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Relation Between Vehicle Characteristics And Highway Design

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Contents

Driver Eye Height and Vehicle Performance in Relation to Crest Sight Distance and Length Of No-Passing Zones

I. Vehicle Data

K.A. STONEX, Assistant Director, General Motors Proving Grounds

● THE AASHO handbook, "A Policy on Geometric Design of Rural Highways," states criteria for vertical curve design. The design for stopping distance is based on a driver's eye height of 4.5 ft above the ground and an obstacle 4 in. high, which is presumably the practical case of the smallest obstacle which a driver would want to avoid. This is illustrated in Figure 1.

There is a growing concern among highway designers that, with the emphasis on reduction of over-all height, the driver's eye height may go down and down to the point where the 4.5-ft standard will no longer apply, and design criteria of the crest vertical curves will be invalid. This concern is based on the trend of over-all height, which is derived from Nagler's paper and shown in Figure 2.

At the General Motors Proving Ground, observations have been made of the driver's eye height on representative fleets of passenger cars since 1936; these data were the basis of the choice of 4.5 ft as the design criterion and the continued use of this value in the 1954 issue of the AASHO policy.

In the development of this test procedure, it was found that the average stature dimension to the eye, or seated eye height, of a group of males was approximately 28½ in. above a rigid seat, and that in 1936 the average seat cushion was depressed 2 in. under the passenger load.

Independent measurement of a considerably larger group of people by another agency in General Motors verified this stature dimension.

The test procedure and the data in this test program are based on 28½-in. stature measurement and a 2-in. seat cushion deflection.

Figure 3 shows percentile distributions of driver's eye height in the fleet of test cars from 1936 through 1957. The fleet includes at least one representative car of each make and model of American passenger car each year. Sports car and foreign car data are not available; competitively, these cars have not been of significance and they have not been included in the engineering car fleet. Whether the number in use is sufficient to merit consideration in highway design is open to question.

It will be noted that there have been what appear to be several phases of styling changes relating to this dimension. The cars from 1936 through 1939 gave median values of eye height of about 57 in. The 1941 styling change, carried through the 1947 models, reduced this to between 55 and 56 in. The next phase appeared on some 1948 cars and disappeared on some 1953 makes. The 1953 cars had a median of 54 in., which is the present AASHO standard. Another phase started with 1954 models and appears to have swept through the industry by 1956; this gave a median driver eye height of about 53 in. A rather significant change appeared in the 1957 styling which reduced the median for that year to 51 in.; data on 1958 models are not yet complete, but it may be assumed that the fleet median may be somewhat lower than in 1957.

In discussing these styling phases, it must be noted that the basic styling trend shown in Figure 2 is established by customer desires. Each step is adopted as related component design matures, and the steps are not reached simultaneously by all manufacturers. Even a styling feature achieving a high degree of customer acceptance, such as panoramic windshields, takes up to three years to sweep through the industry. Consequently the effect of any general change develops over several years in terms of the curves of Figure 3.

Of even greater apparent significance than the immediate effect of the long-range trend is the influence of seat cushion depression. This has always varied from car to car, and amount of depression and the range of variation have increased to the extent that a technique of measuring seat cushion depression was developed and established on a routine basis at the Proving Ground on the 1956 models. In passing, the development of a test technique which gives reproducible and realistic results is not as simple as it first appears.

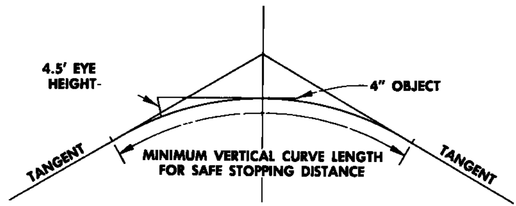

Figure 1. AASHO design heights of eye and object for vertical curves.

Figure 4 shows percentile curves of the depression of a specific point on the seat cushions of 1956 and 1957 cars under an average passenger load. The median value of seat cushion depression was 4. 5 in. in 1956 and 4. 2 in. in 1957. This modifies the driver's eye height on the 1956 and 1957 cars as indicated in Figure 5; this reduces the median eye height on the 1957 cars from a value of slightly below 51 in. on the old procedure to an adjusted value of 48½ in. The over-all change in driver's eye height from 1936 to 1957 is shown on Figure 6. The median height has changed from about 57 in. to 48. 5 in.

To estimate how much lower the driver's eye height may go in volume production passenger cars is difficult. Just as in any design trend, this depends upon customer acceptance and design skill, in this case in developing smaller machinery to fit in the space between the ground clearance line and the line of the depressed seat cushion. If the median eye height observed since 1937 were plotted as a function of time and the curve extrapolated, in the year 2060 the driver's eyeballs would be rubbing the pavement surface. This would not meet widespread customer acceptance, and it is certain that the trend will not continue that long.

A tabulation of median eye heights from Figure 3 and 5 and of average overall height from Figure 2 indicates that the driver's eye is approximately 10 in. below the highest point on the car.

In the "Automotive News" of September 16, 1957, Victor Raviolo, special

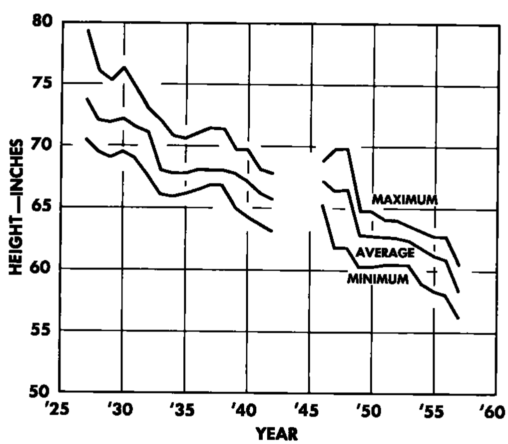

Figure 2. Car over-all height (car loaded).

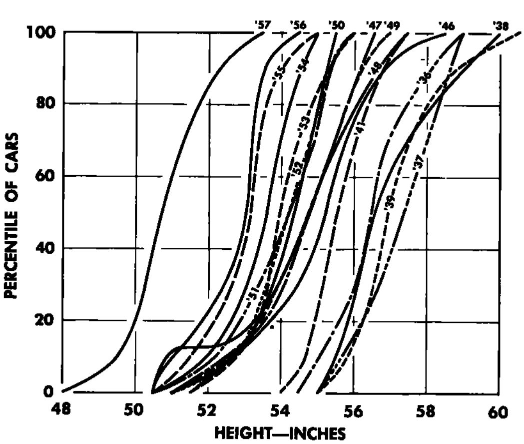

Figure 3. Driver's eye height to ground (defined according to visibility test procedure).

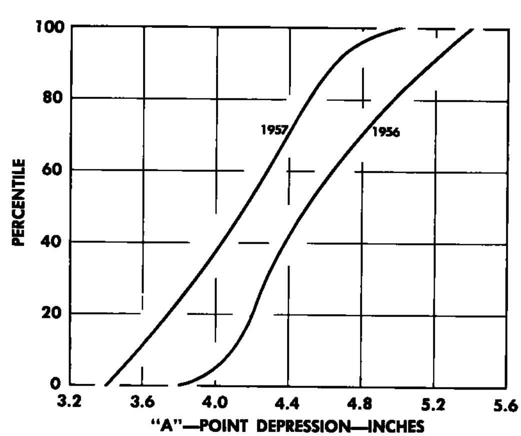

Figure 4. Front seat "A"—point depression percentile distribution.

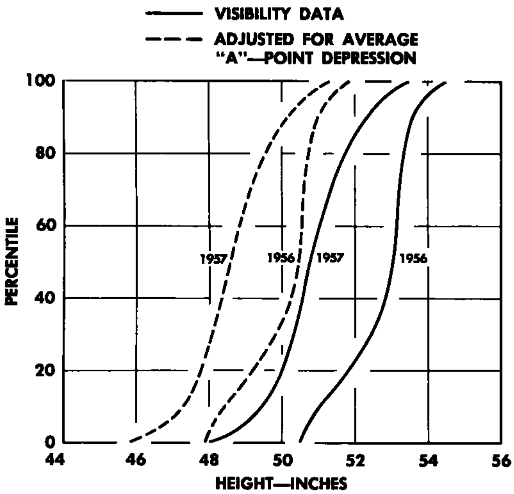

Figure 5. Driver's eye height to ground (defined according to visibility test procedure).

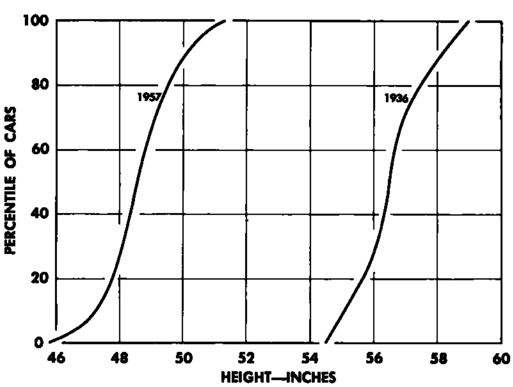

Figure 6. Driver's eye height to ground (defined according to visibility test procedure).

assistant to the engineering and research vice president of the Ford Motor Company, is quoted as saying that 51 in. is the approximate ultimate minimum height for volume production passenger cars, and that in 10 years there will be 52-in. sedans, the height of the Thunderbird. He continued by saying that there are two basic problems, entrance and visibility, that must be worked out before then. It is understood that, at a later informal discussion, this minimum was increased to 53 in. as a more practical value.

If it is assumed that this estimate is right and that 10 in. will remain the approximate vertical dimension between the driver's eye and the top of the car, the ultimate minimum eye height would be 43 in. This is about 5.5 in. lower than the median 1957 value, and about 3 in. below the minimum 1957 value. The evidence suggests that the trend of lower driver eye heights on passenger cars of large volume production is nearing an end.

It must be remembered that there are nearly 60 million cars on the road now, that these cars were designed to be operated on the existing highways, and that all future designs will contemplate satisfactory operation on the highways existing then. Highway designers need not be concerned about radical departures from current automotive designs in terms of satisfactory operation on the highway network; the customers will take care of that problem automatically.

AASHO policies also treat the criteria of passing sight distances, and the trend toward lower vehicle heights will reduce

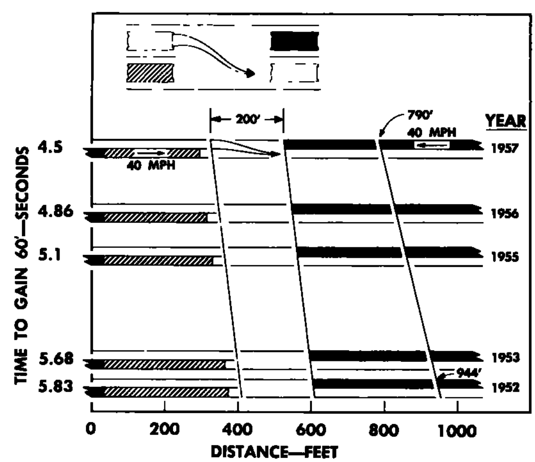

Figure 7. Trend of passing distance average of all cars.

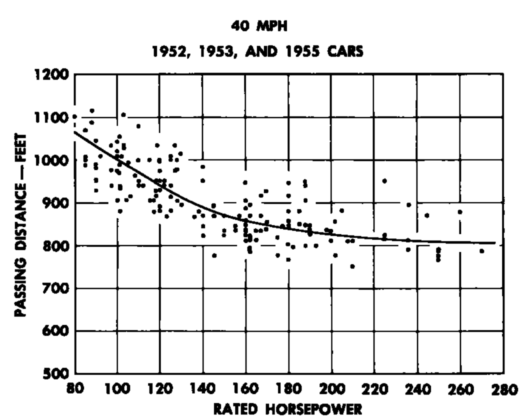

Figure 8. Minimum passing distance versus rated horsepower.

the passing sight distances provided by current design standards. Improved performance has reduced the distance required.

Figure 7 shows the trend of time and distance required to pass a vehicle traveling at 40 mph for the years 1952 through 1957. This shows an improvement in passing ability provided by the superior performance of modern automobiles of more than 16 percent during the period. It is thought that the reduction in passing sight distance provided by the decrease in eye height shown is more than compensated for by improved performance. It has been shown (1) that the rate of reduction in passing distance with increases in rated horsepower falls at the higher values of horsepower (Figure 8). It is anticipated that further reductions in passing distance resulting from greater transmission flexibility will continue, at least until there are 53-in. sedans.

REFERENCE

1. Stonex, K.A., "Lessons Learned by the Proving Ground Engineer in Highway Design and Traffic Control," Proceedings of the Institute of Traffic Engineers (1955).

II. Vertical Curve Design

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Office of Engineering, Bureau of Public Roads

● TODAY there is a single, widely used basis for design of crest vertical curves. Several factors and criteria are combined in this design method and consideration of adjustment in any one of these factors properly should entail review of the whole group of items.

Safety and efficiency in highway operation demand uniform and consistent design treatment along the length of any one type of highway. The highway design speed, selected or otherwise determined for given conditions, is the principal means of attaining this end. Design guides and standards have been established for a number of controls and dimensions for the likely range of design speeds. For safety, to permit control of vehicles in an emergency, the designer provides a sufficient length of clear sight distance ahead along every part of the highway. A stopping sight distance has been determined for each highway design speed to be used as this minimum clear sight length. This distance is calculated by joint use of (a) selected values for driver perception and reaction time to begin a stop and (b) friction factors that establish a vehicle braking distance.

Crest vertical curves are designed to be of sufficient flatness to provide this clear sight length as a tangent sight line between driver's eye height and some object on the highway ahead. The parabolic form of vertical curve is used because of marked convenience in design calculation and construction staking. Using selected criteria of height of eye and height of object, it is relatively simple to calculate the length of parabola between any two profile tangents that meet at an apex that will provide the desired clear sight distance. The two height criteria are important items in the whole related series. The height of driver's eye obviously must be a representative value. That for passenger cars was used, since being the lower, it is more critical than that of truck vehicles. The 4.5-ft value was established in the late 1930's and reaffirmed when design policies were reconsidered in 1954.

The height of object is equally important but is much less direct in derivation. The present height of object criterion actually is a compromise value used to bring into balance for convenient design purposes the different sight distance conditions obtained around a horizontal curve and over a crest curve. The 4-in. height now used was selected as a somewhat arbitrary, single value between the zero or pavement surface level and an 18-in. or higher object on the pavement, which the driver nearly always would need to avoid hitting. Use of the 4-in. height permits all design to be based on a single set of stopping distance values. This 4-in. criterion has sired the picturesque term "dead-cat" sight distance in one area.

With the height of eye as a criterion under question and a sight line on a constructed or designed crest vertical curve as the significant end result, the whole series of interwoven criteria and factors that lie between them needs to be examined. This paper makes a quick review of the effect of lowering the driver's eye height in relation to the other factors and the actual sight condition on a highway crest vertical curve.

Height of Driver's Eye

In the last few years the public has become acutely aware of the reduction in height of passenger cars. From all outward appearances, manufacturers are vying with one another to produce the lowest car on the road, or one that appears to be that. Little by little the total actual height has inched down and the over-all lines have been perfected to make the whole vehicle look even lower than it actually measures. Adults of normal height now can look over most of the recent models.

In a companion paper K. A. Stonex states that these basic vehicle styling trends are established by customer desires. Owners of some of the "low" cars have discovered, to their discomfort, that in some situations it is not easy to attain position in the driver's seat. The center passenger on the front seat has the discomfort of cramped legs on a long journey because of the central hump, even though the inside width has been increased to the point where a driver actually must slide over to reach the right door. The driver used to be up on a seat, with posterior a reasonable height above the floor. Now the rear-sloping cushion is such that his tailbone is, at best, only a few inches above the floor.

Personal neighborhood research reveals that many car owners are not "demanding" that such changes be incorporated in their new cars. They think and feel quite the opposite. They do not like these features and they say so, definitely and emphatically. However, it cannot be denied that they continue to buy such rigged vehicles. People want new and different models, and they spend their cash for style and new-look flash, even though they know or suspect that it means certain inconveniences in use. They continue to make small voices about these and other vehicle dimension changes, but they never seem to band into a strong mass clamor that car-makers would not fail to heed.

Not so obvious to the average user, perhaps, is the effect of the lowered body on operating characteristics. The lower center of gravity promotes stability and improves riding quality on curves. On the other hand, the lower position of the driver lessens his ability to see over undulations in the road ahead. Some highway designers became concerned over this reduced vision several years ago and currently many are wondering if there is occasion to adjust design criteria. Actually, a few states are using flatter vertical curves over summits to compensate for expected lower line of sight of all future drivers.

K. A. Stonex has explained the difficulties in measurement of the average height of eye of the driver of a passenger car. He shows that eye height averages about 10 in. below the highest point on the car and presents data from the proving ground fleet of test cars that shows a downward trend, with about a 5-in. drop in the last 10 years. An eye height of 43, possibly 42, in. is indicated as the lowest practical value to expect. While the test fleet includes all different models, it is in order to examine the proportion of different types and models of vehicles for comparison with the test fleet averages. The most useful, readily available dimension is the over-all height of the unloaded standing vehicle (curb height). This height may not give as precise an indication of the height of eye as reported by Stonex, but it seems to be reasonably acceptable. Statistics [1] for the 1957 model year are summarized in Table 1.

It should be noted that all 1957 cars, domestic and foreign, with the exception of sports cars, have about the same curb height, 58 to 62 in. The typical sports car has

[1] Summarized, with some approximations, from "Automotive Industries," March 15, 1957, and "Ward's Automotive Reports," November 11, 1957.

TABLE 1

OVER-ALL[a] HEIGHTS OF 1957 PASSENGER CARS

Wheelbase in.	Percentage of All New Cars[d]	Type and Make	Over-all Height in.
84 - 96	2	Volkswagen, Renault, etc.[b]	58 - 63 (some 56 - 76)
94 - 102	1	Ford Thunderbird, Chevrolet Corvette, Volkswagen Karmann-Ghia, MG, etc.[c]	50 - 52
108	2	Rambler	59 - 60
115	24	Chevrolet	62
116 - 118	35	Ford, Plymouth	58 - 59
122 - 126	29	Buick, Oldsmobile, Pontiac, Mercury, Dodge, etc.	58 - 62
126 - 133	7	Cadillac, Chrysler, DeSoto, etc.	56 - 64
	100	Average	59.8

[a] Total height of unloaded standing vehicle.
[b] Includes all standard-size foreign cars.
[c] Includes all low sports-type cars, domestic and foreign.
[d] Based on registration for first 9 months of 1957

a height of about 50 to 52 in. Domestic production of sports or personal cars is about 0.4 percent of total passenger car production. Data on foreign sports-type cars are not readily available. Local distributors could not furnish any information as to the proportion of imported cars that are of the sports type. Registrations of all foreign cars for the first nine months amount to 3.1 percent of all new car registrations. Assuming that about one-fourth of the imports are sports-type, it is estimated that total registration of sports cars, both foreign and domestic, is currently about one percent of all new passenger cars, as indicated in Table 1. It is obvious that the incidence of this type of car is not of enough significance to support change in design values. Tabulation of all cars in use as of July 1, 1956, indicated 0.7 percent in the "all others" category, which includes imports. The current percentage of imports of 3.1 percent indicates either that foreign cars have a short life or that the percentage of foreign car registrations is on the increase, or both.

Vehicle dimensions for 1958 model cars are not yet available but preliminary data on the "low-priced three," which accounted for 59 percent of new car sales in the first nine months of 1957, indicate that curb heights have dropped from a range of 58 to 62 in. in 1957 to 56 to 57 in. in 1958. As far as these cars are concerned, the downward trend in height has been suddenly accelerated. These values fall in the general trend range shown by Stonex.

