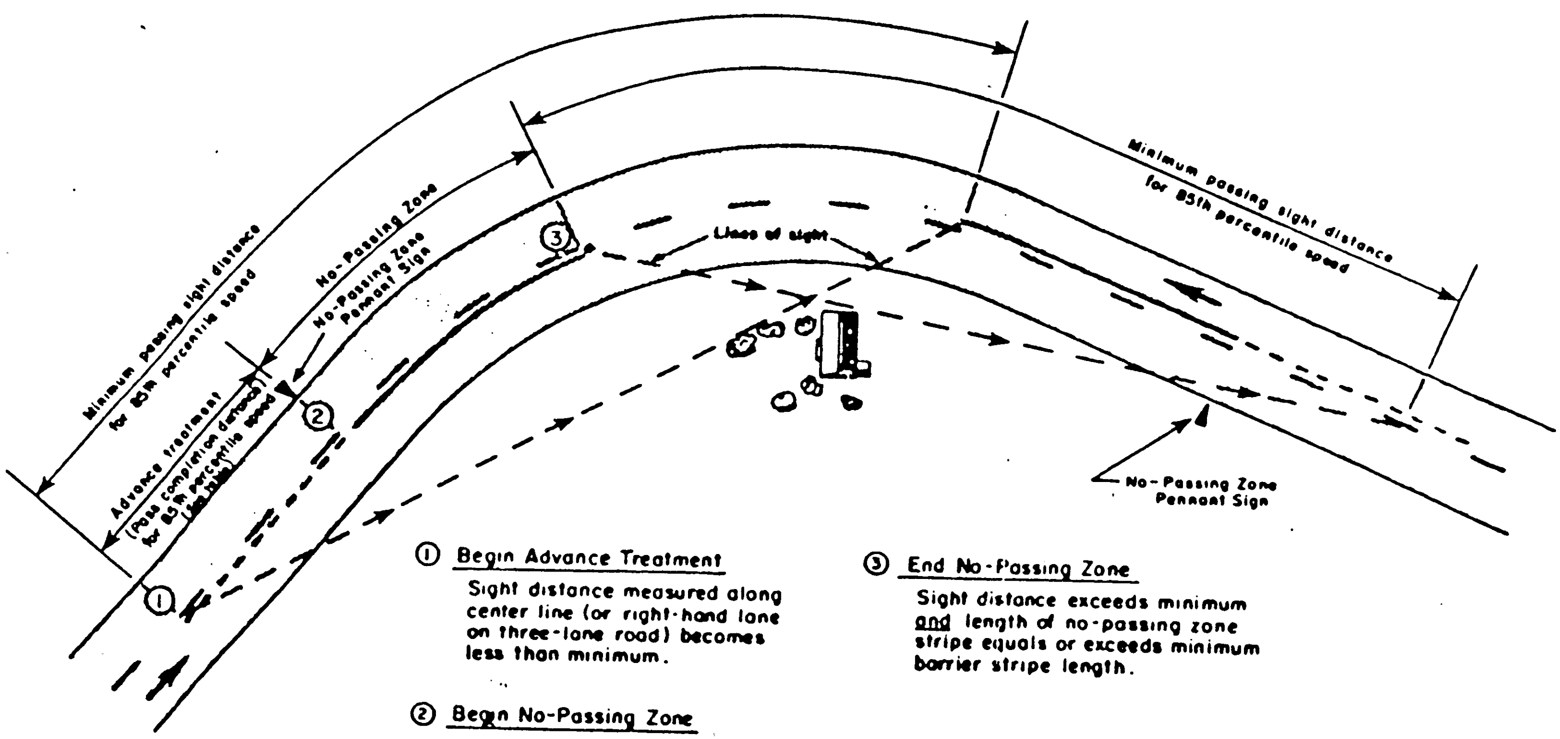


Figure 4. Method of Locating and Determining Limits of No-Passing Zones on Horizontal Curves

(opposing vehicle). AASHTO uses an object height of 4.25 feet. Figure 6 shows the procedure used by AASHTO.

2.2.2 Current State Practices for Marking

There are two concepts which most states use for establishing and marking no-passing zones on two-lane, two-way highways. These are the short zone concept and the long zone concept.

The short zone concept prohibits driving on the left side of an applicable yellow line throughout its length. Human factors studies conducted at the Texas Transportation Institute (Ref. 9) show that drivers actually interpret driving on the left side of the solid yellow line to be illegal and unsafe. Valkenburg and Michael (Ref. 22) point out the shortcoming of the short-zone concept. They explain that it is physically impossible for motorists always to complete a passing maneuver without crossing the yellow line because of the limited visibility of no-passing zone signs and pavement markings. No-passing zones designated under this concept are established when sight distance clearance is below those specified by the MUTCD (Refs. 9 and 22). Consequently, most states have laws that incorporate the short-zone concept.

The alternative to the short zone concept is the long zone concept. This permits completion of a passing maneuver across the solid yellow line, that is, beyond the beginning of the marked no-passing zone. Sight distances under this concept are however longer. The basic idea behind this concept is to allow a driver who is so far advanced into a passing maneuver, ample opportunity to complete. This is to prevent a driver from severe or hazardous braking in an attempt to avoid crossing the yellow line. Table 2 compares the passing sight distances under both concepts with that used for design. Research conducted at the Texas Transportation Institute indicate that:

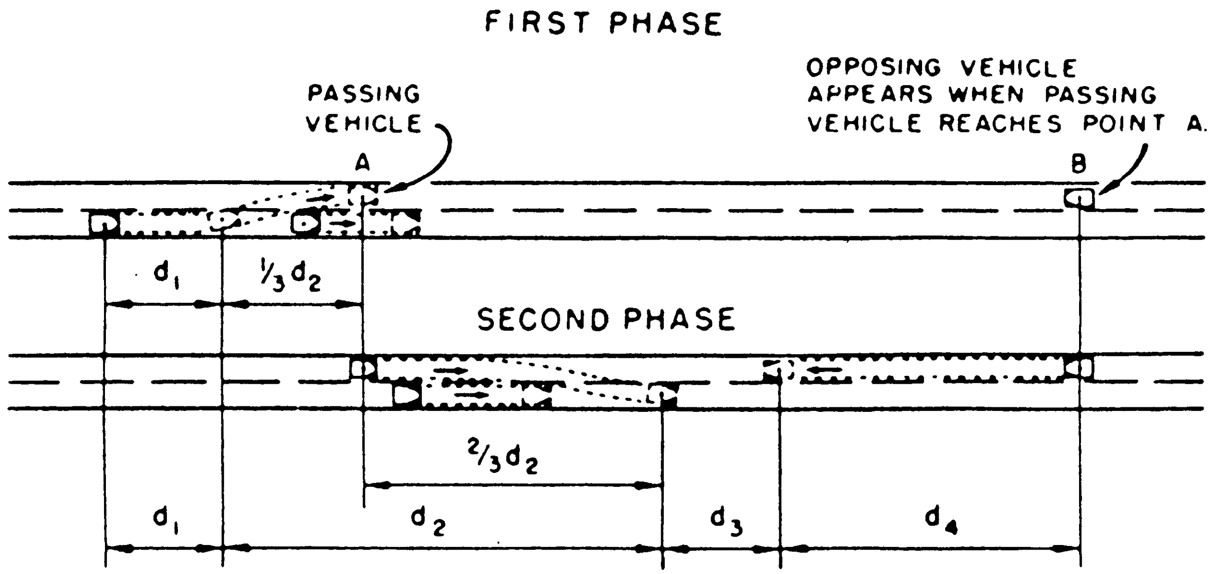


Figure 5. Passing Sight Distance for Two-Lane Two-Way Roads (AASHTO)

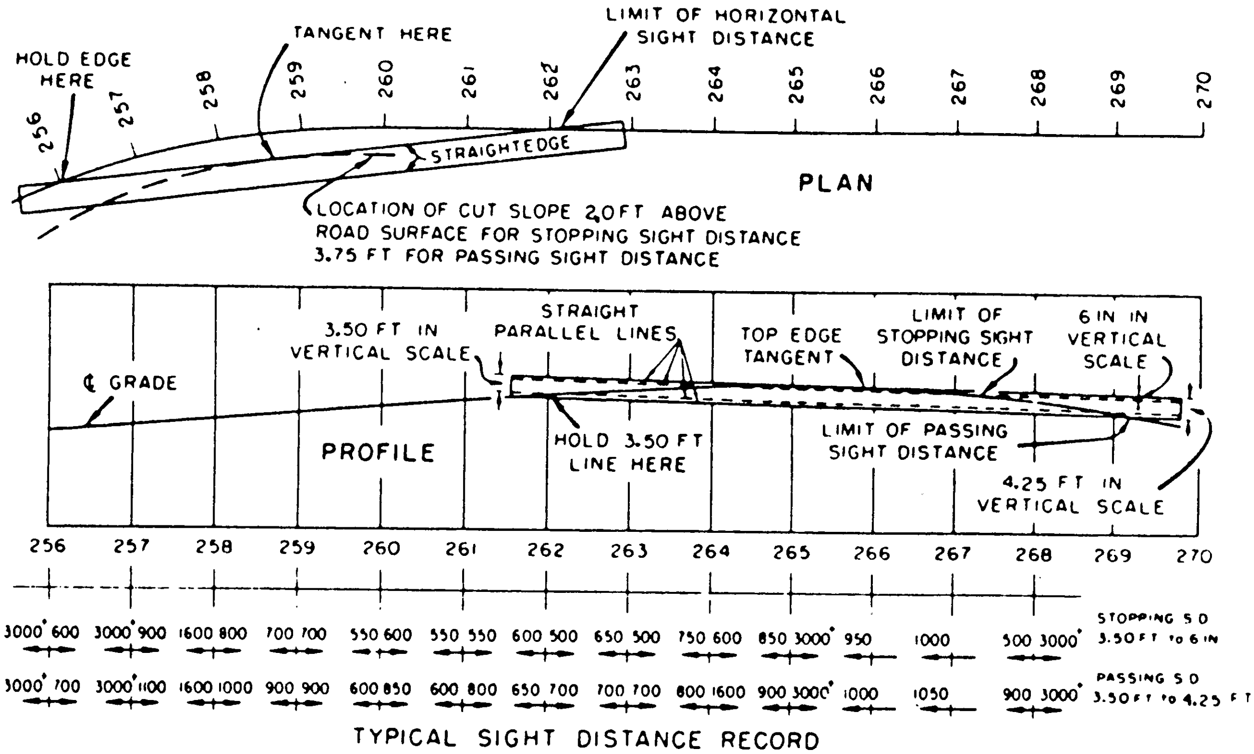


Figure 6. Method of Locating Passing Sight Distance on Plans (AASHTO)

Table 2. Comparison of Passing Sight Disatnces for Design and Marking

85th Percentile Speed (mph)	Minimum Sight Distance (ft)		
	Design	Marking	
		Short Zone	Long Zone
40	1500	600	1050
50	1800	800	1300
60	2100	1000	1600
70	2500	1200	1900

- Almost all states employ the short zone concept of no-passing zone delineation. Illinois, Louisiana, Maine, Missouri, Pennsylvania, and Vermont however, enforce passing operation on the long zone philosophy.
- Wisconsin and California states permit minimum passing zones less than 400 feet in mountaineous areas.
- Idaho, Illinois, Indiana, Kansas, Kentucky and Wisconsin use the regulatory DO NOT PASS sign as a general statewide practice. Idaho uses it because pavement marking is not a regulatory device. Seven other states use it selectively for unique geometry and visibility during snow.
- Vermont uses a PASS WITH CAUTION sign and pavement markings in mountaineous areas.
- At least thirty-four states use the NO PASSING ZONE sign, sixteen of which use it statewide while eighteen use it selectively.

Tables 3 and 4 give details of all state practices.

2.2.3 Problems Associated with the Passing Maneuver

The issue of overtaking on two-lane roads is multi-faceted. It requires good judgement of time gaps, distances and speeds. One of the problems associated with overtaking on two-lane roads is that of accidents. A contributing factor to such accidents is limited sight distance. Consequently, one can infer that poor horizontal and vertical alignment that exist on roads create hazards that frequently are the indirect causes of accidents. Sight distance is especially important because the passing vehicle during the passing maneuver occupies the lane used by the oncoming vehicle. Obviously, warnings of inadequate sight distances for passing should be clear and motorists should always be certain about the meaning of such warnings. Some states emphasize the dangers in overtaking by adding regulatory signs in addition to pavement marking.

Table 3. State Practices for Delineating No-Passing Zones

State	FHWA Region	No-Passing Zone Marking Concept	Minimum Length Between No-Passing Zones (ft)	Uses Regulatory Signs At Beginning of No-Passing Zones		Uses Regulatory Signs At End of No-Passing Zones		Uses No-Passing Zone Pennant (W14-3)	
				Statewide	Selectively	Statewide	Selectively	Statewide	Selectively
Alabama	4	Short	400		R4-1		R4-2	X	
Alaska	10	Short	400		R4-1		R4-2	N.S.	N.S.
Arizona	9	Short	400	N.S.	N.S.	N.S.	N.S.	X	
Arkansas	6	Short	400	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
California	9	Short		None	None	None	None		X
Colorado	8	Short	400	None	None	None	None	None	
Connecticut	1	N.S.	400		R4-1	N.S.	N.S.	N.S.	N.S.
Delaware	3	N.S.	400	None	None	None	None	N.S.	N.S.
Florida	4	Short	400	N.S.	N.S.	N.S.	N.S.		N.S.
Georgia	4	Short	400		N.S.	N.S.	N.S.		X
Hawaii	9	Short	400	None	None	None	None	None	None
Idaho	10	Short	400	R4-1		R4-2			X
Illinois	5	Short (1)	400	R4-1		R4-2		X	
Indiana	5	Short	400	R4-1		R4-2		X	
Iowa	7	Short	400	None	None	None	None	X	
Kansas	7	Short	400	R4-1		R4-2			X
Kentucky	4	Short	400	R4-1		R4-2		X	
Louisiana	6	Short (1)	400		R4-1		R4-2		X
Maine	1	Short (1)	400	N.S.	N.S.	N.S.	N.S.	None	None
Maryland	3	Short	400	N.S.	N.S.	N.S.	N.S.		X
Massachusetts	1	N.S.	400		R4-1		R4-2		X
Michigan	5	Short	400		R4-1		R4-2	X	
Minnesota	5	Short	400		R4-1		R4-2	X	
Mississippi	4	Short	400				N.S.		X
Missouri	7	Short (1)	400	None	None	None	None	None	None
Montana	8	Short	600					X	
Nebraska	7	Short	750		R4-1		R4-2	X	
Nevada	9	Short	400	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
New Hampshire	1	Short	400		R4-1	N.S.	N.S.	X	
New Jersey	1	Short	400	N.S.	N.S.	N.S.	N.S.		X
New Mexico	6	Short	400		R4-1		R4-2	X	
New York	1	Short	400		R4-1		R4-2		X
North Carolina	5	Short	400	N.S.	N.S.	N.S.	N.S.		
North Dakota	8	Short	400			N.S.	N.S.	N.S.	N.S.
Ohio	5	Short	400		R4-1		R4-2		X
Oklahoma	6	Short	400		R4-1		R4-2	None	None
Oregon	10	Short	400		R4-1		R4-2	N.S.	N.S.
Pennsylvania	3	Short (1)	400					X	
Rhode Island	1	Short	400	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
South Carolina	4	Short	400	None	None	None	None		
South Dakota	8	Short	400	N.S.	N.S.	N.S.	N.S.	X	
Tennessee	4	Short	400	N.S.	N.S.	N.S.	N.S.	X	
Texas	6	Short	400		R4-1		R4-2		X
Utah	8	Short	400		R4-1		R4-2		X
Vermont	1	Short (1)	600	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Virginia	3	Short	400						X
Washington	10	Short	400		R4-1		R4-2		X
West Virginia	3	Short	400	N.S.	N.S.	N.S.	N.S.		X
Wisconsin	5	Short		R4-1		R4-2		X	N.S.
Wyoming	8	Short	400	None	None		R4-2	N.S.	N.S.

Note: N.S.—"Not Stated"

Table 4. State Practices for Delineating No-Passing Zones (continuation)

State	FHWA Region	Design Criteria	Demarcation Criteria	Special Practice or Criteria	Pavement Marking System	Pavement Marking Line Width (in)	Marking Maintenance	Sign Maintenance
Alabama	4	AASHTO	MUTCD	-	2-line	4	Annually	As Needed
Alaska	10	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Arizona	9	AASHTO	MUTCD	-	2-line	4	N.S.	N.S.
Arkansas	6	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
California	9	N.S.	MUTCD		1 & 2-line	4	N.S.	N.S.
Colorado	8	N.S.	MUTCD	-	2-line	5	N.S.	N.S.
Connecticut	1	N.S.	(1)	(2)	2-line	4		
Delaware	3	AASHTO	MUTCD	-	2-line	4	N.S.	N.S.
Florida	4	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Georgia	4	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Hawaii	9	(2)	MUTCD	-	2-line	4	N.S.	N.S.
Idaho	10	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Illinois	5	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Indiana	5	N.S.	MUTCD	-	2 & 3-line	4 & 6	N.S.	N.S.
Iowa	7	N.S.	MUTCD	-	2-line	4 & 4.5	N.S.	N.S.
Kansas	7	N.S.	MUTCD	-	2-line	5	As Needed	As Needed
Kentucky	4	N.S.	MUTCD	(2)	2-line	4	Annually	As Needed
Louisiana	6	N.S.	MUTCD	-	2-line	4	Annually	As Needed
Maine	1	AASHTO	MUTCD	-	2-line	4 & 6	Annually	As Needed
Maryland	3	N.S.	MUTCD	-	2-line	4 & 5	Annually	As Needed
Massachusetts	1	N.S.	MUTCD	-	2-line	4 & 6	N.S.	N.S.
Michigan	5	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Minnesota	5	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Mississippi	4	N.S.	MUTCD	(2)	2-line	4	Annually	As Needed
Missouri	7	N.S.	MUTCD	(2)	2-line	4	6-month	N.S.
Montana	8	N.S.	MUTCD (1)	-	2-line	4	N.S.	N.S.
Nebraska	6	N.S.	MUTCD		2-line	4	N.S.	N.S.
Nevada	9	AASHTO	MUTCD	-	2-line	4	N.S.	N.S.
New Hampshire	1	N.S.	MUTCD	-	2-line	4	Annually	As Needed
New Jersey	1	(1)	MUTCD		2-line	4	Annually	As Needed
New Mexico	6	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
New York	1	N.S.	MUTCD	(1)	2-line	4 & 6	N.S.	N.S.
North Carolina	5	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
North Dakota	8	AASHTO	MUTCD	-	2-line	4	Annually	N.S.
Ohio	5	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Oklahoma	6	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Oregon	10	N.S.	MUTCD (2)	-	2-line	4	N.S.	N.S.
Pennsylvania	3	AASHTO	MUTCD	-	2-line	4	6-month	N.S.
Rhode Island	1	N.S.	MUTCD	-	N.S.	N.S.	N.S.	N.S.
South Carolina	4	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
South Dakota	8	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Tennessee	4	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Texas	6	Texas	MUTCD		2-line	4		
Utah	8	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Vermont	1	N.S.	(1)	(2)	2-line	4	N.S.	N.S.
Virginia	3	N.S.	MUTCD	(1)	2-line	4	N.S.	N.S.
Washington	10	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
West Virginia	3	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Wisconsin	5	N.S	(1)		2-line	4	Annually	
Wyoming	8	N.S.	MUTCD (1)	(1)(2)	2-line	4	Annually	N.S.

Note: N.S.—"Not Stated"

More often, the criterion used for determining whether a problem exists is the occurrence of a statistically significant number of accidents. A study of the case of the accident will reveal where the problem actually lies. It is a common misconception that the occurrence of accidents constitutes the problem. Actually, it is rather the end result of a problem that exists. Information regarding the driver's decision-making process during an overtaking maneuver is rather minimal. Observational and experimental research by Farber (Refs. 18 and 19) on the behavioral and judgemental aspects of the passing problem have found 5 percent of overtaking on two-lane, two-way rural roads to be hazardous.

Investiagtion of accident reports on two-lane roads in the United States (Refs. 23, 24 and 25), with particular reference to overtaking, showed that in 1970, 2.3 percent of the total number of fatal accidents and 3.4 percent of all accidents that occurred were related to improper overtaking. In 1974, improper overtaking accounted for 8 percent of all the fatal accidents, 9.6 percent for fatalities on rural roads and 1.4 percent for fatalities on urban roads. Also it accounted for 4.4 percent of all injury accidents, 1.4 percent for urban roads and 8.6 percent for rural roads. Of the accidents that occurred in that year, it accounted for 5.7 percent of the total number of accidents, 3.7 for urban roads and 9.9 for rural roads.

Similarly, in 1980, the statistics showed that 1.7 percent of all fatal accidents were due to improper overtaking, 1.4 percent of all fatal accidents on ruban roads and a corresponding figure of 1.9 percent for rural roads. Injury accidents on urban roads were 0.6 percent and 2.2 percent on rural roads. For total number of injury accidents in that year it accounted for 1.2 percent. It also accounted for 2.2 percent of all accidents, 1.6 percent of all urban road accidents and 3 percent of all rural road accidents. These are summarized in Table 5.

Thus, it can be concluded that on the average 3 to 4 percent of all fatal accidents and about 4-6 percent of all accidents on rural roads are due to improper overtaking. From a total number viewpoint, an average annual figure of 47,400 fatalities would put fatal accidents due to improper overtaken between 1,400 to 1,900. This figure though insignificant would cost approximately 350-500 million dollars annually (Refs. 9 and 30).

Table 5. Accident Rates Related to Improper Overtaking

	Fatal Accidents			Injury Accidents			All Accidents		
Year	Total	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural
1970	2.4	0.9	3.0	2.4	1.9	3.3	3.3	3.0	4.5
1971	2.2	0.6	2.5	2.1	1.3	2.9	3.1	2.8	3.5
1974	8.0	1.4	9.6	4.4	1.5	8.6	5.7	3.7	9.9
1980	1.7	1.0	1.9	1.2	0.6	2.2	2.2	1.6	3.0

Polus and Tomecki (Ref. 3), found that accidents involving overtaking on rural roads are much more severe than other types of rural road accidents. The reported accidents on two-lane, two-way roads account for 2.3 percent of all rural road accidents and 7 percent of the fatalities. The percentage of major injuries in the head-on collision category account for about 43 percent of all rural road accidents. Even though their figures seem higher than those reported in the United States, the importance of the problem created by overtaking accidents is self-evident.

Another problem associated with overtaking, which often times is neglected, is that of driver misapplication and misrepresentation of signs. It has been found that conventionally placed yellow no-passing strip used by most states, does not satisfy driver informational needs during the passing maneuver (Ref. 7). A critical review of the states' practices for delineating no-passing zones, indicate that drivers can be confused by the different signs and markings applied across the country.

