A Device for Establishing a Safe Stopping Distance at Night

CLIFFORD O. SWANSON, Iowa State College, Ames, Iowa

●THAT a safe driving speed at night should be considerably lower than that in daylight is attested by the fact that on a mileage basis about nine times as many accidents occur during hours of darkness as occur during daylight. Some states have differential day and night speed limits. This is advisable, but in most cases the differential is not great enough. In other states, using the basic speed law, it is extremely difficult to demonstrate before a court, law enforcement personnel, or a public group what is meant by a safe nighttime driving speed.

Considerable research has been done at the Driving Research Laboratory at Iowa State College to assemble useful data on this problem. That the approach is valid is shown by the fact that the Commissioner of Public Safety for Iowa, through the Highway Patrol and the courts of the state, has been able to establish a maximum speed limit, in miles per hour, under the basic statute during hours of darkness. This was upheld by a ruling by the Iowa Supreme Court. The data on which the decision was predicated come from standard information and researches of various experimenters throughout the country. No attempt is made to review the literature here.

While acting as a special instructor for the Iowa Highway Patrol and in presenting the data on safe nighttime driving speeds in court cases, the author hit upon the method of presentation described here. It was first necessary to define each term used in such language as to be understood by the average juryman.

The ruling handed down by the Iowa Supreme Court in its decision in the spring of 1956 upholds the Public Safety Commissioner's contention that any driver traveling at a nighttime speed in excess of 65 mph is presumed to be violating the basic speed limitation statute of being able to stop within the assured clear distance ahead.

APPARATUS USED

When attempting to demonstrate to a jury the various factors to be considered in a safe nighttime driving speed it seems helpful to make a visual demonstration of the principles involved whenever possible. In the instruction of highway patrol officers and recruits, driver education students, and interested public groups, this device has proven very beneficial as a visual aid.

In general the apparatus used is in the nature of an enlarged slide rule, which can be set on an easel and used to explain stopping distances as determined (1) by

$$\text{Stopping distance} = \frac{V^2}{30f + 0.3p} + 1.467\ V\ T \qquad (1)$$

in which

V = speed, in mph;
f = coefficient of friction;
p = percent gradient of road surface expressed as a whole number; and
T = reaction time, in seconds.

Its relationship to perceptual distance at night is based on data developed by Roper and others (2). Their data have been studied and adapted to the slide rule device herein presented.

In the present instance, as shown by Figure 1, perceptual distance, B, is given as 191 feet. This distance represents the number of feet a driver with normal vision would be expected to see an object of at least a 7 percent reflection factor on lamps as found on most modern automobiles. Calculations are made for a speed of 60 mph. The atmospheric conditions are presumed to be clear. Otherwise, corrections can be made.

