Applicable formulae for different height criteria are shown in Figure 1. In this design condition the length of control sight distance (S) frequently exceeds the length of vertical curve (L). Accordingly, the two-term formula governs and it is necessary to show the effect of lower criteria as a range of values over likely design values. Table 3 presents these data.

These values show somewhat higher proportional effect, but all less than a 12 percent increase. Except for low design speed, it is usually impracticable to design crest vertical curves to provide for passing sight distance because of the difficulty of fitting the required long vertical curves to the terrain. Ordinarily, passing sight distance will be provided only at places where there are no crest vertical curves. Therefore, a lowering of height of eye will little affect design for passing sight distance.

Also, as in the case of stopping sight distance, the formula for passing sight distance is based on so many variables that a reduction of up to 12 percent in sight distance does not appear to be of coneern at this time. As shown in the diagram on page 437 of the AASHO Policy on Geometric Design there is a generous factor of safety in the formula because the passing vehicle can return to its proper lane at any time before coming abreast of the overtaken vehicle should an opposing vehicle come into view over the crest of a hill.

Trucks vs. Passenger Cars

The above comparisons all concern passenger cars. It is general knowledge that trucks have a greater total height and a higher height of driver's eye than do passenger cars. With a lower weight-power ratio trucks operate slower than passenger cars on upgrades. Also by regulation in some states, their speeds are 5 to 10 mph slower—although this should be discounted in terms of actual speeds found. On the other hand, braking distances for loaded trucks are known to be greater than for passenger cars. In the developed design basis it was assumed and currently accepted that these opposite factors tend to balance each other and passenger car criteria are used. To date there appears to be no concern regarding lowering of truck driver's height of eye, since there is no downward trend as for passenger cars. The same applies to buses, both interstate and urban types.

SUMMARY

While there is a downward trend in the total height and resulting level of driver's eye for passenger cars, its result on the sight distance over crests does not appear to be significant enough to warrant change in presently used design methods and standards. Current passenger car models have driver eye height that reduces crest sight distance by somewhat under 5 percent and the likely lowest future range may reduce the sight distance upwards of 10 percent. These percentages are unimportant considering the variables upon which current design formulae are based. Therefore, it is the opinion of the writers that present and prospective lowering of height of driver's eye in passenger cars does not warrant any change in present methods of designing crest vertical curves.

III. Driver Passing Practices[1]

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● THERE ARE several arguments for and against the increases that have been made since the end of World War II in the horsepower of passenger cars. One of the advan-

[1]An abstract based on material presented at the Annual Meeting of the Institute of Traffic Engineers, September 1957.

tages cited is the ability to complete passing maneuvers in less time, thus reducing the possibility of being caught in the left lane of a 2-lane road with an oncoming vehicle rapidly reducing the time interval between life and death. This is closely allied with the lower height of the driver's eyes in the newer cars which, under certain highway conditions, reduces the distance that the driver can see a clear road ahead. Many persons have become sufficiently concerned with the change in these two characteristics of vehicle design to recommend that their effect as related to the present practices of marking no-passing zones on 2-lane highways be investigated. It can now be reported that a step has been taken in that direction.

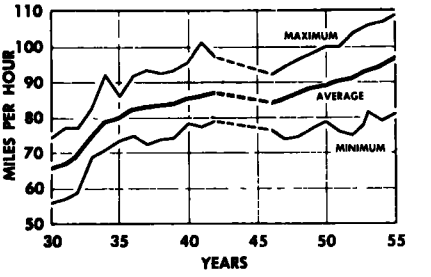

Figure 1. Trend of maximum car speed from 1930 to 1955.

Figure 1 illustrates the increase that has taken place in the speed potential of American stock cars—the vehicles that are operated on the highway systems. The big increase in horsepower from 1954 to 1955 is not reflected in maximum speed. The average 1941 model was capable of attaining a speed of 86 mph, with a range of from 78 to 101 mph. The possible speed of the average 1955 model was 97 mph, with some models capable of about 110 mph.

