

CRITERIA FOR NO-PASSING ZONES

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The concept currently used by most states for establishing and marking no-passing zones on two-lane highways legally prohibits motorists from driving on the left side of a yellow line throughout the length of a no-passing zone. The shortcomings of this concept, called the short-zone concept, are well known. 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. Furthermore, the crossing of a yellow line to complete a passing maneuver begun prior to the beginning of a no-passing zone is not an unsafe practice. An alternative to the short-zone concept is one that allows the yellow line to be crossed for the purpose of completing a passing maneuver. This concept, called the long-zone concept, prohibits the beginning of a passing maneuver in a marked no-passing zone. The purpose of this study was to determine which concept should be adopted to ensure maximum safety and comfort for the motoring public and to determine appropriate criteria and legislation to implement the recommended concept. The results of the research indicate that the long-zone concept, which legally allows the completion of a passing maneuver within a no-passing zone, should be adopted. Criteria for marking no-passing zones and a model law required to implement the concept were developed.

•DESPITE the current emphasis on building freeways, expressways, and superhighways, the bulk of the rural highway network throughout the United States is still the two-lane, two-way highway. At least 90 percent of the total rural mileage is two-lane, and much of this mileage was constructed before modern geometric design standards were established. Consequently the horizontal and vertical alignments create hazards that frequently are the indirect cause of many accidents.

A contributing factor to accidents occurring on two-lane, two-way highways is the limited sight distance, due to poor alignment, that exists on these roads. Sight distance is especially important on two-lane, two-way highways because the passing maneuver requires the use of the lane normally occupied by oncoming traffic. This constitutes a constant danger to the two-lane highway user.

To reduce this danger, traffic engineers for many years have established and marked no-passing zones with yellow paint and with "Do Not Pass" signs to warn drivers of impending sight restrictions. Laws regulating the behavior of motorists within these zones have been passed in every state to preserve the general welfare and safety of the motoring public.

Obviously, warnings of inadequate sight distances for passing on such highways should be clear, and motorists should always be certain of the meaning of such warnings. The criteria for establishment of no-passing zones and the exact meaning of such markings, however, are not uniform and can confuse motorists.

Many states have experimented with the use of additional marking devices to warn of impending no-passing zones. Perhaps the most popular device is the pennant-shaped "No-Passing Zone" sign mounted on the left side of the pavement. In 1967 three states

(Iowa, North Dakota, and South Dakota) were using this sign, and numerous other states were experimenting with it (11). Although the pennant-shaped sign is not in the 1961 Manual on Uniform Traffic Control Devices (MUTCD), it is included in the draft of a revised edition to be published in 1971.

Other devices that have been studied include a broken yellow line and semicircular blobs painted on the pavement preceding the solid yellow line. In Great Britain, large arrows have been painted on the pavement to direct traffic back to the proper lane (11).

The nature of the problem is apparent, but the solution has not been found. Usually studies have shown only a small reduction, if any, in the number of violations of the no-passing zone by the use of additional warning devices (11, 18). Traffic engineers have perhaps been addressing themselves to the wrong question. Instead of asking how to reduce or prevent violations of the no-passing zone, perhaps the question should be, Is it always dangerous to the motoring public when vehicles cross a yellow line? For example, is it dangerous to pass a farm tractor that is moving at a speed of 10 mph through a no-passing zone when it is obvious that there is ample distance free of obstructions or oncoming traffic in which to pass? Is it dangerous to finish a passing maneuver within a no-passing zone? Or, is it more dangerous to slam on the brakes when a no-passing zone is seen midway into a passing maneuver or to swerve abruptly in front of a passed vehicle to avoid crossing a yellow line?

Traffic laws that prohibit driving on the left side of an applicable yellow line throughout its length constitute what is known as the short-zone concept. An alternative to this is the long-zone concept, which prohibits the beginning of a passing maneuver within a no-passing zone.

The short-zone concept is contained within the recommended policy of the Uniform Vehicle Code (UVC) and the MUTCD. Consequently, most states have laws that incorporate the short-zone concept. Only a few states specifically allow the completion of a passing maneuver within a no-passing zone (10).

CRITERIA REVIEW

The 1961 edition of MUTCD contains criteria or warrants for the establishment of no-passing zones on two-lane and three-lane two-way highways. The criteria stipulate that, when the sight distance is less than a specified amount, a no-passing zone should be established (Fig. 1).

Changes in the MUTCD warrants were proposed in the early discussions for the new MUTCD (2). The proposals were not accepted, and the new MUTCD will contain the same minimum sight distances for no-passing zones as the 1961 edition. The sight distances are known to be inadequate for safe passing, however, and the problems associated with no-passing zones have made this topic a frequent matter of study and discussion by concerned committees of the American Association of State Highway Officials, the Highway Research Board, and the Institute of Traffic Engineers.

PURPOSE AND SCOPE OF PROJECT

The purpose of this research project was to improve the safety and efficiency of two-lane, two-way highways by improving the no-passing zone regulations and procedures. This involved two basic goals:

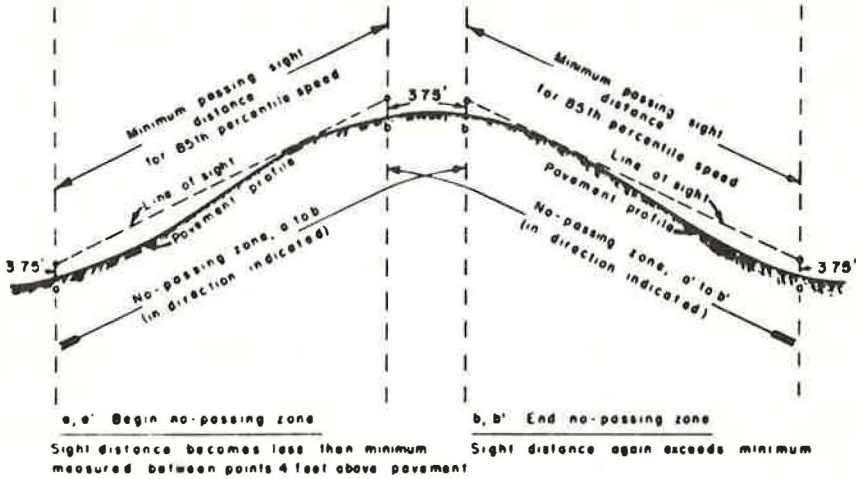
1. Determine the optimum warrants or criteria for the establishment of no-passing zones at horizontal and vertical curves on two-lane, two-way highways; and
2. Determine the necessary legislation to provide a legal and fair basis for the enforcement of restrictions on the passing maneuver, established according to these warrants.