It should be noted that there is a definite time lag between a current model dimension and the average of that dimension for all cars on the road. At current rates of production and retirement of passenger cars, about five years will lapse before a new feature, such as lowered height will be found on one-half of the cars on the road. For example, if the average height of 1958 model cars is found to be 57 in. and this particular dimension is not changed on new cars for five years, at the end of that time about 50 percent of the cars on the road would be 57 in. high. The average height of all cars on the road then would be just under 60 in., with an average height of eye of 4.1 ft. Or, if the car heights should continue to be lowered to eventually reach the 52-in. minimum named, it would require at least 15 and probably 20 years before the average of all driver's height of eye would reach the 42-in. level. Thus, there is no immediate condition that calls for a lowered height of eye criterion. But to design for the future a check is needed as to the results when the height of eye is reduced to about 42 in. or 3.5 ft.

Stopping Sight Distance

For design of crest vertical curves, the formulae and criteria in general use are those shown in the AASHO Policy on Geometric Design of Rural Highways, 1954; see pages 125, 173, etc. Design stopping sight distances have been determined for different design speeds, varying from 200 ft for 30 mph to 600 ft for 70 mph. For convenience, Figure 1 has been prepared to show the usual governing crest case (sight distance is less than length of vertical curve) and applicable formulae regarding height of eye and height of object.

For stopping sight distance, the $S < L$ condition applies, except in rare cases. For any vertical curve, a reduction in

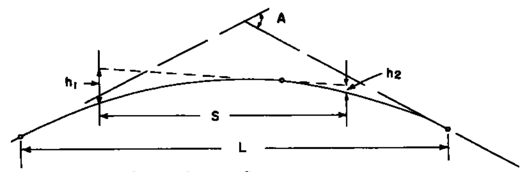
TABLE 2

EFFECT OF DIFFERENT HEIGHT OF EYE CRITERION ON STOPPING SIGHT DISTANCE AT CREST VERTICAL CURVES ($S < L$)

Height of Eye Feet	Height of Eye Inches	Reduction in sight distance to a 4-in. object, percent
4.5	54	0
4.25	51	2.2
4.0	48	4.4
3.75	45	6.8
3.5	42	9.3

height of eye (h_1) results in a reduced sight line (S) measured to the 4-in. high object (h_2). Calculated values for various heights of eye are shown in Table 2.

These data demonstrate that for stopping sight distance design, a lowering of height of eye to 4.0 ft results in only a 4.4 percent decrease in the crest sight distance to the 4-in. object. This would apply for the 1957 models operating on existing crest vertical curves. If in the future all cars were made even lower, to the indicated limit of a 3.5-ft height of eye, the decrease in sight distance would not exceed 9.3 percent. Percentagewise, these reductions in sight distance on crest vertical curves are not disturbing.



L = length of vertical curve, ft
S = sight distance, ft
A = algebraic difference in grades, percent
h_1 = height of eye above roadway surface, ft
h_2 = height of object above roadway surface, ft

When S < L, basic formula $S = 10(\sqrt{2h_1} + \sqrt{2h_2})\sqrt{\frac{L}{A}}$

For h_1 = 4.5 ft and h_2 = 0.33 ft the formula becomes $S = 38.2\sqrt{\frac{L}{A}}$

h_1 = 4.0 ft and h_2 = 0.33 ft the formula becomes $S = 36.5\sqrt{\frac{L}{A}}$

h_1 = 3.5 ft and h_2 = 0.33 ft the formula becomes $S = 34.6\sqrt{\frac{L}{A}}$

h_1 and h_2 = 4.5 ft the formula becomes $S = 60\sqrt{\frac{L}{A}}$

h_1 and h_2 = 4.0 ft the formula becomes $S = 56.6\sqrt{\frac{L}{A}}$

h_1 and h_2 = 3.5 ft the formula becomes $S = 52.9\sqrt{\frac{L}{A}}$

When S > L, basic formula is $S = \frac{L}{2} + \frac{100}{A}(\sqrt{h_1} + \sqrt{h_2})^2$

For h_1 = 4.5 ft and h_2 = 0.33 ft $S = \frac{L}{2} + \frac{728}{A}$

Figure 1. Formulae for computing sight distance on crest vertical curves using different heights of eye and object.

Examine the extent to which the height of object (4-in.) criterion for stopping sight distance would need to be increased to compensate for a lower height of eye. Again resorting to the S < L formulae, for the same length of sight line on a given crest vertical curve, when height of eye is lowered from 4.5 to 4.0 ft the height of object would need to be increased from 4 to 6 in. And a drop of eye height to 3.5 ft would require a height of object increase to about 8.3 in. These heights are less than a typical box dropped on the road or a small animal crossing that would be of sufficient size to be seen and be of concern to an approaching driver. The check of this feature does not suggest warrants for adjusted design criteria.

The basis of derivation of the minimum stopping sight distances is in part somewhat empirical. The perception and reaction time is used as 2½ seconds and at best can be considered definite only within a range of ¼ to ½ second either way from the average used. At 30 mph, ¼ second represents 11 ft of travel and at 70 mph, 26 ft of travel. These distances are 5.5 percent and 4.3 percent respectively of the minimum stopping sight distance and indicate an accuracy of derivation in the range of about 10 percent.

Further, the braking distance is calculated on rounded and general average values of over-all friction factors for brake-tire-pavement conditions. Some studies attempting to pinpoint these values found a high degree of variation between different kinds and makes of tires. From present knowledge, it must be recognized that the accuracy of derivation of the braking distance, particularly for high speeds, is no better than that of the perception and reaction time.

Because of these variables in establishment of the design standards values, the writers can find no reason whereby a 5 to 10 percent reduction in sight distance because of lower height of eye supports a change in the design values for stopping sight distance.

Passing Sight Distance

For design of 2-lane (and 3-lane) highways a sight distance sufficient for a safe passing maneuver should be provided on crest vertical curves wherever feasible. Separate design passing sight distances (varying from 800 ft for 30 mph to 2,300 ft for 70 mph on 2-lane roads and 1,200 to 1,600 ft for 50 to 70 mph on 3-lane roads) were developed for which both the height of eye and of object criterion are the same, 4.5 ft.

TABLE 3

EFFECT OF DIFFERENT HEIGHT OF EYE CRITERION ON PASSING SIGHT DISTANCE AT CREST VERTICAL CURVES

Height of eye and of object, Feet	Height of eye and of object, Inches	Reduction in sight distance percent
4.5	54	0
4.0	48	0 to 6
3.5	42	0 to 12

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 concern 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]

O.K. NORMANN, Deputy Assistant Commissioner for Research
Bureau of Public Roads

● 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.

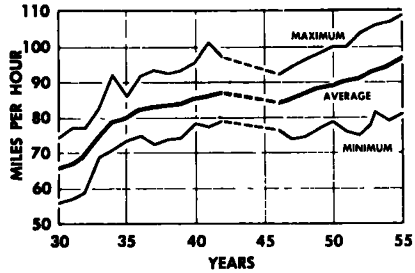


Figure 1. Trend of maximum car speed from 1930 to 1955.

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

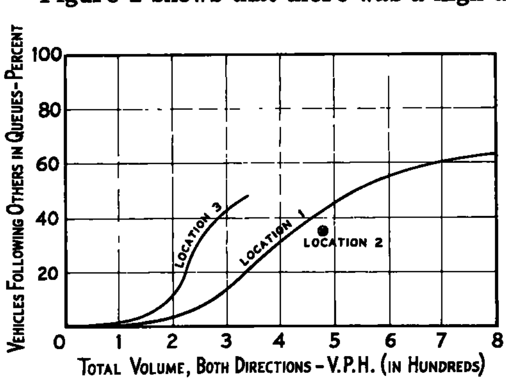


Figure 2.

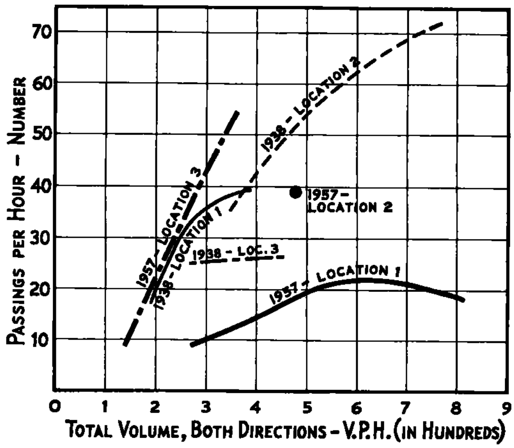


Figure 3.

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.

Passenger Car Overhang and Underclearance As Related to Driveway Profile Design

I. Vehicle Data

W.A. McCONNELL, Ford Motor Company

● THE CURRENT trend in automobile styling appears to be toward lower vehicles. Greater front and rear overhang and reduced road clearances, which make today's cars seem to hug the road, have caused increased concern among highway designers.

The trend, of course, is not new. When automobiles were powered buggies, the driver sat high. Then the engines moved out from under the seat. Pneumatic tires could absorb bumps that the buggy wheels needed size to climb. Independent suspensions allowed the engine to drop between the wheels. The frames moved to the outside, or disappeared altogether with integral body structures. Now, load sensing and leveling devices narrow the margin necessary for spring deflections. With each change, the driver has dropped down and the vehicle has become lower.

Viewed from the beginning, such a trend is alarming. As Stonex' charts [1] would seem to indicate by extrapolation, in another 60 years the driver's eyes will approach the pavement, presumably with the car underbody still in between; and 120-ft personal cars will be traveling on 7-in. wheels. It is suspected that it was from some such worry as this that the Vehicle Characteristics Committee requested a review of automobile underclearance dimensions and a report on the implications of current trends in these dimensions on driveway design. The results, perhaps, are surprising.

The data used in Table 1 are from measurements taken on vehicles of all major domestic makes and several foreign products which are imported in the largest quantities. No attempt was made to determine percentile distributions, either by vehicle make or by numbers of each make in current use, since it is not known what percent might constitute a significant level. It is assumed, however, that complaints will be generated primarily by those vehicles with the most critical dimensions. Because these vehicles are technically or competitively interesting to the manufacturers, they are perhaps also of concern to highway designers.

Have wheelbases been getting longer? The data (Fig. 1) do not show it. Smaller wheels and lower lines just make them look longer. The abrupt rise in the minimum dimension, and likewise the peaks and valleys on some of the accompanying charts, are not necessarily significant; they may only reflect the presence or absence of a single vehicle in the sample for a particular year.

Have angles of approach been shrinking? Not noticeably in the last 10 years, at least (Fig. 2). Sixty years ago there were cars with 180 deg angles of approach, which would roll nicely on the ceiling. This feature must have been of little value for the past 10 years, at any rate.

The 10-year trend used here caught the tail end of the downward progress in angle of departure. It would appear that the limit here has been reached (Fig. 3), and that rear overhangs will get no longer and impact bars no lower. Higher impact bars are not likely, as they must match existing vehicles; one cannot be selective about who hits him. Bumper extensions and spare wheels mounted on behind seem to be losing favor.

Minimum ground clearance curves (Fig. 4) begin to show a slight downward trend. The lowest minimums have been made possible by load-leveling suspensions and progressive bumpers, which decrease the margin necessary for jounce. The low point on cars now is more often found under the passenger compartment, on the muffler or the frame rails, rather than under the rear axle or the engine oil pan as in the past. This is a direct consequence of the emphasis on lowering the occupants, providing no more ground clearance under the floor pan than is necessary for other parts of the vehicle.

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[1] See elsewhere in this Bulletin.

At last there is a trend. Ramp break-over angles (Fig. 5) have dropped 6 deg in six years. This does not necessarily mean that in another ten years all roads must be optical flats. In fact, it is believed that the limit will be reached at about the present 6 deg to 7 deg minimum. As shown later, this has not been as critical a limit as rear overhang, and the reduction merely represents a better balance of clearances.

TABLE 1

DIMENSIONS OF COMPOSITE VEHICLES WITH MINIMUM CLEARANCES[a]

Dimension	Shortest Vehicle	Longest Vehicle
Wheelbase	80 in.	133 in.
Overhang:		
Front	22 in.	42 in.
Rear	32 in.	63 in.
Impact bar, lower edge		
Front	7.5 in.	11.0 in.
Rear	9.0 in.	10.6 in.
Clearance:		
Under wheelbase centerline	4.9 in.	4.0 in.
Minimum ground	3.7 in.	4.0 in.
Angle of approach	15 deg	15 deg
Angle of departure	8 deg	10 deg
Ramp break-over angle	11 deg	7 deg
Front jounce	2 in.	3 in.
Rear jounce	2 in.	3 in.

[a] Critical dimensions taken from various makes of vehicles of same general configuration.

These trend curves themselves do not afford much clue as to the implications of the dimensions in driveway profile design; although they do excite suspicion. Therefore, two composite vehicles —a short one and a long one—have been put together, each combining the worst possible dimensions likely to appear on a future car (Figs. 6 and 7). Because it also has been observed that most real cars experience pavement interference usually only under dynamic conditions, the extremes these dimensions have been observed to reach have been charted: during severe brake stops or "dive"; again with the rear suspension compressed, as sometimes occurs under accelerations, or with heavy rear seat or trunk loads; and with both front and rear suspensions collapsed in full jounce.

The full jounce situation is surprisingly easy to reach on sag curves; for example, 15 to 20 mph on an 80-ft radius, as is found on many crowned intersections, will do it.

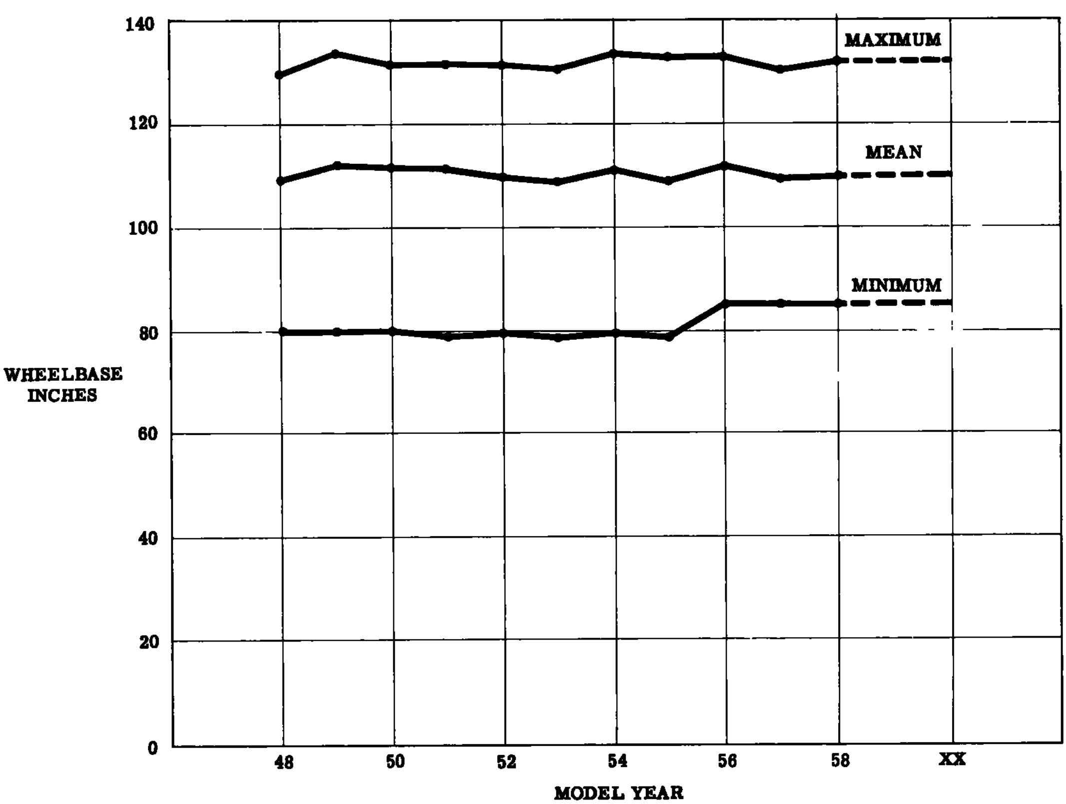


Figure 1. Wheelbase, inches, from 1948 through 1958.

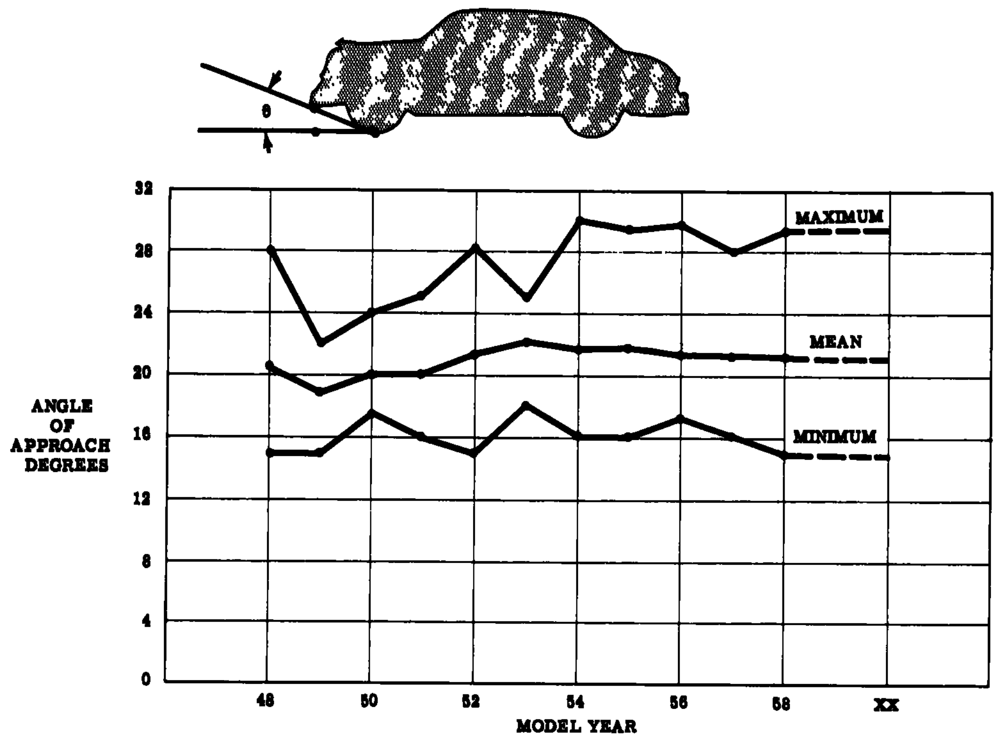


Figure 2. Angle of approach, degrees, from 1948 through 1958.

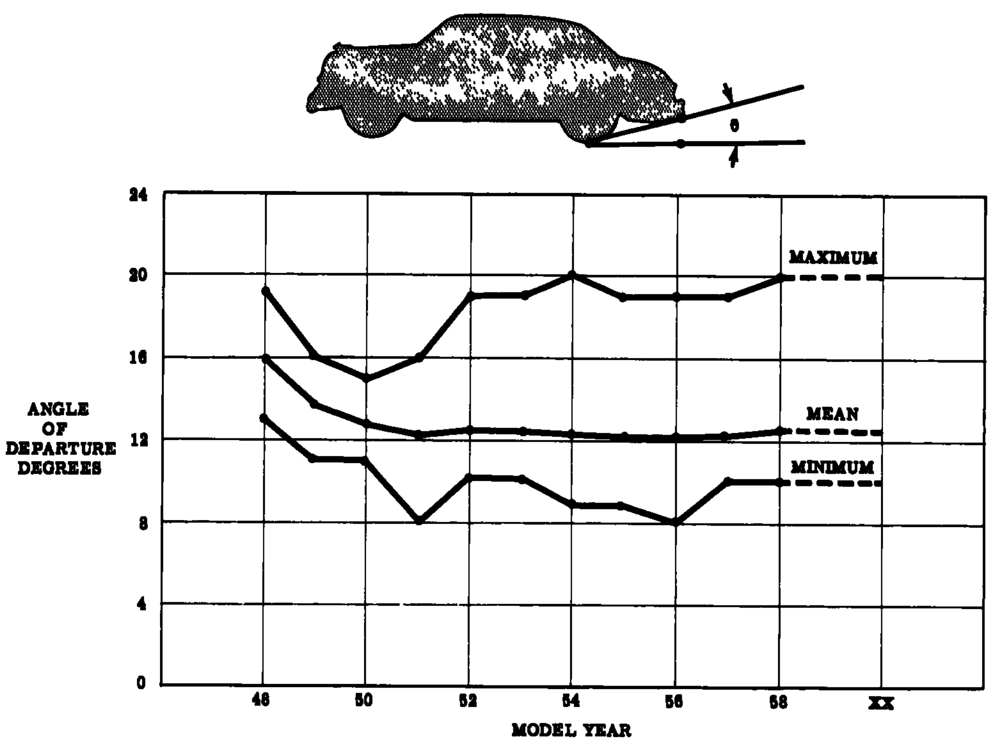


Figure 3. Angle of departure, degrees, from 1948 through 1958.