Between 1938 and 1940 the Bureau of Public Roads conducted a comprehensive series of investigations of passing practices on 2-lane highways. Detailed data were recorded for a total of 21,000 passing maneuvers at 32 locations in seven states. In looking for sites to observe present-day passing practices, it was found that at three of these old locations there had been no change since 1938 in the geometric highway features—surface width and condition, shoulder width, and sight distance conditions remained unchanged for nearly 20 years. Thus they were ideal locations to obtain a comparison of present passing practices with the passing practices in 1938 when cars had much lower horsepower ratings.

The data were obtained during the recent studies by manual observations and were much less detailed than the 1938 records made with a rather elaborate setup of electromechanical equipment. It is believed, however, that the manual recording furnished sufficient information to reveal any marked change in passing practices over the 19-year period.

One of these study sections had an 1,800-ft passing sight distance located between a horizontal and a vertical curve; the second section had a 2,400-ft passing sight distance located between two vertical curves; and the third section had a 3,300-ft sight distance between a vertical and a horizontal curve. Each of the three sections was the best passing location for several miles on the particular highway involved. Fortunately, it was possible to schedule the recent studies so that the traffic volumes and study periods were similar to those for which data were recorded in 1938.

Figure 2 shows that there was a high demand on all three sections for the performance of passing maneuvers as measured by the percentage of vehicles that were following other vehicles at short headways in a queue of two or more vehicles as if waiting for an opportunity to pass. At location 1, the studies were conducted under a wide range of traffic volumes. The percentage of vehicles in queues being restricted in speed by the vehicles ahead, increased with an increase in the traffic volume. At location 2, the traffic volume was constant during the study periods on three different days. Location 3, with the longest sight distance, had the highest percentage of vehicles traveling in queues at

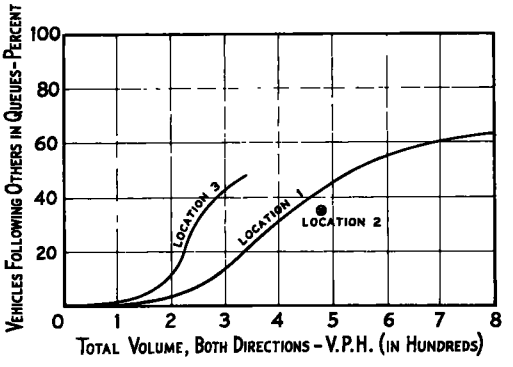

Figure 2.

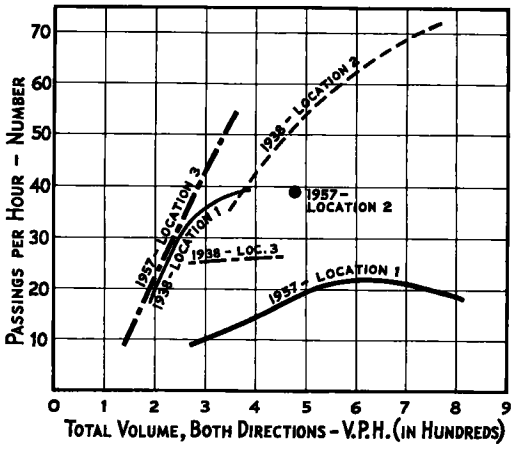

Figure 3.

the low traffic volumes because sight distances sufficient for performing passing maneuvers were less frequent on this highway than on the other two.

Figure 3 shows the number of passings accomplished per hour on each of the three sections during various hourly traffic volumes, in 1938 and 1957. On section 1, which had the shortest passing sight distance, less than one-third as many passings were accomplished during the 1957 studies as during the 1938 studies at similar traffic volumes. At the second location, with the intermediate sight distance length of the three locations, 39 passings per hour were performed in 1957 as compared with 52 passings per hour in 1938 at the same traffic volume. At the third location, with the longest sight distance, more than twice as many passings were performed per hour in 1957 as in 1938 during similar traffic volumes. These comparisons indicate that drivers are now apparently more reluctant to undertake a passing maneuver on the shorter sight-distance sections and less reluctant on the longer sight-distance sections than the drivers were in 1938. One might therefore conclude, that for some reason or other, drivers today are more cautious or have a better understanding of the dangers involved in performing passing maneuvers at short sight-distance locations, despite the increased horsepower of their vehicles, than drivers were in 1938. Such a conclusion is, however, unwarranted by these limited studies.

A comparison of the results of the 1938 and 1957 studies is shown in Table 1.