METHODOLOGY

Passing Distance

Two distances are of primary importance in the determination of the sight distance needed to pass another vehicle: the distance traversed by the passing vehicle and the

VERTICAL CURVE



HORIZONTAL CURVE

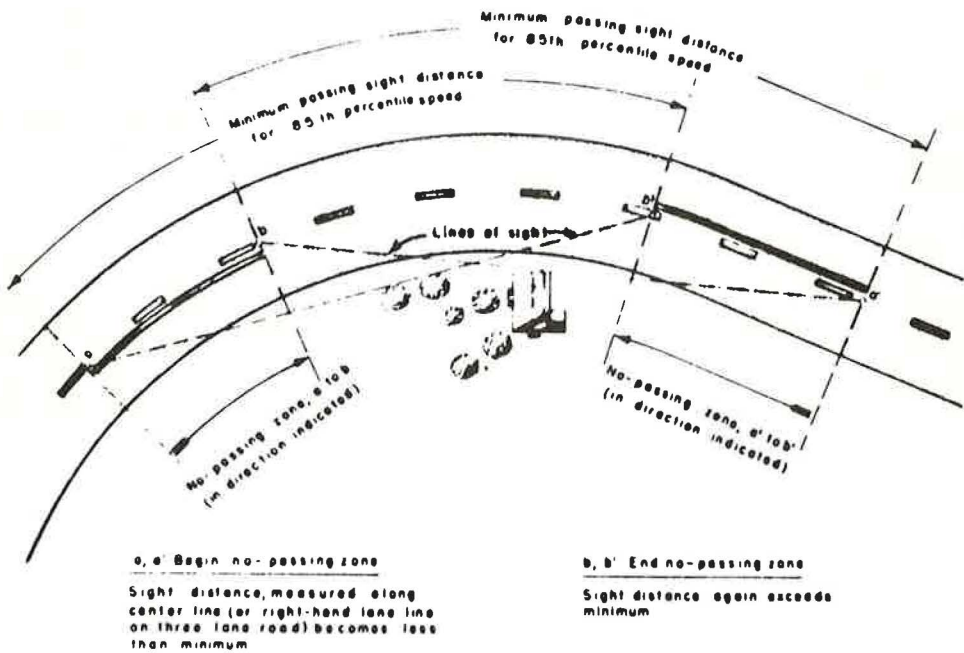


Figure 1. Determination of no-passing zones (Source: Manual on Uniform Traffic Control Devices).

distance traversed by an oncoming vehicle while the passing vehicle is in the "wrong" lane. This second distance is a function of the time needed to complete the passing maneuver, which is dependent on the speed and distance traversed by the passing vehicle.

The passing maneuver is shown in Figure 2. The first part of the passing maneuver, S_0 , is the distance required to move abreast of the overtaken vehicle. The S_0 can be disregarded when calculating the minimum sight distance required for establishing no-passing zones. During this phase of the passing maneuver it is still possible to apply the brakes and pull back into the proper lane if an obstruction or oncoming vehicle comes into view. The exact location of this point (the so-called point of no return) may vary for each individual and among individuals depending on the characteristics of the passing vehicle and the speed of the passed vehicle and/or the speed of an approaching vehicle. However, it is generally assumed that the point of no return occurs when the passing vehicle is abreast or nearly abreast of the vehicle being passed. Based initially on personal judgment and subsequently confirmed through observation, the point chosen for this project occurs where the rear bumper of the passed vehicle is abreast of the middle of the passing vehicle. This is shown as point A in Figure 2. It was assumed that if a vehicle is at or beyond this point, the driver will determine generally that it is safer and easier to continue and complete the passing maneuver than to apply the brakes and pull back into position behind the vehicle being passed.

The minimum required sight distance to be determined by this research project was considered to be the sum of the following distances, as shown in Figure 2:

S_1 = The distance traveled by a passing vehicle between the point of no return and the point where it is completely clear of the "wrong" lane used by opposing traffic.

S_2 = The distance traversed by an oncoming vehicle while the passing car occupies the "wrong" lane as previously described.

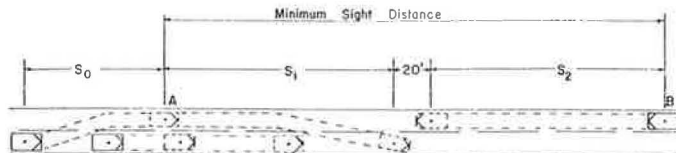
20 ft = An absolute minimum clearance distance between vehicles that would allow the two vehicles to avoid a head-on collision if the other assumptions were all met.

It was necessary to perform extensive field investigations of the passing maneuver to determine S_1 and S_2 . The distance and time taken for passing maneuvers were observed by driving a test car at various speeds over selected sections of rural highways.

Test Roads

It was assumed that there may be a difference in the length and speed of passing maneuvers on different types of roads. Some of the features of a road that might introduce a bias include horizontal and vertical alignment, width and condition of pavement, the number and length of passing zones, and the volume and speed of traffic on the road.

Obviously, it was not feasible to test the effect of all possible variables. However, one important variable—the available sight distance conditions on a road—could be tested



ASSUMPTIONS:

1. The overtaken vehicle travels at a constant speed.
2. The oncoming vehicle reaches point B when the passing vehicle reaches point A.
3. The minimum sight distance is the sum of the distances $S_1 + 20' + S_2$.

Figure 2. The passing maneuver.

if test roads of different geometric designs were chosen. For this reason three test roads, each 5 to 6 miles long and each having different visual restrictions, were chosen. Each test road had two test sections, one in each direction.

Test road S. R. 43N is a 5.53-mile long portion of State Route 43 located about 8 miles north of West Lafayette. The horizontal alignment on this stretch of road is generally straight with numerous vertical curves that restrict the sight distance on the southern end. There are five no-passing zones totaling 1.53 miles in the northbound direction and four no-passing zones totaling 1.40 miles in the southbound direction. About 28 percent of the road has a sight distance of less than 1,500 ft.

Test road S. R. 43S is a 6.20-mile portion of State Route 43 located about 7 miles south of Lafayette. There are five no-passing zones in each direction totaling 2.72 miles in the northbound direction and 2.82 miles in the southbound direction. About 40 percent of the road has a sight distance of less than 1,500 ft.

Test road S. R. 25 is a 5.4-mile portion of State Route 25 located northeast of Lafayette. The road has many hills and horizontal curves that restrict sight distance; 63 percent of the road has a sight distance of less than 1,500 ft. There are eight no-passing zones totaling 1.81 miles in the northbound direction and nine no-passing zones totaling 1.53 miles in the southbound direction.

Equipment and Personnel

The test car used throughout the experiment was a blue, 1962, 4-door Chevrolet sedan owned by Purdue University. A Stewart Warner survey speedometer with an odometer that reads to one-hundredth of a mile (52.8 ft) was mounted under the dashboard where it could be seen easily by both the driver and a passenger sitting in the front seat. A stopwatch was used to measure the time used during the passing maneuver. The same personnel, consisting of a driver and recorder, were used throughout the experiment.

Experimental Procedure

Numerous test runs were made by the test vehicle over the test roads to measure the lengths of the passing maneuvers and the time to complete a pass. The odometer was reset to zero at the beginning of each test run at the same beginning point for each test section. Therefore, the location of each passing maneuver within the test section could be plotted.

The type of vehicle and type of pass were noted for each pass. For instance, a pass made by a foreign car, pickup truck, single-unit truck, or semi-trailer truck was noted. It was noted also if the finish of a pass maneuver was hurried or forced by the presence of an oncoming vehicle or yellow line. Obviously, this was a judgment factor, but in most cases the abrupt, unnatural movement of the passing vehicle could be discerned easily.

Test runs were made only when the pavement was dry between the off-peak hours of 9:30 a. m. and 3:30 p. m. Monday through Saturday during the months of January, February, and March 1969.

The speed of the test car was maintained constant throughout each test run. Data were collected for three speedometer readings of the test car—40, 50, and 65 mph. The actual speeds of the test car corresponding to these speedometer readings were 38, 47, and 61 mph respectively. These speeds span the range of average traffic speeds that are usually found on two-lane, two-way roads during the off-peak hours.