2.3 Reasonableness of the MUTCD Passing Sight Distances

Sight distance is the distance along a roadway that an object of specified height is continuously visible to the driver. This distance is dependent on the height of the drivers eye above the road surface and the height of side obstructions within the line of sight.

The parameters to be discussed are object and driver eye heights, speeds of passing, opposing and impeding vehicles and relative speeds during the overtaking maneuver. An important component in the passing maneuver is the vehicle. Its performance characteristics dictates the minimum distances whereby one vehicle can overtake another. From an engineering standpoint it is the integral component which is used in establishing the minimum passing zone lengths. As such, vehicular characteristics and dimensions should be given due regard in developing a safe criteria for passing operations.

Vehicle physical dimensions, particularly object height and concommittant driver eye height are the major elements for perceiving an approaching vehicle. Therefore the criteria for delineating no-passing zones should logically consider the limitations imposed by these two variables. Donaldson (Ref. 8) points out that inadequate safety is particularly acute when vehicles with low power and low height of eye (such as many subcompact cars) attempt to pass large trucks at 85th percentile speeds in excess of 44 mph.

The current MUTCD uses 3.5 feet for both object and eye height for marking purposes. The old criteria used 3.75 feet. However review of both manuals indicate that the minimum sight distance requirements remains unchanged. The reduction in object and eye height would increase the number of no-passing zones.

Research by Khasnabis and Taddi (Ref. 13) show that for crest vertical curves, a 3-inch reduction in eye height causes a 5.3 percent change in length of curve. AASHTO confirms this and indicates that change in eye height from the 3.75 feet to 3.5 feet has the effect of lengthening minimum crest vertical curves by approximately 5 percent, thereby providing 2.5 percent more sight distance. The impact of this is shown in Figure 7. Inspection of Figure 7 reveals that the crest vertical length changes from about 100 to 400 feet, by a reduction in eye height from 3.75 feet to 3.5 feet. This view is shared by Uzan and others (Ref. 24).

Another issue to be tackled is that of speed. It has been found by Weber (Ref. 10), Glennon and Weaver (Ref. 11) that the relative velocity between the passing vehicle and the impeding vehicle is different for the MUTCD and AASHTO. AASHTO uses a speed differential of 10 mph. However with the MUTCD the relative velocity ranges from 10 mph to 25 mph for passing speeds of 30 mph to 70 mph. The MUTCD also assumes that the speed of the oncoming vehicle and that of the passing vehicle are not identical. An inspection of Table 6 shows that the difference in speed between the oncoming and passing vehicle increases from 5 mph to 25 mph for passing speeds of 30 mph to 70 mph.

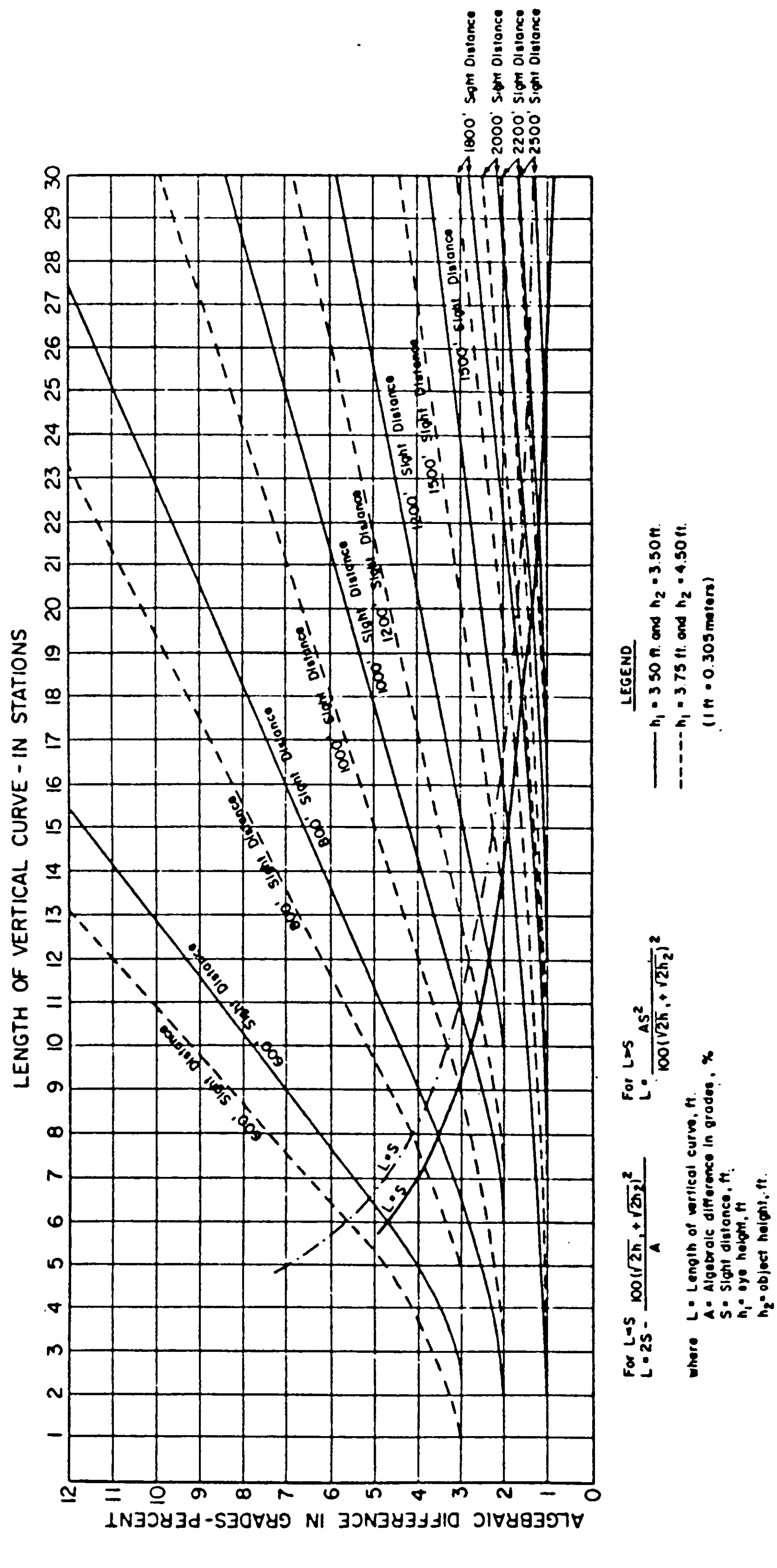


Figure 7. Length of Crest Vertical Curve to Provide for Total Passing Sight Distance

Table 6. Assumed Speeds of Passed, Passing and Oncoming Vehicles For Given Design Speeds

Design Speed (mph)	Design			Marking		
	Passed (mph)	Passing (mph)	Opposing (mph)	Passed (mph)	Passing (mph)	Opposing (mph)
30	26	36	36	20	30	25
40	34	44	44	27.5	40	32.5
50	41	51	51	35	50	40
60	47	57	57	40	60	47.5
70	54	64	64	45	70	55

Findings of research by Polus and Tomecki (Ref. 3) indicate a maximum average relative velocity of 19 mph for the 320 vehicles studied. Their results also showed the speed differential to be 18.7 mph at a passing speed of 57.8 mph and 16 mph for passing speed of 61.2 mph. A similar situation is reported by Troutbeck in an Australian study of 680 passing maneuvers (Ref. 4). It is reported that the mean relative velocity was 26.5 km/hr (16.4 mph) for accelerative overtaking by cars and 17.8 km/hr (11 mph) for accelerative overtakings by commercial vehicles when the overtaken vehicle was travelling at 70 km/hr (43.2 mph). The study also indicated that relative velocity decreases as the speed of the passing vehicle increases. This is confirmed by Polus and Tomecki and the research by Weaver and Glennon. Glennon and Weaver found that the speed differential between the passing and impeding vehicle decreases from 10.97 mph at a 50 mph passing speed to a relative velocity of 6.8 mph for a passing velocity of 65 mph.

Furthermore, considering the fact that the critical case in the passing maneuver would be a situation where the oncoming vehicle and passing vehicle travel at about the same speed, the MUTCD's assumptions seem rather liberal.

From the review so far, it is well established that sight distances during an overtaking are very crucial. However, it is realized most of the studies have been limited to completing the passing maneuver only and not tackling the issue of either completing or aborting together. Thus, there is the need for further investigation to explore the extent of the inadequacy of the MUTCD passing sight distance.

3.0 THEORY

3.1 What Is Passing Dilemma?

Before the model describing the kinematics of the passing maneuver can be properly understood, it is prudent to give an insight into how it is physically performed. A schematic diagram (Figure 8) showing the distance elements in the process of overtaking is used. The positions shown are relative to a moving coordinate system with respect to an impeding vehicle, I. The origin of this system is at the front of the passing vehicle at position, A.

A vehicle P, the passing vehicle, which has attained its maximum relative velocity V_0, catches up with a second vehicle, which is the slow moving or impeding vehicle. A distance d_1 is travelled in which time the driver assesses the situation whether to pass or not. This time period is referred to as the pre-maneuver time. It depends on the driver's judgment of the speed of his vehicle, that of the opposing vehicle O, reaction time and acceleration.

Once the decision to pass is made, he moves to the left lane and travels for a distance d_2. It will also be noticed that during the left lane occupancy time by the passing vehicle, the opposing vehicle moves a certain distance, d_4 from the position B. If the maneuver is to be executed successfully, then after completion there should be a clearance distance d_3 between vehicles P and O.

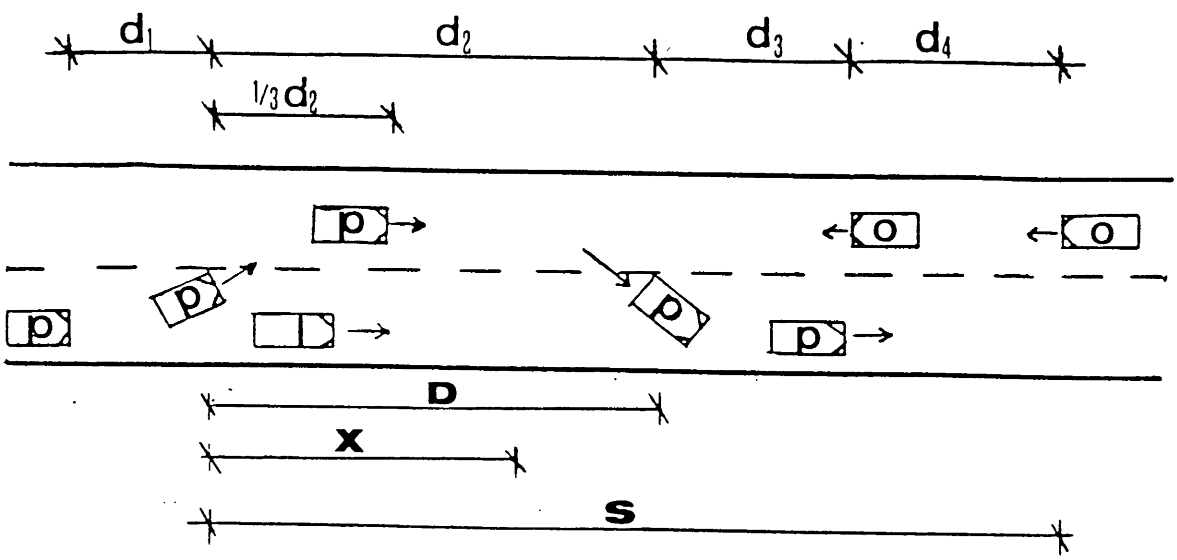


Figure 8. Distance Elements of the Passing Maneuver

If a decision to abort is however made, then this should be done before a certain critical position. Between the critical positions for either aborting or completing the passing maneuver, there is a zone where it is neither safe to complete or abort. This zone is referred to as the passing dilemma zone.

Based on this rationale, it is evident that the passing vehicle should have sufficient sight distance to be able to either complete or abort the maneuver. This can be done by making the dilemma zone zero. Under such situation the passing vehicle always has at least one safe option. The following section deals with derivation of the passing dilemma model.

3.2 List of Variables Used

d_1 = *Distance traveled during the perception and reaction time*

d_2 = *The left lane occupancy distance travelled by the passing vehicle*

d_3 = *Clearance between the passing and the opposing vehicle*

d_4 = *Distance travelled by the opposing vehicle while the passing vehicle occupies the left lane*

a_1 = *Acceleration*

a_2 = *Deceleration*

D_1 = *Perception reaction time to complete the passing maneuver*

D_2 = *Perception reaction time to abort the passing maneuver*

D = *Additional separation to oncoming vehicle that is gained by the dropping back of the passing vehicle*

V_o = *Relative velocity between the passing and impeding vehicle*

V_I = *Velocity of the impeding vehicle*

V_p = *Velocity of the passing vehicle*

V_c = *Velocity of the opposing vehicle*

V = *Closing rate between the passing and opposing vehicle*

X = *Relative position of the passing vehicle*

X_c = *Critical distance for completing the passing maneuver*

X_a = *Critical distance for aborting the passing maneuver*

3.3 *Derivation of the Passing-Dilemma Model*

The passing-dilemma model which will be used for the analysis in this report is based on a similar one developed by Herman (Ref. 6). In deriving the model, it is assumed that there is a constant acceleration a_1 , for completing the maneuver and a constant deceleration a_2 , for aborting. To take into account the effect of decision-reaction time lags, it is assumed that acceleration and deceleration begin after time D_1 and D_2, respectively.

The maximum relative velocity, V_o, of the passing vehicle with respect to the impeding vehicle is:

$$V_o = V_p - V_I \text{..............(1)}$$

As explained earlier, during the left lane occupancy time, the opposing vehicle O, traveling at a velocity V_c, moves a certain distance. Since we are dealing with a moving coordinate system, there is a closing rate, which is expressed as:

$$V = V_c + V_I \text{....................(2)}$$

The time for the oncoming car to reach the return position C, that is, the maximum time for completion of the pass is:

$$T_1 = (S - D)/V \text{............(3)}$$

The distance D, is the additional separation to the opposing vehicle by the dropping back of vehicle P. The time taken for the opposing vehicle to reach the position A, which is the maximum time for aborting the pass is:

$$T_2 = S/V \text{.........................(4)}$$

From equations 3 and 4, it can be seen that the time taken for completion T_1, is less than the time for aborting the pass T_2 , by an amount of D/V.

In order to complete the maneuver and avoid collision, then the relative distance R_D, which the passing driver must travel should be less than or equal to the relative distance R_D^1, he is able to travel. The distance R_D, is expressed as:

$$R_D = (D - X) - V_o D_1 \text{.............}(5)$$

Using Newton's equation of motion, the relative distance that he is able to travel in the time interval $(T_1 - D_1)$, is of the form:

$$R_D^1 = V_o(T_1 - D_1) + \frac{1}{2} a_1(T_1 - D_1)^2 \text{...................}(6)$$

Thus for safe completion $R_D \leq R_D^1$. If $R_D = R_D^1$, then there was nearly a collision. Thus, this is the minimum margin of safety to avoid collision. Therefore from equations 5 and 6,

$$(D - X) - V_o D_1 \leq V_o(T_1 - D_1) + \frac{1}{2} a_1(T_1 - D_1)^2 \text{........}(7)$$

Substituting the value of T_1 from equation 3, equation 7 becomes:

$$(D - X) \leq V_o D_1 + V_o[(S - D)/V - D_1] + \frac{1}{2} a_1[(S - D)/V - D_1]^2 \text{....}(8)$$

From the above equation, the critical position X_c, for completion of the maneuver at a maximum acceleration a_2, that is, the minimum relative distance at which the passing vehicle P, can be and still complete passing safely, is given by:

$$X_c \leq D - V_o(S - D)/V - \frac{1}{2} a_1[(S - D)/V - D_1]^2 \text{....}(9)$$

However if the driver should decide to abort, then the relative distance of the passing vehicle P, with respect to the safe return position A, behind the impeding vehicle, should be less than the distance Y, the vehicle is able to drop back at a deceleration rate a_2, in a time interval T_2. An inequality which describes this is of the form:

$$X \leq Y$$

That is

$$X \leq -V_o D_2 - L - \frac{1}{2} a_2 (t_2 - D_2 - t^1)^2 \text{............}(10)$$

where t^1 and L are the time and distance required to nullify the relative speed. The passing vehicle would only begin to drop back when the relative velocity becomes negative. The quantities t^1 and L are expressed as

$$t^1 = V_o / a_2 \text{............}(11)$$

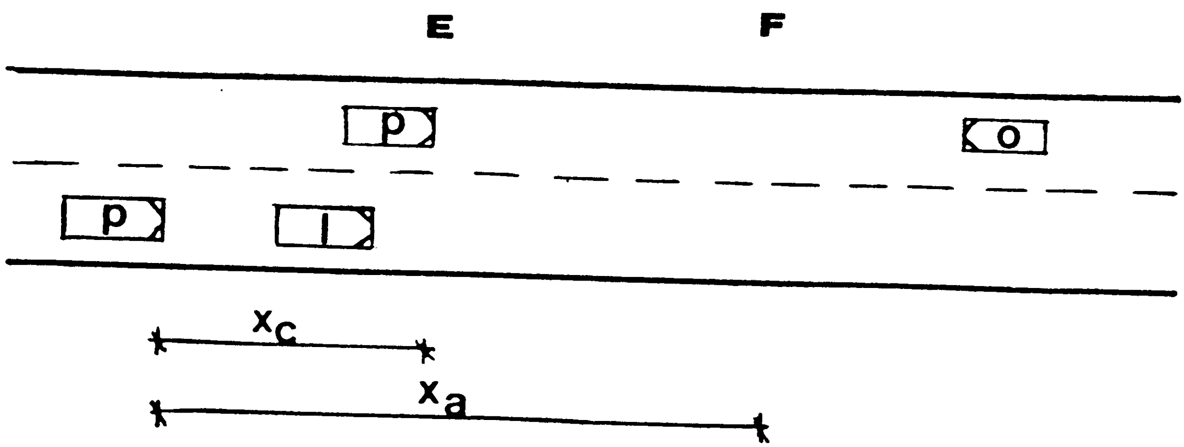
$$L = V_o^2 / 2a_2 \text{.............}(12)$$

The maximum relative distance X_a, which the passing vehicle can advance, at a maximum deceleration rate a_2, is obtained by substituting equations 4, 11 and 12 into 10 and solving for X. This is given by:

$$X_a \leq \frac{1}{2} a_2 [S/V - D_2 - V_o / a_2]^2 - V_o D_2 - V_o^2 / 2a_2 \text{...}(13)$$

From equations 9 and 13, it is seen that there is always one alternative when X_c less than $X_a (X_c \leq X_a)$. This situation is shown in Figure 7. Inspection of Figure 7 shows that when X is greater than X_c the passing vehicle can complete the maneuver. If X is less than X_c, then completion is not possible. Similarly if X is greater than X_a, then the passing vehicle cannot abort, but rather has a greater margin of safety for completion. Thus when X is between $X_a and X_c$ as in Figure 9, then he can either complete or abort.

However, this is always not the case. When X_c is greater than $X_a (X_c > X_a)$, as shown in Figure 10, the passing vehicle cannot complete when X is less than X_c. Also when X is greater than



Notes:

(i) Cannot complete before E
(ii) Cannot abort after F
(iii) Can either abort or complete between E and F

Figure 9. Relative Positions of Vehicle to Complete or Abort the Passing Maneuver

X_a, aborting is also not possible. In this case when X is between $X_c and X_a$, that is between position G and H, the passing driver is in a dilemma. Under this situation it is neither safe to complete or abort. This is passing dilemma zone described earlier on. The only choice left for the passing vehicle will be to evade. Therefore it is realized that during the passing maneuver, drivers are faced with the following options:

i) Safe to complete
   Safe to abort
ii) Safe to complete
   Unsafe to abort
iii) Unsafe to complete
   Safe to abort
iv) Unsafe to do either (there is a passing dilemma).

To eliminate the problem of the dilemma zone, the following condition should be met for at least one safe option always. The condition is

$$X_c \leq X_a$$

This inequality can be solved for the minimum sight distance by equations 8 and 13 and solving for S. This is expressed as

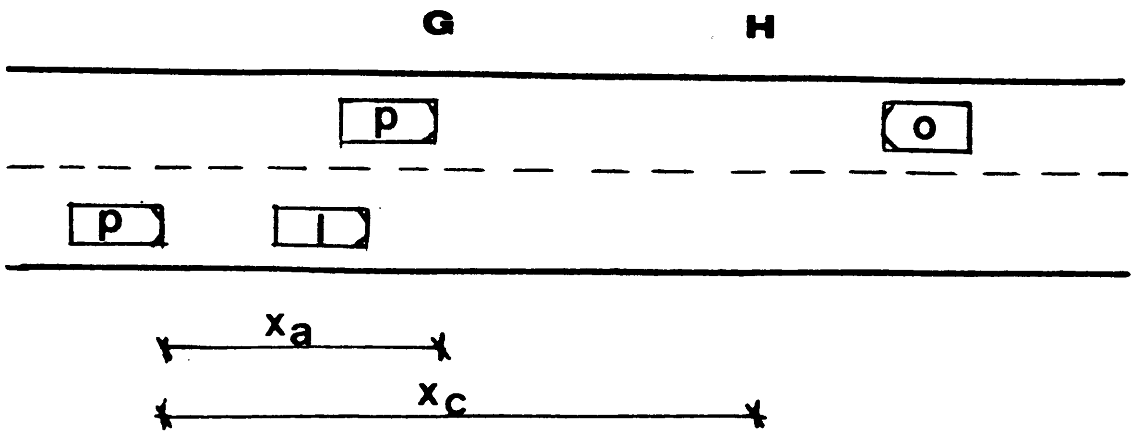
$$\frac{1}{2} a_2[S/V - D_2 - V_o/a_2]^2 - V_o D_2 - V_o^2/2a_2 = D - V_o(S - D)/V - \frac{1}{2}[(S - D)/V - D_1]^2$$

Expanding and simplifying the left-hand side (LHS) yields

$LHS =$

$$\frac{1}{2} a_2^2 V^2[S^2/V^2 - 2S/V(D_2 a_2 + V_o)/a_2^2 + (D_2^2 + 2D_2 a_2 V_o + V_o^2)/a_2^2] .....(15)$$

Similarly the right-hand side (RHS) yields



Notes:
(i) Cannot abort after G
(ii) Cannot complete before H
(iii) Can neither complete nor abort between G and H

Figure 10. Relative Position of Vehicles Showing Delima Zone

$RIIS =$

$$- V_o(S - D)/V - \frac{1}{2} a_1[(S^2 - 2SD + D^2)/V^2 - 2D_1(S - D)/V + D_1^2] \ldots (16)$$

Combining equations 15 and 16 and factorizing yields a quadratic given by:

$$a_2(a_1 + a_2)S^2 + 2Va_2[- a_1 D_1 - a_2 D_2 - a_1 D/V]S + 2Va_2[\frac{1}{2} a_1 D_1^2 + \frac{1}{2} a_2 D_2^2$$
$$- D - (V_o - a_1 D_1)/V + \frac{1}{2} a_1 (D/V)^2] = 0 \ldots\ldots\ldots (17)$$

Dividing through by $2a_2$, yields an equation of the form

$$\alpha S^2 + \beta VS + \gamma V^2 = 0 \ldots\ldots\ldots (18)$$

where

$$\alpha = (a_1 + a_2)/2 \ldots\ldots\ldots (19)$$

$$\beta = - a_1 D_1 - a_2 D_2 - a_1 D/V \ldots\ldots (20)$$

$$\gamma = \frac{1}{2} a_1 D_1^2 + \frac{1}{2} a_2 D^2 - D - (V_o - a_1 D_1)D/V + \frac{1}{2} a_1 (D/V)^2 \ldots (21)$$

Solving 18 for the minimum sight distance yields

$$S_m = V[- B + \sqrt{(B^2 - 4\alpha\gamma)}]/2\alpha \ldots\ldots\ldots\ldots (22)$$

This minimum sight distance refers to the distance between A and B. However, for the purpose of marking, the minimum sight distane required would be from the point where $X_c = X_a$ (that is at E or G). Thus the minimum sight distance for marking is of the form

$$S_{\min} = S_m - D \ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

AASHTO'S values of d_2 are used as safety control variables. Equation 23 is the zero-passing dilemma zone model. This will be used for the analysis of the MUTCD passing sight distances.