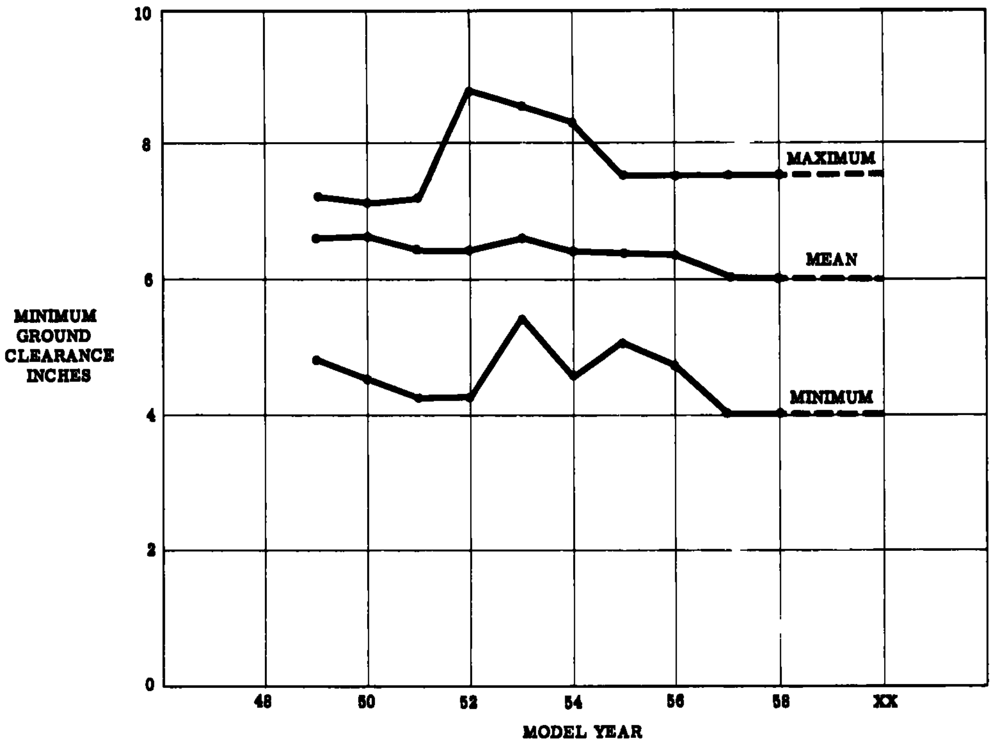


Figure 4. Minimum ground clearance, inches, from 1949 through 1958.

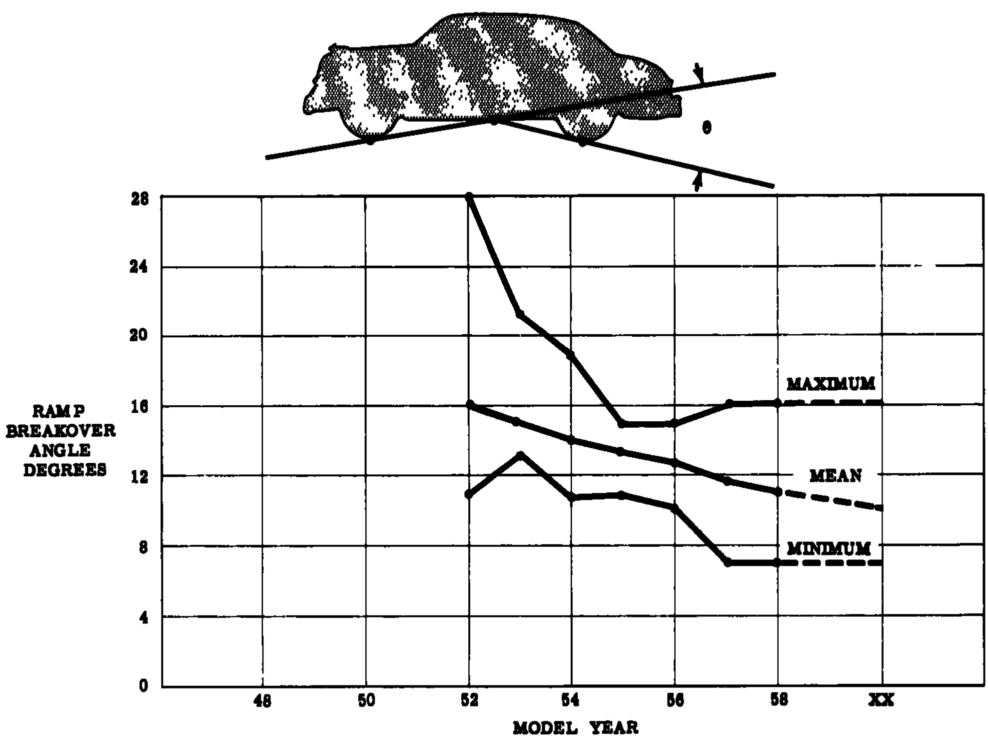


Figure 5. Ramp breakover angle, degrees, from 1952 through 1958.

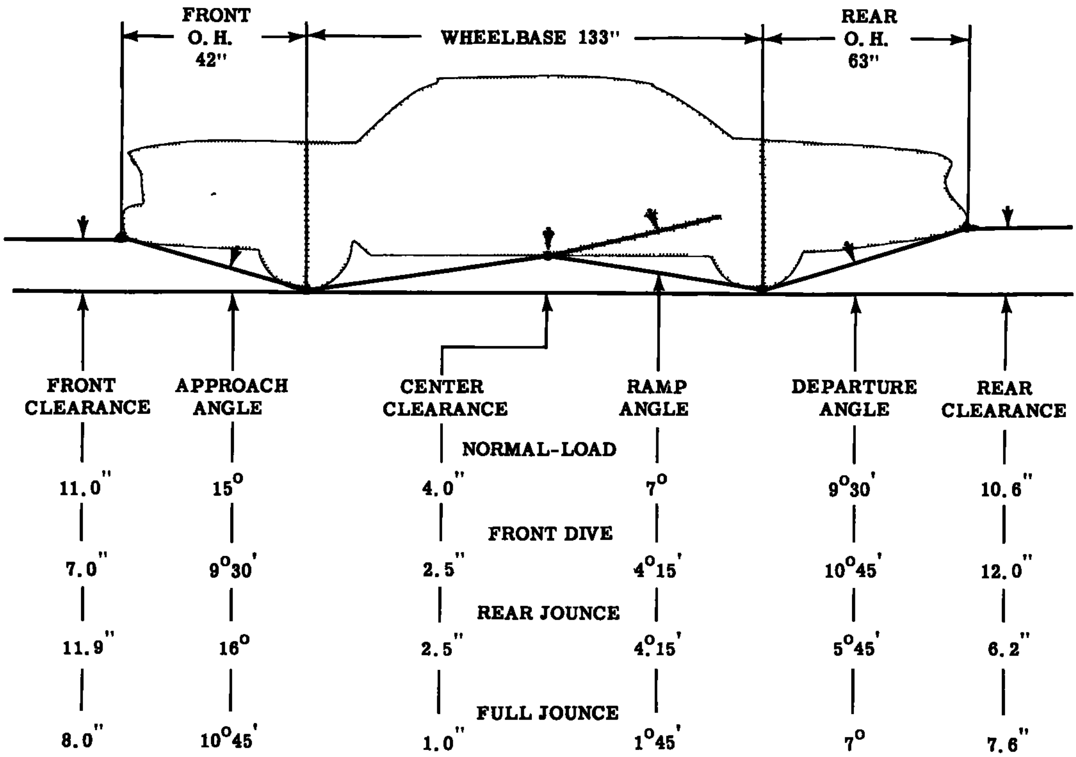


Figure 6. Composite longest vehicle, clearance dimensions under various conditions.

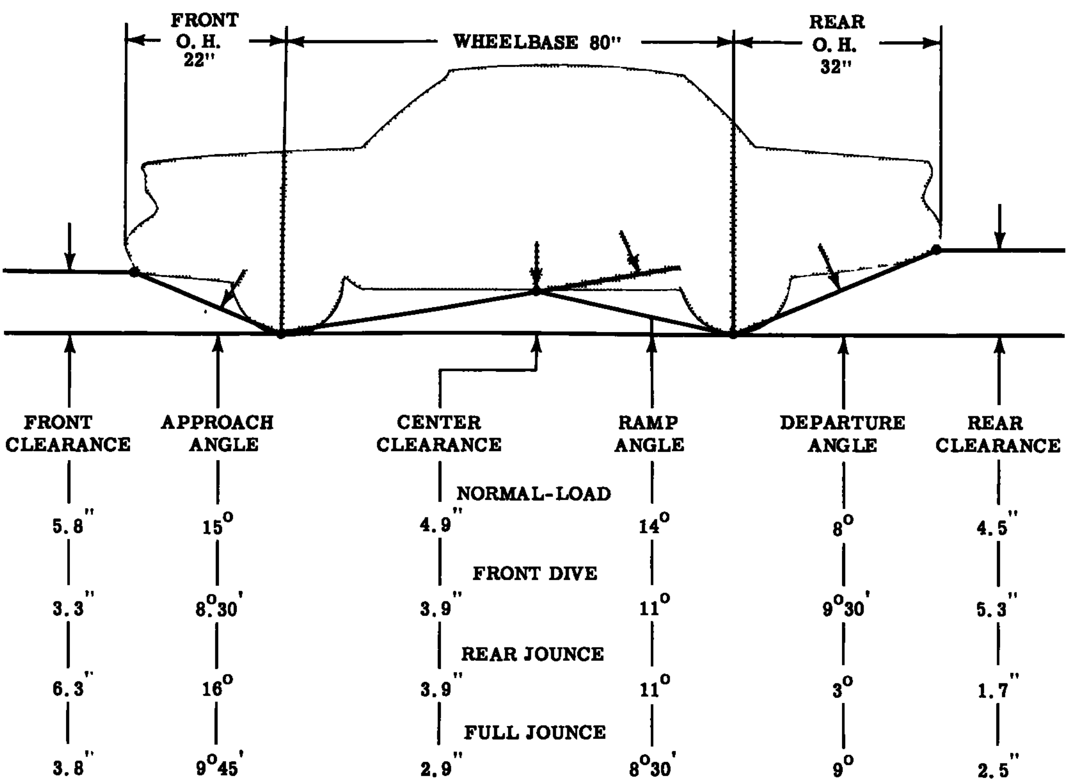
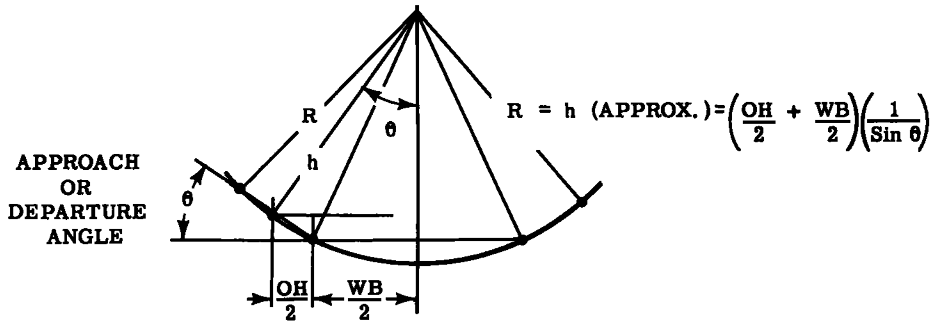
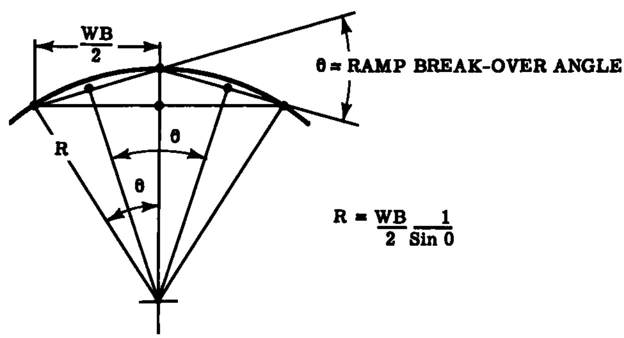


Figure 7. Composite shortest vehicle, clearance dimensions under various conditions.



SITUATION	θ	$\left(\frac{OH}{2} + \frac{WB}{2}\right)$	Sin θ	RADIUS
LONG VEHICLE				
NORMAL LOAD - FRONT INTERFERENCE	15°	7.3'	.2588	28'
NORMAL LOAD - REAR INTERFERENCE	9°30'	8.16'	.1651	50'
DIVE - FRONT INTERFERENCE	9°30'	7.3'	.1651	44'
JOUNCE REAR INTERFERENCE	5°45'	8.16'	.1002	81'
SHORT VEHICLE				
NORMAL LOAD - FRONT INTERFERENCE	15°	4.25'	.2588	17'
NORMAL LOAD - REAR INTERFERENCE	8°	4.67'	.1392	34'
DIVE - FRONT INTERFERENCE	8°30'	4.25'	.1478	29'
JOUNCE - REAR INTERFERENCE	3°	4.67'	.05234	89'

Figure 8. Sag vertical curve radii for overhang clearance.



SITUATION	θ	Sin 0	$\frac{WB}{2}$	RADIUS
LONG VEHICLE				
NORMAL-LOADED	7°	.1219	5.55'	46'
DIVE - FRONT	4°15'	.0741		75'
JOUNCE - REAR	4°15'	.0741		75'
FRONT & REAR JOUNCE	1°45'	.0305		180' *
SHORT VEHICLE				
NORMAL-LOADED	14°	.2419	3.33'	14'
DIVE-FRONT	11°	.1908		18'
JOUNCE - REAR	11°	.1908		18'
FRONT & REAR JOUNCE	8°30'	.1478		23'

*NOTE: THIS CONDITION EXPERIENCED ON CREST CURVES ONLY UNDER UNUSUAL CIRCUMSTANCES OF LOADING AND PAVEMENT GEOMETRY.

Figure 9. Crest vertical curve radii for underbody clearance.

Although this will bottom the suspension, center clearance is never a problem on sag curves. The author's organization has been unable to produce center interference requiring a full jounce condition, except on one rather unusual railroad crossing. Front or rear jounce alone, however, is relatively easy to experience, as in jumping curbs or on steep driveways.

On the composite vehicles, as might be expected, center clearance is quite low, and can be troublesome. However, the most critical interference is at the rear, during a rear jounce condition. On driveways and ramps, the rear impact bars will strike, even though the center may clear.

What is perhaps surprising is that the shortest vehicle is even more critical than the long one under dynamic conditions. Rear clearances are especially affected by pitch, and the short wheelbase more than offsets the shorter overhang and smaller deflections.

The relative severity of the possible points of interference can be visualized most easily by determining the radii of sag curves (Fig. 8) and crest curves (Fig. 9) which will produce interference. The most critical condition is the rear overhang on short wheelbase vehicles under conditions of rear jounce. A sag vertical curve radius less than about 90 ft would bother the composite short car. The composite long car would experience the same trouble on a sag radius of 80 ft or less. Crest radii must be below about 75 ft before underbody scraping occurs on the long-low specimen, and then only under unusual conditions.

Because no self-respecting highway engineer would build a turnpike with a vertical curve having a radius as low as 90 ft, it is only on driveways and ramps where interferences might occur. And because it is difficult to measure radii in such places, the following checks are suggested to avoid interferences:

1. There should not be more than a 5 percent change in slope between any two 10-ft chords. Thus, the ramp over a 6-in. curb should be at least 10 ft long.
2. There should be no more than $1\frac{1}{2}$ in. of clearance between the pavement and a 10-ft straightedge.

In conclusion, one significant point should be emphasized in the dimensional data reviewed. Although the names of the manufacturers were deleted from the curves, in very few instances was a critical extreme dimension found on the same make vehicle for more than two years in a row. A customer who finds his vehicle grounded with all four wheels firmly resting on nothing will be just as angry as the owner of a buggy with high clearance with all four wheels fallen off. His wrath will be directed as much at the manufacturer as at the highway commissioner, and no manufacturer with his eye on the road and his hand on his pocketbook wants that to happen.

As was implied earlier, the pavement still dictates the dimensions of the car, and probably will continue to do so as long as cars must travel on existing highways, and until highway designers and construction men can put out a completely new road system every two years, with a major face lift in between.

Discussion

ELMER R. HAILE, JR., Highway Design Engineer, Bureau of Public Roads—McConnell has presented some interesting data on vehicle dimensions based on measurements of vehicles in his test fleet, and has arrived at minimum controls for use in the design of driveway profiles. In this discussion, additional data are presented on vehicle dimensions, and less stringent controls are suggested for driveway profile design.

The author's data indicate that most of the critical passenger car dimensions affecting underclearances have not changed appreciably in the last ten years. This is surprising to many, because popular opinion is that it is becoming increasingly difficult to negotiate private driveways in the newer cars without striking a bumper or a tailpipe.

The Automobile Manufacturers' Association has established standard methods of measuring dimensions. Trade journals publish these dimensions for each model year.

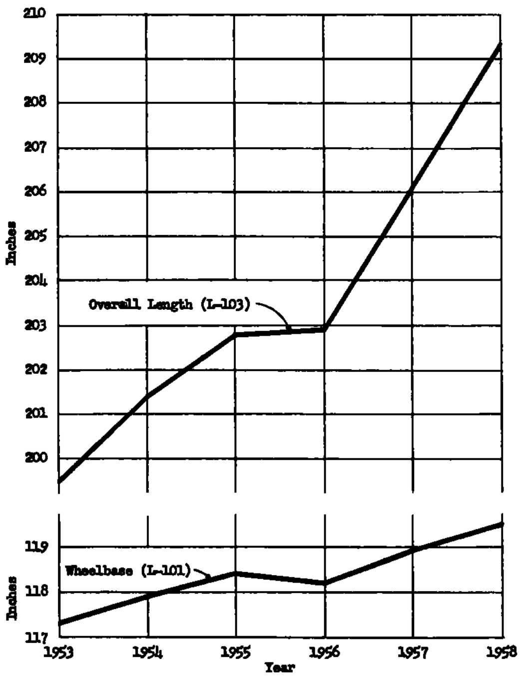


Figure 10. Weighted average wheelbases and over-all lengths of passenger cars.

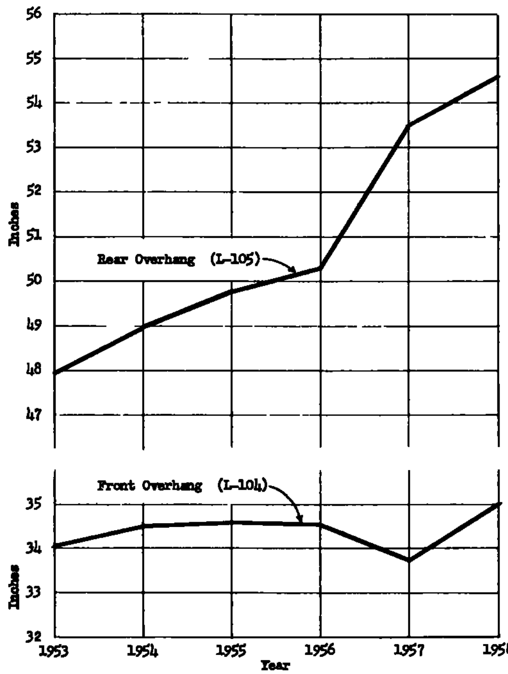


Figure 11. Weighted average overhang of passenger cars.