The distance to pass was determined by taking a reading of the odometer when a vehicle was at the point of no return and taking another reading when the back wheels of the test car passed over the point where the left rear wheel of the passing vehicle crossed the centerline. The difference between these two readings gave a close approximation of the distance taken to pass.

The time to pass was determined by starting the stopwatch when the passing vehicle reached the point of no return and stopping it when the passing vehicle crossed the centerline as previously described. The decision of when the passing vehicle was at the beginning and ending points of the passing maneuver was made always by the driver

of the test car. The driver also operated the stopwatch to minimize error due to perception and reaction time. The duty of the recorder was to read the odometer on the instruction of the driver and to record the readings.

A sight distance survey was made for each test section with sight distance measured along the centerline of the highway. For this survey the height of eye and target was 3.75 ft above the highway, in accordance with MUTCD criteria.

Speed studies were also made on the test sections to determine the speed distribution of traffic. The location in each case was on a tangent, level portion of the road where there was no restriction to the passing maneuver. This type of location was picked because this is where passing maneuvers occur most frequently.

EXPERIMENTAL RESULTS AND ANALYSIS OF DATA

General Observations

More than 3,000 miles were driven to collect data on the length and speed of the passing maneuver. Information on 915 passing maneuvers was recorded over a period of 3 months. The locations of no-passing zones, passing maneuvers, and sight distance were plotted for each of the six test sections. A portion of one of these test sections is shown in Figure 3.

There were frequent violations of the no-passing zones; i. e., the passing vehicle crossed an applicable yellow line at some point. There were 104 known violations (12 percent of all passes) of which 85 or 82 percent were passing vehicles returning to the right lane after the beginning point of a no-passing zone. Most of the remaining violations occurred when a vehicle initiated a passing maneuver prior to the end of a no-passing zone, especially when the passed vehicle was traveling at a slow speed or where the no-passing zone had been unduly extended.

It was also observed that traffic did not pass where sight distance was low, whether marked or unmarked. It appears that most drivers do not make a passing maneuver judgment only on the basis of the absence of an oncoming vehicle and the absence of a yellow line. If drivers cannot see what they consider to be a safe distance in front of them, they will not initiate a passing maneuver even though there may be no yellow line to warn them. Such a situation occurred most noticeably on test road S. R. 43N in the vicinity of station 1.4. In this area there is a horizontal curve that is not marked by a yellow line; yet not a single pass was completed at any speed in this area. The motorists did not think that they could see far enough to make a safe passing maneuver (maximum sight distance at one point is only 1,100 ft).

Data Classification

The types of passing vehicles were separated into four groups: automobiles, pickups, single-unit trucks, and semi-trailer trucks. The number of passing maneuvers completed by pickups, trucks, and semi-trailer trucks totaled 67, 24, and 27 respectively for all types of passing maneuvers and on all roads. A statistical analysis comparing the length and speed of passing maneuvers by these various vehicles was not undertaken because there were not enough observations to warrant conclusions. However, from inspection of the mean lengths and speeds of the passing maneuvers (Table 1) it is evident that criteria cannot be evolved for all types of vehicles without increasing the lengths of no-passing zones beyond that which would be reasonable or tolerable. Therefore, the statistical analysis was confined to passing maneuvers of automobiles only.

The types of passes were separated into four basic categories. An "accelerative pass" was a pass by a motorist who for one reason or another slowed down to the speed of the test car and followed behind the test car before initiating the passing maneuver. A "fly pass" was a pass by a motorist who did not slow down to the speed of the test car but passed the car "on the fly."

"Voluntary return" is a term used to describe the completion of a pass by a motorist when there was nothing forcing him to return to the right-hand lane. A "forced return" indicated that the motorist was forced to return to the right-hand lane by the presence of an approaching vehicle or the beginning of a no-passing zone.

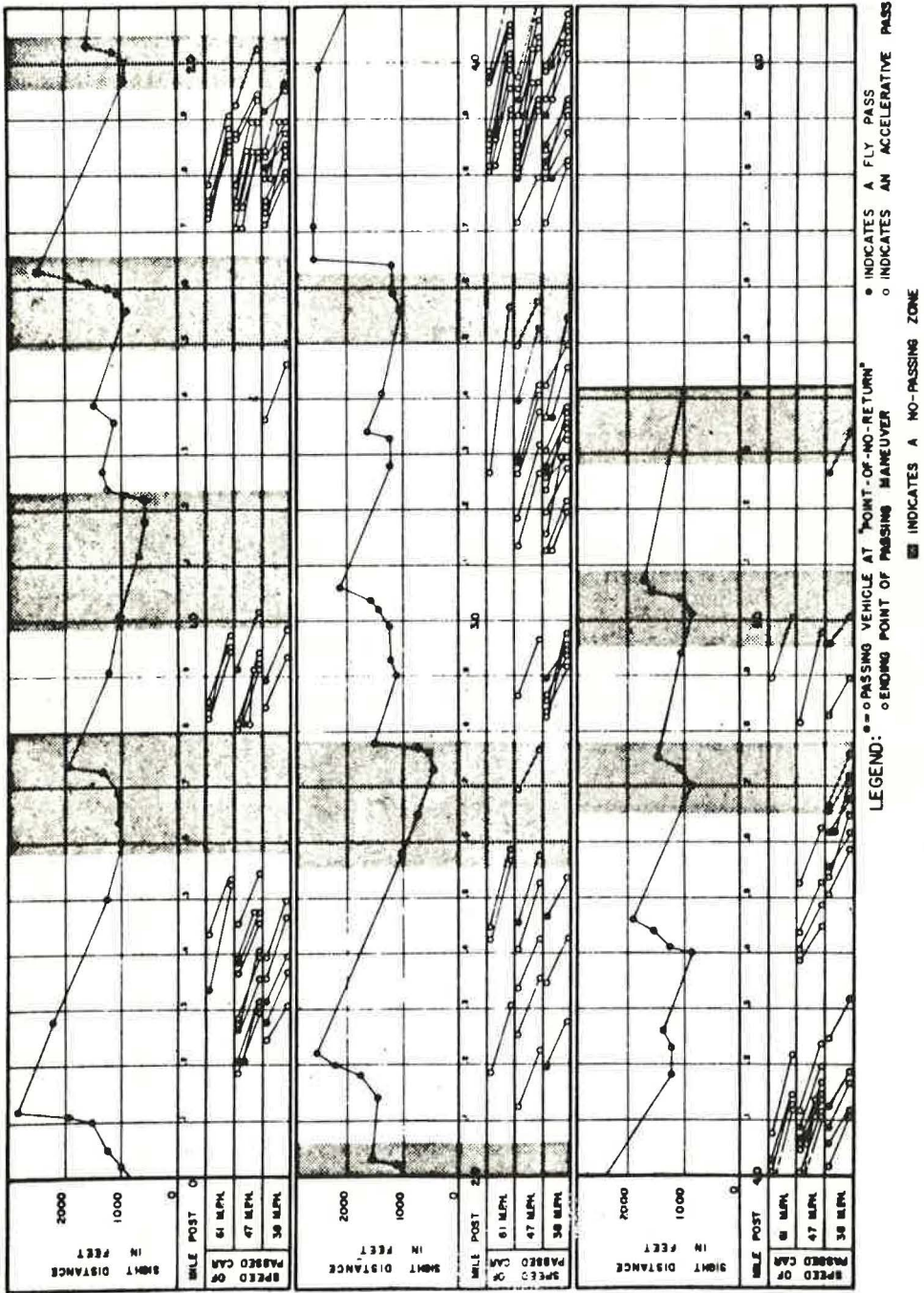


Figure 3. Location of passing maneuvers—S.R. 25 southbound.