4.0 ANALYSIS AND RESULTS

4.1 Analysis

From the passing dilemma model it is seen that the minimum sight distance is based on several variables. It is therefore important to explain the assumptions relating to these variables that have been used in this report.

It is assumed that the velocity of the oncoming vehicle and that of the passing vehicle are the same. This is the most critical situation. This is the assumption used by AASHTO. A review of studies by Prisk (Ref. 17), Polus (Ref. 3), Troutbeck (Ref. 4) and Weaver and Woods (Ref. 9) show that the same assumption has been made.

A relative velocity V_o, of 10 mph is that which is used as a safety control variable to attest the adequacy of the MUTCD passing sight distance. However, relative velocities ranging from 5 mph to 25 mph were also considered. The idea is to cover the entire range of relative velocities that the MUTCD assumes. The value of 10 mph is based on findings by Glennon (Ref. 11), Prisk (Ref. 17) and Weaver and Woods (Ref. 9). A decision reaction time of 1 second has been assumed. The reason being that, in an overtaking situation, drivers are usually alert. Herman (Ref. 6) assumes this in his analysis. Olson and Cleveland (Ref. 20) report values between 0.7 seconds and 1.3 secs.

They given an 85 percent value of 0.95. This is consistent with what is reported with Troutbeck (Ref. 4). He reports a figure of 0.9 sec. to be the 90th percentile value.

With regard to acceleration characteristics, values in the range of zero to 6 ft/sec^2 (0 - 4 mph/sec) have been used. A review of 1976 t0 1980 vehicle acceleration capabilities (see Tables 7 and 8 and Fig. 11) indicate that the 95th percentile acceleration rate is 0.85 mph/sec (1.25 ft/sec^2) This is the value adopted in determining the minimum sight distance for marking.

Deceleration characteristics used ranged from zero to 14 ft/sec^2. Lieberman (Ref. 15) indicates that a deceleration rate of 0.37 g, where g is the acceleration due to gravity, is the maximum value to abort a passing maneuver. Olson and Rothenberg (Ref. 29) confirm this and specify a value of 8 ft/sec^2 as a desirable deceleration rate, and a limit of 12 ft/sec^2. Saito in another study (Ref. 5) reports that value of reasonably comfortable deceleration is in the proximity of 0.3 g, approximately 9.7 ft/sec^2. He also reports that deceleration becomes severe and uncomfortable above 13.9 ft/sec^2. Deceleration rates between 11 ft/sec^2 and 13.97 is referred to as undesirable deceleration, while rates between zero and 9.7 ft/sec^2 are classified as comfortable deceleration. These figures have been summarized in Table 10. The maximum comfortable deceleration rate is that which is as a safety control variable.

Using the parameters just discussed as safety control variables, a computer program in basic was written to solve for the minimum passing sight distance, based on the zero-passing dilemma zone model. A SAS graph program on the mainframe was used to generate the graph for the investigation. These programs are in Appendix B of this report.

Table 7. Summary of Vehicle Acceleration Characteristics

Model	Bodystyle	Acc. Time 45-65 mph (72.4-104.6 km/h) (sec)	Acc. Time 0-60 mph (0-96.5 km/h) (sec)	Acc. Time 0-30 mph (0-48.2 km/h) (sec)
Chevrolet Caprice Classic	Passenger Car	8.2	12.5	5.0
Oldsmobile Cutless Supreme	Passenger Car	13.0	19.0	6.2
Dodge Monaco	Passenger Car	8.8	13.7	5.1
Mercury Cougar	Passenger Car	9.5	14.9	5.6
Volvo 245	Passenger Car	9.7	15.7	-
Plymouth Volare Premier V-8	Passenger Car	8.6	13.2	-
Peugeot 504	Passenger Car	15.5	21.9	-
Toyota Mark II	Passenger Car	10.5	15.5	-
Volkswagen Rabbit	Compact Car	9.1	14.5	5.2
Pontiac Sunbird Coupe	Compact Car	12.0	16.0	5.4
Toyota Corolla	Compact Passenger Car	12.2	18.2	6.4
Ford Mustang II	Compact Passenger Car	10.0	15.8	5.9
AMC Pacer	Compact Passenger Car	9.4	15.6	5.6
Pontiac Catalina Safari	Compact Passenger Car	9.7	14.3	5.6
Plymouth Voyager Sport	Van	9.9	14.8	6.1
Chevorlet Beauville Sportvan	Van	9.3	14.2	5.3
Ford Chateau Club Wagon	Van	9.4	14.6	5.1

Table 8. Frequency Distribution of Passing Times of Vehicles During HighSpeed Passing

Passing Time Group (sec)	Average Acceleration (mph/sec)	Frequency	Cumulative Frequency	Cumulative Percentage (%)
8-9	4.96	0	0	
9-10	4.01	1	1	0.2
10-11	3.31	3	4	0.8
11-12	2.79	11	15	3.1
12-13	2.37	28	43	8.8
13-14	2.04	40	83	17.0
14-15	1.78	100	183	37.6
15-16	1.57	85	268	55.0
16-17	1.39	68	336	69.0
17-18	1.23	42	378	77.6
18-19	1.11	35	413	84.8
19-20	1.00	35	448	92.0
20-21	0.91	8	456	93.6
21-22	0.83	15	471	96.7
22-23	0.75	5	476	97.7
23-24	0.70	3	479	98.4
24-25	0.64	3	482	99.0
25-26	0.59	2	484	99.3
26-27	0.55	2	486	99.8
over 30		1	487	100.0

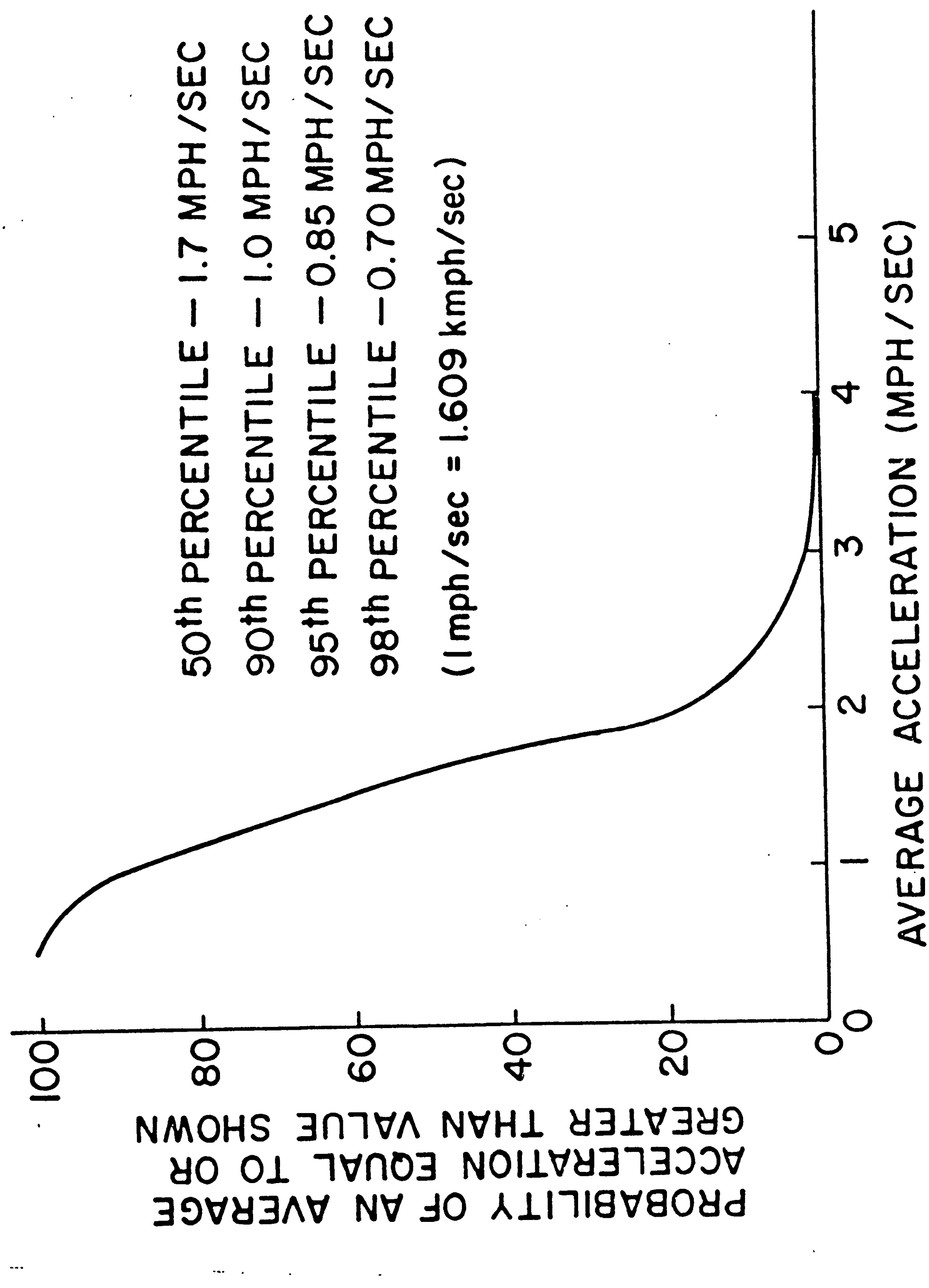


Figure 11. Acceleration Capability of Vehicles.

Table 9. Acceptable Deceleration Rates

Deceleration Rate ft/sec^2	Condition
0 - 9.7	Comfortable deceleration (preferred by driver)
9.7 - 11	Acceptable deceleration
11 - 13.9	Undesirable deceleration
13.9 - 20	Severe and uncomfortable deceleration

4.2 Results

Minimum passing sight distance was plotted against deceleration for different acceleration rates (1, 2, 4 and 6 ft/sec^2) and speed (40, 50 and 60 mph). For each graph a family of curves was plotted for relative velocities ranging from 5 mph to 25 mph.

Also, graphs of minimum passing sight distance versus 85th percentile passing speed for different combinations of acceleration (2-6 ft/sec^2) and deceleration rates (4-14 ft/sec^2) were plotted. Similarly, for each graph a family of curves was plotted for relative velocities ranging from 5 mph to 25 mph. The plot of MUTCD passing sight distances was superimposed on both types of graphs described. Only two graphs have been shown in this section. However, the entire range of acceleration and deceleration rates considered are shown in Appendix A of this report.

Analysis of the results indicate that the MUTCD passing sight distances are inadequate for both completing and aborting the passing maneuver. They are only acceptable at high acceleration and deceleration rates. Recommended passing sight distances based on the safety control variables discussed are summarized in Table 11. The control variables used are:

- Acceleration - 1.25 ft/sec^2
- Deceleration - 9.7 ft/sec^2
- Relative Velocity - 10 mph
- Alert perception - reaction time lags - 1 sec.

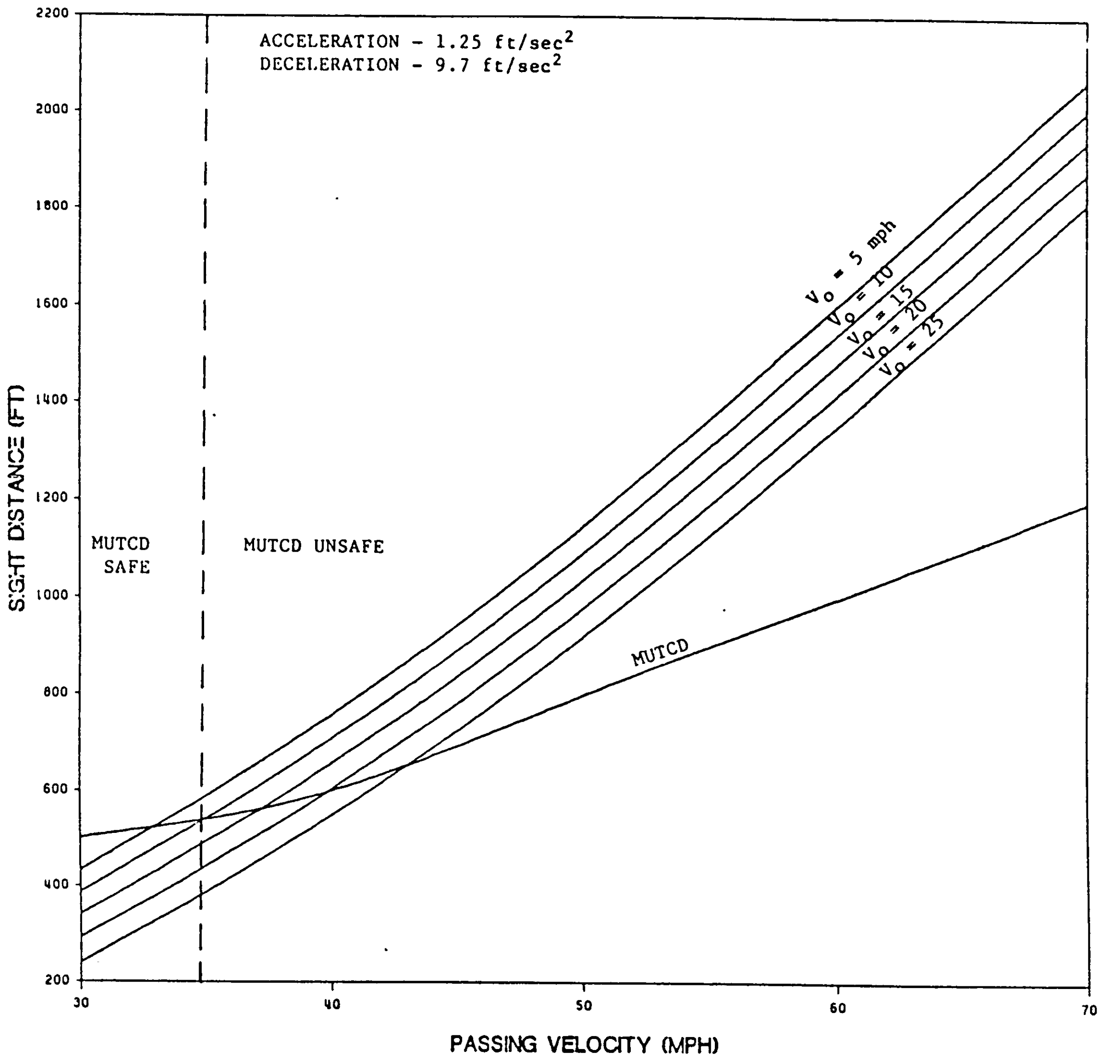


Figure 12. Family of Curves of Passing Sight Distance Versus Passing Speed

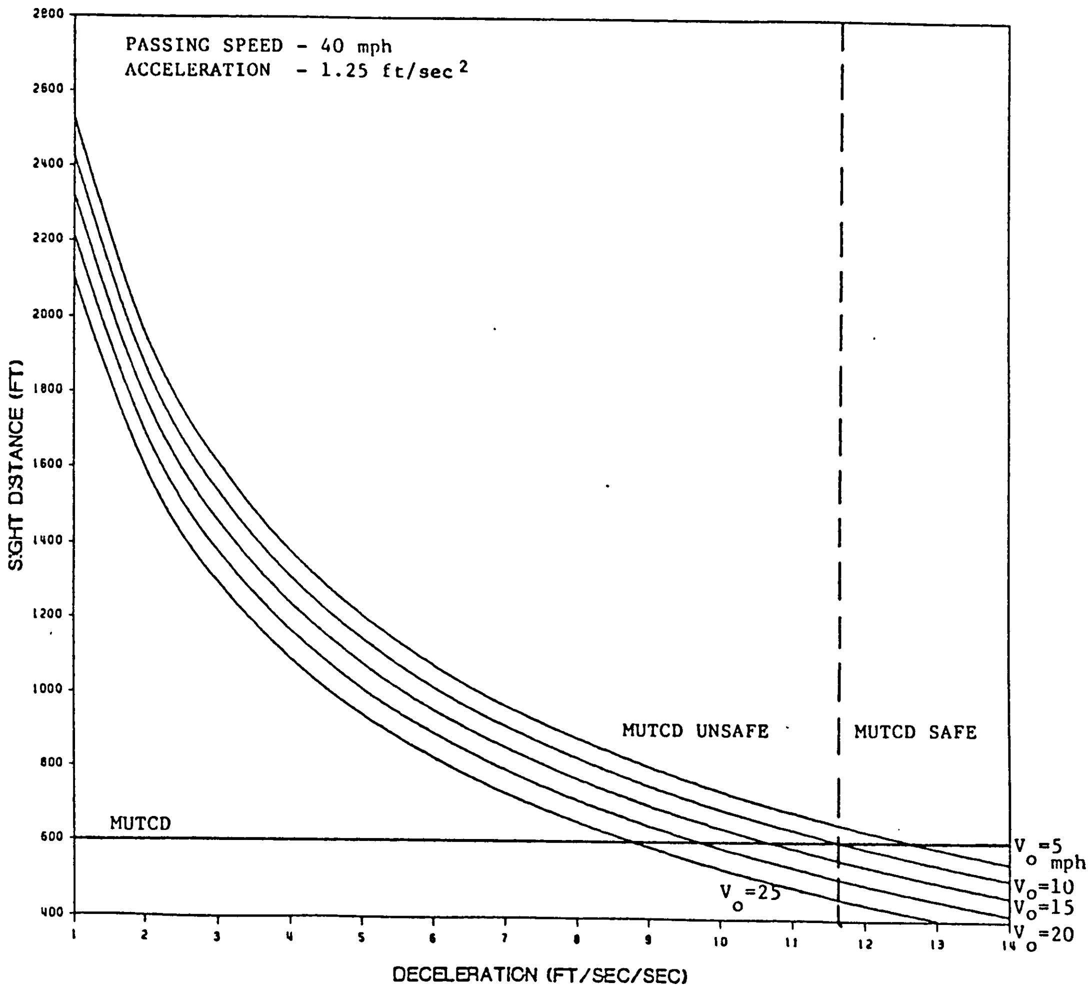


Figure 13. Family of Curves of Passing Sight Distance Versus Deceleration

Table 10. Recommended Minimum Passing Sight For Marking No-Passing Zones

Speed (mph)	Passing Sight Distance (ft) Recommended Values	MUTCD
30	400	500
40	710	600
50	1100	800
60	1550	1000
70	2000	1200

5.0 SUMMARY AND CONCLUSIONS

A kinematic model which incorporates both acceleration and deceleration during the passing maneuver on two-lane, two-way roads has been presented. This model is based on the fact that, during the passing maneuver, there exists a dilemma zone where it is neither safe to complete or abort the pass. The formulations of the model is based on making the dilemma zone zero, thus providing at least one safe option always. Sight distances are developed based on the zero-dilemma zone model.

A parameter study was done to investigate the sensitivity of passing sight distances with acceleration, deceleration, relative velocity and passing speed. The results were compared with the MUTCD minimum passing sight distances which is used for marking no-passing zones on two-lane highway roads. The results indicate that the MUTCD sight distances are inadequate for speeds greater than 38.5 mph. They become increasingly inadequate as speed increases. The MUTCD values are found to be only adequate at very high acceleration and deceleration rates. It is also noticed that sight distances decrease with increase in deceleration and acceleration, but increase with speed.

The report also shows that the MUTCD values are approximately the sum of AASHTO's clearance distances and distance travelled by the oncoming vehicle while the passing vehicle occupies the left lane.

Based on these results, it appears that the MUTCD minimum passing sight distances should be reviewed. This report recommends passing sight distances based on the 95th acceleration rate of 1.25 ft/sec^2 and deceleration rate of 9.7 ft/sec^2 This is the maximum deceleration in the comfortable deceleration zone. It is also based on a relative velocity of 10 mph and decision-reaction time lags of 1 sec. These sight distances would provide greater margin of safety than those currently used for marking.

It should be noted that, the recommended sight distances are based on 95th percentile acceleration capabilties of vehicles. However, it is possible to express acceleration as a function of speed. This will produce sight distances close to the MUTCD values at low passing speeds. Thus the recommended passing sight distances are a bit conservartive at low passing speeds. The issue of expressing acceleration as a function of speed is an area that can be researched further.