They also publish registration records of each make of car for each year. The average dimensions shown in the attached graphs (Figs. 10-12) were determined by weighting the dimension for each make according to the number of units registered during the year. This method gives an approximation of the average dimensions of vehicles placed on the road each year. It should be noted that the A. M. A. dimensions apply basically to the 4-door sedan or equivalent. Other body styles have dimensions that may differ from the 4-door sedan, but for the purpose of establishing a trend for successive years, it is believed that 4-door sedan dimensions serve the purpose. Seven-passenger limousines and imported cars are excluded from the averages because published data on such vehicles are incomplete.

The weighted average wheelbase of passenger cars is about 119 in., or about 9 in. longer than the average wheelbase of the cars in the test fleet described by McConnell. The value of 119 in. appears to be representative of the cars marketed in 1957, because the wheelbases of the 11 best-selling makes were in the range of

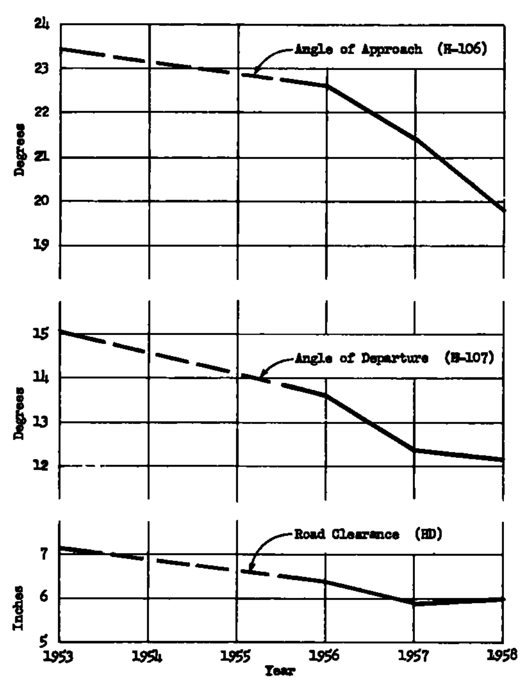


Figure 12. Weighted average road clearance and angles of approach and departure. (Values not computed for 1954 and 1955.)

115 to 133 in. These 11 makes (Ford, Chevrolet, Plymouth, Buick, Oldsmobile, Pontiac, Mercury, Dodge, Cadillac, Chrysler, and DeSoto) accounted for 92 percent of all 1957 cars registered (domestic and imported).

Figure 10 reveals a trend to longer wheelbases in the last 5 years; the aggregate increase is about 2¼ in. The average wheelbase for 1958 is tentative, because it is based on 1958 dimensions and 1957 registrations. The weighted average for 1958 will go down if short cars, such as the Rambler, appropriate a larger share of the market in 1958. Conversely, the average may go up if the Cadillac, for example, takes a larger portion of the market. Also included in Figure 10 is a graph of over-all lengths, which have increased about 10 in. in 5 years.

Figure 11 shows changes in overhang; front overhang has increased only 1 in. in the last 5 years, but rear overhang has increased nearly 7 in., or 14 percent, in the same period.

Figure 12 shows road clearances and angles of approach and departure. Road clearances have decreased 16 percent in 5 years. Angles of approach have fallen off 3.6 deg, a reduction of 15 percent. Angles of departure have decreased 2.8 deg, a reduction of 19 percent.

These graphs confirm what was already suspected, that dimensions affecting underclearances have been getting worse in recent years. This trend is unlikely to continue much longer. Sales volumes of imported cars and the small cars of American Motors are reportedly on the increase. Some of the major manufacturers may react to this report by making a few experimental reductions in length, wheelbase, or overhang. If this takes place, the critical dimensions may begin to show improvement, and the trend of the last few years will be ended.

Accordingly, it is believed that the dimensions on the composite car described by McConnell can be eased off a little. The composite car has an over-all length of 238 in. The longest 1957 car was the 224.6-in. Lincoln, and the longest 1958 car is the 229-in. Lincoln. The former can drive a sag vertical curve of 63-ft radius; the latter can take a sag vertical of 57-ft radius. The longest wheelbase, in both 1957 and 1958, is the Cadillac 60, which can negotiate a 52-ft radius vertical curve.

The critical dimension appears to be the angle of departure. The Dodge had the smallest angle in 1957, requiring a 73-ft radius sag vertical curve. Chrysler has the smallest angle in 1958, requiring a 74-ft radius. Therefore, it is suggested that a 75-ft minimum radius for sag vertical curves be used for design of driveways. In other words, there should be not more than 2 in. of clearance between the pavement and a 10-ft straightedge, or not more than a 6.7 percent change in slope between two successive 5-ft chords.

In a companion paper, Bauer (see succeeding paper) shows a minimum design of a driveway with ascending grade to lot (walk adjacent to curb). The 75-ft radius sag vertical curve suggested herein will be found to conform closely to the profile given in Bauer's Figure 9 except at the hump 3 ft right of the gutter.

As for crest vertical curves, it is suggested that a minimum road clearance of 5 in. be used for design, as most 1958 models have an underclearance of 5.3 in. or more. The composite car with a 5-in. road clearance can travel on a crest vertical curve with 45-ft radius.

It will be noted that a 45-ft radius curve conforms closely with Bauer's profile of a driveway descending to a lot.

In conclusion, it is suggested that the following minimum standards be used in the design of driveway profiles:

Sag vertical curves—75-ft minimum radius.
Crest vertical curves—45-ft minimum radius.

W.A. McCONNELL, Closure—In reviewing passenger car dimensions related to highway design, the author chose to present maximum, minimum, and average dimensions of the various makes of vehicles offered to the public, without regard to their market penetration, because these data reflect trends in automotive design philosophy. It is noted that the critical maxima and minima have remained virtually unchanged in recent years.

Weighted averages used by Haile, adjusted for the number of units of a particular make registered, reveal trends in public buying preference. Similarly, the trends for the three most popular makes plotted by Nagler (see p.) show that the public has displayed a clear desire for the longer, lower, wider offerings. The popular makes have approached the extremes in dimension in order to remain popular, even, in several cases, to the extent of employing the identical body shell as their more expensive luxury line relations. People who own only one automobile must select a unit to accommodate their occasional maximum needs, rather than their average requirements.

The author is aware that the checks proposed for driveway profiles are stringent. They are intended to be suitable not only for the most popular vehicles of the present, but also for the more extreme vehicles of the present and future, under critical operating conditions. In designing automobiles, provision must be made for satisfactory performance under occasional extreme conditions as well as under average operation, just as highway designers build their bridges to support the heaviest anticipated load. No less stringent guide should be acceptable in highway geometrics.

It is not believed that public interest is served by setting minimum standards for new construction to meet only current average requirements. In the absence of better objectives, minimum standards tend to become standards. To protect the investment in facilities intended to be useful 20 to 50 years hence, it is unwise to adopt criteria which will not be suitable for the most extreme conditions which can now be foreseen.

II. Street and Highway Design

L.A. BAUER, Expressways Engineer, City of Cincinnati

● FOR THE past several years, the automobile industry has been changing their design of cars, by making them lower and longer. On most makes and models of cars the underclearance has been reduced and both the wheelbase and over-all lengths have been increased to such an extent, that sufficient underclearance is not being provided for a safe and satisfactory entrance into many of the driveways throughout the country. This is especially true in the City of Cincinnati and like communities where topography is rugged and many steep driveway entrances, either ascending or descending from the main roadway must be used to gain access to the abutting property.

This discussion will deal with experiences in the City of Cincinnati, which experiences, it is presumed, are prevalent in many other areas and communities similarly situated.

The problem of insufficient underclearance of cars entering or leaving driveway entrances exists primarily in the suburban or residential districts, principally on streets which were improved many years ago before the automobile age or, at least, prior to the advent of present day styled cars. Many of these streets have high-crowned macadam roadways, rather deep gutters and often walks are constructed at a considerable height above the curbs.

Figure 1 shows the dimensions of underclearances, wheelbase, overhangs and over-all length of the model car which will be used in the illustrations which follow. As can be noted, this is one of the largest of the cars made.

Figure 2 shows a typical driveway profile where a high-crowned roadway and deep gutters exist. As a car enters the driveway (position 1), the front bumper will often strike the driveway ramp between the walk and gutter. When the car reaches position 2, with back wheels in the gutter, the rear bumper usually strikes the street paving because of the high crown, and the center of the car will drag or scrape over the walk. Often further trouble is encountered wherever the driveway ascends or descends on a steep grade after crossing the sidewalk. This situation occurs quite frequently in suburban areas and is a source of many complaints from users of the driveways involved. Obviously the trouble can be corrected only through extensive walk and driveway reconstruction, pavement remodeling and raising of the gutter or a combination of all at considerable expense.

When a new street is made or an older street is reconstructed and repaved, the highway designing engineer must design the driveway entrances to meet the clearance requirements of the modern automobiles. Even in new construction, some trouble is very often encountered, in connecting existing driveways properly to the new improvement.

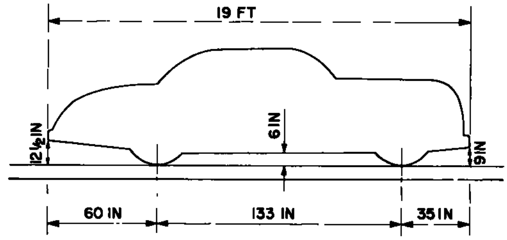


Figure 1.

The following discussion will deal with the construction methods for connecting driveways to new highway improvements worked out by the City of Cincinnati, which discussion will be appropriately illustrated.

There are two typical cases involved, one case where there is a ribbon walk some distance (say 8 ft) from the curb, and another case where the pedestrian walk is placed adjacent to the back of the curb.

In the first case, where the ribbon walk exists, two examples are being illustrated.

Figure 3 shows the ribbon walk type of construction with an ascending driveway.

Since there is a considerable distance between the curb and ribbon walk, little or

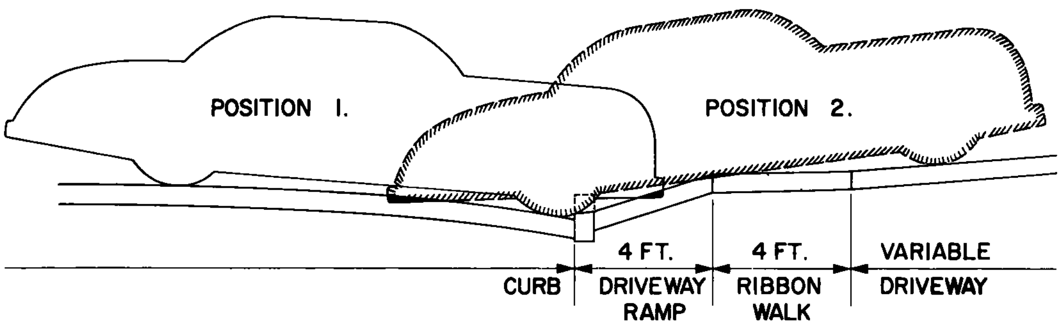


Figure 2.

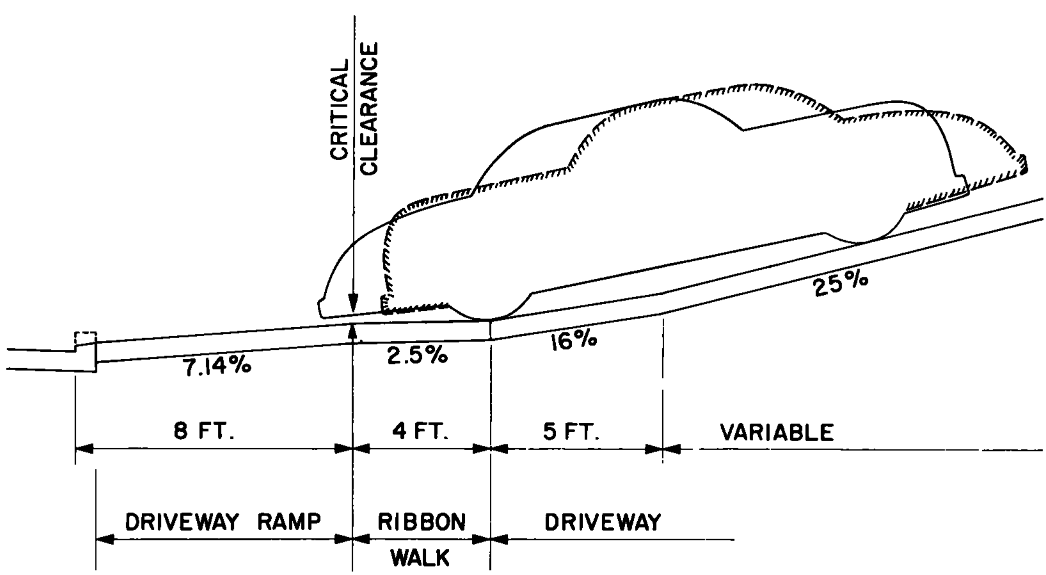


Figure 3.

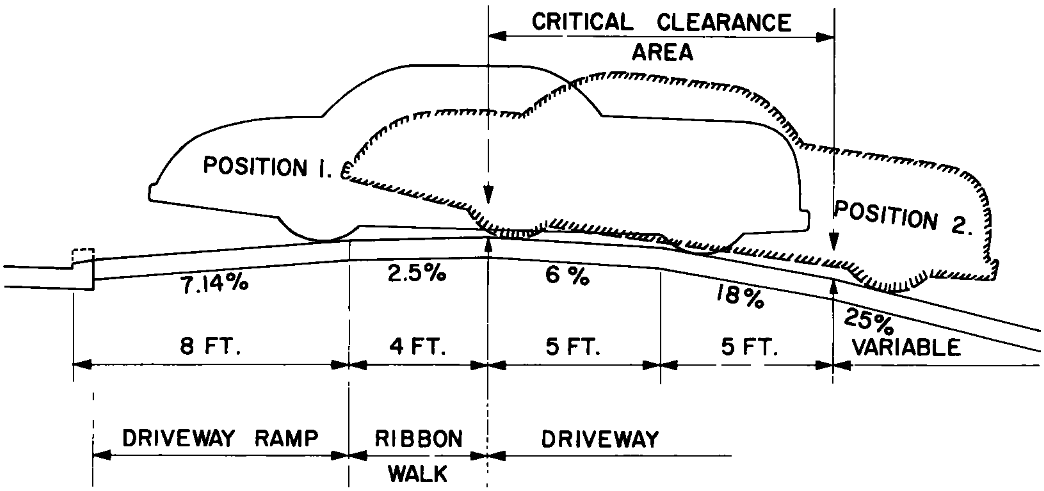


Figure 4.

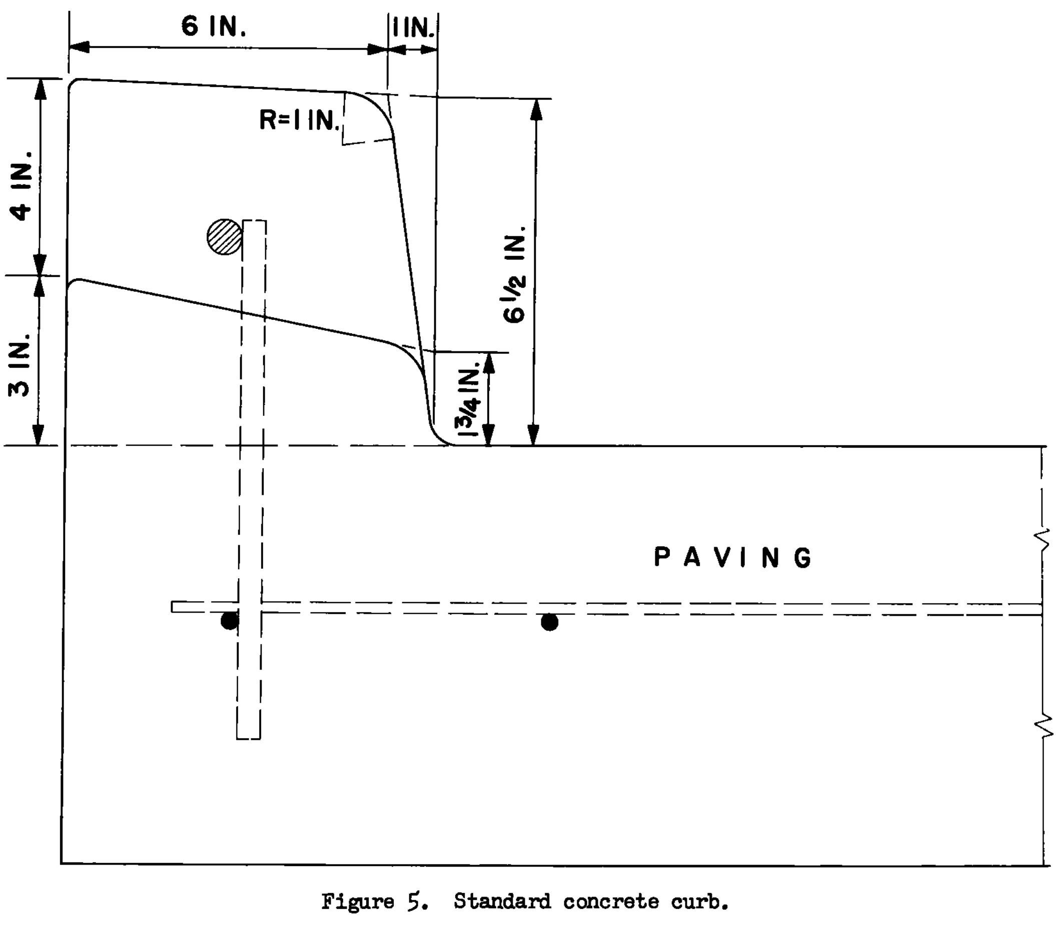


Figure 5. Standard concrete curb.