TABLE 1
MEAN LENGTH AND SPEED OF PASSING MANEUVERS

Type of Pass	Speed of Passed Vehicle (mph)	Type of Passing Vehicle							
		Automobiles		Pickup Trucks		Single-Unit Trucks		Trailer Trucks	
		Dist. (feet)	Speed (mph)	Dist. (feet)	Speed (mph)	Dist. (feet)	Speed (mph)	Dist. (feet)	Speed (mph)
Accelerative	38	496	49.6	531	48.1	666	48.2	906	42.7
Voluntary	47	618	56.9	693	54.6	642	52.0	965	52.2
Return	61	808	71.2	—	—	—	—	—	—
Flying	38	449	55.4	496	50.4	—	—	—	—
Voluntary	47	567	63.3	513	58.8	—	—	—	—
Return	61	619	74.4	—	—	—	—	—	—
Accelerative	38	339	49.1	—	—	—	—	—	—
Forced	47	430	61.3	—	—	—	—	—	—
Return	61	572	70.9	—	—	—	—	—	—
Flying	38	302	—	—	—	—	—	—	—
Forced	47	403	—	—	—	—	—	—	—
Return	61	—	—	—	—	—	—	—	—

Test Results

The mean length of passing maneuvers is given in Table 1 for the four types of passes: accelerative-voluntary return, flying-voluntary return, accelerative-forced return, and flying-forced return. Of these four types of passes, the mean length of the accelerative pass with a voluntary return by automobiles was consistently longer when passing the test car at speeds of 38, 47, and 61 mph than for the other types of passes. This is shown in Figure 4.

The mean speeds of passing vehicles of the various types for the four types of passing maneuvers are also given in Table 1. A plot of the mean speeds of the passing cars versus the speeds of the passed cars for three types of passing maneuvers is shown in Figure 5. From this it was apparent that the speed of passing vehicles in an accelerative type of pass with a voluntary return was lower than for other types of passes.

It was concluded, therefore, that both the speed and the length of an accelerative-voluntary return type of pass were most critical. Also, this type of pass occurred more

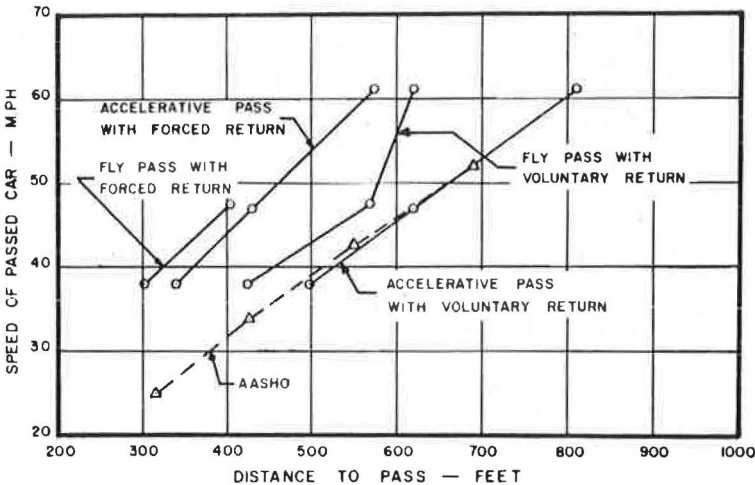


Figure 4. Length of passing maneuvers.

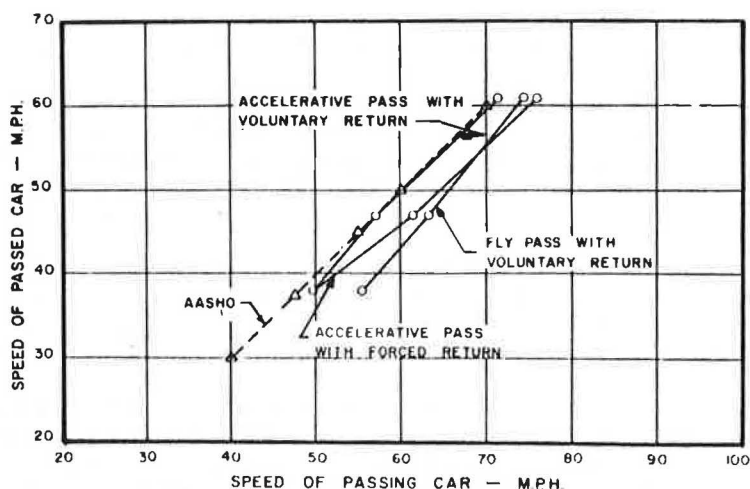


Figure 5. Speed of passing maneuvers.

frequently than any other. Therefore, the minimum sight distance requirements were based on the accelerative-voluntary return type of pass.

A comparison of the study results with AASHO criteria is shown in Figures 4 and 5. The dashed lines represent the AASHO criteria as taken from A Policy on Geometric Design of Rural Highways (4).

According to AASHO, "Speeds of overtaken vehicles were approximately 10 miles per hour less than speeds of passing vehicles." This was substantiated in this project and is shown in Figure 5. The dashed line in Figure 5 is a plot of the speed of the overtaken or passed car versus the speed of the passing car, assuming that the speed of the passing car is 10 mph faster than the passed car. As can be seen, the plot of the mean speed of accelerative-voluntary return type of pass nearly coincides with the AASHO plot.

Similar values taken from AASHO (4) were plotted by subtracting 10 mph from the average passing speed to obtain the average speed of the passed car. This plot, shown by a dashed line in Figure 4, falls very close to the plot of the mean length of the accelerative-voluntary type of pass obtained in this research project. The close proximity of these plots is coincidental. The AASHO plot is based on an acceleration pass with a forced or hurried return (4).

The AASHO data were also obtained from a study of selected no-passing zones by observing passing maneuvers at each from a fixed observation post (5). The procedure used in this research project made it possible to collect data under varying geometric conditions over test roads totaling about 17 miles in length. The AASHO data for the range of 60 to 70 mph for passing vehicles (corresponding to 50 to 60 mph for passed vehicles) is also based on extrapolated values. The results of this research, in addition to substantiating the accuracy of the AASHO data, suggest use of a different type of pass as the basis for no-passing criteria and extends the results to varying geometric conditions and higher passing speeds.

Statistical Analysis

The primary purpose of the statistical analyses was to determine if there was a significant difference in mean length to pass on various test roads and at various speeds. Through these analyses it was possible to determine what effects these variables had on the mean lengths and speeds and to place confidence limits on the test results.

An analysis of data within each test road concluded that overall it could be stated with a confidence level of 95 percent that there was no significant difference in the lengths

of the accelerative-voluntary return type of passing maneuver in one direction over the other for a given test road. Test data taken in both directions were, therefore, combined.

Further analysis indicated that the individual test roads had an insignificant effect on the length of the passing maneuver. A maximum difference of mean passing distance between roads within the same speeds for the passed vehicle of only 0.015 mile or about 80 ft was found. On the other hand, the length of the passing maneuver increased significantly as the speed of the overtaken car increased, with a maximum difference of about 315 ft.