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Appendix A Supplementary Graphs

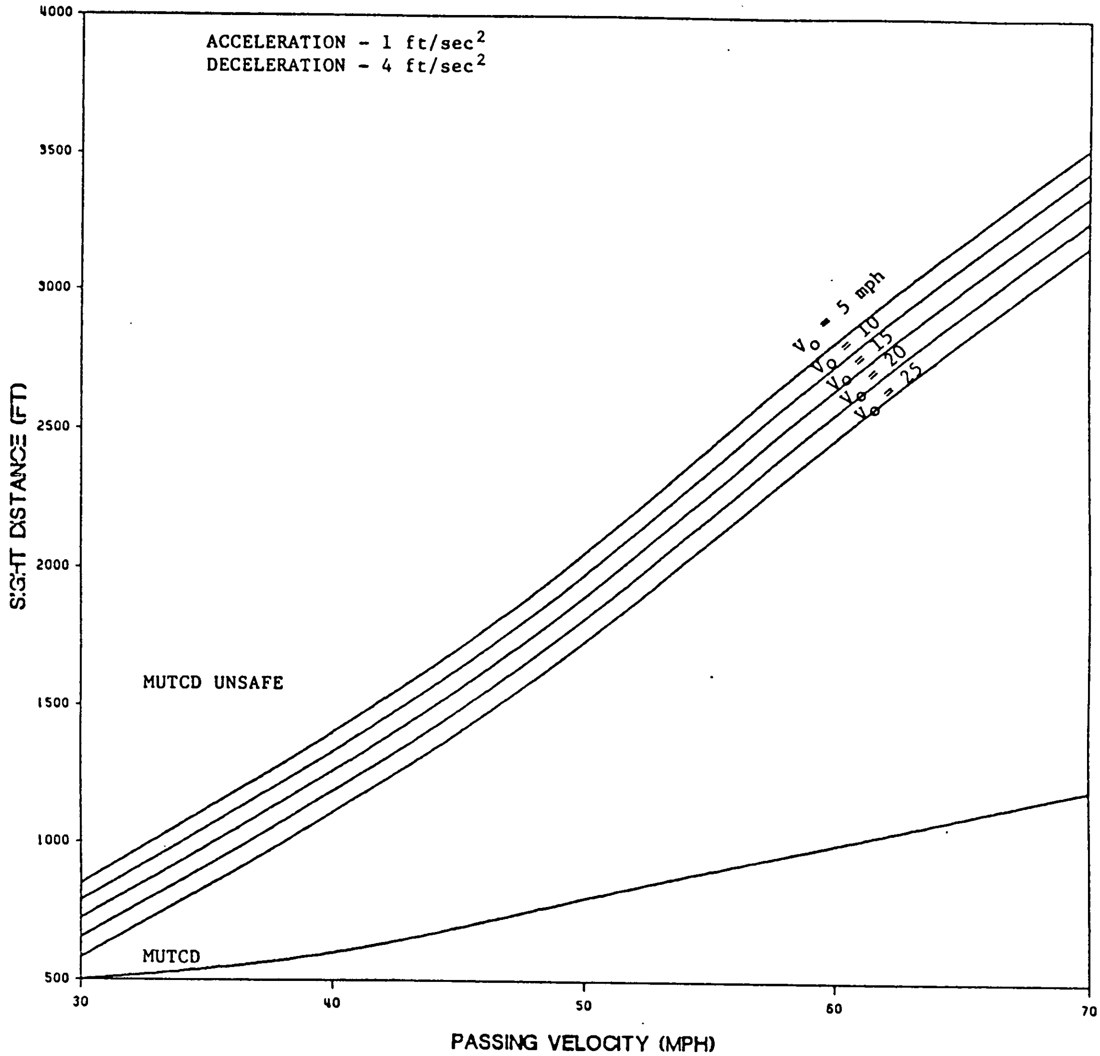


Figure A1. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

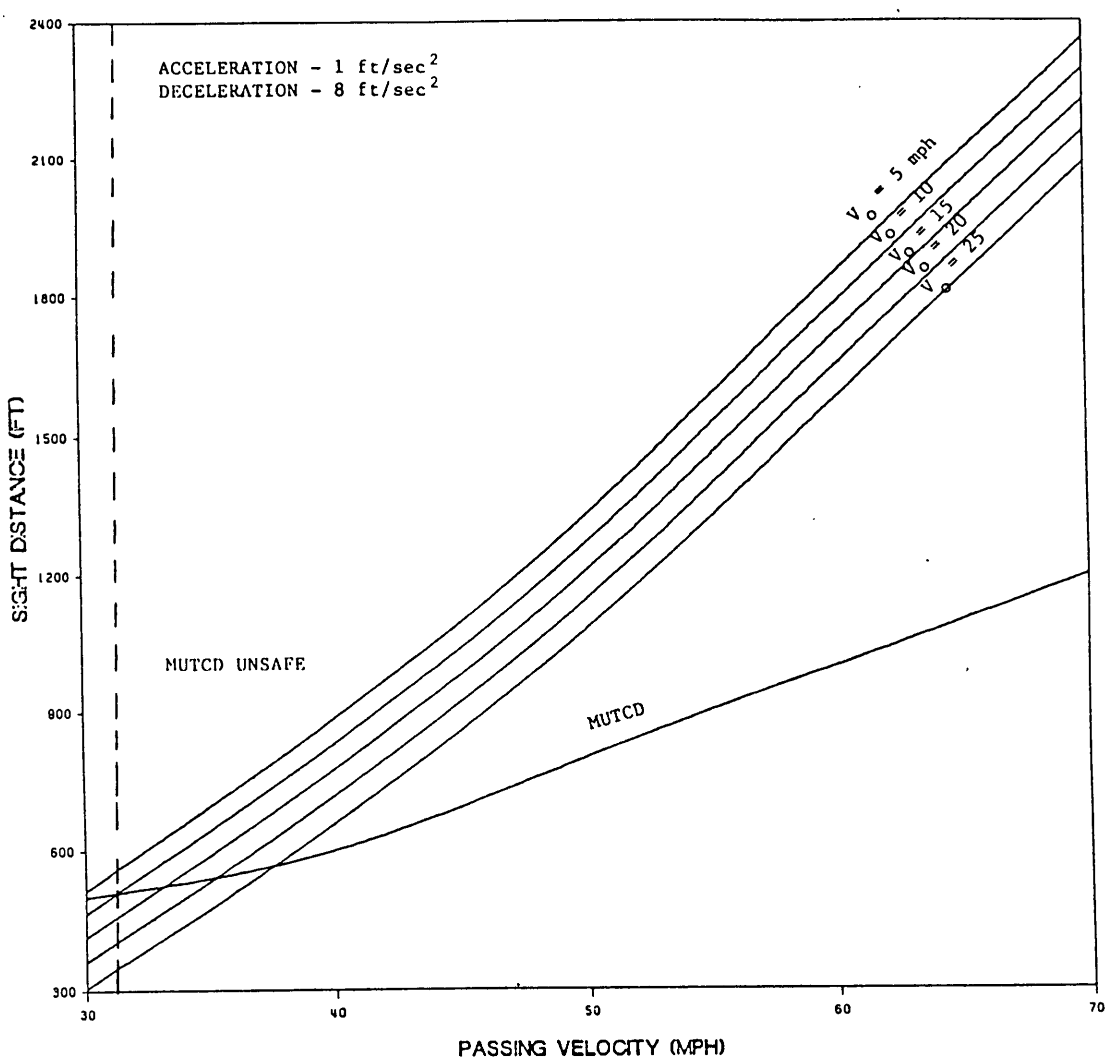


Figure A2. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

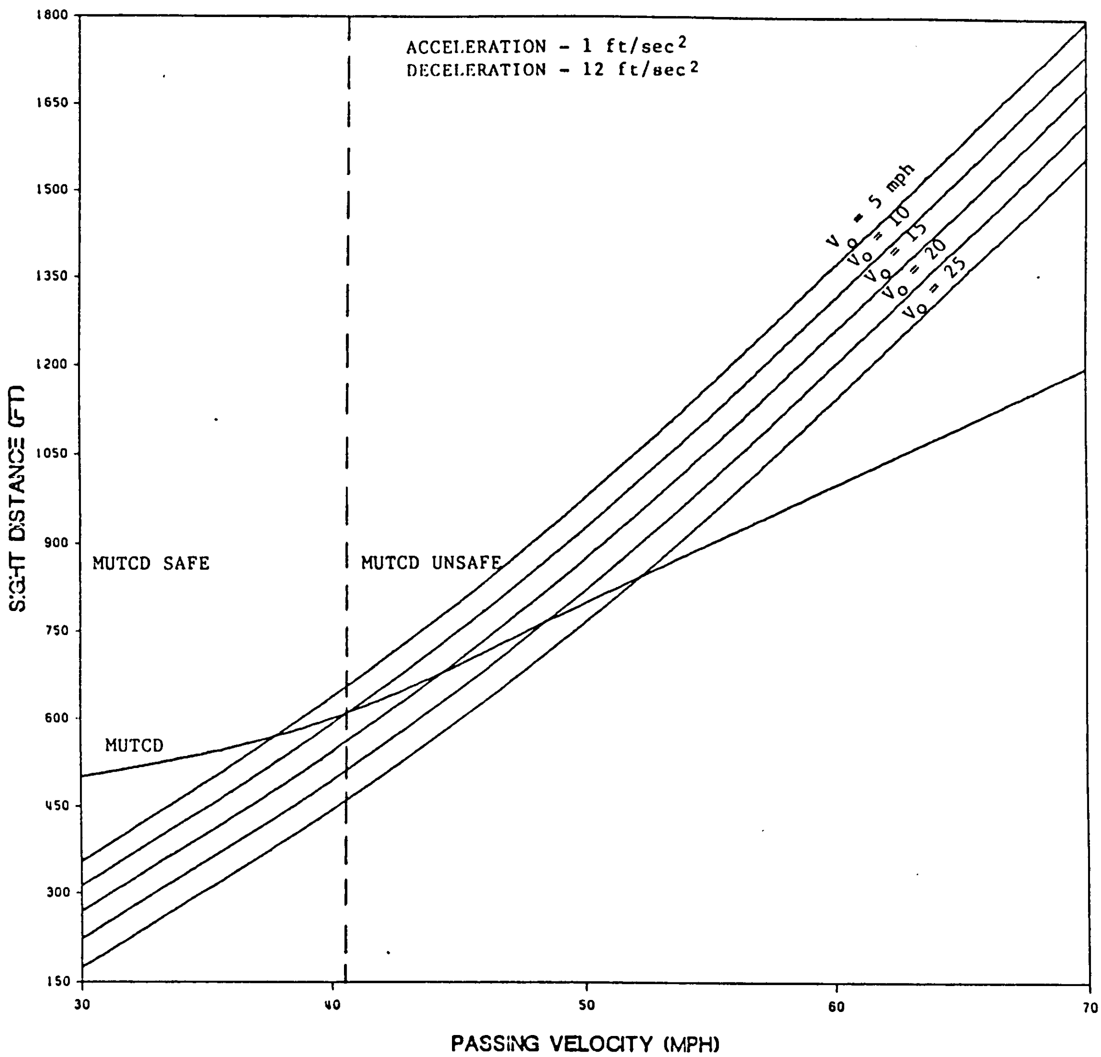


Figure A3. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

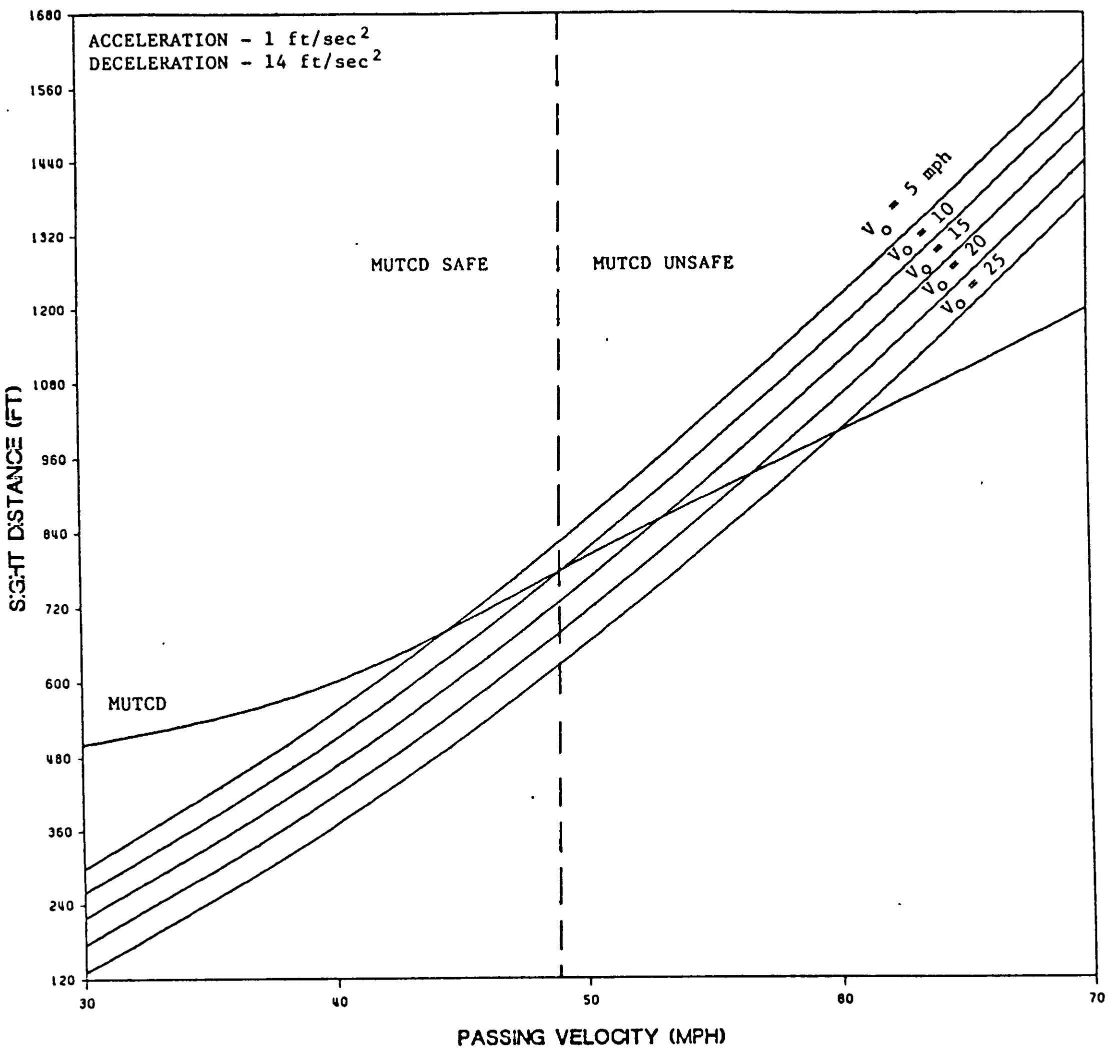


Figure A4. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

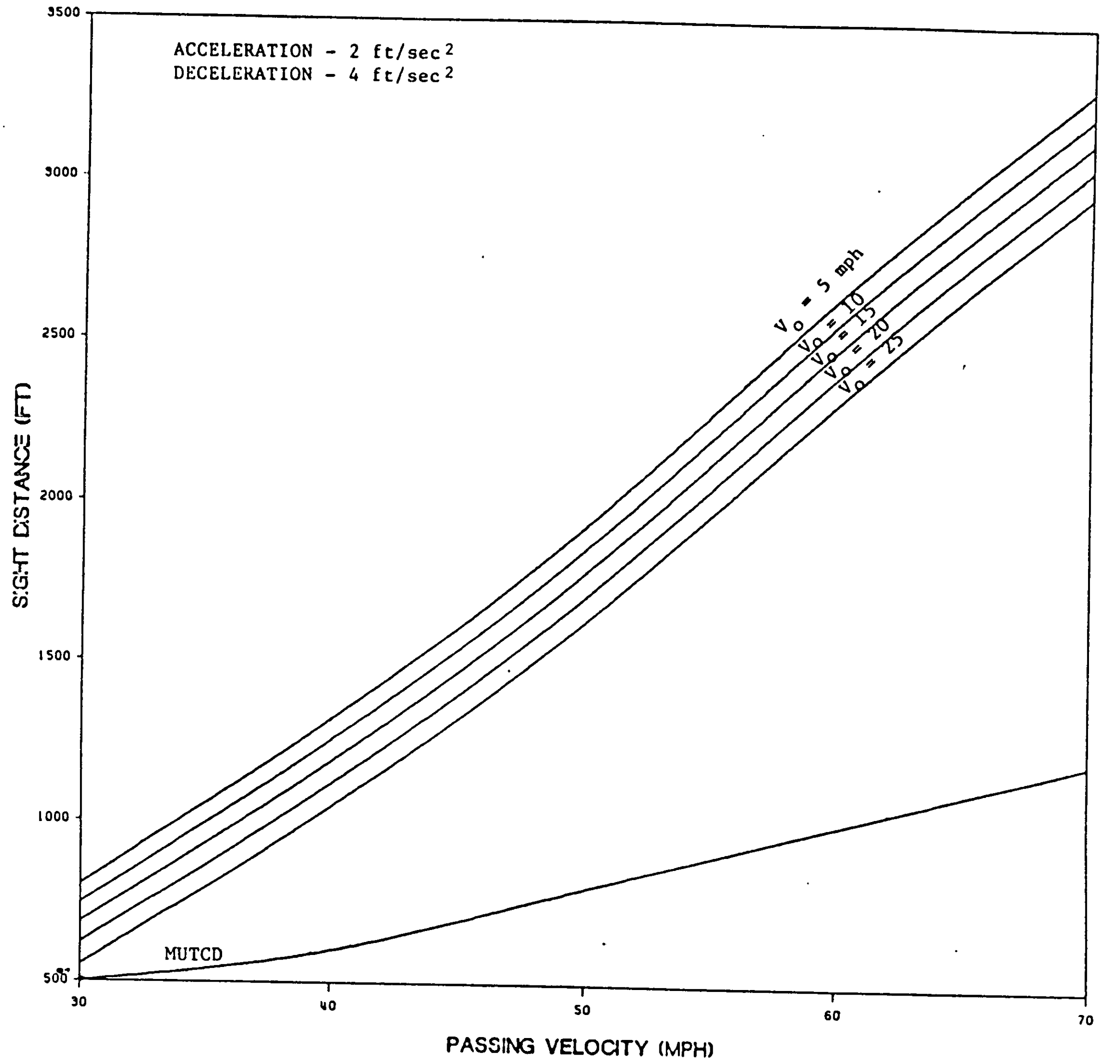


Figure A5. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

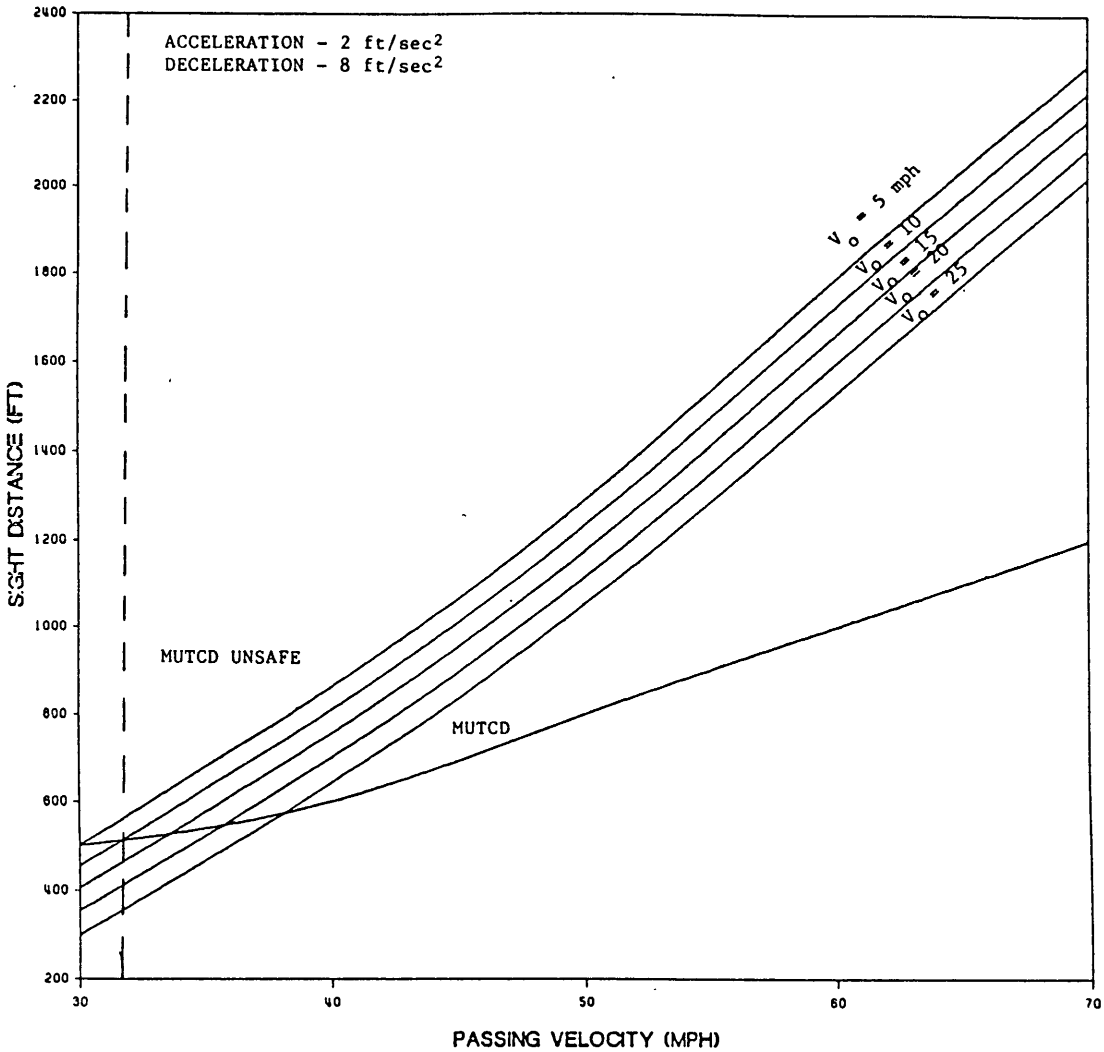