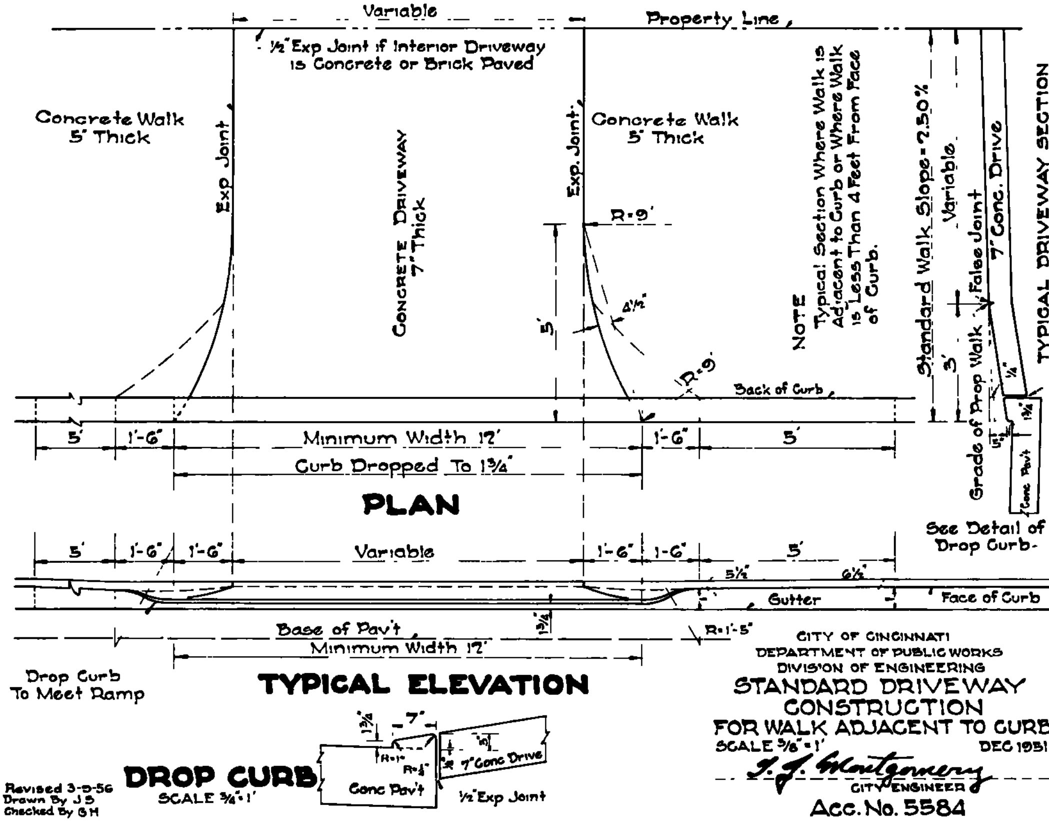


Figure 6.

no difficulties are encountered in this area, as this portion of the ramp (between curb-line and walk) usually has a gentle grade. When the driveway ascends steeply from the back of the walk into the owner's property, the ascent for the first 5 ft back of the walk should not be more than 10 in., or at the rate of 16 percent, otherwise the car will be tilted too much before it crosses the walk and the bumper will strike the ribbon walk at the break in grade nearest to the street curb.

The 25 percent grade shown on the illustration is the maximum recommended grade for driveways on private property.

In the design of the driveway profile, care is taken to insure a 2-in. underclearance at all critical points for all makes of cars. This 2-in. clearance is used as a safety factor to take care of the downward thrust that cars take when traversing the varying profile grade of the driveway and when brakes are applied.

Figure 4 shows the same type of ribbon walk construction as in Figure 3, however in this profile a steep descending grade is shown. In this instance the clearance under the middle of the car is the controlling factor to be considered in the design. The maximum rate of descent from the back of the walk into the owners property should not be more than 6 percent for the first 5 ft and 18 percent for the next 5 ft, or a total drop of 1 ft and 2½ in. in the first 10 ft.

The second case to be considered is where the pedestrian walk on a street is placed adjacent to the back of the roadway curbing. This type of construction is frequently used in the City of Cincinnati, even in the outlying areas for the following reasons. Most of the existing right-of-way widths on important thoroughfares are either 50 ft or 60 ft. It is advantageous to avoid buying property along improved lots, in making new improvements on these streets. Therefore, 36-ft roadways often are constructed in the 50-ft right-of-ways and 44-ft roadways in the 60-ft right-of-ways. This leaves 7 or 8 ft of space from the curb line to the property line for sidewalk purposes, including space for poles and fire hydrants. Since this 7 or 8 ft wide space is rather narrow for both a ribbon walk and grass plot, a 6 or 7 ft wide walk is usually placed adjacent to the curb, or when a ribbon walk is used the street edge of the walk is not more than 3 ft from the curb face. Therefore, the maximum distance available for a driveway ramp from the gutter up to the walk grade is 3 ft.

In February 1942, the City of Cincinnati adopted a standard section of concrete curbing for all new concrete roadway improvements. This curb standard, designated

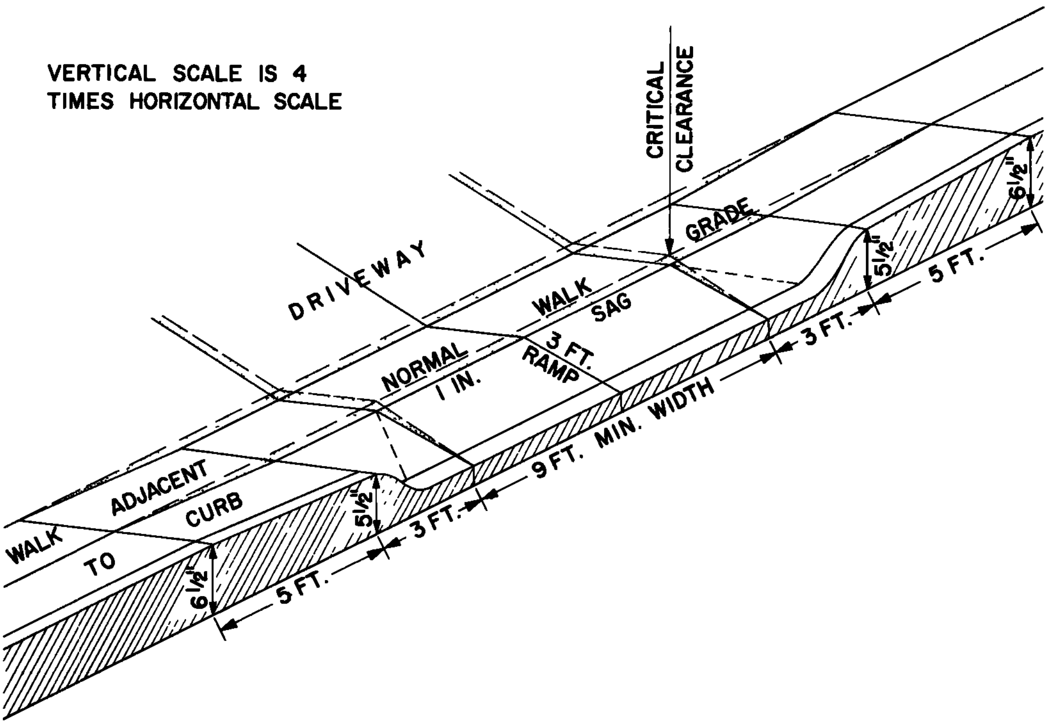


Figure 7.

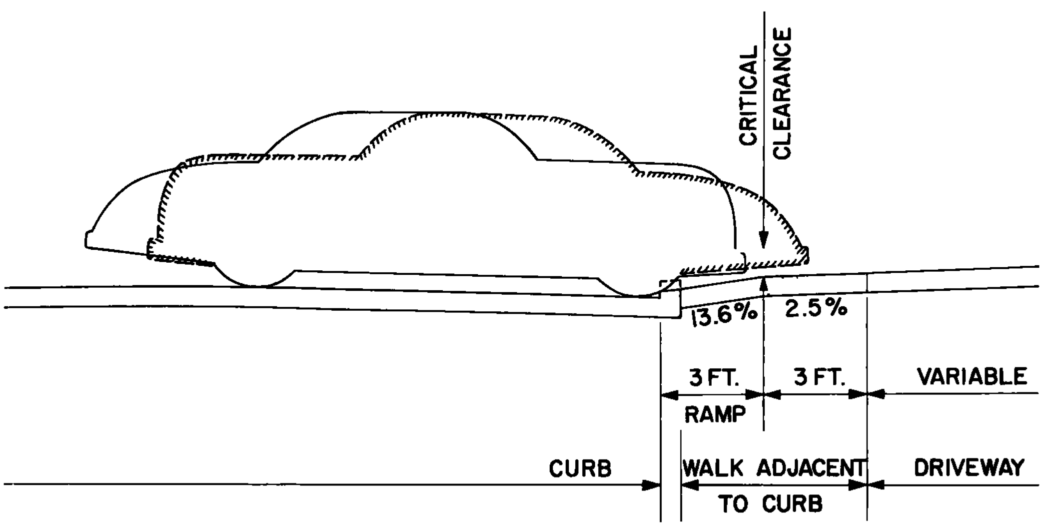


Figure 8.

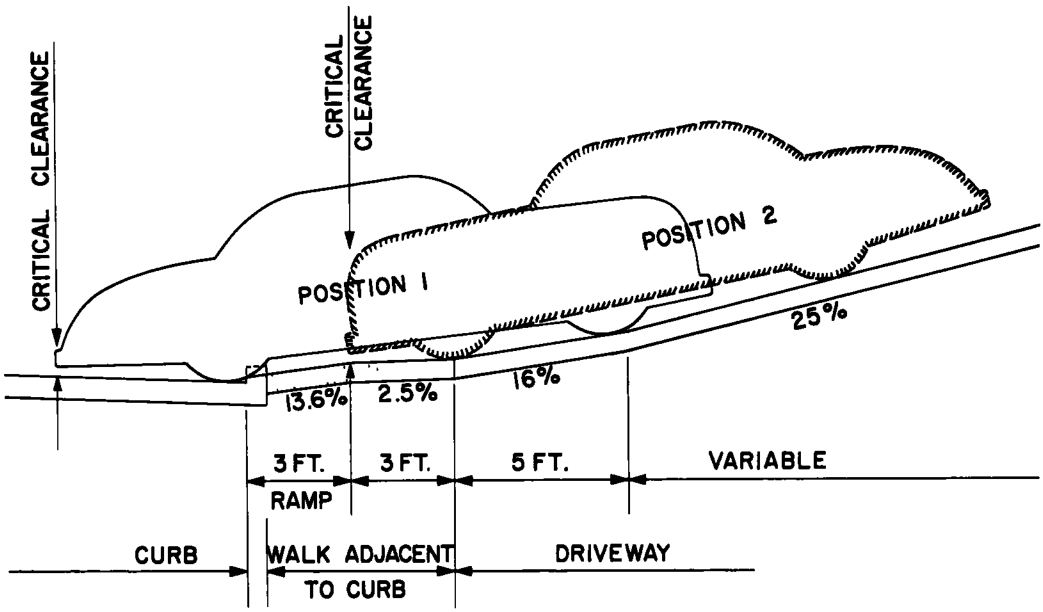


Figure 9.

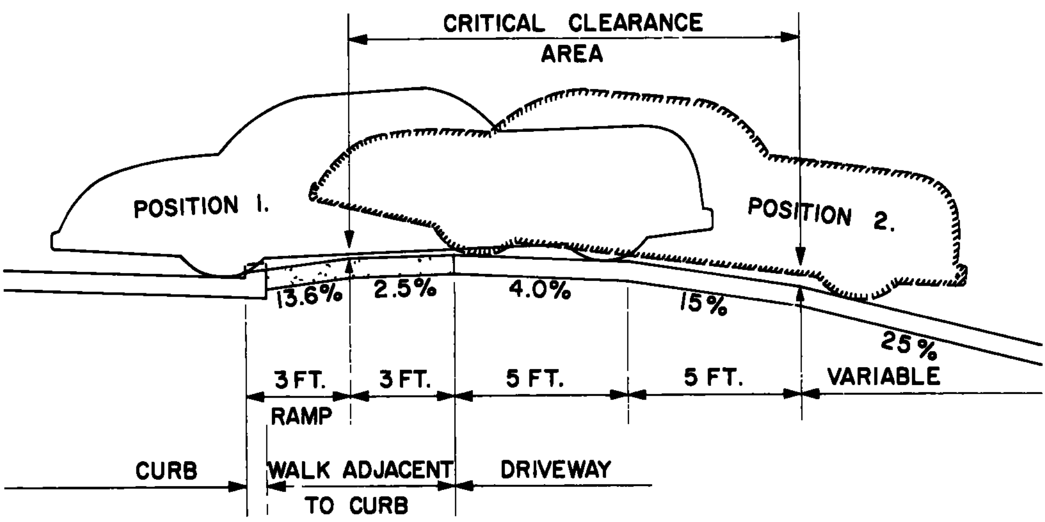


Figure 10.

as Figure 5, has a battered vertical face and a depth of 6½ in. from gutter to top of curb. The depth of more than 6 in. was designed for the purpose of permitting a future surfacing of the concrete pavement while still retaining a satisfactory gutter depth. This 6½-in. curb depth, plus an additional rise of about an inch across the 3 ft of walk space make a total rise of 7½ in. from gutter to sidewalk. The resultant driveway profile proved satisfactory for the older passenger cars, however, with the advent of the newer cars having longer overhangs, the city received complaints of bumper scraping at the top of the ramp 3 ft from the curb line. This forced the city in 1951 to adopt a new standard driveway design, designated as Figure 6. This design decreases the curb depth from 6½ in. to 5½ in. across the driveway and sags the walk grade a corresponding 1 in. This seems to have satisfactorily solved the problem up to the present time.

The reduced curb depth and sagged walk across the driveways is brought out more clearly in the projection shown in Figure 7.

The vertical scale in this projection is four times greater than the horizontal scale. The 1-in. sag in the walk grade across the driveway is made with an easy run-off and is not noticeable in the completed improvement.

Figure 8 shows a car entering and leaving a driveway, which is ramped through the walk adjacent to the curb in a distance of 3 ft, with the walk grade sagged 1 in. It can be noted that either the front or back bumper will clear the walk by 2 in. when the car is standing still. The car's bumpers will just clear the walk when its wheels are in the gutter, while entering or leaving the driveway.

Figure 9 shows the situation where the walk is adjacent to the curb and an ascending grade into the owner's property. Just as in Case 1, Figure 3, the rise from the back of walk into the owner's property should be not more than 16 percent for the first 5 ft or a rise of 10 in.

Figure 10 shows the same walk situation with a descending grade into the owner's property after crossing the walk. The descent should not be more than 2⅜ in. or 4 percent in the first 5 ft from the back edge of the walk and not more than 9 in. or 15 percent in the next 5 ft, making the maximum permissible descent about 1 ft in the first 10 ft.

In planning and working out proper grades for driveways so many different kinds of situations are encountered that the preparation of a set of standards that will cover all cases is almost an impossibility. In the foregoing examples an attempt has been made to cover the subject as completely as possible and the standards proposed can be applied in most cases. However, every driveway encountered presents a slightly different problem. Widths of sidewalk spaces, differences in elevation between roadway and walks, position and grades of the existing drives and other conditions all vary in different instances. In order to be assured of the proper driveway design in questionable cases, the following procedure is recommended.

1. Design the driveway profile as nearly as possible to available standards.
2. Plot the profile on a natural (2 ft to 1 in.) scale.
3. Prepare a cut out model car on the same scale as the profile (see Fig. 1 for dimensions).
4. Slide the cut out model along the profile for finding any trouble spots and adjust the profile where necessary.

This discourse has been on the matter of driveway profiles where they connect to the roadway and are carried across the walk area of the street. Some difficulties are also encountered in getting in and out of garages, especially where the grades are steep.

It is hoped that this discussion has brought out the salient difficulties facing the highway design engineers and the property owners themselves, caused by the reduction in underclearances in recent automobile designs.

It is strongly recommended that no further reduction of underclearance by made on cars by the manufacturers and if at all possible a minimum underclearance of 7 in. be adopted for all makes of cars.

Passenger Car Dimensions as Related to Parking Space

I. Vehicle Data

L. H. NAGLER, Administrative Engineer, American Motors Corporation

The author presents data showing trends in car sizes—lengths, widths and heights—during the past three decades. Figures are presented principally as yearly averages for the industry but, in addition, maximum and minimum values for each year are shown and some comparative data are supplied on low and medium-low priced cars in highest production volume.

Lengths and widths remained relatively constant only in the period from 1946 to 1954. The figures indicate significant increases in both lengths and widths of cars in the last four years. The rates of growths of these two car dimensions approximate the corresponding increase in the pre-war years.

Car heights have shown a decrease throughout the 30-year period, with the post-war changes continuing the pre-war trend. Heights remained relatively static only in the period from 1934 to 1938.

● THIS REPORT presents a study of trends in car sizes—lengths, widths, and heights —for the 32 years from 1927 to 1958.

Car sizes are of particular significance in connection with modern automobile usage—particularly in terms of traffic congestion, and design of parking facilities and highways.

Casual observations indicate that today's cars are larger, wider and lower than those of previous years. It is the intent of this paper to establish statistically, for reference purposes, the magnitude and timing of such changes. The trends in lengths, widths and heights are indicated on the charts herewith. An analysis of the trends follows.

ANALYSIS OF TRENDS

Length

1. Average lengths of passenger cars have increased about 4.5 in. during the past four years.
2. Significant increases in car lengths also are shown for the three makes of automobiles which represent 54 to 59 percent of the total production during this period. For these three the average length of new cars has increased nearly 12 in. since 1954 and is rapidly approaching the industry-average value.
3. Maximum and minimum lengths of new cars have shown no major change during the entire post-war period. These maximum and minimum values represent cars generally in rather limited production.
4. The early post-war period (1946-1954) evidenced no significant trend toward longer cars—trend curves are relatively flat.
5. Pre-war cars showed a major increase in length, particularly in the 1931-1937 period. These increased lengths resulted from several evolutions in car design, such as built-in trunks (affecting rear overhang) and the forward shift of both the engine and passenger areas (affecting front overhand). The trunk luggage space was provided to satisfy public demand for convenience; the relocation of passenger areas has important engineering implications in terms of ride and stability.
6. It is interesting to note that the Ford Model T of 1927 measured only 137 in.

TABLE 1

LENGTH

Year	Minimum		Averages F-C-P[a]	Averages Industry	Maximum
1927	137	Ford "T"	147.3	165.5 (17)[b]	190.3 Hudson[c]
1928	152.5	Ford[c]	159.2	169.7 (14)	213.8 Cadillac
1929	138	Ford	153.7	171.7 (19)	212 Cadillac
1930	140	Ford	152.7	169.3 (18)	205 Cadillac
1931	143	Ford	153.3	168.2 (19)	194.8 Cadillac[c]
1932	154.5	Ford	158.8	174.1 (21)	210 Cadillac
1933	168.4	Essex	173.1	187.4 (17)	213.6 Cadillac
1934	170.6	Chevrolet	174.8	193.2 (19)	215.4 Cadillac
1935	171	Chevrolet	181.9	193.4 (22)	209.7 Studebaker
1936	186.8	Ford	188.1	197.6 (22)	213.6 Cadillac
1937	180.5	Ford	189.6	198.8 (27)	216.3 Packard
1938	184.8	Chevrolet	189.1	199.1 (27)	220.4 Cadillac
1939	185.8	Studebaker	189.6	199.1 (30)	225.5 Cadillac
1940	187.1	Studebaker	192.7	201.6 (30)	226.9 Cadillac
1941	190	Studebaker	196.1	204.8 (30)	225.8 Cadillac
1942	193.6	Studebaker	196.0	207.0 (24)	225.9 Cadillac
1943-1944-1945 World War II					
1946	194.7	Plymouth[c]	196.9	206.8 (16)	218.8 Lincoln
1947	191.5	Studebaker	197.0	208.1 (18)	223.8 Cadillac
1948	191.3	Studebaker	196.8	207.2 (26)	225.6 Cadillac
1949	191.5	Plymouth	195.1	206.1 (26)	226.8 Cadillac
1950	192.6	Plymouth	195.6	206.4 (29)	224.9 Cadillac
1951	193.8	Plymouth	196.3	206.8 (31)	224.5 Cadillac
1952	187.8	Ford	193.2	206.5 (30)	224.5 Cadillac
1953	189.2	Plymouth	194.2	206.4 (30)	224.8 Cadillac
1954	186.2	Rambler	196	207.7 (33)	227.4 Cadillac
1955	186.2	Rambler	199.3	208.8 (41)	227.3 Cadillac
1956	191.14	Rambler	200.3	209.0 (40)	229.6 Imperial
1957	191.14	Rambler	203.6	210.1 (33)	224.7 Lincoln
1958	191.15	Rambler	207.8	212.2 (33)	229.0 Lincoln

[a] Ford-Chevrolet-Plymouth.
[b] Figures in parentheses indicate number of cars or models used to obtain average.
[c] These values may not be minimum or maximum of industry in that year, due to limited number of cars obtained for measurement and comparisons.

over-all. The Ford Fairlane of 1958 measures 207 in.—an increase of 70 in., or nearly 6 ft.