Throughout the study, it was the intent to be conservative. Passing maneuvers that were forced and subsequently much shorter—at least 150 ft (Fig. 4)—than those with a voluntary return were classified separately. On the other hand, passes by motorists who were obviously lazy in returning to the proper lane were included in the voluntary return classification.

It was the intent of this research project to develop criteria that could have a broad application to all roads. To do this, however, it would have been necessary to select a random sample of test roads throughout the United States. Therefore, the criteria, which were developed by combining data on all three test roads in this study, are theoretically applicable only to roads in the central area of Indiana. However, the statistical analyses indicate that the effect of roads on the length and speed of passing maneuvers is minimal. Therefore, it is suggested that the recommended criteria are sufficiently representative and conservative to be applicable to all roads.

Confidence limits on the mean length and speed of the passing maneuver were computed to provide an idea of how close the computed mean is to the true mean. One can be 95 percent confident that the true means of the length and speed of passing maneuvers are between the upper and lower limits given in Tables 2 and 3. The upper limit is the most important from a safety viewpoint. As can be seen in Table 2, the greater the speed of the overtaken car is, the greater is the variation in the length of the passing maneuver. The upper confidence limit at 61 mph for all roads combined was still only 0.007 mile (37 ft) longer than the mean length. From this it seems apparent that the test results are well within the accuracy necessary to establish safe criteria for no-passing zones.

Speed of Traffic on Test Roads

The speed studies showed that the mean speeds of traffic did not differ by more than 2 mph between test roads. The speed distribution curves indicated that about 70 percent of the traffic (15th to 85th percentile) traveled in a speed range of about 20 mph (48 to 68 mph). About 50 percent traveled within a range of ± 5 mph of the mean speed of traffic.

TABLE 2
CONFIDENCE LIMITS OF THE MEAN DISTANCE TO PASS

Speed of Passed Car (mph)	Road	Number of Observations	Variance	Standard Deviation	Mean Distance (miles)	95 Percent Confidence Limits	
						Upper	Lower
61	S. R. 43N	41	0.00129	0.036	0.162	0.173	0.151
	S. R. 43S	40	0.00117	0.034	0.152	0.163	0.141
	S. R. 25	38	0.00173	0.042	0.146	0.157	0.135
	All	119	0.00141	0.038	0.153	0.160	0.147
47	S. R. 43N	79	0.00079	0.028	0.120	0.126	0.114
	S. R. 43S	61	0.00092	0.030	0.119	0.127	0.111
	S. R. 25	63	0.00077	0.028	0.112	0.119	0.105
	All	203	0.00083	0.029	0.117	0.121	0.113
38	S. R. 43N	58	0.00068	0.026	0.101	0.108	0.094
	S. R. 43S	60	0.00055	0.023	0.089	0.095	0.083
	S. R. 25	66	0.00049	0.022	0.092	0.097	0.087
	All	184	0.00058	0.024	0.094	0.098	0.090

TABLE 3
CONFIDENCE LIMITS OF THE MEAN SPEED OF THE PASSING VEHICLE

Speed of Passed Car (mph)	Road	Number of Observations	Variance	Standard Deviation	Mean Speed (mph)	95 Percent Confidence Limits	
						Upper	Lower
61	S. R. 43N	40	13.4276	3.6644	69.38	70.55	68.21
	S. R. 43S	39	17.7997	4.2190	70.78	72.14	69.42
	S. R. 25	35	13.6759	3.6981	71.63	72.90	70.36
	All	114	15.6016	3.9499	70.55	71.28	69.82
47	S. R. 43S	30	15.5175	3.9392	55.74	57.20	54.27
	S. R. 25	55	26.4066	5.1387	57.99	59.39	56.60
	All	85	23.5114	4.8489	57.20	58.24	56.15
38	S. R. 43S	31	26.8275	5.1795	48.60	50.50	46.70
	S. R. 25	52	22.2244	4.7143	50.57	51.89	49.26
	All	83	24.5611	4.9559	49.84	50.92	48.75

The frequency at which a vehicle will be passed is a function of its speed. Considerable passing of vehicles traveling less than the mean speed will likely occur while fewer vehicles traveling above the mean speed will be passed. Approximately 75 percent of the passing maneuvers, in fact, were noted to be of vehicles traveling at the mean speed or less. Therefore, it was decided to base no-passing zone criteria on the sight distance required to pass an automobile traveling at the mean speed of traffic. It must be assumed that drivers who pass a vehicle traveling above the average speed of traffic will realize the danger associated with this pass decision and will exercise appropriate safety precautions.

The speed of the oncoming vehicle (which may be out of sight) is an unknown quantity to the driver who is about to pass another vehicle. To base the minimum sight distance requirements on the average speed of oncoming vehicles might be dangerous because half of the approaching vehicles would be traveling faster than the average speed. Therefore, it seems logical to choose a speed that would include most of the oncoming traffic. Obviously, it is not practical to design for the 100th percentile speed. Therefore, it is simply a matter of judgment as to which speed to choose. The decision is not too critical, however, because the difference in speed between the 85th and 90th percentile, for instance, would be only about 2 mph.

Because the 85th percentile speed is often used in traffic engineering, this value was chosen for the speed of oncoming traffic in this study. The 85th percentile speed varied between 5 and 7 mph above the average speed on the test roads. This is also confirmed by annual speed studies conducted by Purdue University (1). Therefore, a speed of 7 mph faster than the average speed of the traffic was used as the speed of the oncoming vehicle.

Minimum Sight Distance

The minimum sight distance required to safely pass another vehicle is the sum of three distances, as follows: S_1 , the distance to pass; S_2 , the distance traveled by an oncoming car during that pass; and S_3 , a clearance between the passing vehicle and the oncoming vehicle. The distance needed to pass and the speed of the passing vehicle have been established and are shown in Figures 4 and 5. Values were taken from these figures for each incremental speed, and the duration of the passing maneuvers could be calculated from the distance and speed of the passing maneuvers. From this the distance S_2 was calculated.

The total resulting minimum required sight distance is shown in Figure 6. The dashed line indicates extrapolated values outside the limits of this study.

Comparison With MUTCD Criteria

The sight distance criteria both from the 1961 edition of MUTCD and from an early draft of the proposed new MUTCD are shown in Figure 6. The MUTCD minimum sight

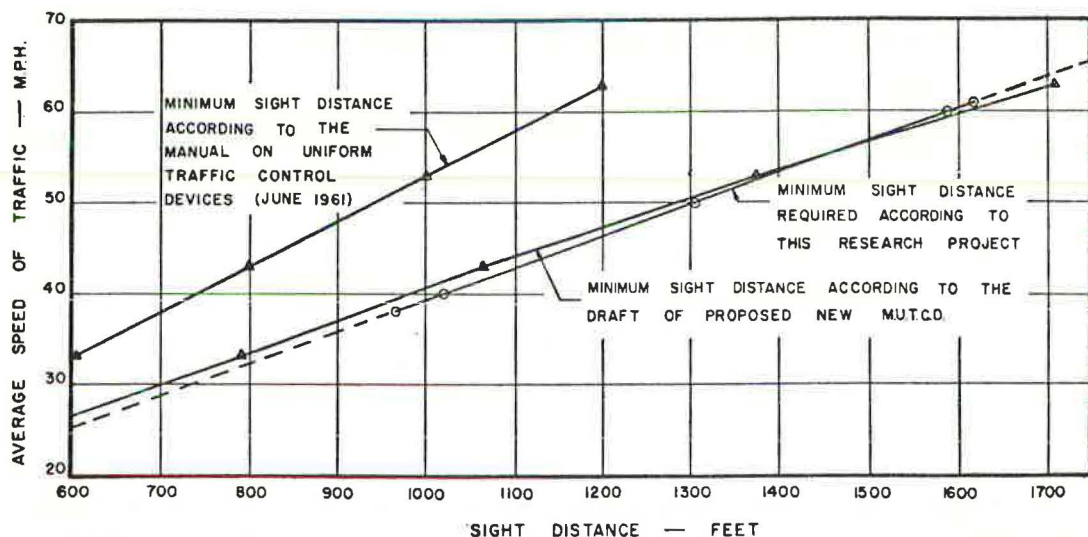


Figure 6. Minimum sight distance required to pass.