Figure A6. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

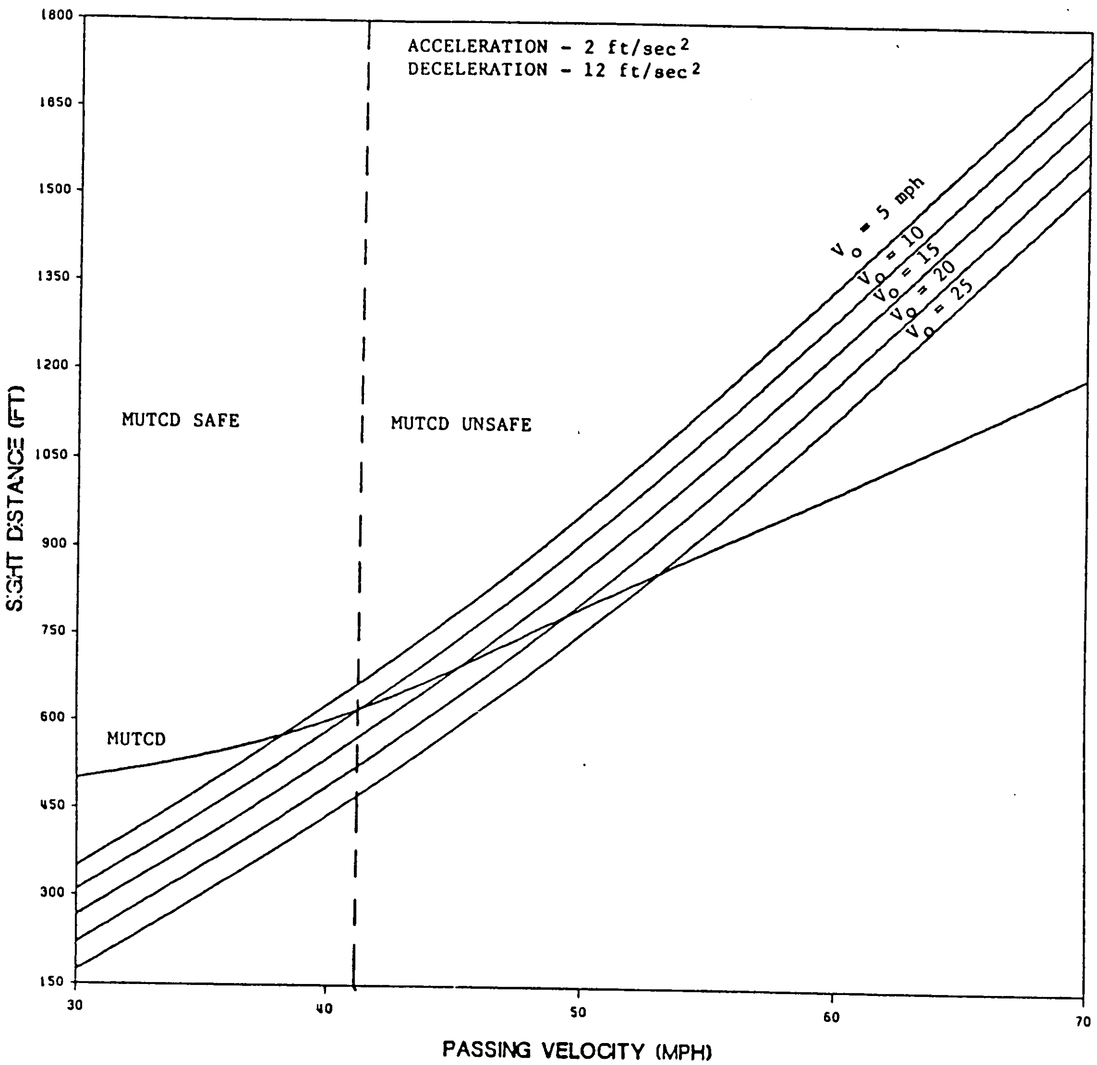


Figure A7. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

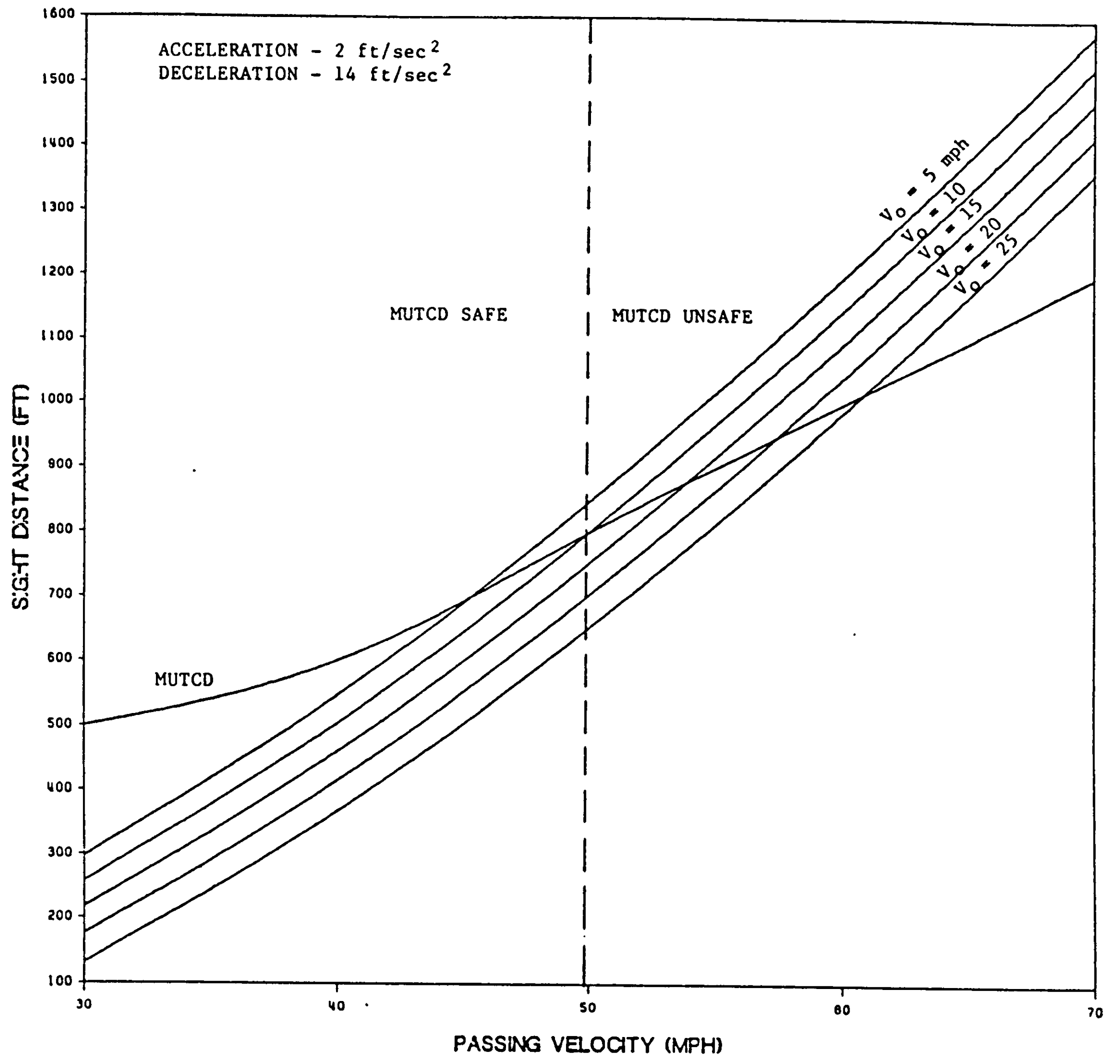


Figure A8. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

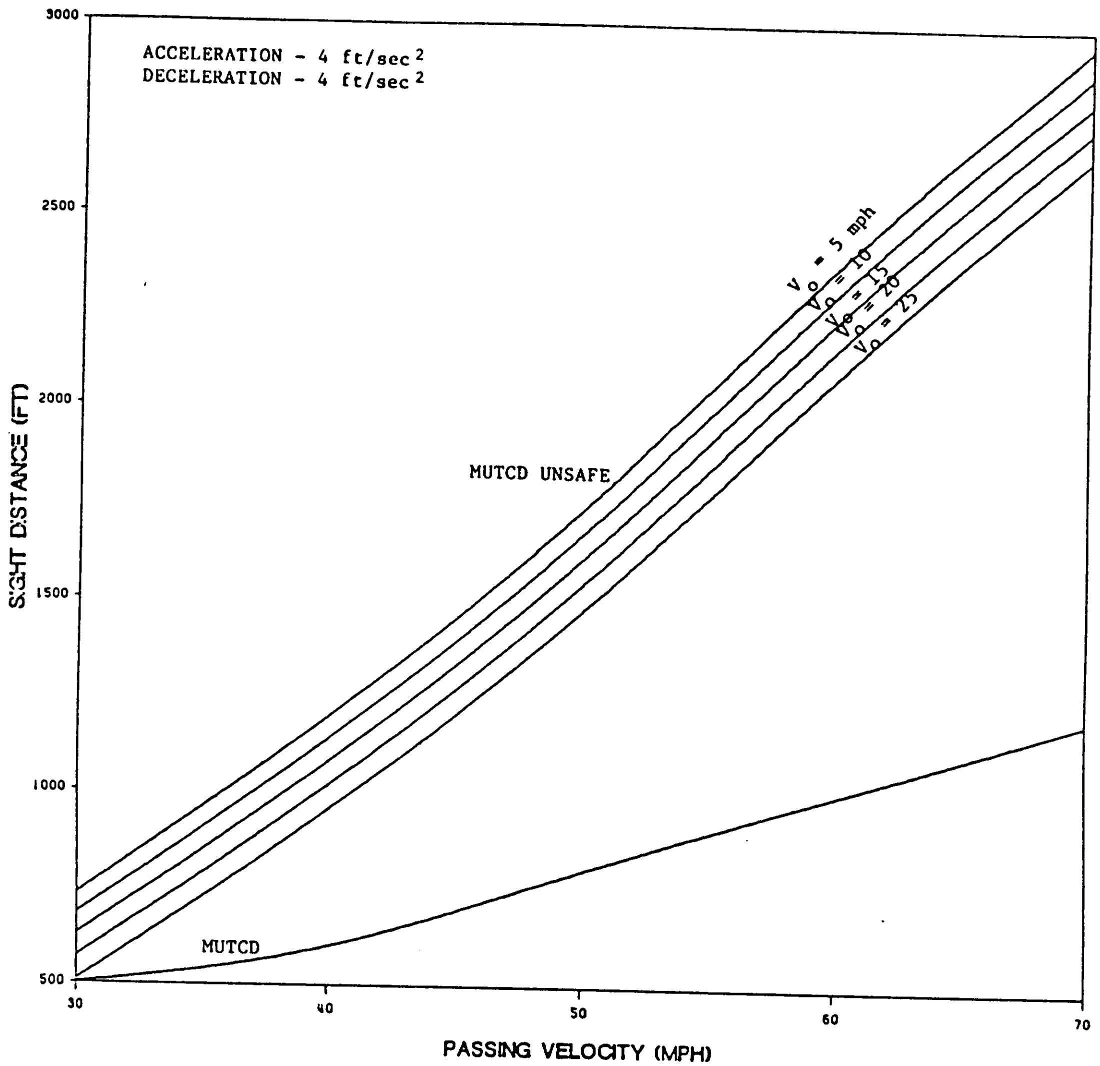


Figure A9. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

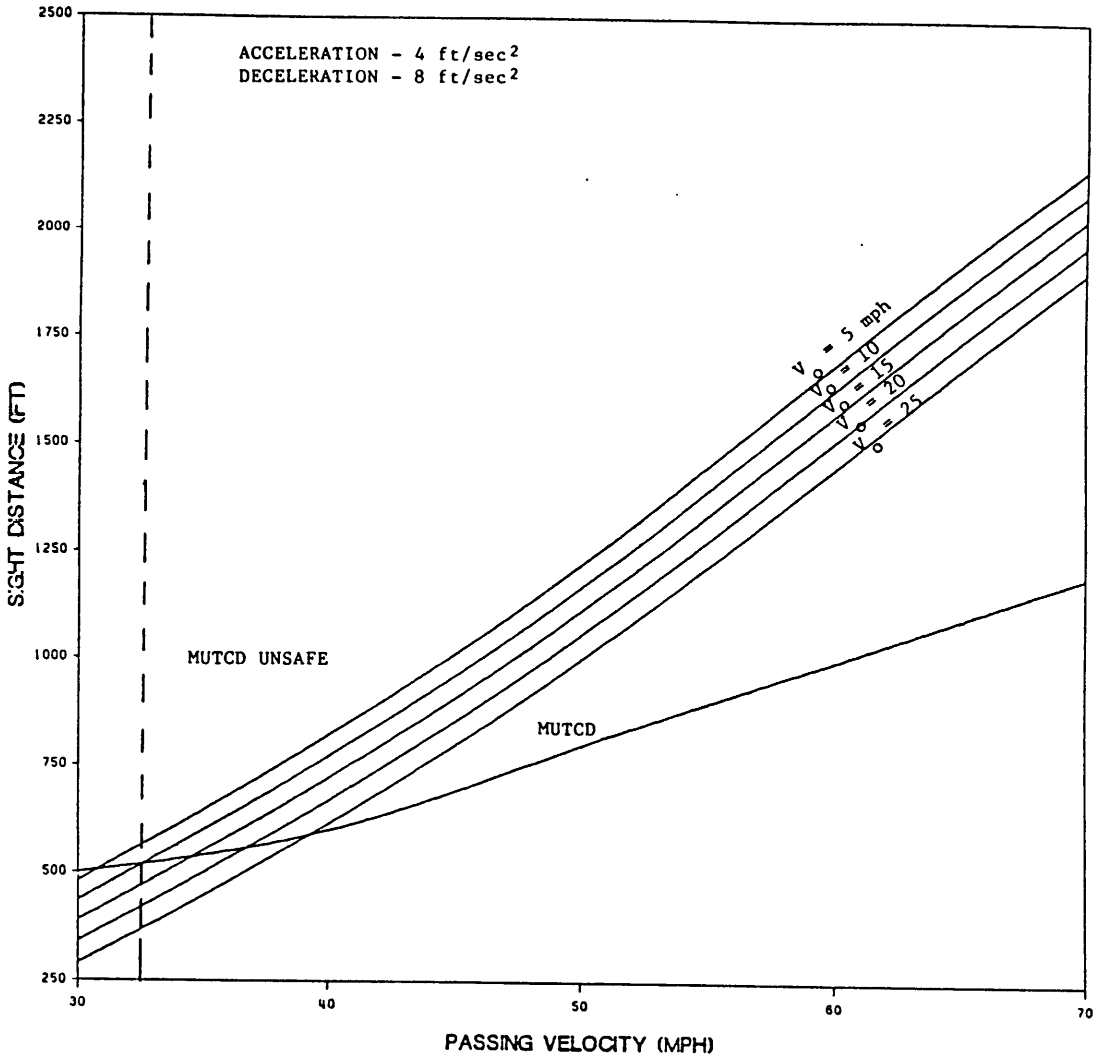


Figure A10. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

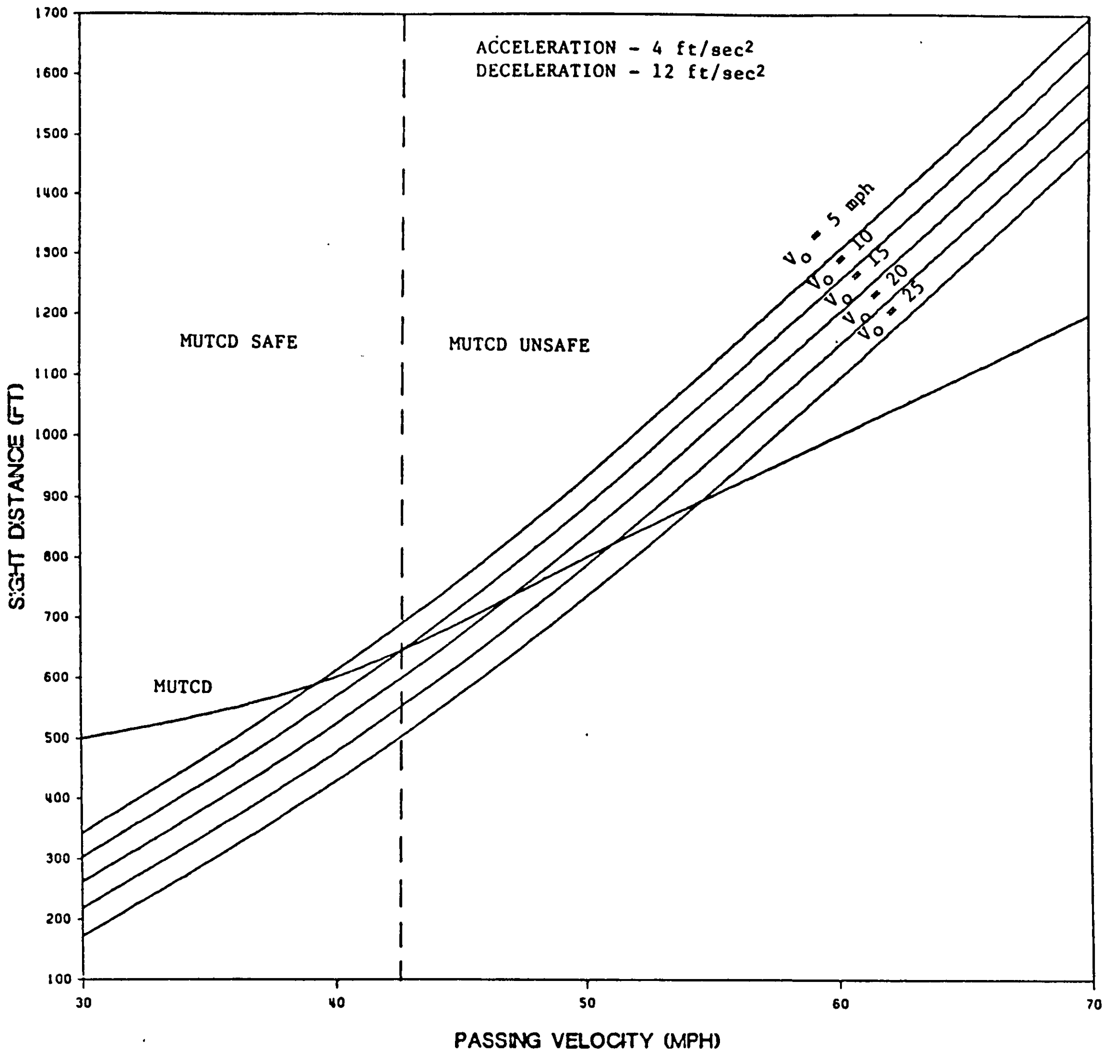


Figure A11. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

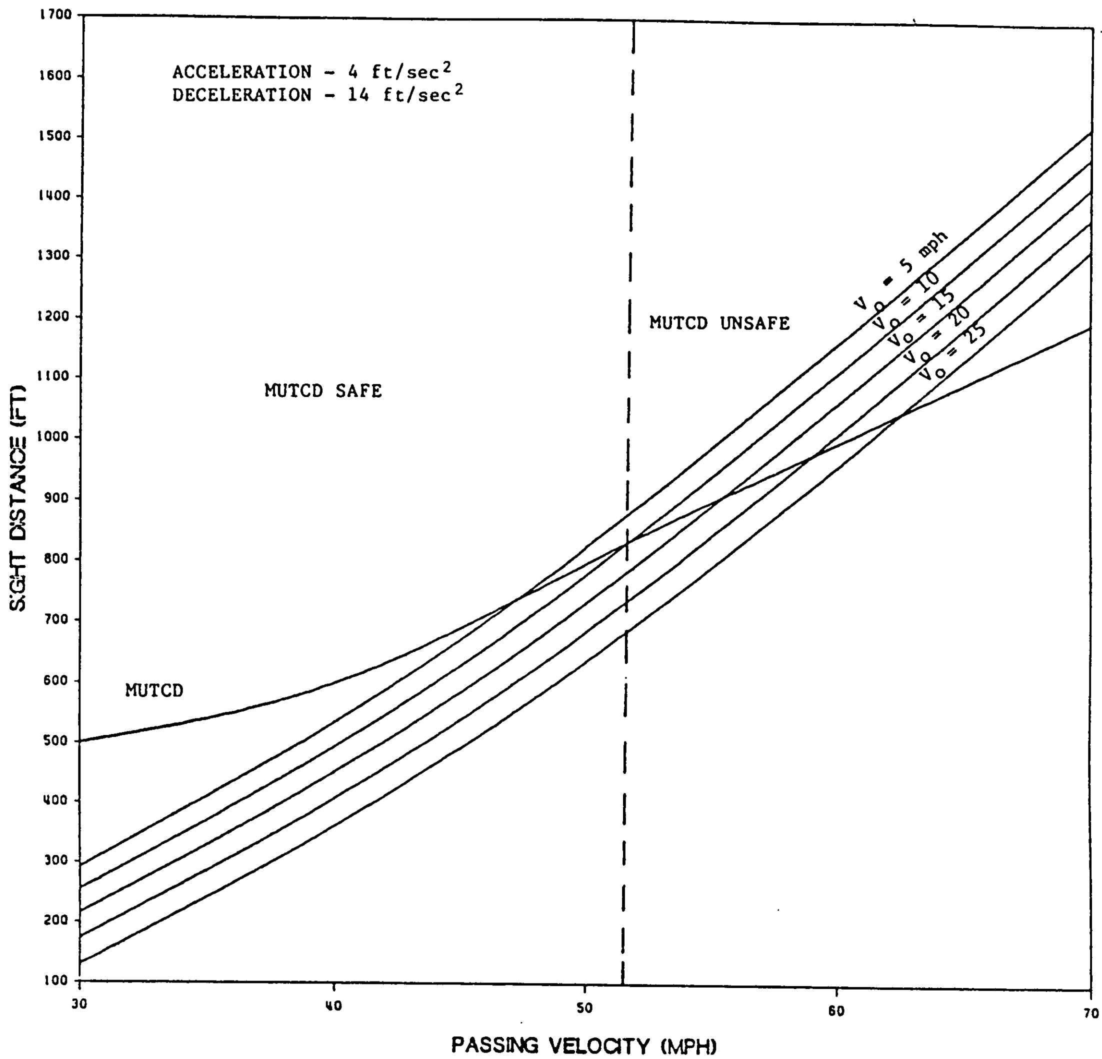
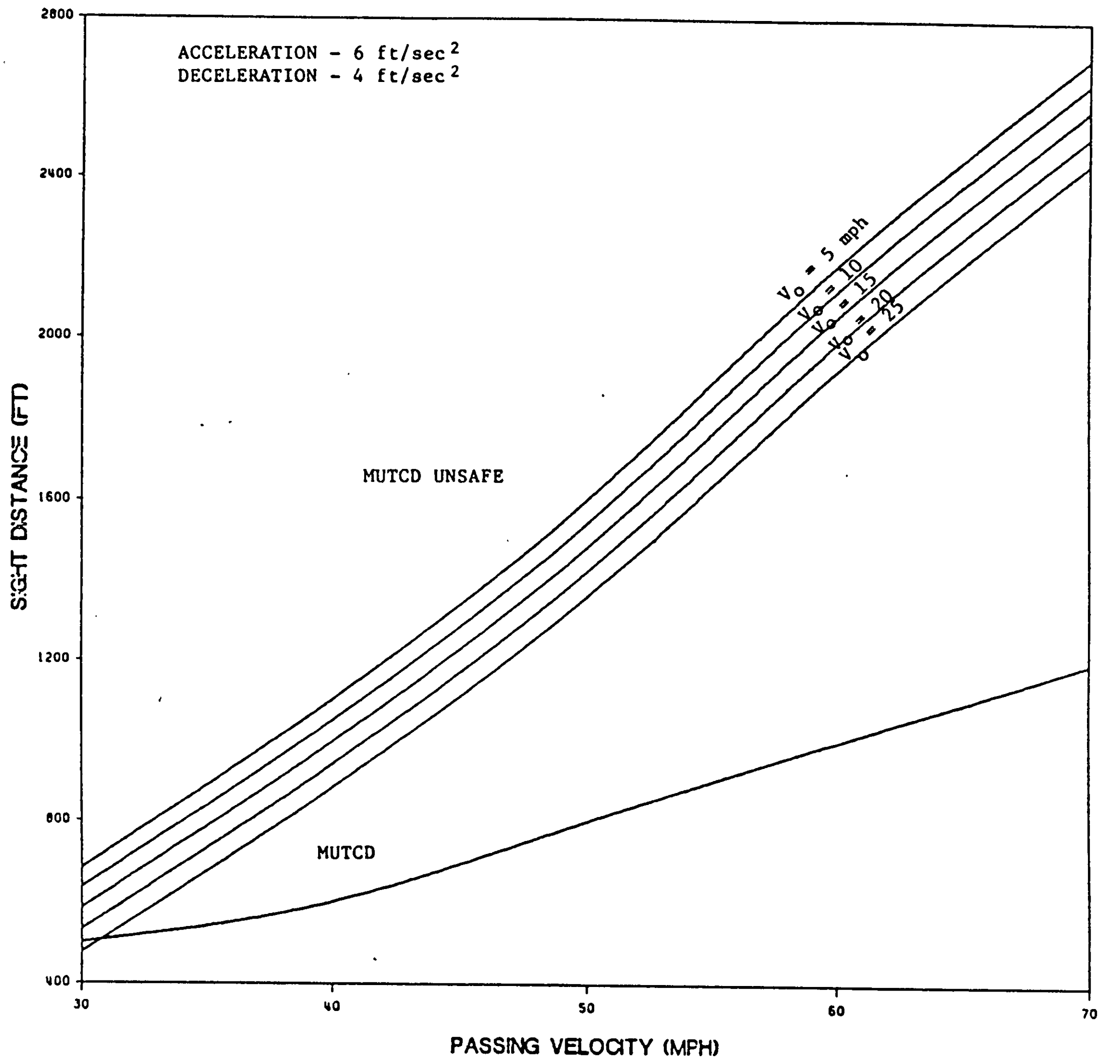