Width

1. Widths of new cars have increased materially in the last two years—evidenced by the marked increases in industry averages. The three big-volume cars have been widened about 3.4 in. in the past two years, and now for the first time are very close to the industry average. Since 1954 the industry-average width has increased 2.2 in.

2. The greatest increase in width occurred in pre-war cars—about 8-in. increase in the new-car industry average from 1927 to 1942. This increase was associated with the adoption of wider seats to accommodate three persons side-by-side, instead of two as in the 1920's. However, part of the increased passenger capacity was provided by widening the car body to full car width, eliminating exterior running boards, as discussed later.

Height

1. Heights have shown consistent decreases both in pre-war and post-war cars as the industry developed cars with lower appearance and lower center of gravity. The

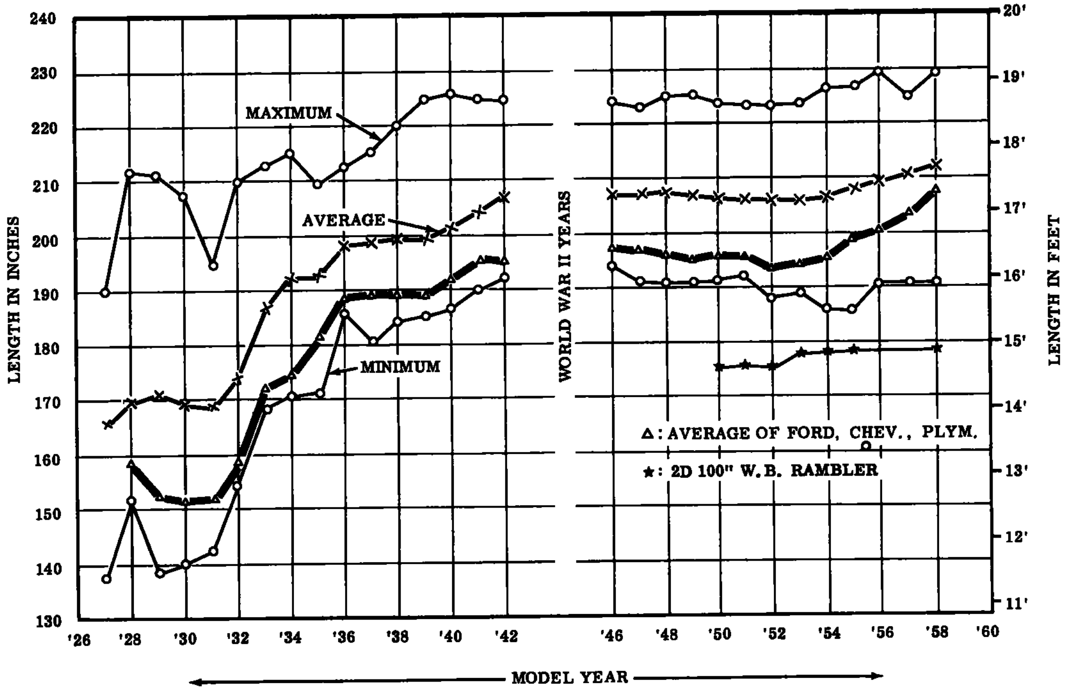


Figure 1. Over-all length of 5 to 6 passenger, 4-door sedans.

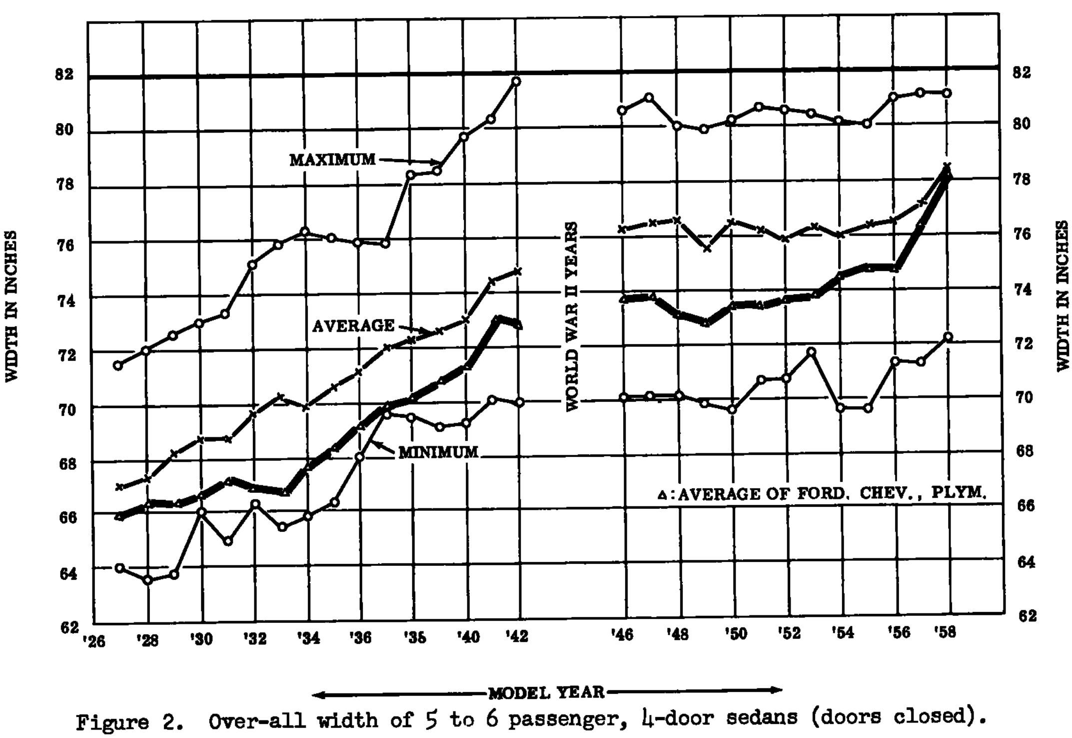


Figure 2. Over-all width of 5 to 6 passenger, 4-door sedans (doors closed).

TABLE 2

WIDTH

Year	Minimum	Averages		Maximum
		F-C-P[a]	Industry	
1927	64 Essex	65.87	67.0 (16)[b]	71.5 Lincoln
1928	63.5 Essex	66.5	67.3 (13)	72 Cadillac
1929	63.8 Essex	66.37	68.2 (19)	72.5 Hudson
1930	66.0 Essex	66.63	68.7 (18)	73 Cadillac
1931	65 Essex	67.13	68.7 (18)	73.3 Cadillac
1932	66.3 DeSoto	66.83	69.6 (21)	75.1 Cadillac
1933	65.4 Chevrolet	66.77	70.3 (17)	75.9 Cadillac
1934	65.8 Chrysler	67.63	69.9 (19)	76.3 Cadillac
1935	66.3 Chevrolet	68.37	70.7 (22)	76.0 Cadillac
1936	68 Chrysler	69.1	71.1 (22)	75.9 Cadillac
1937	69.5 Ford	69.73	72.0 (27)	75.8 Cadillac
1938	69.4 Ford	70.07	72.3 (27)	78.4 Cadillac
1939	69.1 Studebaker	70.73	72.7 (30)	78.5 Cadillac
1940	69.2 Studebaker	71.27	73.0 (30)	79.7 Cadillac
1941	70.1 Studebaker	73.0	74.4 (30)	80.6 Cadillac
1942	70 Studebaker	72.7	74.7 (24)	81.8 Cadillac
1943-1944-1945 World War II				
1946	70.3 Studebaker	73.53	76.2 (16)	80.7 Cadillac
1947	70.3 Studebaker	73.75	76.3 (18)	81.2 Cadillac
1948	70.2 Studebaker	73.12	76.4 (26)	80.0 Cadillac
1949	69.8 Studebaker	72.83	75.6 (26)	79.9 Cadillac
1950	69.6 Studebaker	73.4	76.4 (29)	80.1 Cadillac
1951	70.7 Studebaker	73.4	76.2 (30)	80.7 Oldsmobile
1952	70.7 Studebaker	73.9	75.9 (30)	80.6 Cadillac
1953	71.7 Studebaker	73.57	76.2 (30)	80.5 Cadillac
1954	69.5 Studebaker	74.47	76.2 (33)	80.1 Cadillac
1955	69.5 Studebaker	74.73	76.6 (41)	80.0 Buick
1956	71.3 Rambler	74.93	76.7 (40)	81.0 Chrysler
1957	71.3 Rambler	76.37	77.1 (32)	81.2 Imperial
1958	72.2 Rambler	78.32	78.4 (33)	81.2 Imperial

[a] Ford-Chevrolet-Plymouth.
[b] Figures in parenthesis indicate number of cars or models used to obtain average.

highest cars now in production are considerably lower than the lowest of only 5 years ago.

Car heights have only incidental effects on parking considerations. For this reason the changes in heights are mentioned here primarily as a matter of interest. Vehicle heights have other important effects, however, such as safety, stability, and ease of handling.

SOURCE OF DATA

Data in this paper on car lengths, widths and heights for pre-war new cars (1927 to 1942) were obtained from actual engineering measurements made on sedans by one of the automobile manufacturers, on its own and competitive cars purchased for tests and comparisons. In most years, sufficient cars were purchased and measured to represent a comprehensive coverage of the industry in those years. A few two-door sedans were included for the early years of this study, but otherwise the cars were of the four-door, five- or six-passenger variety. No foreign-built cars were included.

Car makes and models were selected to provide a reasonable continuity for statistical purposes, as will be discussed later. Post-war cars were selected to include all makes and major series produced in 1956-1957-1958. A total of 51 makes and models resulted. A relatively few makes were eliminated—Kaiser, Frazer, Henry J, Hudson Jet, the 100-in. Rambler, Willys Aero, Crosley. (Some of these makes or models were not "qualified" as they were not available in four-door sedan models.)

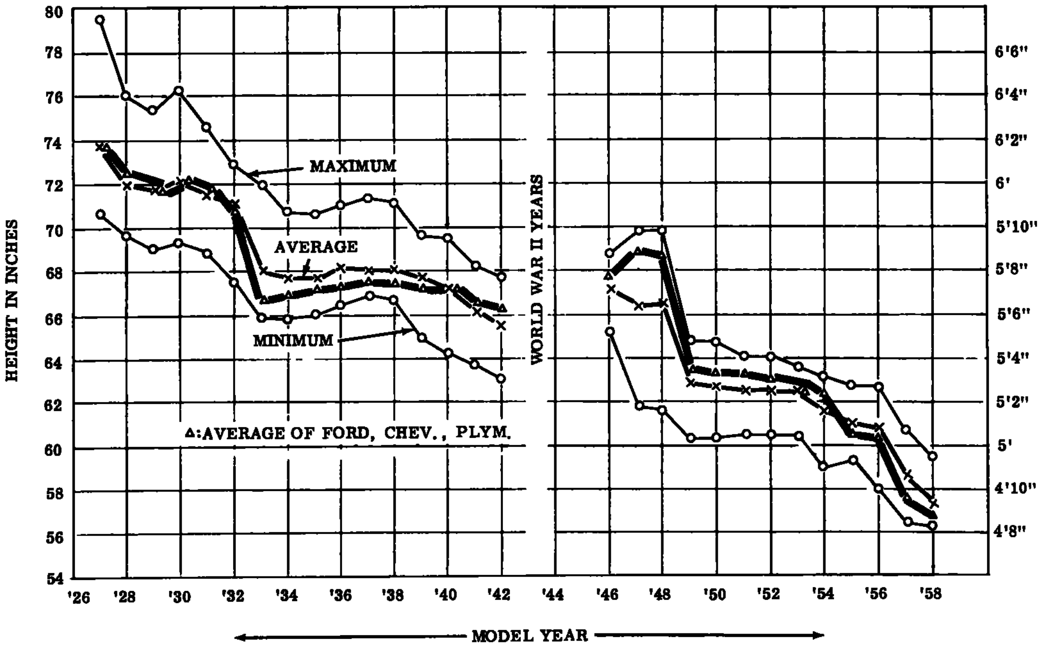


Figure 3. Over-all car height of 4-door sedans loaded with 5 passengers.

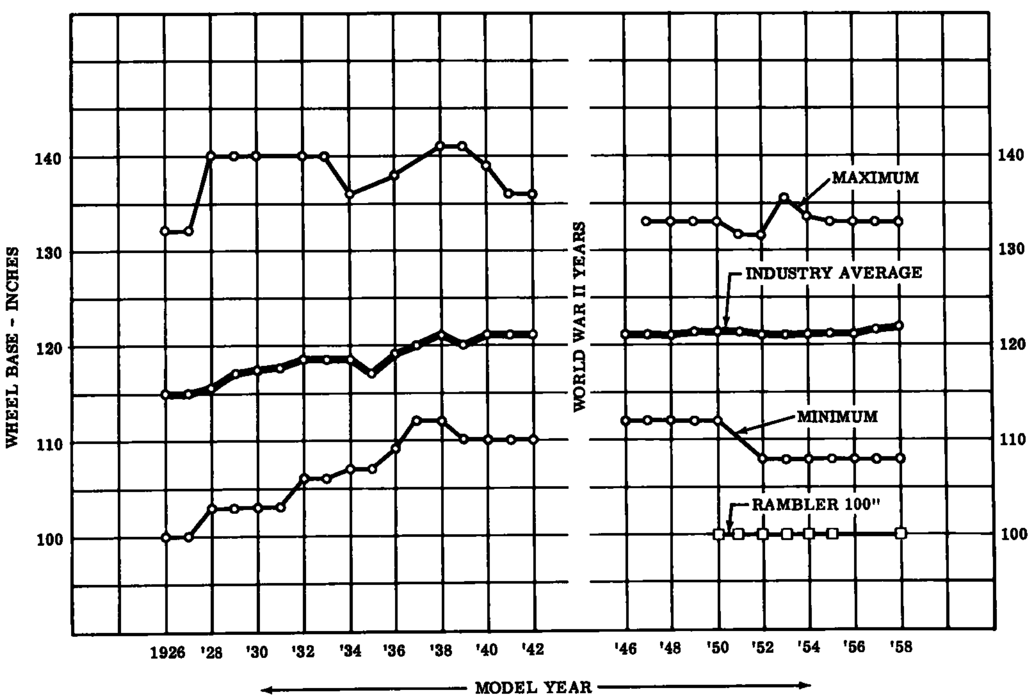


Figure 4. Wheelbase of 5 to 6 passenger, 4-door sedans.

TABLE 3

HEIGHT

Year	Minimum		Averages			Maximum	
			F-C-P[a]	Industry			
1927	70.6	Nash	73.8	73.7	(16)[b]	79.4	Buick
1928	69.5	Dodge	72.4	72.0	(14)	76	Cadillac
1929	69	Chrysler	71.9	71.9	(19)	75.3	Cadillac
1930	69.4	Buick	72.13	72.1	(18)	76.3	Cadillac
1931	68.9	Dodge	71.87	71.5	(19)	74.6	Cadillac
1932	67.6	Hudson	70.37	71.1	(21)	73	Cadillac
1933	65.9	Chevrolet	66.57	68.0	(17)	72	Cadillac
1934	65.8	Chev. & DeSoto	66.83	67.7	(19)	70.7	Packard
1935	66.0	Chevrolet	67.2	67.8	(24)	70.6	Packard
1936	66.4	Lincoln	67.3	68.1	(24)	71	Packard
1937	66.8	Studebaker	67.63	68.0	(27)	71.4	Packard
1938	66.7	Studebaker	67.37	68.0	(27)	71.3	Packard
1939	65	Studebaker	67.4	67.7	(30)	69.7	Cadillac
1940	64.2	Studebaker	67.07	67.1	(30)	69.6	Nash
1941	63.8	Cadillac	66.77	66.1	(31)	68.1	Cadillac
1942	63.1	Oldsmobile	66.3	65.6	(25)	67.7	Nash
1943-1944-1945 World War II							
1946	65.3	Buick	67.8	67.3	(16)	68.8	Mercury
1947	61.8	Studebaker	69.0	66.4	(18)	69.9	Ford
1948	61.7	Hudson	68.9	66.5	(26)	69.9	Ford
1949	60.2	Hudson	63.33	62.8	(26)	64.7	Packard
1950	60.2	Hudson	63.3	62.7	(29)	64.7	Packard
1951	60.4	Hudson	63.3	62.6	(31)	64.0	Chrysler
1952	60.4	Hudson	63.0	62.6	(30)	64.0	Chrysler
1953	60.4	Hudson	62.37	62.4	(30)	63.5	Oldsmobile
1954	59.0	Rambler	62.37	61.7	(33)	63.2	Pontiac
1955	59.4	Rambler	60.53	61.1	(41)	62.7	Lincoln
1956	58.0	Rambler	60.33	60.9	(41)	62.7	Buick
1957	56.2	Ford	57.48	58.4	(33)	60.4	Nash
1958	56.22	Ford	56.78	57.38	(33)	59.6	Buick

[a] Ford-Chevrolet-Plymouth.
[b] Figures in parenthesis indicate number of cars or models used to obtain average.

Fortunately these post-war makes also represented the popular cars in medium-to-high production for the entire 32-year period, with relatively few exceptions.

Makes and typical series of new cars for the post-war years included:

Buick 40-50-60-70
Cadillac 61-62-60S
Chevrolet 6 and V8
Chrysler W., N.Y., Imp.
DeSoto 6, Str. 8, V8
Dodge 6 and V8
Ford 6 and V8
Hudson Comm., Hornet, Wasp, V8's
Lincoln
Mercury
Nash 600, States., Amb. 6 and V8
Oldsmobile 66, 68, 88, S88, 98
Packard 200, 300, 400, Clipper, Patrician
Plymouth 6 and V8
Pontiac 6, Str. 8, V8
Rambler 6 and V8
Studebaker Champ., Comm., Pres., L.C.

Models and/or series of each make were chosen to provide continuity and resulting statistical significance. (Such continuity was considered necessary for the data to be statistically significant in providing valid and comparable industry averages.) For example, the same number of dimensions were used for consecutive years wherever data were available, even though dimensions in any one year might happen to be the same for every model of a given make.

For the pre-war years the same domestic makes were included, but some of the model and series names were different, representing the normal evolution characteristic of the industry. Pre-war (1927-1942) models totaled 31 and included the following:

Buick Std., 40, 50, Roadmaster	LaSalle Str. 8, V8 (by Cadillac)
Cadillac 60, 61, 70	Lincoln, Zephyr, V12
Chevrolet 4 and 6	Mercury (since 1938)
Chrysler 6, Str. 8, N.Y.	Nash Spec. 6, Adv. 6, Amb. 6, 600
DeSoto	Oldsmobile 6, Str. 8's, 66, 68, 78, 88
Dodge	Packard 110, 120, Super 8, Custom 8
Essex, Terraplane (by Hudson)	Plymouth 4 and 6
Ford T, A, B, 60, 85, 6, V8	Pontiac 6 and 8
Hudson Super 6, Commodore	Studebaker Ch., Comm., Pres., Land Cr.

Many more pre-war makes were produced and sold than are listed above. However, makes produced in the 20's and 30's but later discontinued were purposely omitted, to avoid possibility of interference with the continuity of models considered necessary for best statistical procedures. Such makes not included in the dimensional study include the following:

Durant	Jordan	Hupmobile	Graham-Paige
Flint	Franklin	Locomobile	Jewett
Star	Stutz	Rickenbacker	Reo
Willys Knight	Marmon	Pierce-Arrow	Gardner
Whippet	Moon	Peerless	Chandler

Most of these makes were casualties of the depression years in the 1930's. These discontinued makes generally represent cars in relatively low production volume. If included they might erroneously affect the validity of the industry averages.

In the 1952-1958 period, opportunity was offered for comparing the previously described new-car industry averages with two independent compilations of yearly averages using (a) all cars in production of the four-door six-passenger sedan types, and (b) the eight domestic makes in highest production volume during the 1938-1958 period, and representing over 80 percent of the total production in that period.[1] The dimensional trends were substantially the same for all three methods. It was apparent that the statistics using the post-war 51 "continuing" makes and models produced acceptable results for the purpose of this paper.