distances are stated for the 85th percentile speed of traffic, whereas the minimum sight distances developed in this research project are for average speed of traffic, i.e., the speed of the passed vehicle. As noted previously, the 85th percentile speed of traffic on two-lane, two-way state arterial highways in Indiana is approximately 7 mph faster than the average speed. As a consequence the minimum sight distances required by the MUTCD were plotted in Figure 6 with speeds 7 mph slower than the stated 85th percentile speeds for comparison with the average speeds used in this study. It is apparent that the proposed, but later rejected, MUTCD minimum sight distances coincide with the distances established in this research project.

The proposed new MUTCD draft also is associated with the same regulation as the 1961 MUTCD recommendations concerning the crossing of yellow lines. It is recommended in the MUTCD that an applicable yellow line not be crossed at any time. In effect this extends each no-passing zone by several hundred feet.

As an example, assume a motorist begins to pass a vehicle that is traveling at a speed of 60 mph and just as his vehicle reaches the point of no return he sees a no-passing zone sign ahead. At that moment he has the choice of braking the car to fall back into line or continuing the pass. Assuming that the pass is normal and average as defined in this study, he will need to be approximately 800 ft from the no-passing zone to be able to complete the pass and avoid crossing the yellow line (Fig. 4). Ordinarily a no-passing sign can only be seen about 300 to 400 ft away, and a yellow line is even less visible. The motorist would most likely be trapped into crossing the yellow line and would thereby become an offender of the law.

Many motorists are aware of the law, and rather than continue a normal passing maneuver they swerve abruptly in front of the passed car to avoid crossing the yellow line. This dangerous movement was observed frequently during this experiment. It was obvious that such a maneuver did not contribute to the safety and pleasure of either the passed or passing motorists and their passengers.

Minimum Distance Between No-Passing Zones

The minimum distance between no-passing zones that should be allowed without making one continuous zone is stipulated in the 1961 MUTCD as 400 ft. The early proposals

for the new MUTCD would have increased this distance, especially at higher speeds, in line with requirements of the short-zone concept. If this minimum distance were increased, the effect would be to increase further the length of no-passing zones and decrease the legal opportunities to pass slow-moving vehicles. Consequently, capacity would be reduced and the frustration of motorists following slow-moving vehicles would be increased.

The distance required to initiate a passing maneuver was investigated. Assuming that the initial phase of the passing maneuver is equal to one-third of the total distance to pass (as assumed by AASHO), one-half of the distance S_1 as measured in this study would correspond to the length of the initial phase. This distance represents the average distance that a motorist would need to accelerate and arrive at the point of no return if he were watching and waiting for the end of the no-passing zone to appear. These distances were found to vary from 190 ft at 30 mph to 460 ft at 70 mph. It appears that the existing 400-ft minimum distance is adequate and could even be reduced for slower speeds under the long-zone concept.

CONCLUSIONS AND RECOMMENDATIONS

The most obvious conclusion reached during this research project was the inadequacy of the short-zone concept currently utilized by nearly all of the states. The large number of motorists who illegally cross an applicable yellow line should not all be classed as law offenders. The law is clearly inconsistent with the physical capabilities of the driver and vehicle. Consequently the law cannot always be obeyed. Such a situation can only contribute to disregard of laws in general and utter frustration for the unfortunate few who are apprehended.

The long-zone concept allows the completion of a passing maneuver across the yellow line. If the motorist is so far into the maneuver that a severe braking action is required to stop the maneuver in order to avoid crossing the barrier line, the motorist is allowed to continue the maneuver, for by design such as continuation would be safe. The beginning of a no-passing zone becoming visible during a passing maneuver would, however, provide a cautionary warning similar to the yellow caution light in traffic signals. The approach of an applicable no-passing zone during a passing maneuver should demand safe and reasonable action on the part of the motorist. Enforcement against violators requires no more judgment on the part of law enforcement personnel than the enforcement of traffic signal regulations.

There is another important aspect to the problem that cannot be ignored. Uniformity of traffic laws and criteria throughout the nation is a necessary and desirable goal. It is true that several years will be required before all states would or could change their laws to adopt the long-zone no-passing concept. However, the shortcomings of the short-zone concept are well known, and many individuals will not be convinced that their state should adopt a law that is known to be unsatisfactory. But most important, many motorists either are unable or do not want to comply with the short-zone concept, as evidenced by the large number of violations of no-passing zones in this study and others (11, 18).

The logical alternative is to allow the applicable yellow line to be crossed for the purpose of finishing a passing maneuver that was well under way before the beginning of a no-passing zone was reached. This can be achieved through the universal adoption of laws and criteria to implement the long-zone concept. Criteria and legislation that might be adopted to implement the findings of this research are given in the following. The major changes in the wording of the Manual on Uniform Traffic Control Devices and Uniform Vehicle Code suggested are italicized (except the tabulated values which are also changes).

Criteria for No-Passing Zones at Curves (MUTCD)

... Where centerlines are installed, a curve warrants a no-passing zone and should be so marked where the sight distance is equal to or less than that listed below for the prevailing (off-peak) average speed:

Average Speed, Off-Peak (mph)	Minimum Passing Sight Distance (ft)
30 and under	750
31 to 35	900
36 to 40	1,050
41 to 45	1,200
46 to 50	1,300
51 to 55	1,450
56 to 60	1,600
61 to 65	1,750
66 to 70	1,900

The following table indicates the minimum distance between no-passing zone markings necessary for initiation of a passing maneuver:

Average Speed, Off-Peak (mph)	Minimum Distance Between Zones (ft)
30 and under	250
31 to 40	300
41 to 50	350
51 to 60	400
61 to 70	450

Where these minimum distances cannot be provided, the no-passing zone markings should be connected to form one continuous zone.

Legislation (UVC)

The following change in the Uniform Vehicle Code, Section 11-307, No-Passing Zones, is suggested so that the long-zone concept may be incorporated into no-passing zone legislation:

Model Law—No-Passing Zones

- (a) (No change from current wording.)
- (b) Where signs or markings are in place to define a no-passing zone as set forth in paragraph (a) no driver shall at any time drive on the left side of the roadway within such no-passing zone or on the left side of any pavement striping designed to mark such no-passing zone *except for the purpose of safely completing a passing maneuver begun prior to the beginning point of such a zone.*
- (c) (No change from current wording.)

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DISCUSSION

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This report provides much-needed research for reevaluating pavement-marking law and practices. As Figure 6 shows, the authors' recommended minimum passing sight distances closely match those originally proposed for the 1970 edition of the Manual on Uniform Traffic Control Devices. However, because supporting research was not available at the time, the proposal was not accepted by the National Joint Committee. This study produced needed up-to-date data on current passing practices of drivers.