Figure A12. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED



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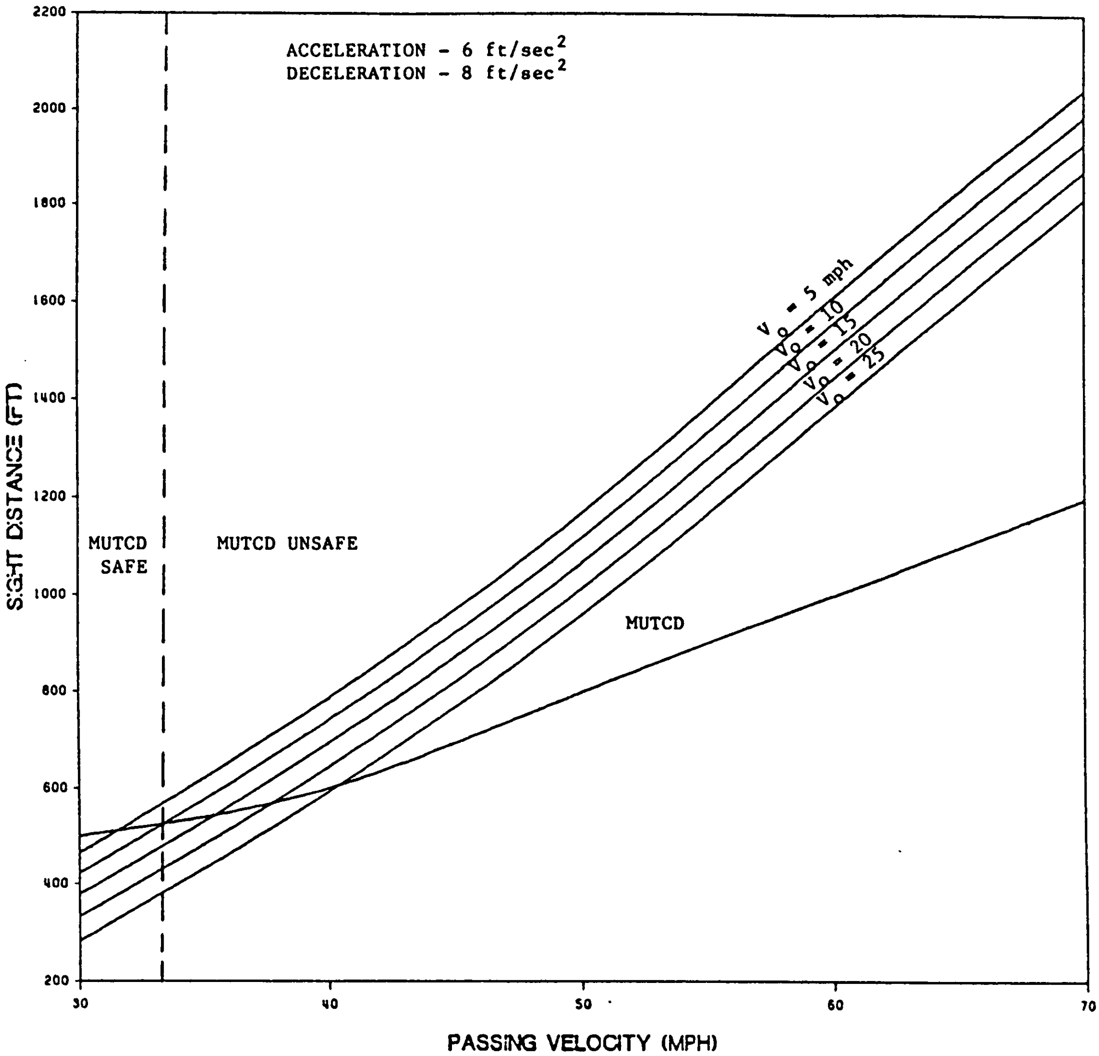