In each year certain long-wheelbase, low-production, specialized types of passenger vehicles were eliminated from the tables. Such vehicles included the seven- and eight-passenger sedans and limousines such as offered in the Cadillac 75, the larger Packards and the Chrysler Imperial. It was considered that these specialized cars would unduly affect the maximum values for each year, as well as the average.

Data for each year are herein reported as:

1. The range of sizes offered (represented by the maximum and minimum values).
2. The arithmetic average of the individual values for each year, giving each make and/or model equal weight.[2]
3. The average of Ford-Chevrolet-Plymouth sedans, to give an idea of the largest proportion of car production. This Ford-Chevrolet-Plymouth average was used in lieu of the complex mathematical procedures needed if exact "weighting" were given to

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[1]The independent 1952-1958 industry averages, and the 8-car 1938-1958 averages are not reported in this paper.

[2]A few exceptions to comprehensive industry coverage are apparent in the charts, but generally they affect the minimum and maximum values rather than the averages. Specific examples include the maximum lengths noted in 1927 and 1931—larger cars were in production in both of these years.

relative production of each make and model. Such an involved statistical procedure was considered prohibitive as to research time requirements, and unnecessary for the purpose of this paper.

4. Wheelbase trends for the years 1930-1958 are shown in Figure 4, as a matter of general interest. It will be noted that, unlike over-all length, wheelbases remained relatively constant throughout this period.

While interpreting the yearly dimensions presented herein, it should be noted that there is a considerable delay before any change in the industry-wide yearly values materially affects the majority of cars in actual service. At any one time there are on the roads, not only cars of the current models, but also cars one, two, three, four, and more years of age. The average car in service is 5.5 years old. In the replacement cycle, new cars are supplanting cars 10 to 20 years old as these early vehicles reach the end of their serviceable life.

The significance of this situation is that a trend toward longer, wider or lower cars becomes progressively accentuated, but at a rate slower than that indicated in the charts presented herein. On the other hand, a relatively fast increase in car lengths such as in the last four years, even if arrested or reversed in the 1959 and later models, will become of increased significance to designers of parking facilities in the years to come, as greater numbers of the shorter cars of the 1934 to 1954 model years are retired.

GENERAL COMMENTS

Psychological phases importantly affect an observer's concept of car sizes. Although over-all widths increased about 8 in. from 1927 to 1942, bodies and seats increased in width considerably more. Bodies were widened to the over-all car width, running boards were eliminated and doors hung close to the extreme "beam" of the car. The resulting greatly increased over-all width with doors open gave the magnified impression of the car's actual width, particularly as the occupants experience difficulty in entrance and exit in a restricted space, such as in a one-car garage of a 1920 home. Often this problem is accentuated with two-door models which are necessarily equipped with wide doors.

Car styling likewise has a major effect on our conception of exterior dimensions. The "long-look" of modern cars is partly due to the lower lines and reduced over-all height, which changes the relation between height and length. The 1958 Rambler is actually more than an inch narrower over-all than its 100-in. wheelbase predecessor of the 1950-1955 model years—yet it appears considerably wider.

Today, the results of two major automotive forces pulling against each other are apparent. Changes in car usage pull in the direction of more compact, more economical means of personal transportation. On the other hand the established design concepts of the major U.S. producers have tended toward longer, wider, more powerful cars. This traditional design concept is not to be taken lightly—it has been commercially successful; the bigger the new cars got, the more millions were sold.

Size of cars seems to be "going down a dead-end highway." The U.S. car market shows evidence of undergoing a fundamental change. The growing popularity of small, economical foreign cars is one expression of this changing market. The increasing demand for compact, more economical American-built cars is another.

The customer's selection of automobiles—and consequently the length, width and height of the vehicle he drives, parks and garages—might well be an appropriate subject for an entirely separate study in some other field than that of engineering and statistics. The customer today has a wider range of choice, for instance, between the longest and shortest automobile he might purchase. The current interest in smaller more compact cars is of major significance.

Discussion

WILLIAM F. HALLSTEAD, III, Senior Highway Designer, Whitman, Requardt and Associates, Baltimore—In their symposium presentations at the HRB Convention, January 8, 1958, both Mr. Stonex and Mr. McConnell placed the responsibility for the "big car" trend on the driving public. Mr. Nagler, whose interest in compact cars is apparent, opposed the trend but did not fire what would have been justified broadsides at his competitors.

George Romney, President of American Motors, is far more outspoken than was his representative at the HRB symposium. He has said: "Cars 19 ft long, weighing two tons, are used to run a 118-lb housewife three blocks to the drugstore for a 2-oz package of bobby pins and lipstick. . . . The automobile industry is noted for its super-salesmanship. It has demonstrated it by selling people on the idea that big, heavy, bulky cars are safer and more comfortable."

Vance Packard, an expert in the analysis of American advertising, has stated that automobile advertising caters to the promotion of "big carism," and resulting "no roomism" in cities. He says that Chrysler's dart shape with its high tailfins is styled primarily as a prestige symbol. Buick designs its cars for "socially mobile people who still aspire to rise higher in social status." According to Packard, many a man buys a new and more powerful car every year or so simply to reassure himself of his own masculinity. This is hardly far-fetched because sales motivation researchers have recently come to the conclusion that a man's automobile is an extension of his personality. Dealers are being warned not to kick the tires of cars brought in for appraisal because the owner may subconsciously take that kick personally.

It appears that automobiles are styled basically for emotional appeal, and that the car manufacturers profit from such an approach. The key words in automobile advertising during the past few years have been "massive" (Mercury); "mightiest muscles" and "most powerful car" (Chrysler); "big," "longer" and "wider" (most manufacturers, but notably Chevrolet in 1958).

TABLE 4

COMPARATIVE VEHICLE LENGTHS[a]

Vehicle	1953[b]	1957	1958	1-Yr Change	5-Yr Change
Buick					
Special	206.4	208 4	211.8	+3.4	+5.4
Century					
Super	211.2	215.3	219.1	+3.8	+7.9
Roadmaster					
Limited	-	-	227.1	-	-
Cadillac					
Series 60	225.6	224.4	225.3	+0.9	-0.3
Series 62	216.0	215.9	216.8	+0.9	+0.8
Series 75	242.4	236.2	237.1	+0.9	-5.3
Eldorado	-	222.1	223 4	+1.3	-
Chevrolet					
All models	195.6	200.0	209.1	+9 1	+13.5
Chrysler					
Windsor	211.2	219.2	218.1	-1 1	+6.9
Saratoga	-	219.2	220 2	+1.0	-
New Yorker	-	219.2	220 2	+1.0	-
De Soto					
Firesweep	213.6	215 8	216.5	+0.7	+2 9
Firedome	-	218 0	218 6	+0.6	-
Fireflite					
Dodge					
All models	200.4 190.8	212.2	213.8	+1.6	+13 4 & +23.0
Edsel					
Ranger	-	-	213.2	-	-
Pacer					
Corsair	-	-	218.9	-	-
Citation					
Ford					
Custom	198.0	201.7	202 2	+0.5	+4.2
Fairlane	-	201.7	207.2	+5.5	-
Imperial					
All models	-	224.0	225.0	+1.0	-
Lincoln					
All models	213.6	224.6	229.0	+4.4	+15.4
Mercury					
Monterey	201.6	211.1	213 1	+2.0	+11.5
Montclair					
Park Lane	-	-	220.1	-	-
Oldsmobile					
88	204.0	208.2	208.2	none	+4.2
Super 88					
Ninety-Eight	214.8	216.7	216.7	none	+1.9
Plymouth					
All models	188.4	204.6	204.6	none	+16.2
Pontiac					
Chieftain	202.8	206.8	210.5	+3.7	+7.7
Super Chief	202.8	206.8	215.5	+8 7	+12.7
Star Chief	-	214.8	215 5	+1.7	-
Bonneville	-	-	211.7	-	-
Studebaker					
Champion	198.0	202.4	202.4	none	+4.4
Commander	202.8	202.4	202.4	none	-0.4
Hawk Series	-	203.9	203.9	none	-

	1953	1957	1958
Longest	Cadillac 75 242 4	Cadillac 75 236.2	Cadillac 75 237.1
Shortest	Plymouth 188.4	Chevrolet 200 0	Ford Custom 202.2

Greatest 1-yr increase	Chevrolet	+9.1 (All models)
Greatest 1-yr decrease	Chrysler	-1.1 (Windsor, New Yorker)
Greatest 5-yr increase:	Dodge	+23.0 (Apparent)
Greatest 5-yr decrease:	Cadillac	-5.3 (Series 75)

[a] In inches. Does not include "compact" types or station wagons

[b] Approximate lengths of comparable models.

The traffic and highway engineers are not overly concerned with the eye-appeal of car styling. Their fundamental interest is its effect. Is the big car trend actually damaging to present vehicle facilities?

The writer recently completed a stop survey of all the major automobile manufacturers, 29 selected traffic departments, the National Parking Association and the American Automobile Association. Replies to this survey were received from about 50 percent of the traffic engineers contacted. Of the 14 automobile manufacturers contacted, only American Motors, Chevrolet, Chrysler and Dodge replied. The National Parking Association was of considerable assistance.

The replies to this survey were most detailed, and the 50 percent response of engineers is felt to be extremely high because the survey was made in the name of an individual with no inference of any official connection to any organization. All but one response (exclusive of the manufacturers) expressed concern over increasing vehicle dimensions. The high response rate is considered indicative of the growing alarm of engineers toward the effects of the big car trend.

TABLE 5

COMPARATIVE VEHICLE WIDTHS[a]

Vehicle	1953[b]	1957	1958	1-Yr Change	5-Yr Change
Buick					
Special	75.6	74.8	78.0	+3.2	+2.4
Century					
Super	80.4	77.6	79.7	+2.1	-0.7
Roadmaster					
Limited	-	-	79.7	-	-
Cadillac					
Series 60	81.6	80.0	80.0	none	-1.6
Series 62	80.4	80.0	80.0	none	-0.4
Series 75	80.4	80.0	80.0	none	-0.4
Eldorado	-	80.0	80.0	none	-
Chevrolet					
All models	74.4	73.9	77.7	+3.8	+3.3
Chrysler					
Windsor	76.8	78.8	79.6	+0.8	+2.8 &
Saratoga	81.6				-2.0
New Yorker					
De Soto					
Firesweep	76.8	78.2	78.3	+0.1	+1.5
Firedome					
Fireflite					
Dodge					
All models	74.7	77.9	78.3	+0.4	+3.9 &
	73.2				+5.1
Edsel					
Ranger	-	-	78.8	-	-
Pacer					
Corsair	-	-	79.8	-	-
Citation					
Ford					
All models	74.4	77.0	78.0	+1.0	+3.6
Imperial					
All models	-	81.2	81.2	none	-
Lincoln					
All models	78.0	80.3	80.1	-0.2	+2.1
Mercury					
Monterey	74.4	79.1	81.0	+0.9	+6.6
Montclair					
Park Lane	-	-	81.0	-	-
Oldsmobile					
All models	76.8	76.4	78.5	+2.1	+1.7
Plymouth					
All models	73.2	78.2	78.2	none	+5.0
Pontiac					
Chieftain	76.8	75.2	77.4	+2.2	+0.6
Super Chief					
Star Chief	-	75.2	77.4	+2.2	-
Bonneville	-	-	77.4	-	-
Studebaker					
Champion	69.6	75.8	75.8	none	+6.2
Commander					
Hawk Series	-	71.3	71.3	none	-

	1953	1957	1958
Widest	Cadillac 60 Chrysler V8C59 81.6	Imperial 81.2	Imperial 81.2
Narrowest	Studebaker 69.6	Stud Hawks 71.3	Stud. Hawks 71.3

Greatest 1-yr increase	Chevrolet	+3.8 (All models)
Greatest 1-yr decrease	Lincoln	-0.2 (All models)
Greatest 5-yr increase	Mercury	+6.6 (Monterey, Montclair)
Greatest 5-yr decrease	Chrysler	-2.0 (Apparent)

[a] In inches. Does not include "compact" types or station wagons.
[b] Approximate widths of comparable models.

TABLE 6

PASSENGER VEHICLES 18 FT AND OVER IN LENGTH

1953	1957	1958
Cadillac	Cadillac	Buick
Series 60	Series 60	Super
Series 62	Series 75	Roadmaster
Series 75	Eldorado	Limited
Chrysler	Chrysler	Cadillac
V8-C-59	Windsor	Series 60
Packard	Saratoga	Series 62
8-2626	New Yorker	Series 75
	300	Eldorado
	Continental	Chrysler
	De Soto	Windsor
	Firedome	Saratoga
	Fireflite	New Yorker
	Imperial	300
	All models	Continental
	Lincoln	De Soto
	All models	Firesweep
	Oldsmobile	Firedome
	Ninety-Eight	Fireflite
		Edsel
		Corsair
		Citation
		Imperial
		All models
		Lincoln
		All models
		Mercury
		Park Lane
		Oldsmobile
		Ninety-Eight

Much of the data accumulated by the survey is of interest. The following cities reported recent, current or planned lengthening of the distance between parking meters: Boston, Elmira, N.Y., Kansas City, Mo., Pittsburgh, and Wichita.

In addition, Los Angeles reported using a double stall arrangement with 8-ft adjacent maneuvering areas. Cleveland, and several of the other cities mentioned, reported difficulty with off-street parking facilities.

Thus, almost ⅓ of the cities contacted (24) in a purposely random sampling reported difficulty in coping with parking facilities for late model cars. Several of the replies strongly denounced the trend. Two of the replying traffic engineers urged government regulation of vehicle dimensions.

Dodge and Chrysler spokesmen defended the big car on the grounds that public demand forces such styling. The Chevrolet representative stated that Chevrolet's length had increased only 4⅛ in. since 1942. Just one month later, Chevrolet announced the 1958 models, 9.1 in. longer than those of 1957, resulting in a 5-yr increase of 13.5 in. American Motors answered the survey letter as previously indicated.

In summary, this spot survey, though limited in its scope, produced a high percentage of opinion that big car styling is an increasingly serious detriment to the capacity of existing and future parking facilities. Such styling is already producing economic loss in the form of meter moving and pavement repainting costs, reduction of parking capacities and consequent reduction of meter and commercial facility revenues, and the fact that new off-street facilities must be designed to accomodate these large vehicles.

Tables 4, 5 and 6 show automobile length and width increase over 1- and 5-yr periods, and the increase of 18 ft long passenger vehicles over 1- and 5-yr periods.

L. H. NAGLER, Closure—Mr. W. F. Hallstead is to be complimented on his analysis of the "big-car complex." As he indicates, the buying public has been preconditioned to accept big, heavy cars as marks of social prestige, riding comfort and safety. This result has been accomplished through expenditure of many millions in advertising budgets by the major car manufacturers, taking advantage of and further promoting the typical American proneness for bigger, more powerful, more impressive property.

Bigness and overweight are not necessary for automotive riding comfort and safety on the highways. It is difficult to combat the public misconception of these phases—merely offering sensibly-sized, sensibly-powered cars apparently is not enough, when unsupported by huge advertising budgets. There are indications that the driving public is becoming more aware of some of these factors, and is finding that compact cars are ideally suited to their needs for personal transportation. Moreover, compact cars can be purchased and operated at considerably less cost.

Supplementing Hallstead's data on car sizes, Table 7 indicates average lengths and widths represented by the eight makes in normal highest production volume, for the years 1938-1958. These data were mentioned in the original paper, but specific values were not presented.

Another index of the growth of car size is to be found in Table 8, which shows the theoretical "shadow" of cars at 10-yr intervals.

TABLE 7

AVERAGE LENGTHS AND WIDTHS[a]

Year	Average Length	Average Width
1958	211.67	77.61
1957	208.64	76.68
1956	206.51	76.11
1955	206.12	76.05
1954	205.12	75.84
1953	202.51	75.55
1952	203.44	75.65
1951	204.15	75.96
1950	203.04	76.12
1949	203.49	75.58
1948	205.69	76.17
1947	205.95	76.45
1946	205.67	76.70
1942	202.79	74.17
1941	203.42	74.42
1940	198.68	72.17
1939	195.24	71.71
1938	193.53	70.83

[a] Makes of cars were Ford, Chevrolet, Plymouth, Buick, Oldsmobile, Pontiac, Dodge, and Mercury. These makes represented from 72.90 percent to 88.90 percent of total domestic production for the 18 years covered.

TABLE 8

THEORETICAL "SHADOW"

Year	Average Width and Length	"Shadow" (sq in.)	Increase in 10-Yr Period (%)
1958	78.4 x 212	16,621	5[a]
1948	76.4 x 207.2	15,797	10
1938	72.3 x 199.1	14,338	25
1928	67.3 x 169.7	11,440	-

[a] Total increase 50 percent in 30-yr period.

II. Parking Facility Design

WILLIAM R. B. FROEHLICH, Executive Director
Public Parking Authority of Pittsburgh

The author traces how increasing length and width of passenger cars in the past 30 years have adversely affected parking in residential garages, at the curb, in parking lots and in parking garages. Many residents of older homes have been limited in car choice, the number of spaces available at the curb has decreased due to increased space length, and capacities of lots and garages have been reduced because of greater car sizes.

Recent design standards of lots and garages are discussed briefly.

It is recommended that parking facility design be flexible so that maximum spread of car sizes may be accommodated without losing too much efficiency. Also, it is recommended that the automobile manufacturers set up some self-policing regulations regarding maximum passenger car dimensions.

● EVERYONE connected with highways and traffic knows of the increasing registration and use of motor vehicles through the years. There are projections which estimate that vehicle registration will increase from 63,000,000 in 1957 to 100,000,000 in 1975. Due to the construction of more expressways in urban areas and the general trend of the populace to desert mass transportation in favor of their own personal transportation, more passenger automobiles will be traveling into the central business districts of towns and cities.

This increasing pattern of registration and usage focuses the increasing need on having adequate parking accommodations at both terminals of the trip—at the origin and destination—the residence, the central business district, the cultural center, the medical center or any other terminal area.

As the demand for parking space increases, additional facilities will be needed. Not only is it important that these new parking facilities be adequately designed for efficient use, but it is equally important that present parking facilities will be able to accommodate the same number of cars in the future as they can today.

This paper will examine the effect that the changing dimensions of passenger automobiles have had on all types of parking space, will show how present-day design has attempted to adapt to the changes, and will discuss, briefly, possible remedies.

THE RELATIONSHIP OF AUTOMOBILE PHYSICAL CHARACTERISTICS TO PARKING SPACE

The dimensions of a passenger car are directly related to the size of parking space, whether in a residential garage, at the curb or in an off-street parking facility. Naturally, the length of the car affects the length of parking space, although in off-street parking facilities the term "unit parking depth" is more often used in discussing standards. Unit parking depth may be defined as the width of an aisle plus the length of the two parking spaces on either side of the aisle, measured normal to the aisle. Thus, any number of unit depths may be laid side by side to create a parking lot or parking garage.

The width of the space must be determined by car widths. The width of a space also is affected by the location of door hinges and the width of car doors, since it is necessary for drivers to get in and out of cars parked side by side.

Another dimensional characteristic which affects design of parking space is overhang—both front and rear. Overhang is an important consideration in the design of bumper curbs to protect end walls from being bumped by cars being parked and to protect parking meters in metered lots where the car heads or backs into the parking meter.