In discussing the concepts for marking no-passing barriers, the authors describe the short-zone concept as being based on the legal precept that driving to the left of any portion of the no-passing barrier is illegal. They describe the long-zone concept as being based on the legal precept that the passing maneuver legally may be completed by crossing the yellow barrier. A third concept also merits evaluation—that the no-passing barriers be advisory only and be used only as guides for enforcement purposes. In this case, the passing prohibition would be enforceable only at those locations where the proper regulatory signs have been installed. The logic for this concept is that pavement markings, because they are subject to wear and are hard to see during inclement weather, are not suitable devices for enforcement purposes. The standard "Do Not Pass" regulatory sign would be required for this purpose.

Perhaps the item that should be examined more closely, in regard to making a change from the present short-zone concept, is the degree of hazard in initiating a passing maneuver in those areas just in advance of the beginning of the no-passing barrier.

The authors indicate that we have a problem in the manner of marking no-passing zones. I concur with their conclusions that the long-zone concept is a safer legal base on which to design the no-passing zones. It is interesting to note that the Uniform Vehicle Code position was adopted in 1956. Since then the vehicle and, to a degree, the highway have undergone significant changes. An indication of the seriousness of the passing problem is the fact that between 18 and 21 percent of the fatalities on rural highways involve two vehicles traveling in opposite directions. Use of these values should not be misinterpreted. We cannot presume that they were all passing accidents. Included in this percentage are all head-on crashes, including those in which one vehicle crosses the centerline for reasons other than to pass. It also includes wrong-way driving on divided highways. Fortunately, this percentage has decreased in recent years. A part of this is undoubtedly due to the increasing share of the traffic using the Interstate and other limited-access facilities. On the other hand, the increasing use of the Interstate System requires that the guidance we give the motorist off the Interstate System be the best possible because fewer and fewer drivers have learned to cope with the passing situation on two-lane highways.

If motorists had accurate depth perception and could estimate the speed of an approaching vehicle, perhaps only a minimum-length sight distance marking would be required to permit a driver to make a safe passing maneuver. Farber and Silver (20) indicate that drivers are fairly competent at judging the distance element but are very poor at determining approaching vehicle speed. This becomes critical when the passing driver has begun his maneuver and the oncoming vehicle suddenly appears in sight.

Two new ideas have been proposed by the authors. The first is the development of a valuable new term, point of no return, to describe a long-held concept. The other is the use of the average speed of traffic as the speed of the passed vehicle and as the basis on which no-passing zones should be marked. I subscribe to the point-of-no-return concept and believe that most drivers operate on that assumption. However, there is some question whether the point of no return is truly the point at which slowing to fall back behind the passed vehicle is more difficult or more hazardous than completing the pass. It is entirely possible that the total closing distance traveled by opposing vehicles while the passing vehicle is braking from the point of no return to fall back behind the passed vehicle would be less than the distance traveled by both vehicles while completing the passing maneuver. This, of course, would be dependent on (a) the passed vehicle maintaining its speed and not slowing to assist the passing vehicle in completing his maneuver, (b) the acceleration characteristics of the passing vehicle, and (c) the actual speed of the passed vehicle. To be valid, this comparison should be based on a forced return rather than a voluntary return. Research similar to that used by the authors for this paper would be helpful to provide the data needed for this comparison.

When forced to return to the right-hand lane in a limited distance because of the pavement marking, either drivers will make the return regardless of the dangerous "cutting-in" process, or they may ignore the legal regulation and enter the no-passing zone to the left of the no-passing barrier marking. The more desirable alternative would certainly be the latter, even though it tends to diminish a driver's respect for the barrier. The use of the barrier line concept as recommended by the authors (permitting the completion of the passing maneuver over the barrier line) would appear to reduce the attention the driver must give to markings. This would permit his concentration on the possible appearance of an opposing vehicle on the road ahead. The 12 percent violation of no-passing barriers suggests that many drivers are relying on their judgment in passing rather than on the absence or existence of a barrier line. The driver who endangers himself or others by trying to comply with the legal statute by "cutting in" probably creates a greater hazard than the one who violates the short-zone concept.

According to the averages developed by the authors, the traveled distance required for a forced return is about 30 percent shorter than for a voluntary return (Table 1). Inasmuch as safety is the paramount consideration in marking no-passing zones, we should look at the potential hazard of the present marking practices and compare it with that proposed by the authors. Because of the high correlation between the authors' findings and the data developed by AASHO for design of two-lane highways, AASHO def-

initions can be used for this comparison. The AASHO term d_4 (the distance traveled by the opposing vehicle) is considered to be two-thirds of d_2 and equal to the distance traveled by the passing vehicle while completing its maneuver. The sum of these two values relates very closely to the minimum sight distance +20 ft as used by the authors ($S_1 + S_2 + 20$ ft). Figure 5 compares these values with the values used in the 1961 Manual on Uniform Traffic Control Devices and the authors' recommendations. It appears that the current practice (1961 Manual) does not provide an adequate safety factor for completing the pass. On the other hand, the proposal of the authors would provide a comfortable margin of safety. Figure 6 compares the present practice with $\frac{7}{10}$ of the values for the voluntary return; i. e., $0.7 (d_4 + \frac{2}{3} d_2)$. Examination of Table 1 indicates that passing distances with a forced return approximate $\frac{7}{10}$ of the passing distances with voluntary returns. This seems to indicate why the current practice is not completely unworkable. Thus, it would appear that the current practice assumes a forced return.

Another item that needs further investigation is the distance between the passing vehicle and the approaching vehicle at which the passing driver begins to feel uncomfortable and forces a return to the right-hand lane. In Figure 2, the 20-ft distance between driver positions selected as an absolute minimum between the passing and the approaching vehicles may be a little short. It is considerably less than the distance in the AASHO Policy on Geometric Design for Rural Highways, and no indication was given of how this distance was selected. For design, the AASHO policy uses a clearance distance varying according to the speed of the two approaching vehicles, ranging from 100 ft at 30 mph to 250 ft at 53 mph. In a study performed in Saskatchewan (21), a distance of 40 ft was used for the clearance. From my viewpoint, even 40 ft appears less than most drivers would tolerate and tends to result in erratic maneuvers.

In terrain where no-passing zones are frequent, the use of the short-zone concept requires the inclusion of criteria for connecting adjacent zones when time to initiate and complete a pass does not exist. The authors have recommended values ($\frac{1}{2} S_1$) for minimum distances between no-passing zones. I agree that, under the concept that permits completion of a passing maneuver once initiated, the use of much shorter distances between successive no-passing zones is appropriate. Because the driver is aware that the end of the zone is being approached, the use of $\frac{1}{3} d_2$, or perhaps even a shorter value, would allow safe completion of the passing maneuver.

This sampling of the passing practices of drivers improves our understanding of the problem. What is still unknown is the extent to which drivers place themselves in danger when performing a passing maneuver. If we are to attempt to place a barrier line at a given location on the basis of a single speed representing approaching traffic and a single speed for the traffic being passed, it undoubtedly will not fit all situations and just as obviously will not be suitable for precise interpretation by enforcement personnel. The recommendation of the authors proposing use of median speed for calculating the length of no-passing zones provides a desirable factor of safety for marking existing highways. For newly constructed two-lane highways, markings must be based on assumed speeds. Perhaps the design speed should be assumed to be the 85th percentile, and the markings should be based on a median speed 7 mph slower. As an example, for initial markings, use an assumed median speed equal to 7 mph slower than the design speed of the new highway. As a compromise between the short-zone, rigid-enforcement concept and the advisory concept, the authors' proposal seems appropriate.