Detailed data were obtained for 608 passing maneuvers in 1938 and for 476 passing maneuvers in 1957. The 1957 data were separated into two groups, one including passing maneuvers performed by 1954-model or older vehicles, the other including 1955, 1956, and 1957 model vehicles. The break was made between the 1954 and 1955 models because between these two years most automobile manufacturers made the greatest increase in the horsepower of models they were producing or went to new models with a very substantial increase in horsepower.

From 1938 through 1954, of course, there had been periodic increases in the horsepower of practically all makes which, over the years for some of them, totaled considerably more than the 1954-1955 increase. Nevertheless, it seemed desirable to divide the 1957 study data into two groups, particularly since the one group thus includes only "new" vehicles—those less than 2½ to 3 years old. A grouping by horsepower or by horsepower-weight ratio for the newer vehicles might have been desirable for this study, but it was

TABLE 1

COMPARISON OF PASSING PRACTICES IN 1938 AND 1957

Study section	1938 study	1957 study	
	All models	1954 and older models	1955-57 models
	Number of passings studied		
1	130	46	90
2	245	69	139
3	233	45	87
Total	608	160	316
	Average speed of passed vehicles, mph		
1	34	34	36
2	35	38	39
3	36	42	42
Average	35	38	39
	Average speed of passing vehicles while in left-hand lane, mph		
1	44	48	50
2	45	51	50
3	46	54	56
Average	45	51	52
	Average time passing vehicles were in left-hand lane, sec		
1	11.4	9.0	9.0
2	9.0	9.3	9.0
3	10.1	11.9	11.1
Average	10.2	10.1	9.7
	Average distance passing vehicles were in left-hand lane, ft		
1	740	630	650
2	540	700	660
3	640	950	910
Average	640	760	740
	Average speed of free moving vehicles, mph		
1	42	44	
2	41	42	
3	40	49	
Average	41	45	

impossible to make such a classification from a visual identification since different horsepower engines are often used in the same body model. To stop the vehicles for a more accurate identification anywhere on the highway being studied would have made a marked change in the pattern of operation, especially with respect to speeds, the formation of queues, and the frequency of passing maneuvers.

The speeds of both the passed and passing vehicles were higher in 1957 than in 1938 (Table 1). The passed vehicles in 1957 were moving three to four miles per hour faster than in 1938, and the speeds of the passing vehicles were six to seven miles per hour higher. In this connection it is also important to recognize that the average speed of vehicles unobstructed by a vehicle ahead was five miles per hour higher in 1957 than in 1938. It should also be noted (Table 1) that the average difference between the speed of the passed vehicles and the speed of the passing vehicles, during the maneuver, was 10 mph in 1938 and 13 mph in 1957.

TABLE 2

SHORTEST TIME PASSING VEHICLES WERE IN THE LEFT-HAND LANE

Study section	Delayed start			Flying start		
	1938 Study	1957 Study		1938 Study	1957 Study	
	All models	1954 and older models	1955-57 models	All models	1954 and older models	1955-57 models
	Minimum time, sec					
1	5.6	4.0	4.5	5.5	5.0	4.0
2	4.3	4.5	4.0	3.8	3.0	4.0
3	4.6	5.0	6.0	4.1	5.0	5.2
Average	4.8	4.5	4.8	4.5	4.3	4.4
	Average time for 10 percent of the passings made in the shortest time					
1	7.6	5.0	5.0	6.9	5.0	5.9
2	5.1	5.9	5.2	4.6	5.6	5.2
3	5.8	5.8	6.4	4.9	6.2	6.6
Average	6.2	5.8	5.5	5.5	5.6	5.9

TABLE 3

SHORTEST DISTANCE PASSING VEHICLES WERE IN THE LEFT-HAND LANE

Study section	Delayed start			Flying start		
	1938 Study	1957 Study		1938 Study	1957 Study	
	All models	1954 and older models	1955-57 models	All models	1954 and older models	1955-57 models
	Minimum distance, ft					
1	300	340	370	350	350	300
2	170	290	200	170	150	500
3	310	300	450	260	250	430
Average	260	310	340	260	250	410
	Average distance for 10 percent of the passings made in the shortest distance					
1	450	380	430	450	410	490
2	320	460	310	240	480	530
3	370	420	550	360	400	510
Average	380	420	430	350	430	510