Three other characteristics of passenger car design affect parking space. One is

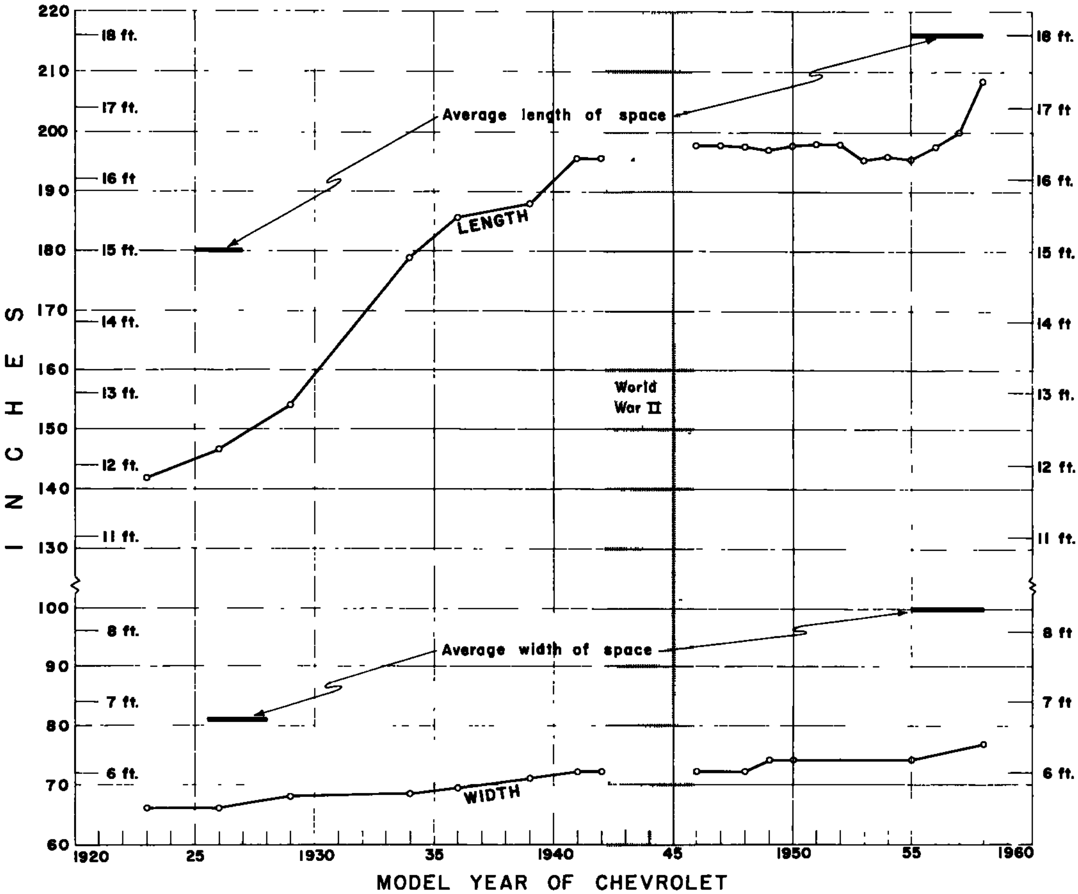

Figure 1. Typical low-priced car dimensions compared with garage space dimensions.

the turning radius of the vehicle and the other two relate to whether or not the vehicle is equipped with power steering and automatic transmission.

TREND OF AUTOMOBILE DIMENSIONS

The changing dimensions of automobiles have had a marked effect on the use of older parking areas and on the design of parking facilities in recent years. Another paper presented in this symposium shows quite clearly that the length and width of passenger automobiles have increased substantially since the mid-1920's. This increase has forced considerable changes in the operation of parking facilities and has added to the area needed per car space in off-street facilities. Fortunately, there has been little change in the turning radius of passenger cars during this period. Also, cars that are equipped with automatic transmission and power steering are more easily parked than the same model car without these features. Although these items of equipment, which still are optional on most models, have helped the parking maneuver, they cannot change the actual physical dimensions of the cars which control, primarily, the size of parking space.

Figure 1 shows how the increasing length and width of cars have necessitated similar increases in the length and width of parking spaces. The car depicted is a Chevrolet, chosen because it is one of the low-priced three (Chevrolet, Ford and Plymouth) which account for a majority of the market. In regard to width of space, note that the difference between car width and space width in the period between 1955 and 1957 is greater than that shown in the period from 1926 to 1928. This is due to the fact that cars built before 1936 had running boards which caused the door hinges to be closer to the center of the car, thus decreasing the width of the car with doors open. It is interesting to note that the width of a 1929 Pierce Arrow (a large car for its day) with both doors open in 110 in., while various 1957 models range from 140 to 159 in. with doors open. Note that the average length of parking space in public parking garages has increased from 15 ft in the 1920's to 18 ft in the late 1950's. Note also how the increasing length of this low-priced car depicted in Figure 1 has pushed the car length very near the 18-ft space length.

THE EFFECT OF INCREASE IN SIZE ON PARKING SPACE

Increasing dimensions of passenger cars have forced an increase in the size of parking space at all terminal points—in home garages, at the curb, in parking lots and in parking garages.

Home Garages

Residents of most homes built before 1940, which still constitute the majority of residences in the United States, find that they are limited in the selection of a new car unless they are willing to incur a substantial expenditure to increase the size of their garages.

In the period 1932 to 1936, a well-designed rental housing development called Chatham Village was built in Pittsburgh. Single garages were constructed integral with the basement of each housing unit or in a separate garage compound. In 1956, the Chatham Village management found it necessary to build additional garages. Table 1 shows how the inside dimensions of these garages have changed from 1936 to 1956. With an over-all inside length of 17 ft 6 in. (or 210 in.) in the 1936 garage, it can be determined that the 200 families residing in these houses cannot buy a 1958 Dodge, Edsel, Pontiac, Buick, Chrysler, De Soto, Mercury, Oldsmobile 98, Packard, Cadillac, Continental, Imperial or Lincoln and expect to close the garage door.

Table 2 shows how the Federal Housing Administration had to increase its minimum requirements for the inside dimensions of residential garages in November 1955. Since the width of 1957 models with all doors open ranges from 11 ft 8 in. to 13 ft 3 in., it would be quite difficult to wash a car properly inside a single garage 10 ft wide.

TABLE 1

SINGLE GARAGES BUILT IN CHATHAM VILLAGE, PITTSBURGH

Built	Inside Dimensions: Length	Width	Clear Width at Door
1936	17'6"	8'3"	7'10"
1956	20'4"	11'0"	8'10"

Curb Space

Prior to the late 1940's, the length of space for cars parked in the street at the curb averaged 18 ft. Since then, many cities have increased this length to either 20 ft or 22 ft. In the past three years, the City of Pittsburgh has increased all of its marked curb spaces to 22 ft. A check was made of three typical blocks in smaller business districts in the City of Pittsburgh to determine how many spaces were lost due to the increase of space length from 18 ft to 22 ft. It was found that this 22 percent increase in space length had resulted in a 17 percent decrease in the number of curb spaces.

TABLE 2

F.H.A. MINIMUM REQUIREMENTS FOR INSIDE DIMENSIONS OF HOME GARAGES

	Single Garage		Double Garage	
	Length	Width	Length	Width
Prior to Nov. 1955	19'	10'	19'	17'6"
Since Nov. 1955	20'	10'	20'	18'4"

Parking Lots

Parking lots, unbroken by curbs or

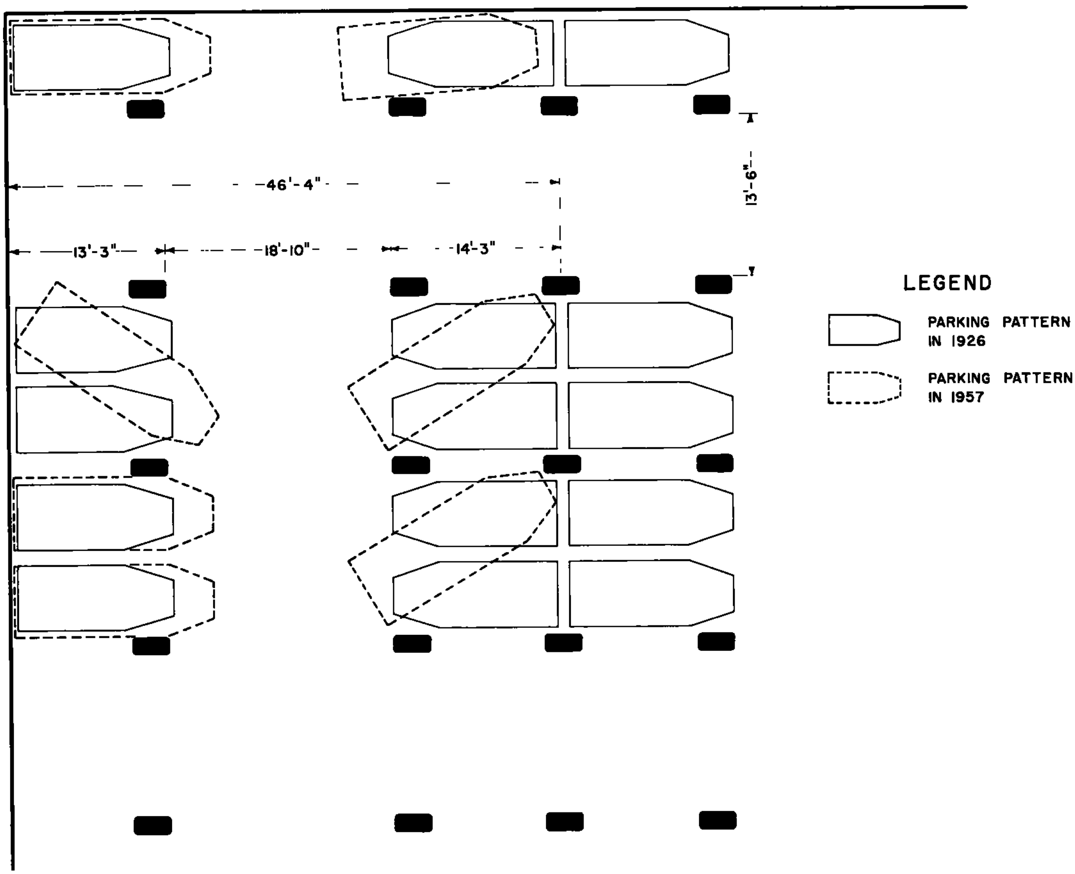

Figure 2. Dimensions of a typical parking garage constructed in 1926.

other barriers, have been least affected by the increasing size of cars since their layout can be changed rather easily. Space widths have increased from 6 ft 9 in. or 7 ft in the late 1920's to 8 ft or 8 ft 6 in. at the present time. Unit depths for 90 degree parking have increased from 46 ft in the late 1920's to approximately 60 ft today.

In recent years, a substantial number of lots with parking meters installed on raised islands have come into greater use. Because of the installation of these parking metered islands, the parking layout of these lots is quite inflexible. If the width of stalls or the unit depth must be changed due to further increased car dimensions, the cost of such alteration would be substantial. Fortunately, these metered lots are relatively new and, generally, have been designed to more modern standards.

Parking Garages—Mechanical

The two types of mechanical parking garages predominantly in operation today operate on the same basic principle of moving cars vertically and horizontally by means of an elevator which runs on a track between two tiered parking structures on either side of the elevator track. In one type, the Pigeonhole Garage, cars are moved onto the elevators through a dolly mechanism which goes under the car and pulls it on or off the elevator. Operators of some of the first garages constructed have found that about 2 percent of all the cars which patronize the facility cannot be moved by the dollies, either because of the suspension mechanism of the car or because the clearance from the ground to the car undercarriage is too small. Recently the dollies have been redesigned so that cars are moved by lifting the wheels rather than lifting the undercarriage. New pigeonhold garages are being constructed with 3-car parking bays at

22 ft 6 in. center-to-center of columns, with an average minimum clear space of 21 ft 10 in. Since cars need not be driven during the parking maneuver and it will not be necessary to open car doors, the pigeonhold operation should present no particular problem operationally until car widths approach the 87-in. width of stall. It may be noted that 1958 car models range from 72.2 to 81.2 in. in width.

The second type of mechanical garage, the Bowser Garage, is somewhat different in operation in that cars are driven on and off the elevators by attendants. Since each Bowser structure is individually designed, spaces may be constructed to any width. Normally, the clear width of space in most Bowser garages has been 8 ft.

Parking Garages—Ramp-Type

The ramp-type parking garage has been, and still remains, by far, the most significant type of parking structure from the standpoint of volume of cars parked. A substantial number were built during the mid-twenties, very few were constructed during the depression of the 1930's and World War II, but many more have been constructed in the post-war years following the lifting of materials priorities.

All of the earlier ramp garages, and most of the recent ones, have been constructed with columns dividing the parking areas in 2-, 3-, or 4-car bays. Although consideration had been given to removing columns from the parking areas, it was generally decided that the cost of increasing span lengths to eliminate the columns dividing parking bays would be prohibitive. In order to note the effect changing car dimensions has had on parking capacity and parking patterns of some of these older garages, two garages constructed in 1926, both of which still are in operation, will be examined. It should be pointed out that these older garages constitute an important proportion of the total parking supply in many cities. In downtown Pittsburgh, six of these garages built before 1930 supply 2,400 of the 16,000 off-street spaces.

Parking Garage No. 1, depicted in Figure 2, is a staggered-floor straight-ramp garage with a unit depth of 46 ft 4 in. and 2-car bays with 13 ft 6 in. of clear space between columns, resulting in spaces 6 ft 9 in. wide. In the 3½-bay section shown, the capacity in 1926 was 14 cars. Today, because of the increased length and width of cars, the capacity has been reduced to nine—a 36 percent loss in space count. If this garage were being designed today with the same basic layout, the unit depth should be 60 ft and the 2-car bays should have 17 ft of clear space between columns. Figure 3 shows how cars are actually parked in this same area. Figure 4 is a photograph of a typical 13 ft 6 in. clear 2-car bay showing how tightly two late-model low-priced cars must be squeezed into the spaces. Note the felt padding on the columns to prevent fender scratching.

Parking Garage No. 2, one area of which is shown in Figure 5, is another staggered-floor straight-ramp garage. In its early years it was the pride of the city with every space being advertised as a "front space." Then its capacity was 490; today its capa-

Figure 3.

Figure 4.

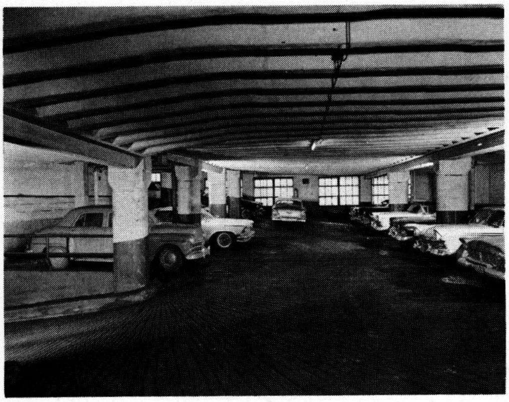

Figure 5.

Figure 6.

city is 286. Three-car bays now park only two cars (Fig. 6) and 2-car bays park one.

Figure 7, a photograph taken in Parking Garage No. 2, shows how greater rear overhang has forced expedient measures to be taken to prevent cars from bumping a concrete block wall. In the case of the 1957 model car shown, even two added railroad ties did not prevent the car from bumping.

The foregoing case studies are typical of conditions existing in most garages of pre-1930 vintage. To be sure, they do not reflect the operating situation in garages constructed after World War II. However, if there are significant increases, in the future, in the length and width of passenger cars beyond their present dimensions, a number of post World War II garages will be similarly affected.

Recent Garage Design Practices

In the past few years, many parking garage designers have become increasingly sensitive to the growing dimensions of passenger cars and have adopted more liberal design standards.

Recent garages with 90 degree (perpendicular) spaces have been built with unit depths of approximately 60 ft and space widths of 8 ft 6 in. minimum. A recent publication of the Eno Foundation (1) recommends minimum dimensions for a 90 degree layout as follows:

Stall width—8 ft for attendant-parking
8 ft 6 in. for customer-parking
Unit parking depth—58 ft

As an editorial comment to the standards just listed, it might be noted that the prudent garage designer should keep in mind that

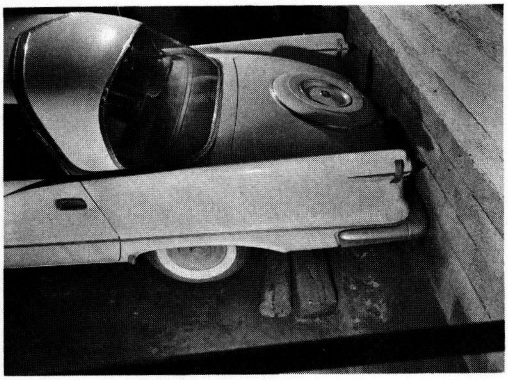

Figure 7.

Figure 8.

a garage operated as attendant-parking today might be converted to a customer-parking operation in the future. Therefore, serious consideration should be given to using 8 ft 6 in. as minimum space width, particularly if there are columns between parking stalls.

To improve parking maneuver, spans bridging the aisle should be increased as much as possible. The ultimate and ideal situation would evolve when the span length equals unit parking depth and columns are eliminated from the parking and aisle areas entirely. Under such a design, space widths could be changed with changing car widths merely by shifting the floor striping. However, these spans of 58 to 60 ft would increase the depth of beam substantially, which would, in turn, increase floor-to-floor height, ramp grades and, above all, cost of construction. However, recent developments in high-strength steel and prestressed concrete design may help to minimize most of these objections.

One ingenious garage design of the clear span type, which has been developed in the past two or three years, merits special mention. Basically, the structure is a sloping-floor customer-parking garage with 60 degree spaces and a 52-ft unit parking depth with clear span construction. The angled spaces permit an easy parking maneuver and make possible a span reduction to 52 ft, thus economizing somewhat on structural design. Aisles are one-way in the "up" direction with exiting being accomplished by way of a straight ramp or circular ramp outside the main sloping-floor section. Figure 8 shows a typical floor of the W. Watts Garage in Miami, Florida, an angle-parking clear-span garage completed in 1957.

RECOMMENDATIONS

This paper has shown that increasing dimensions of passenger cars in the past 30 years have had considerable effect on parking facilities of all kinds.

Unfortunately, the nature of the automobile industry is so competitive and so dependent on secret style changes that designers of parking space do not have the benefit of even short-range, two- to three-year projections on size of cars, and certainly have no authoritative information on size projections for longer periods.

Under present conditions, the layout of parking space at the curb and in parking lots must be planned to accommodate today's vehicles adequately, with the realization that this layout may have to be changed in the future.

The architect or home builder, in designing a residential garage, can only take account of the trend of increasing sizes and design a garage a little longer and a little wider than necessary for the present day car with the hope that he will have guessed right.

Designers of off-street parking structures have a more difficult assignment because their design affects a larger number of car spaces and involves a more substantial investment. The best they can do is to attempt to design flexibility into an inflexible structure of steel and concrete so that the maximum spread of car sizes may be accommodated without significant sacrifices in efficiency of operation and without losing too many car spaces.

Substantial public and private investment, both in roadway and terminal facilities, must be safequarded from obsolescence due to uncontrolled changes in sizes of passenger vehicles. It seems logical that the automobile industry should assume some responsibility for this, if only out of selfish interest, since they, too, will suffer if highways and parking facilities do not serve their functions properly.

Therefore, it is suggested that the automobile manufacturers, possibly through the Automobile Manufacturers Association, work with the Highway Research Board and the Institute of Traffic Engineers, with the goal of setting up some "self-policing" regulations on the ultimate size of passenger cars. Some may question whether this self-policing procedure would be effective in such a fiercely competitive industry. Certainly it is worth a try and preferable to mandatory legislation either at the national or state level. However, if such cooperative measures cannot be agreed to, or are not effective, then legislation which would limit maximum dimensions of vehicles should be considered. The time has passed when both automobile industry representatives and highway and transportation officials can sit back and merely complain about inadequate roadways and parking facilities which, in part, have been made inadequate by the increasing size of vehicles. The time has come for sincere cooperative effort to attempt to reach a reasonable solution.

REFERENCE

1. Ricker, Edmund R., "Traffic Design of Parking Garages." p. 95 (1957).

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