This research project provides a nucleus and, as such, is a valuable contribution to the engineering field. The authors are to be commended for developing a relatively simple research procedure. It would be desirable for others in different parts of the country to use the technique to add to the data base and to increase the usefulness of the recommendations.

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Edward F. Kearney, National Committee on Uniform Traffic Laws and Ordinances

One of the principal conclusions of the paper is that our general driving rules should be changed to allow a motorist to complete a passing maneuver after he has entered an area designated by signs or markings as a no-passing zone. In my opinion, the information presented in the paper does not support that conclusion. Indeed, the existing rule requiring passing drivers to return to the right side prior to reaching the zone is the one more in accord with the authors' research findings.

Specifically, the paper indicates that of 915 passing maneuvers observed at three locations, drivers crossed the yellow line in only 12 percent of the cases. If we assume that this 12 percent refers to crossing the line at the conclusion of a pass upon entering a zone, it suggests that 88 percent of the passes were completed without using space on the left side of the roadway within a no-passing zone. This does not support statements appearing at several points in the paper suggesting that there were frequent violations of the no-passing zones, that a high percentage of motorists crossed the yellow line, and that many motorists either were unable or did not want to comply with the "short-zone" concept as evidenced by the large number of violations.

In 1968, the National Committee on Uniform Traffic Laws and Ordinances rejected, by a vote of two to one, a proposal to allow completion of a pass within a no-passing zone. One of the principal reasons for this rejection was that the requirement to return to the right side prior to reaching the zone is both well understood and complied with. The paper's revelation that at least 88 percent of the drivers passed without improper use of the left side of the roadway within a no-passing zone is very reassuring and completely justifies the National Committee's decision. Also the 12 percent reported in this study as not negotiating a timely return to the right side may be high because "passes by motorists who were obviously lazy in returning to the proper lane were included" and "passing maneuvers that were forced" may have been excluded and because the paper suggests that the zone markings may have been unduly extended.

At this point it may be well to consider the purpose of a no-passing zone. I think its purpose is to indicate an area on a two-lane, two-way roadway where driving on the left during any portion of a passing maneuver is so highly fraught with peril it must be prohibited. Any other statement of its purpose does not make sense because other rules of the road require driving on the right and prohibit any form of passing that would interfere with the safe operation of any overtaken vehicle or any vehicle approaching from the opposite direction.

The suggestion that passes can be safely completed within a no-passing zone indicates a lack of appreciation as to why such areas exist. Further, the suggestion that safe passes be allowed to be completed within a zone is meaningless because it is already required that all passes be accomplished without interfering with oncoming and overtaken vehicles. In addition, not only does the paper advocate allowing completion of a pass begun well before the commencement of a zone, the draft of the proposed model law would allow driving on the left side of a zone to complete a passing maneuver begun a few feet before the zone. Another curious feature of the draft is that it would not allow completion of a pass in an unmarked zone (such as within 100 ft of an intersection) but would allow such completion if the zone were marked.

Allowing a driver to complete a pass within a no-passing zone is a contradiction in terms. Although some people may think that "passing" includes only the act of actually passing another car, courts hold that "passing" includes moving left, overtaking, passing, or returning to the right side for the purpose of passing a moving vehicle. Because the paper suggests banning only the first of these four elements within a no-passing zone, it would allow the other three—hence the legal contradiction.

It seems to me that advocates of the "long-zone" theory of designating unsafe passing areas think that extending their length is necessary or desirable for advance notice of the existence of the zone. I disagree with this contention because such zones do not exist in isolation. They generally exist because of a hill, curve, intersection, or some other condition that makes passing unsafe. Usually, advance notice of these conditions is provided by appropriate warning signs. Also, signs placed on the left and right sides of the highway can convey sufficient advance notice of the zone without extending its

length. One also should question the practicality of giving advance notice by paint on a level roadway.

Clearly, a driver passing to the left of another car on a two-way roadway has a heavy burden to discharge because he may not interfere with the safe operation of a vehicle approaching from the opposite direction nor the one being overtaken or passed. Safe and efficient highway travel demands that a passing driver return to the right side of the roadway prior to reaching the zone. The paper does not justify changing these rules or telling 110 million drivers that they may lawfully complete a pass once inside a no-passing zone. The better rule of the road is and should remain: Return to the right side prior to reaching the zone.

AUTHORS' CLOSURE

We thank each of the discussers for his thoughtful comments. Special appreciation is due Mr. Foley for his complimentary remarks about our research and findings. We heartily agree that additional research, especially concerning accidents involving vehicles that initiate a pass just prior to a no-passing zone, would be advisable.

One of the discussers suggests that the short-zone regulation is well-obeyed by motorists and that the 12 percent violation statistic is proof of this. The fact is, however, that most passing maneuvers cannot be in violation of the law because of the locations on the road where passing maneuvers generally occur, i. e., where oncoming no-passing zones do not exist. Further, a very high percentage of those maneuvers that occur where there is a chance to be in violation are in violation. We cannot agree, therefore, that the data substantiate good observance of the present no-passing laws.

The same discussor also claims that to be to the left of a no-passing line at any time is "highly fraught with peril." This is not true for the greatest part of every passing situation. A vehicle that is completing a passing maneuver will require only about 100 ft to return safely to the right lane, not the total distance indicated as not available by the no-passing line. Contrary to what the short-zone law states, the no-passing line does not indicate that it is unsafe to be to the left of the line. It means only one thing: At every point along a given line a specific sight distance is not available, and therefore, in the normal passing situation, if you start a passing maneuver at this point you do not have adequate sight distance. The no-passing line does not mean that if you are halfway through, three-quarters of the way through, or nine-tenths of the way through the pass you cannot safely complete the maneuver. It is only applicable to the beginning of the passing maneuver. The completion of a pass initiated even only a few feet prior to a no-passing zone is a safe maneuver; it does not interfere with oncoming or overtaken vehicles if the no-passing zones are correctly marked. (They are not correctly marked under the short-zone concept.) On the other hand, a vehicle in the left lane that is swerved abruptly to the right to avoid violating a no-passing zone does interfere with the overtaken vehicle.

The most serious shortcoming of the present short-zone concept, however, is that at certain hazardous zones there is no marking at all. For example, on a 60-mph average-speed road it is clear that a minimum sight distance of 1,600 ft is required for safe passing. The short-zone distances given in MUTCD, however, provide for marking no-passing zones only if 1,150 ft are not available. Therefore, for this 60-mph road all locations where sight distances between 1,150 and 1,600 ft are available will not be marked under the short-zone concept, even though it is clear that minimum passing sight distance is not available. Such situations are often more common than very short sight distances on two-lane highways, and many unsafe passing areas are not marked under the short-zone concept. Under the long-zone concept they would be marked.

We subscribe to the suggestion that we should consider making no-passing zones advisory. It is ridiculous to tell a driver that it is unsafe to pass a slow-moving farm wagon where 1,000 ft of sight distance is available, and it will be treated in that way by many drivers.

It is possible that a change in the no-passing laws may require wording different from that suggested in order to be legally correct; however, such revisions could easily be made.