The time spent in the left-hand lane by the newer vehicles in 1957 was 0.5 sec shorter than the time in 1938. The distance traveled in the left lane, however, increased 100 ft. Thus it would appear that increasing the average horsepower (from 1938 to 1956) by about 75 percent has decreased the time needed to perform passing maneuvers by about 5 percent but has resulted in an increase of the distance traveled in the left lane by about 19 percent. This obviously is not in accordance with what might have been expected and illustrates the importance of research, for inquiry into the manner in which people operate their vehicles must be based on careful study of actual performance rather than on speculation or assumed driving practices. It is only by so doing that sound, effective highway design and traffic control can be developed.

TABLE 4

PERCENTAGE OF PASSING MANEUVERS COMPLETED WITH SHORT DISTANCES TO ONCOMING VEHICLES OR AT POINTS WHERE THE SIGHT DISTANCES WERE SHORT

Study section	1938 study	1957 study	
	All models	1954 and older models	1955-57 models
	Percentage of Passing Maneuvers		
	Oncoming vehicle less than 200 ft away		
1	1.5	6.5	0
2	3.7	1.5	1.4
3	2.2	2.2	0
Average	2.5	3.4	0.5
	Oncoming vehicle less than 300 ft away		
1	4.7	8.7	5.6
2	9.8	3.0	5 1
3	5.2	2.2	0
Average	6.6	4.6	3.6
	Sight distance less than 300 ft		
1	5.4	0	0
2	4.1	1.4	0.7
3	0.9	0	0
Average	3.5	0.5	0.2
	Sight distance less than 600 ft		
1	29.3	26.1	22.2
2	11.5	8.6	12.2
3	5.6	11.1	2.3
Average	15.5	15.3	12.2

Even from carefully planned and executed studies, however, average values may be misleading. More important in connection with passing maneuvers may be the ability of a driver to accelerate his vehicle quickly and get out of a tight spot. Examine the passing maneuvers that were made in the shortest time intervals and shortest distances during the 1938 and 1957 studies. Table 2 shows the shortest time intervals and the average for the 10 percent of the maneuvers that were made most rapidly. Values are included for two types of passing maneuvers, called "delayed starts" and the "flying starts." The delayed starts include the maneuvers made by vehicles that had slowed down to the approximate speed of the vehicle to be passed prior to entering the left lane. The flying starts include the maneuvers made by vehicles that entered the left lane at a speed considerably higher than the speed of the vehicle to be passed. There is no consistent difference between the 1938 and 1957 values for either of these groups, and the significance of the figures is obscure. It can only be observed that, in general, the new vehicles were in the left lane a slightly shorter time than in 1938, but the time for the fastest maneuvers has not changed.

Similar information for the maneuvers in which the passing vehicles occupied the left lane for the shorter distances, as shown in Table 3, indicates approximately the same relative difference between the 1938 and 1957 data as the average values.

Since there were no accidents at these three locations during either the 1938 or 1957 studies, and accident data are not available as yet which relate horsepower to accidents during passing maneuvers, the accident potential of increased horsepower must be measured by the percentage of maneuvers completed shortly before meeting an oncoming vehicle or after reaching the no-passing zones. Table 4 shows the percentage of the passing maneuvers which were of this type.

When the distance between two vehicles traveling toward each other at 50 mph on a 2-lane highway is less than 200 ft, they will meet in about 1.4 sec. Two and one-half percent of the passing maneuvers studies in 1938 and one-half of one percent of those studied in 1957 involving the newer group of cars were completed with oncoming vehicles less than 200 ft away. This is a significant difference. The figures for the other items shown in Table 4 are also lower for the late model cars observed during the 1957 studies than for the 1938 studies. Whether or not the horsepower ratings had anything to do with these results cannot be determined. Driver training and a variety of other factors may have had a more pronounced effect than the horsepower of the vehicles. Certainly, the new-car drivers in 1957 were taking fewer chances.

In conclusion, it may be stated that there is little evidence to indicate that present

practices of marking no-passing zones should be changed due to the changes that have taken place during the past years in vehicle design and driver performance. This does not mean, however, that present practices cannot be improved to take advantage of the technical information made available during the past several years.