Figure A14. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

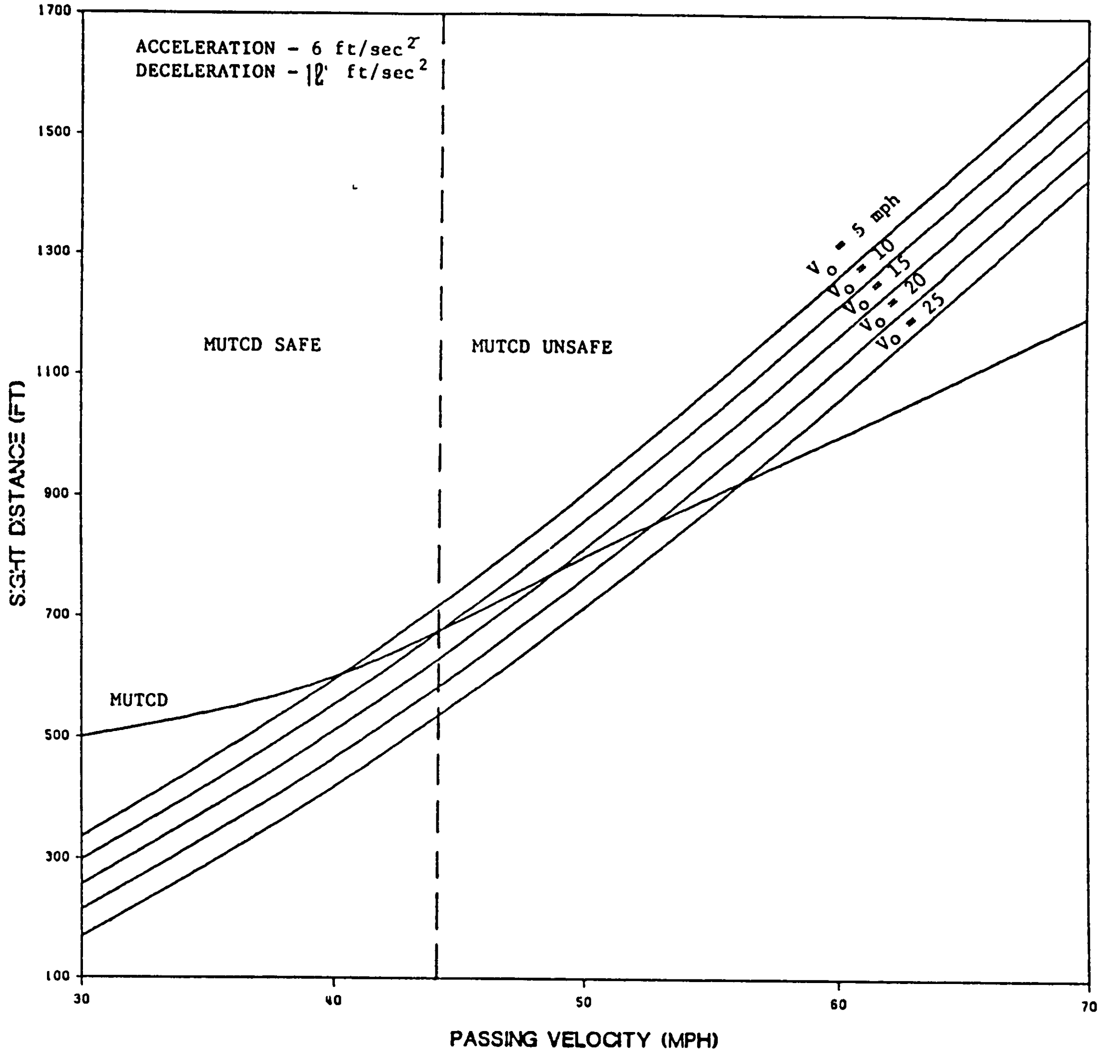


Figure A15. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

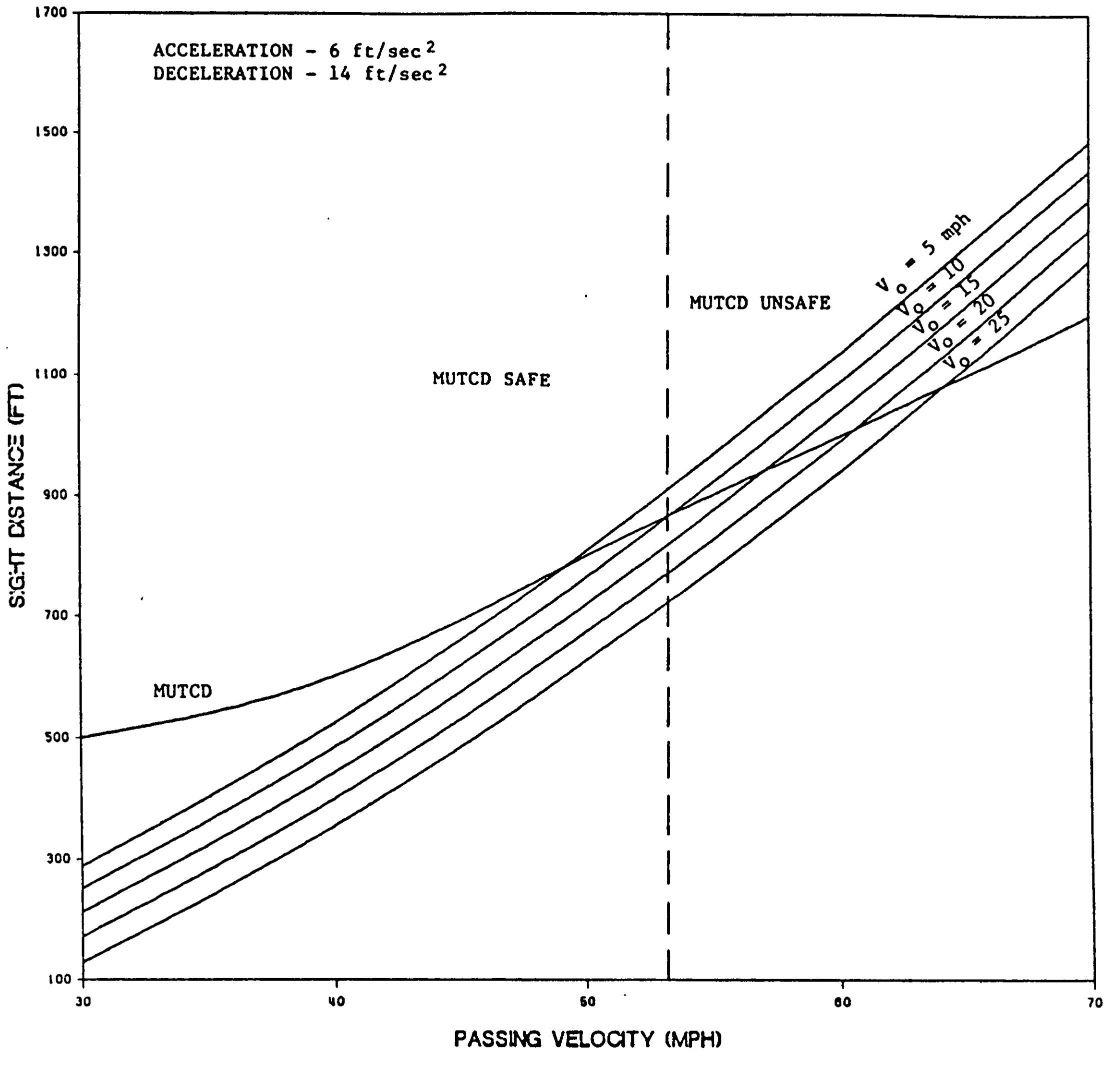


Figure A16. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS PASSING SPEED

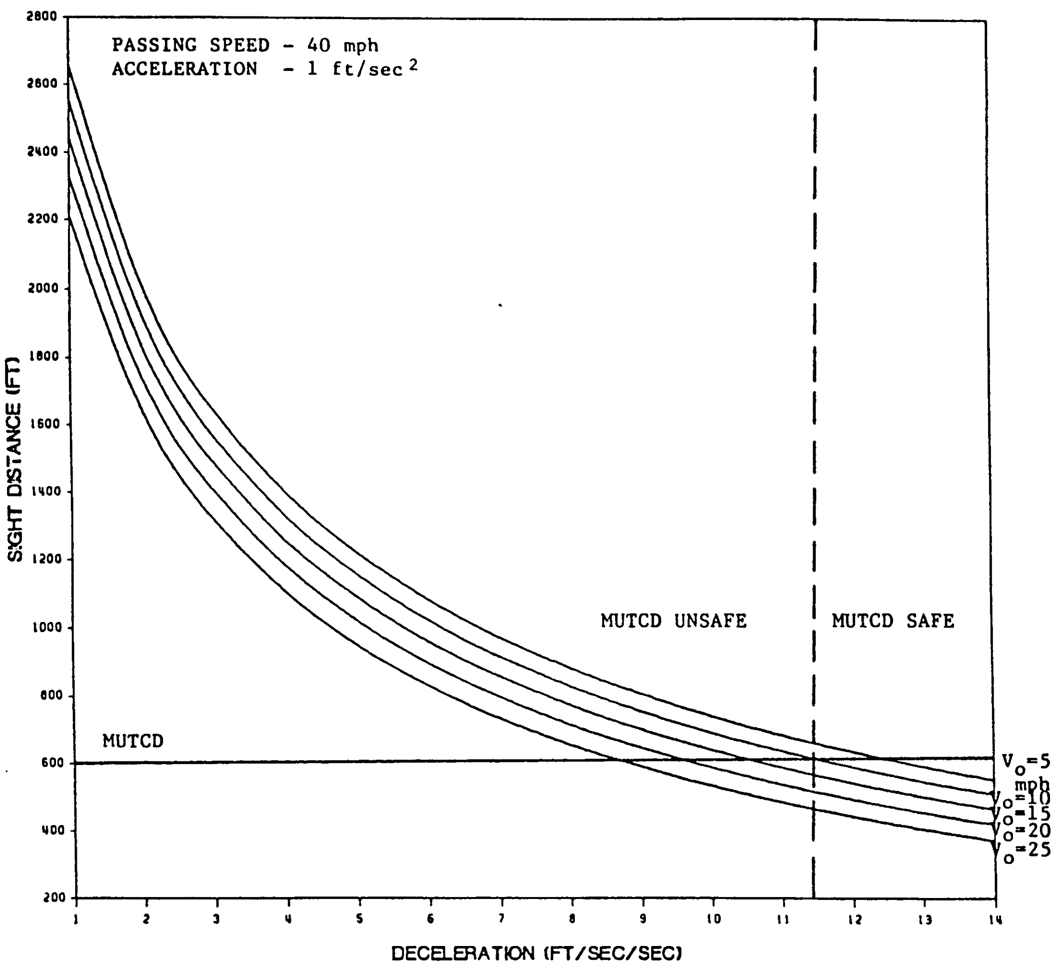


Figure A17. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS DECELERATION

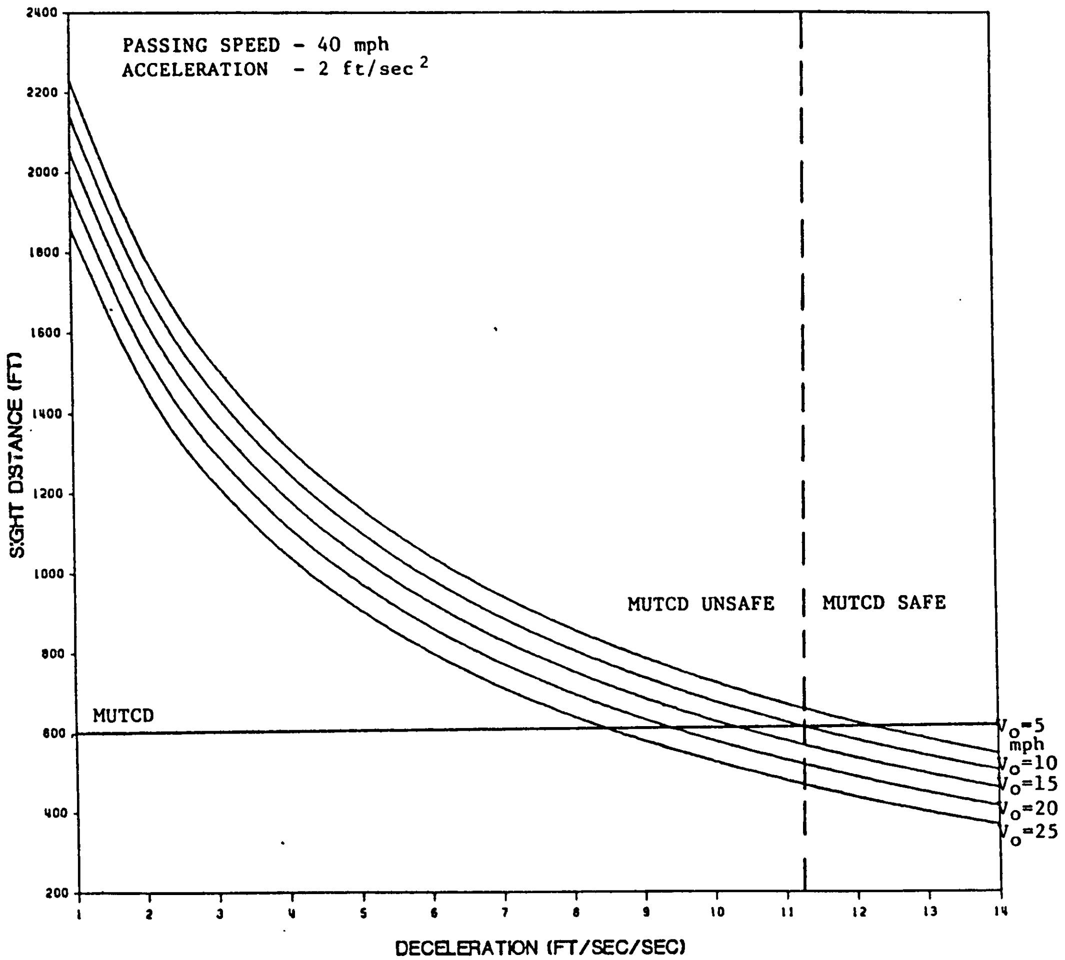


Figure A18. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS DECELERATION

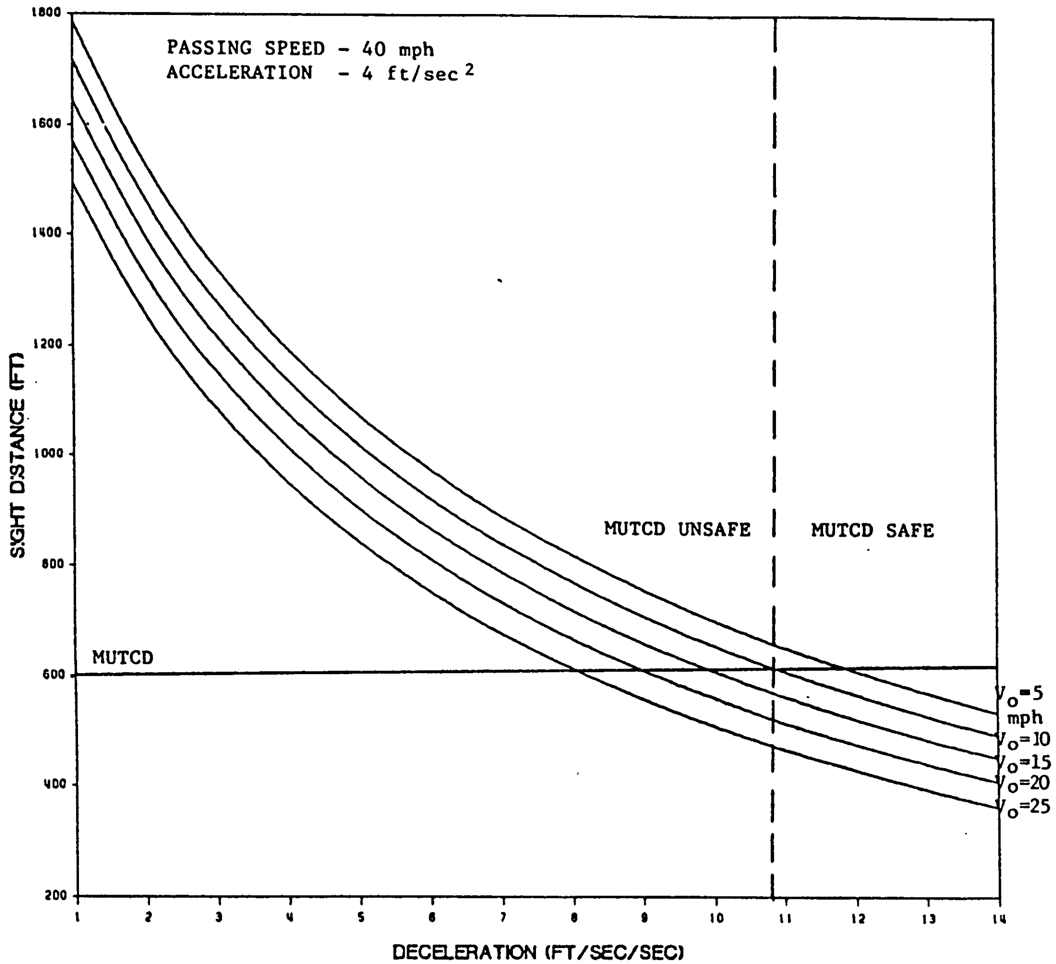


Figure A19. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS DECELERATION

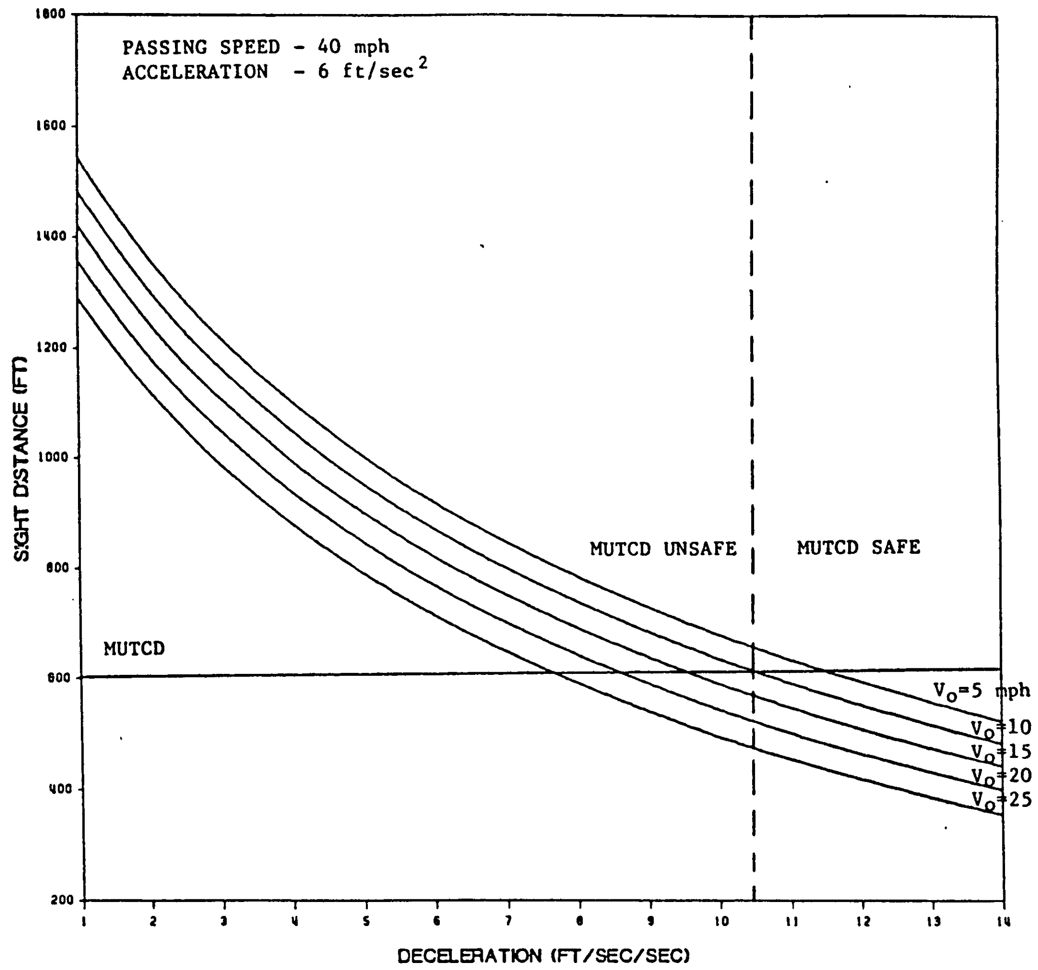


Figure A20. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS DECELERATION

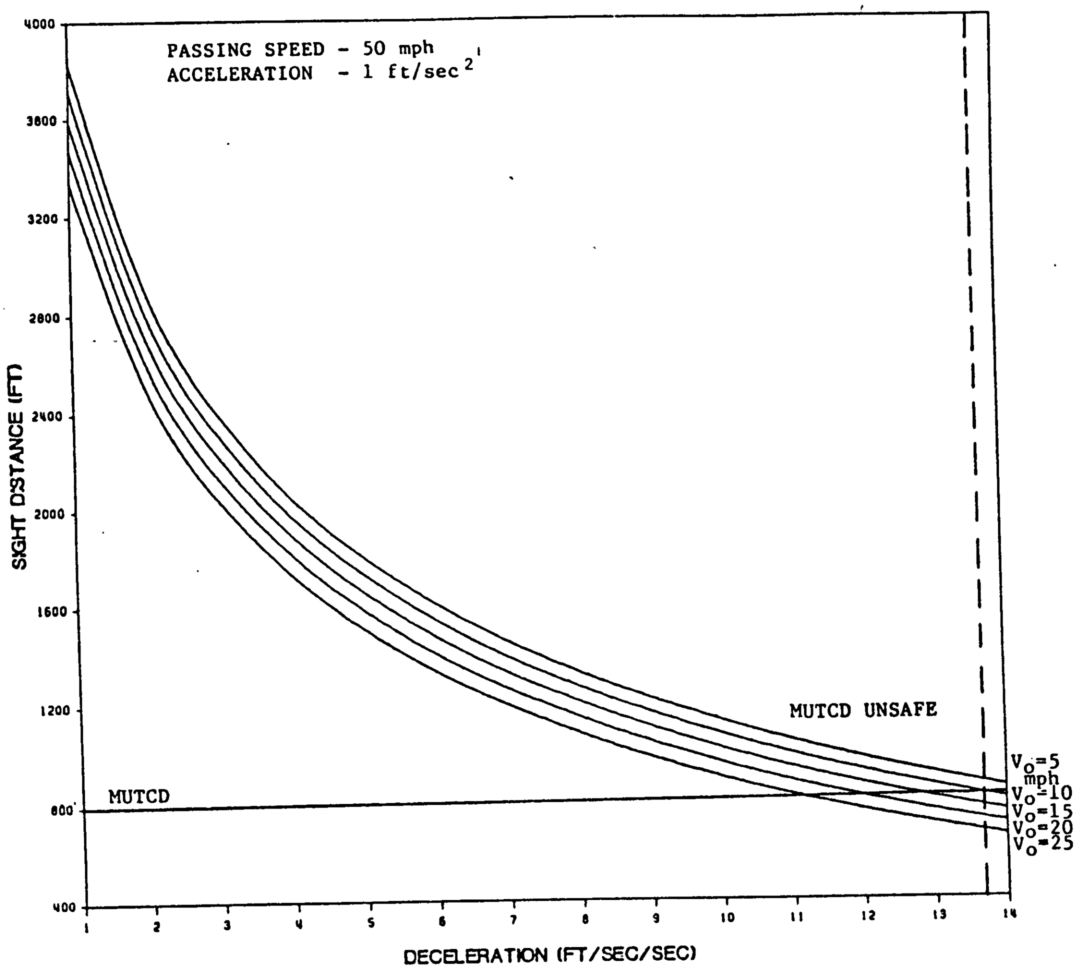
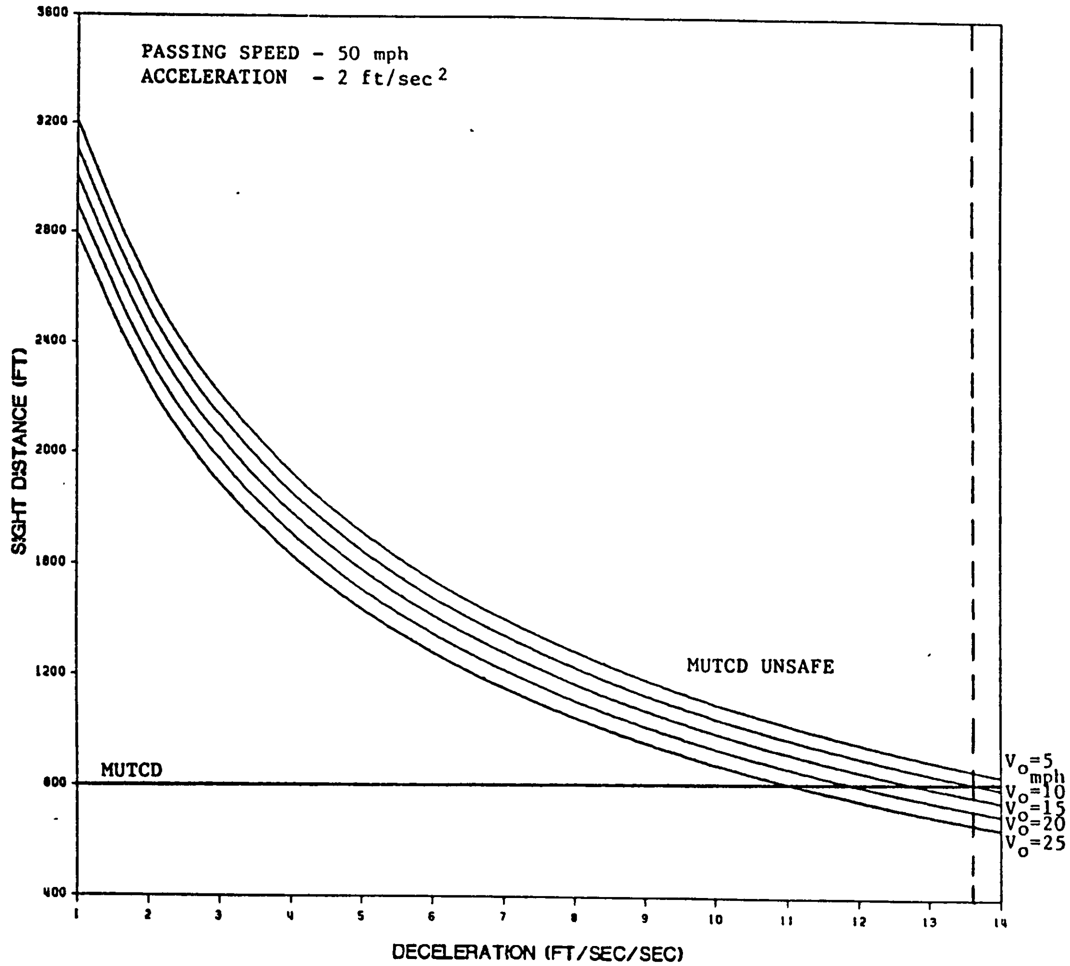


Figure A21. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS DECELERATION



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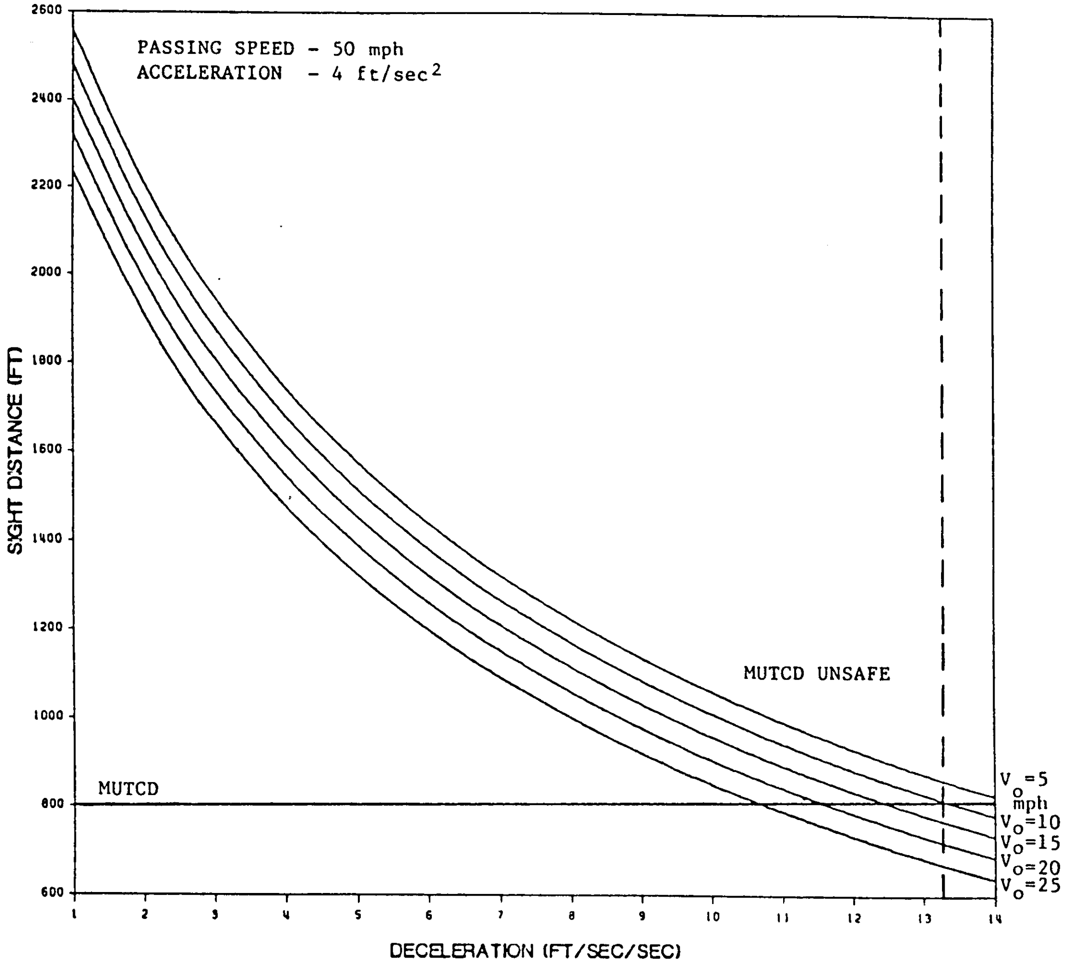

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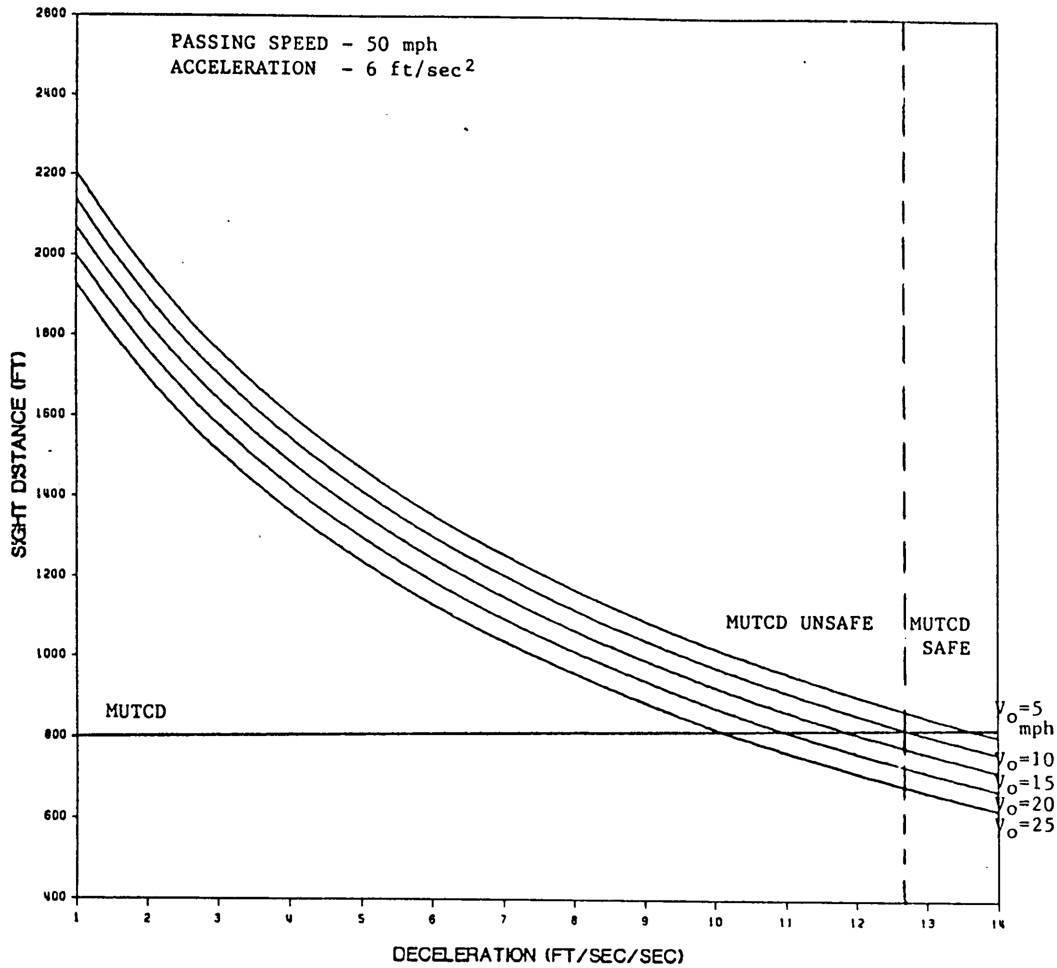

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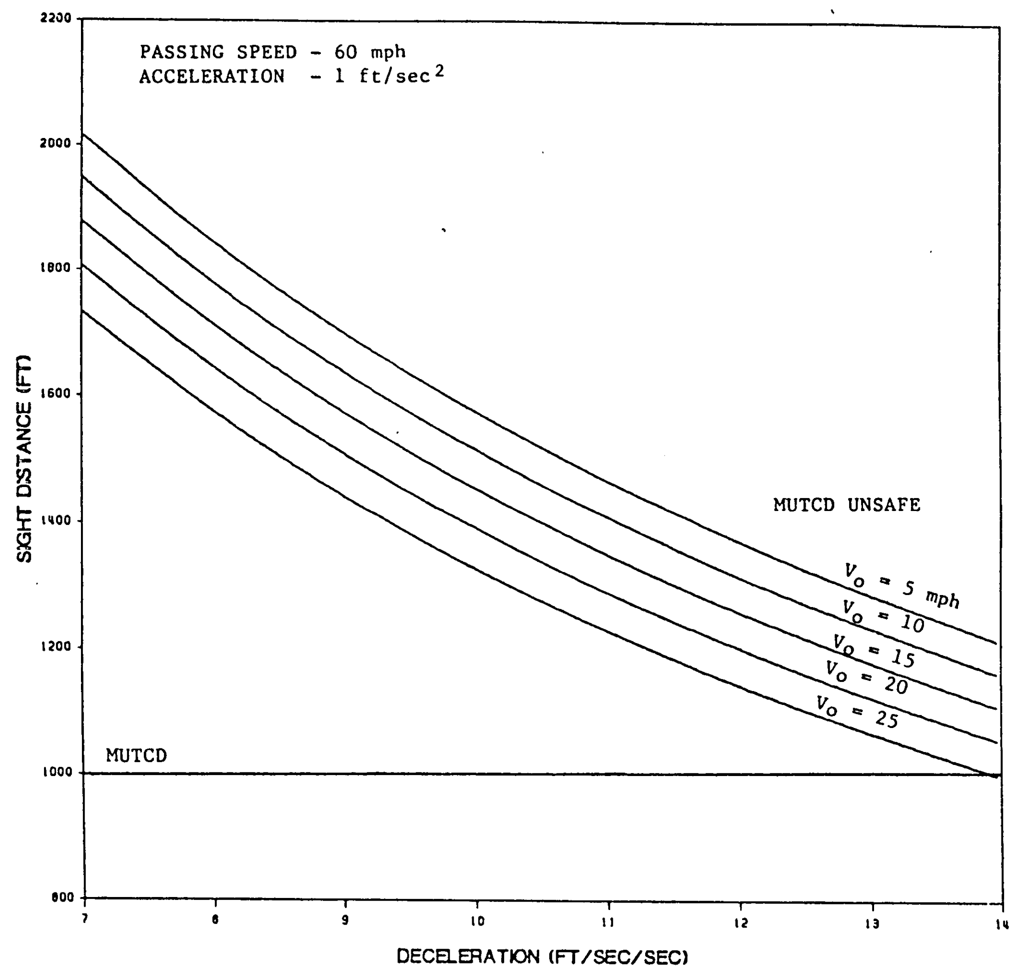

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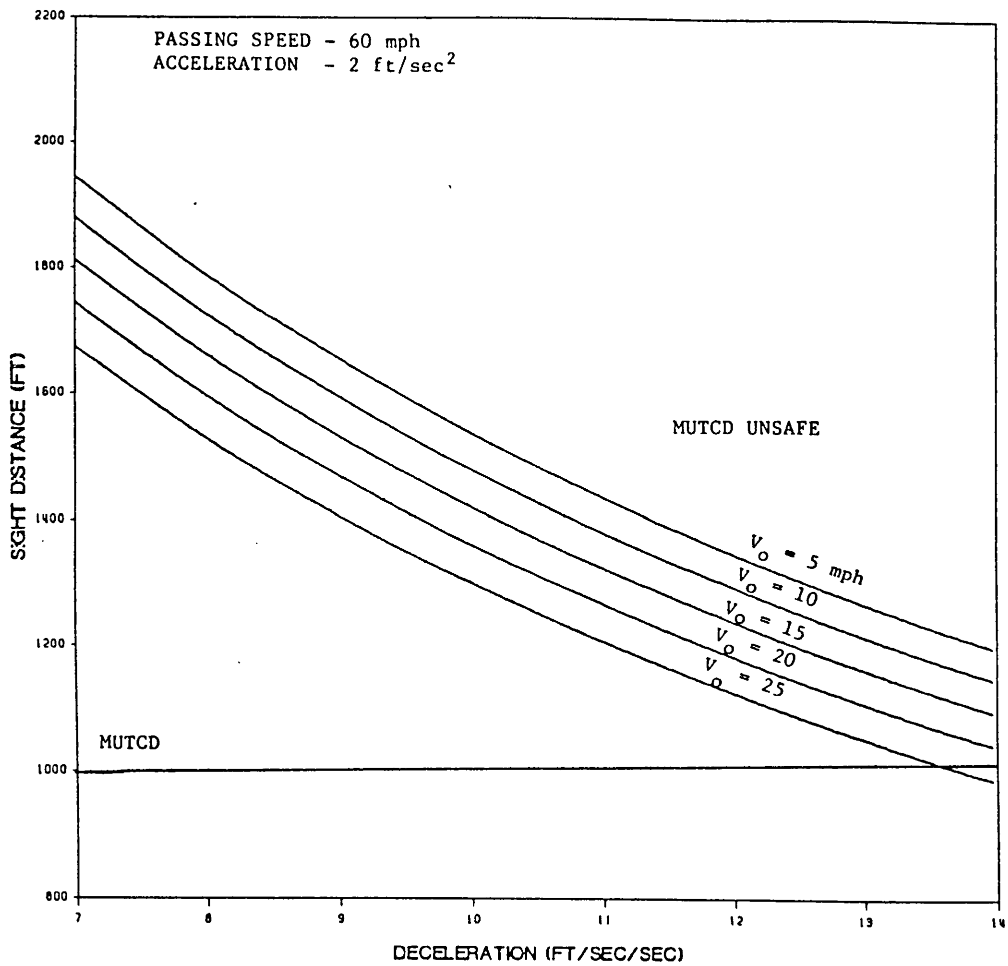
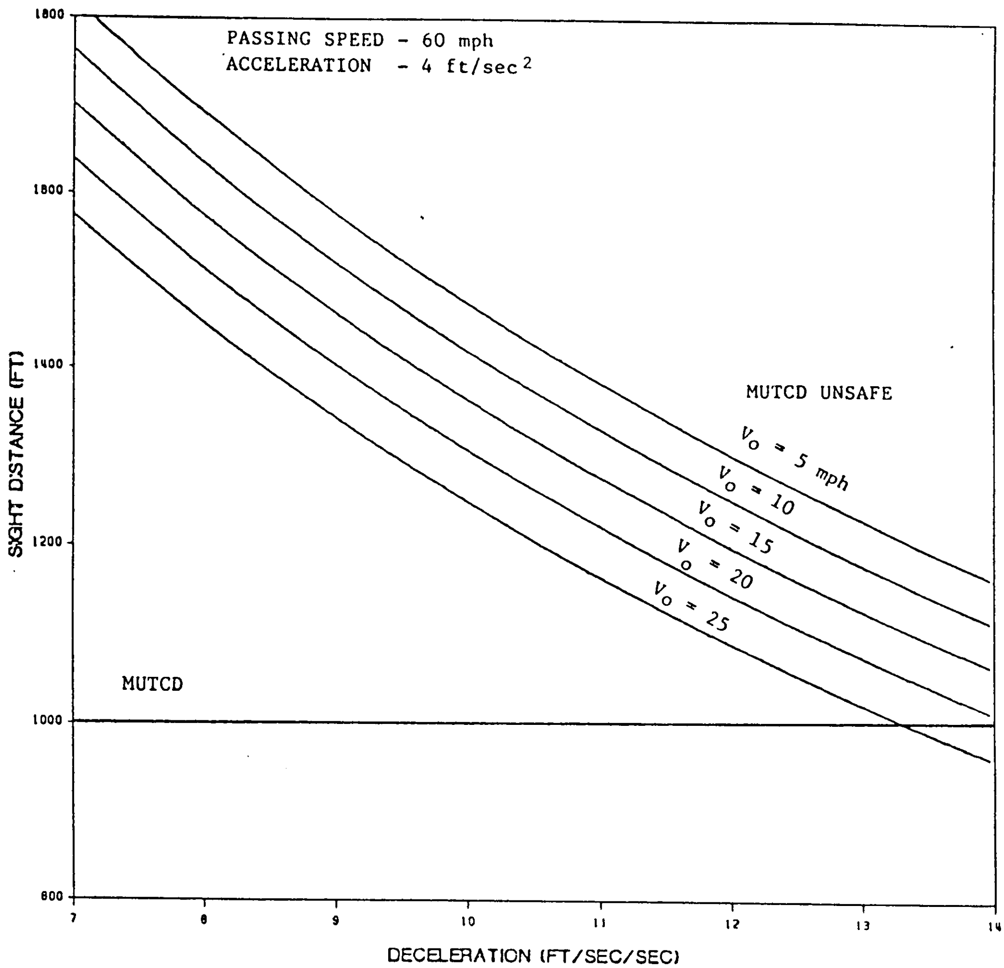


Figure A26. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS DECELERATION



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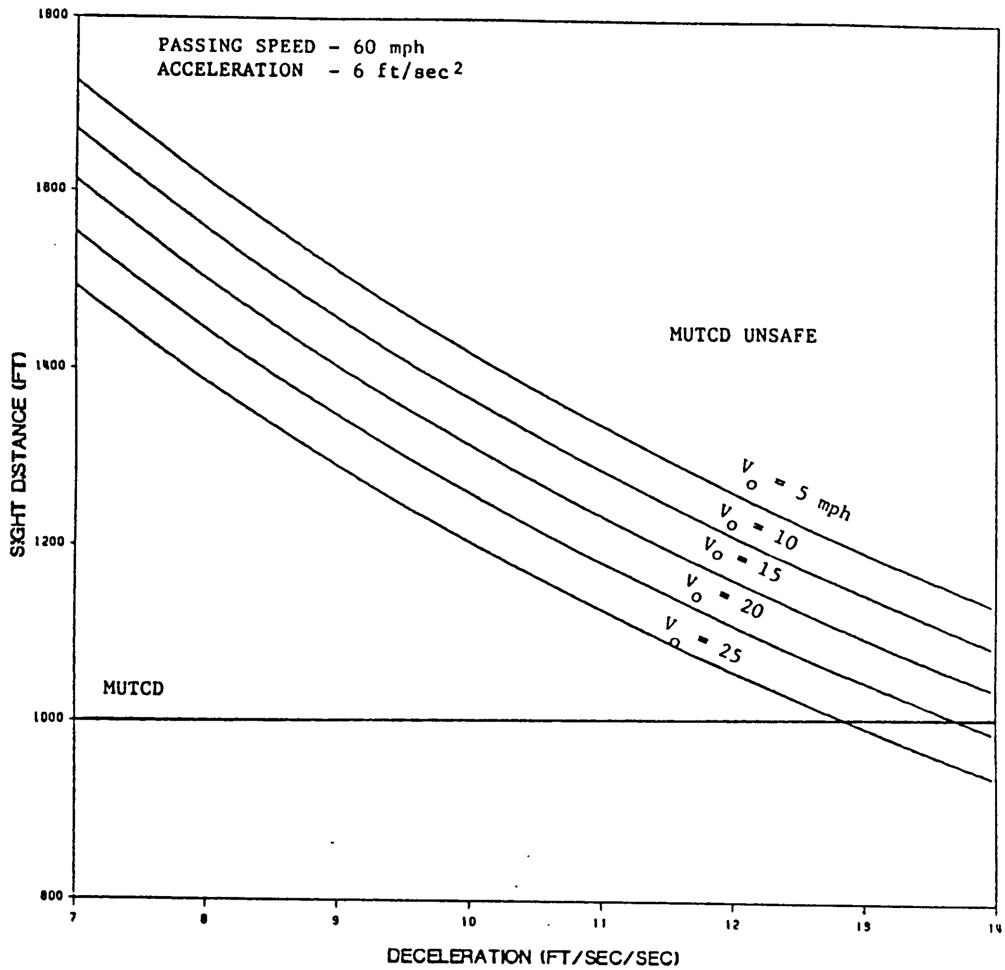

Figure A28. FAMILY OF CURVES OF MINIMUM PASSING SIGHT DISTANCE VERSUS DECELERATION

Appendix B Computer Programs

PROGRAM TO CALCULATE AND PLOT MINIMUM PASSING SIGHT DISTANCE

VERSUS PASSING SPEED

```
50 TED=0
100 CLS
200 PRINT "INPUT VALUES FOR ACCELERATION IN ft/sec/sec":INPUT A1:DELTA1 = 1:DELT
A2 = 1
210 PRINT "INPUT VALUES FOR DECCELERATION IN ft/sec/sec":INPUT A2
215 PRINT "INPUT  VALUES FOR PASSING VELOCITY IN MPH IN MULTIPLES OF 5MPH":INPUT
 VP
220 PRINT "INPUT  VALUES FOR RELATIVE VELOCITY IN MPH":INPUT VO
400 IF VP >=30 AND VP<40 THEN D1=145:D2=475
500 IF VP>=40 AND VP<50 THEN D1 = 215:D2=640
600 IF VP>=50 AND VP<60 THEN D1 = 290:D2=825
700 IF VP>=60 AND VP<70 THEN D1 = 370:D2=1030
710 IF VP=70 THEN D1 = 440:D2=1100
800 IF VP=30 THEN SP=500
810 IF VP = 35 THEN SP = 550
900 IF VP=40 THEN SP=600
910 IF VP = 45 THEN SP = 700
1000 IF VP=50 THEN SP=800
1010 IF VP = 55 THEN SP = 900
1100 IF VP=60 THEN SP=1000
1110 IF VP = 65 THEN SP = 1100
1200 IF VP =70 THEN SP =1200
1205 IF TED=1 THEN RETURN
1300 D = D2
1400 V = (2*VP-VO)*1.47:ALPHA = (A1+A2)/2:BETA=-(A1*DELTA1+A2*DELTA2+A1*D/V)
1500 GAMMA=.5*A1*(DELTA1^2)+.5*A2*(DELTA2^2)-D-(1.47*VO-A1*DELTA1)*D/V +.5*A1*(D
/V)^2
1600 B=BETA:A=ALPHA:G=GAMMA:S=      (-B+(B^2-4*A*G)^.5)*V/(2*A)
1610 SMIN = S - D2
1700 PRINT "ACCELERATION =";A1;"ft/sec/sec":PRINT "DECCELERATION =";A2;"ft/sec/s
ec":PRINT "PASSING VELOCITY =";VP;"MPH":PRINT "RELATIVE VELOCITY =";VO;"MPH":PRI
NT "DESIGN SPEED=";VP;"MPH"
1800 PRINT" SMIN =";SMIN
1900 PRINT "  DO YOU NEED VALUES OF SMIN FOR OTHER VALUES OF PASSING VELOCITY?(Y
/N)"
1910 INPUT J$:IF J$="N" OR J$="n" THEN PRINT "PROGRAM TERMINATED" ELSE GOTO 8000

1912 END
2000 PRINT "DO YOU WANT A GRAPHICAL DISPLAY(Y/N)":INPUT G$:IF G$="N" OR G$ ="n"
THEN PRINT "PROGRAM TERMINATED":END
2010 SCREEN 2:WIDTH 80:CLS:KEY OFF
2020 LOCATE 10,1:PRINT "SMIN":LOCATE 25,34:PRINT "P SSING VELOCITY";:LINE (96,0)
-(96,170):LINE (96,170)-(639,170)
2030 QMAX=0:QMIN=1000000!:FOR VO=RMIN TO RMAX STEP RINC:FOR VP=MIN TO MAX STEP I
NC:GOSUB 20000:IF SMIN>QMAX THEN QMAX=SMIN
2040 IF SMIN<QMIN THEN QMIN=SMIN
2050 NEXT:NEXT
2055 IF SP<QMIN THEN QMIN=SP
2056 IF SP>QMAX THEN QMAX=SP
2060 QMAX=QMAX/10:QMAX=INT(QMAX+1):QMAX=QMAX*10
2070 QMIN=QMIN/10:QMIN=INT(QMIN-1):QMIN=QMIN*10
2080 FOR I=4 TO 164 STEP 16:LINE (96,I)-(91,I):NEXT
2090 J=1:QINC=(QMAX-QMIN)/10:FOR I=QMAX TO QMIN STEP -QINC:LOCATE J,5:PRINT INT(
I):J=J+2:NEXT
2100 FOR I=100 TO 639 STEP 40:LINE (I,170)-(I,174):NEXT
2110 WINC=(MAX-MIN)/13:J=11:FOR I=MIN TO MAX STEP WINC:LOCATE 23,J:PRINT USING "
##.#";I
2130 J=J+5:NEXT
2134 FOR VO=RMIN TO RMAX STEP RINC
2135 VP=MIN:GOSUB 20000:Q=QMAX-QMIN:SCAL=160/Q:Y1=(160-(SMIN-QMIN)*SCAL)+4:Q1=MA
X-MIN:SCAL1=520/Q1:X1=(VP-MIN)*SCAL1+100
2140 FOR VP=MIN TO MAX STEP INC
2150 GOSUB 20000
2160 Q=QMAX-QMIN:SCAL=160/Q:Y=(160-(SMIN-QMIN)*SCAL)+4
2170 Q1=MAX-MIN:SCAL1=520/Q1:X=(VP-MIN)*SCAL1+100
2180 LINE (X1,Y1)-(X,Y):X1=X:Y1=Y
```

```
2190 NEXT:NEXT
2195 VP=MIN:TED=1:GOSUB 400:TED=0:Y=(160-(SP-QMIN)*SCAL)+4:X=(VP-MIN)*SCAL1+100:
X1=X:Y1=Y
2200 FOR VP=MIN TO MAX STEP INC:TED=1:GOSUB 400:Y=(160-(SP-QMIN)*SCAL)+4:X=(VP-M
IN)*SCAL1+100:LINE (X1,Y1)-(X,Y):X1=X:Y1=Y:NEXT:TED=0
2210 LOCATE 3,3
2220 BEEP
2230 A$=INKEY$
2240 IF A$="" THEN 2230
2250 CLS:SCREEN 0:LOCATE 3,3:PRINT "DO YOU WANT TO RUN AGAIN (Y/N)";:INPUT A$:IF
 A$="Y" OR A$="y" THEN RUN
2260 END
8000 PRINT "SPECIFY RANGE OF VALUES OF PASSING VELOCITY--MAXIMUM,MINIMUM,INCREME
NT":INPUT MAX,MIN,INC:PRINT "MAXIMUM =";MAX;"MPH":PRINT:PRINT"MINIMUM =";MIN;"MP
H":PRINT:PRINT"INCREMENT =";INC;"MPH"
8100 PRINT "SPECIFY RANGE OF VALUES OF RELATIVE VELOCITY--MAXIMUM,MINIMUM,INCREM
ENT":INPUT RMAX,RMIN,RINC
8150 PRINT "MAXIMUM =";RMAX;"MPH":PRINT:PRINT"MINIMUM =";RMIN;"MPH":PRINT:PRINT"
INCREMENT =";RINC;"MPH"
8160 PRINT"INPUT VALUES FOR ACCELERATION IN ft/sec/sec":INPUT A1
8165 PRINT" ACCELERATION =";A1;
8167 PRINT"INPUT VALUES FOR DECCELERATION IN ft/sec/sec":INPUT A2
8170 PRINT"DECCELERATION =";A2;"ft/sec/sec"
8172 PRINT"PASSING VELOCITY(MPH)             SMIN(ft)"
8173 PRINT"-------------------------             ----------":PRINT
8175 FOR VO = RMIN TO RMAX STEP RINC:PRINT "RELATIVE VELOCITY = ";VO;"MPH":PRINT
:FOR VP = MIN TO MAX STEP INC
8200 GOSUB 20000
8250 PRINT VP,,"          ";SMIN:NEXT:PRINT:PRINT:NEXT
8300 PRINT"DO YOU WANT SMIN FOR ANY OTHER VALUES ?(Y/N)":INPUT Q$
8305 IF Q$="Y" OR Q$="y" THEN GOTO 8000 ELSE GOTO 2000
20000 D = D2
20100 V = (2*VP-VO)*1.47:ALPHA = (A1+A2)/2:BETA = -(A1*DELTA1 + A2*DELTA2 + A1*D
/V)
20150 GAMMA=.5*A1*(DELTA1^2)+.5*A2*(DELTA2^2)-D-(1.47*VO-A1*DELTA1)*D/V+.5*A1*(D
/V)^2
20200 B=BETA:A=ALPHA:G=GAMMA:S=(-B+(B^2-4*A*G)^.5)*V/(2*A):SMIN=S - D2:RETURN
```

PROGRAM TO CALCULATE AND PLOT MINIMUM PASSING SIGHT DISTANCE

VERSUS DECELERATION

```
100 CLS
200 PRINT "INPUT VALUES FOR ACCELERATION IN ft/sec/sec":INPUT A1:DELTA1 = 1:DELT
A2 = 1
210 PRINT "INPUT VALUES FOR DECCELERATION IN ft/sec/sec":INPUT A2
215 PRINT "INPUT  VALUES FOR PASSING VELOCITY IN MPH IN MULTIPLES OF 5MPH":INPUT
 VP
220 PRINT "INPUT  VALUES FOR RELATIVE VELOCITY IN MPH":INPUT VO
400 IF VP >=30 AND VP<40 THEN D1=145:D2=475
500 IF VP>=40 AND VP<50 THEN D1 = 215:D2=640
600 IF VP>=50 AND VP<60 THEN D1 = 290:D2=825
700 IF VP>=60 AND VP<70 THEN D1 = 370:D2=1030
710 IF VP=70 THEN D1=440:D2=1100
800 IF VP=30 THEN SP=500
810 IF VP = 35 THEN SP = 550
900 IF VP=40 THEN SP=600
910 IF VP = 45 THEN SP = 700
1000 IF VP=50 THEN SP=800
1010 IF VP = 55 THEN SP = 900
1100 IF VP=60 THEN SP=1000
1110 IF VP = 65 THEN SP = 1100
1200 IF VP =70 THEN SP =1200
1300 D = D2
1400 V =( 2*VP-VO)*1.47:ALPHA = (A1+A2)/2:BETA=-(A1*DELTA1+A2*DELTA2+A1*D/V)
1500 GAMMA=.5*A1*(DELTA1^2)+.5*A2*(DELTA2^2)-D-(1.47*VO-A1*DELTA1)*D/V +.5*A1*(D
/V)^2
1600 B=BETA:A=ALPHA:G=GAMMA:S= (-B+(B^2-4*A*G)^.5)*V/(2*A):SMIN=S-D2
1700 PRINT "ACCELERATION =";A1;"ft/sec/sec":PRINT "DECCELERATION =";A2;"ft/sec/s
ec":PRINT "PASSING VELOCITY =";VP;"MPH":PRINT "RELATIVE VELOCITY =";VO;"MPH":PRI
NT "DESIGN SPEED=";VP;"MPH"
1800 PRINT" SMIN =";SMIN
1900 PRINT "  DO YOU NEED VALUES OF SMIN FOR OTHER VALUES OF DECCELERATION?(Y/N)
"
1910 INPUT J$:IF J$="N" OR J$="n" THEN PRINT "PROGRAM TERMINATED" ELSE GOTO 8000

1912 END
2000 PRINT "DO YOU WANT A GRAPHICAL DISPLAY(Y/N)":INPUT G$:IF G$="N" OR G$ ="n"
THEN PRINT "PROGRAM TERMINATED":END
2010 SCREEN 2:WIDTH 80:CLS:KEY OFF
2020 LOCATE 10,1:PRINT "SMIN":LOCATE 25,34:PRINT "DECCELERATION";:LINE (96,0)-(9
6,170):LINE (96,170)-(639,170)
2030 QMAX=0:QMIN=1000000!:FOR VO=RMIN TO RMAX STEP RINC:FOR A2=MIN TO MAX STEP I
NC:GOSUB 20000:IF SMIN>QMAX THEN QMAX=SMIN
2040 IF SMIN<QMIN THEN QMIN=SMIN
2050 NEXT:NEXT
2055 IF SP<QMIN THEN QMIN=SP
2056 IF SP>QMAX THEN QMAX=SP
2060 QMAX=QMAX/10:QMAX=INT(QMAX+1):QMAX=QMAX*10
2070 QMIN=QMIN/10:QMIN=INT(QMIN-1):QMIN=QMIN*10
2080 FOR I=4 TO 164 STEP 16:LINE (96,I)-(91,I):NEXT
2090 J=1:QINC=(QMAX-QMIN)/10:FOR I=QMAX TO QMIN STEP -QINC:LOCATE J,5:PRINT INT(
I):J=J+2:NEXT
2100 FOR I=100 TO 639 STEP 40:LINE (I,170)-(I,174):NEXT
2110 WINC=(MAX-MIN)/13:J=11:FOR I=MIN TO MAX STEP WINC:LOCATE 23,J:PRINT USING "
##.#";I
2130 J=J+5:NEXT
2134 FOR VO=RMIN TO RMAX STEP RINC
2135 A2=MIN:GOSUB 20000:Q=QMAX-QMIN:SCAL=160/Q:Y1=(160-(SMIN-QMIN)*SCAL)+4:Q1=MA
X-MIN:SCAL1=520/Q1:X1=(A2-MIN)*SCAL1+100
2140 FOR A2=MIN TO MAX STEP INC
2150 GOSUB 20000
2160 Q=QMAX-QMIN:SCAL=160/Q:Y=(160-(SMIN-QMIN)*SCAL)+4
2170 Q1=MAX-MIN:SCAL1=520/Q1:X=(A2-MIN)*SCAL1+100
2180 LINE (X1,Y1)-(X,Y):X1=X:Y1=Y
2190 NEXT:NEXT
2200 Y=(160-(SP-QMIN)*SCAL)+4:LINE (100,Y)-(620,Y)
2210 LOCATE 3,3
```

```
2220 BEEP
2230 A$=INKEY$
2240 IF A$="" THEN 2230
2250 CLS:SCREEN 0:LOCATE 3,3:PRINT "DO YOU WANT TO RUN-AGAIN (Y/N)";:INPUT A$:IF
 A$="Y" OR A$="y" THEN RUN
2260 END
8000 PRINT "SPECIFY RANGE OF VALUES OF DECCELERATION--MAXIMUM,MINIMUM,INCREMENT"
:INPUT MAX,MIN,INC:PRINT "MAXIMUM =";MAX;"ft/sec/sec":PRINT:PRINT"MINIMUM =";MIN
;"ft/sec/sec":PRINT:PRINT"INCREMENT =";INC;"ft/sec/sec"
8100 PRINT "SPECIFY RANGE OF VALUES OF RELATIVE VELOCITY--MAXIMUM,MINIMUM,INCREM
ENT":INPUT RMAX,RMIN,RINC
8150 PRINT "MAXIMUM =";RMAX;"MPH":PRINT:PRINT"MINIMUM =";RMIN;"MPH":PRINT:PRINT"
INCREMENT =";RINC;"MPH"
8160 PRINT"INPUT VALUES FOR PASSING VELOCITY IN MPH":INPUT VP
8165 PRINT" PASSING VELOCITY =";VP;"MPH"
8167 PRINT"INPUT VALUES FOR  ACCELERATION IN ft/sec/sec":INPUT A1
8170 PRINT"ACCELERATION =";A1;"ft/sec/sec"
8172 PRINT"DECCELERATION(ft/sec/sec)            SMIN(ft)"
8173 PRINT"--------------------------            -----------":PRINT
8175 FOR VO = RMIN TO RMAX STEP RINC:PRINT "RELATIVE VELOCITY = ";VO;"MPH":PRINT
:FOR A2 = MIN TO MAX STEP INC
8200 GOSUB 20000
8250 PRINT A2,,"        ";SMIN:NEXT:PRINT:PRINT:NEXT
8300 PRINT"DO YOU WANT SMIN FOR ANY OTHER VALUES ?(Y/N)":INPUT Q$
8305 IF Q$="Y" OR Q$="y" THEN GOTO 8000 ELSE GOTO 2000
20000 D = D2
20100 V = (2*VP-VO)*1.47:ALPHA = (A1+A2)/2:BETA = -(A1*DELTA1 + A2*DELTA2 + A1*D
/V)
20150 GAMMA=.5*A1*(DELTA1^2)+.5*A2*(DELTA2^2)-D-(1.47*VO-A1*DELTA1)*D/V+.5*A1*(D
/V)^2
20200 B=BETA:A=ALPHA:G=GAMMA:S=(-B+(B^2-4*A*G)^.5)*V/(2*A):SMIN=S-D2:RETURN
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The two page vita has been removed from the scanned document. Page 2 of 2