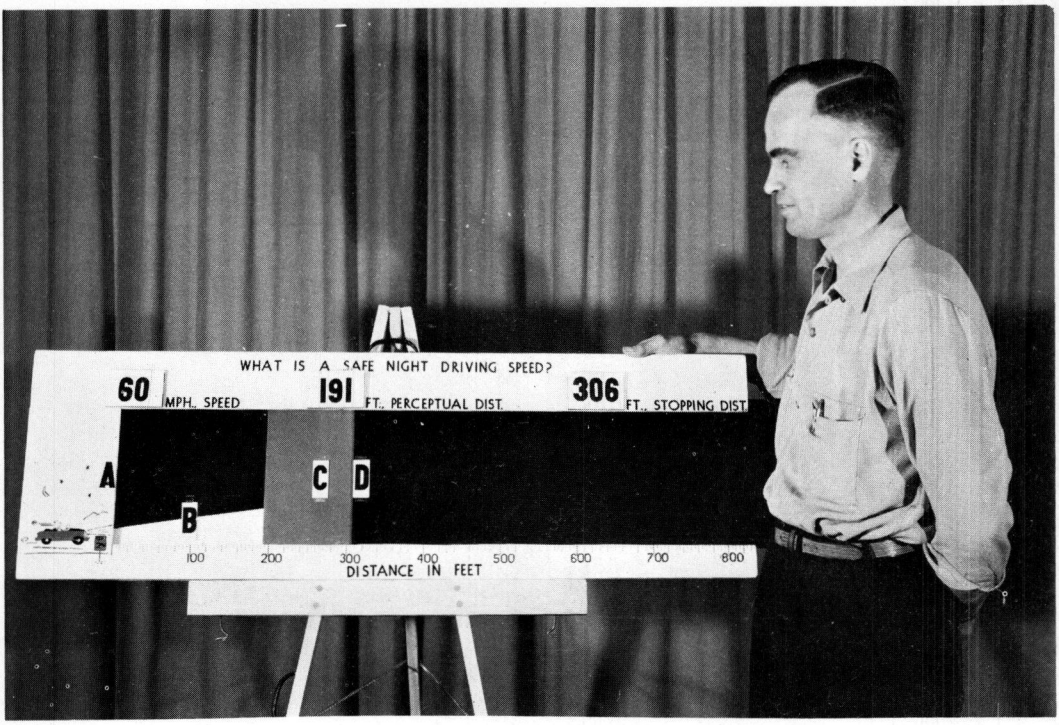

Figure 1. Device for demonstrating method of determining safe night driving speed. Stopping distance must not exceed perceptual distance to stay within safe driving speed range.

The beam candle power of the new quadri-lights is not known, but statutes in Iowa and some other states are patterned after Section 12-226 "Number of Driving Lamps Required or Permitted," of the revised 1954 version of the Uniform Vehicle Code, which permits "not more than a total of four of any such lamps on the front of a vehicle . . . lighted at any one time when upon a highway." However, it is a requirement that the total beam candle power will remain within legal provisions. At least one manufacturer is making the quadri-lights standard equipment; for most others they will be optional on cars delivered in states where they are legal. The apparent assumption is that those states making them illegal, or at least not providing for their use, will not enforce the statute provisions.

A road user with average reaction time and traveling on a dry, level concrete road surface at 60 mph would be able to stop in a minimum of 306 feet. The difference (represented by C in Figure 1) then becomes the danger zone, because stopping distance exceeds the perceptual distance at this speed and under these conditions. Any set of values may be used for demonstration purposes: the principle illustrated is but one example. Both the values for perceptual distance and stopping distance were obtained from formulas and data previously cited.

Point A on the board represents a zero line at which a driver receives the initial warning or stimulus in the process of stopping his vehicle. Space B then becomes the perceptual distance of the driver, with possible corrections made for his visual acuity and the atmospheric conditions as they exist for a given beam headlight candle power. Because older car lights are likely to be deficient in some respects, 40,000 to 50,000 candle power on high beams can be considered to be the average to be expected on the road prior to making the foregoing corrections. However, any strength of beam candle power could be used for calculations, as shown in tables or graph of perceptual distance for varying amounts of light.

The space A to D represents the distance required to stop a vehicle for a given set

of conditions. This value takes into consideration the reaction time of the driver, road gradient in percent, and the friction coefficient of the road surface assuming 100 percent brake efficiency.

A safe night driving speed for the driver under the existing conditions can be established. This is represented in miles per hour whereby a stopping distance AD would be equal to or less than distance B. In other words, the C space as illustrated would be completely eliminated when such a speed is maintained, assuming the variables involved remain constant. These values as calculated make no allowance for a safety factor, however. Most engineers would allow a 100 percent margin of safety. This can be taken into consideration by being given judicial notice by the courts, often a necessary detail in court procedures.

The differences, as represented by the danger zone C, are far too prevalent for drivers traveling on the road at night, as is attested by nighttime accidents over those occurring during daylight on a mileage basis. Considering an average of 40,000 beam candle power for the lowermost distribution of light, 100 percent brake efficiency, and other variables as normal, no nighttime road user should exceed 50 mph.

GENERAL SUMMARY

The method used in establishing a safe stopping distance at night and its conversion into miles per hour considering the existing light conditions was devised originally at the request of Iowa's Commissioner of Public Safety for purposes of enforcement of the basic speed limitation type statute. Because no known method of obtaining specific values indicative of a safe and legal nighttime speed for single vehicles was available that was applicable in the enforcement of the "reasonable and proper" aspect of this type of speed law, the present system was devised.

Even though Roper and Howard (2) in their experiment had determined what is being termed here as perceptual distance for various beam candle power values, a method of application was necessary. Certain corrections are necessary in the original values as given to compensate for the conditions as they exist in an actual situation. For example, correction in the perceptual distance of a road user is necessary should his visual acuity be less than normal or atmospheric conditions be other than clear. Stopping distances are determined as previously cited (1), with corrections being applied as they exist at the time and place of apprehension.

While acting as a special instructor of highway patrol personnel the difficulty was encountered of satisfactorily explaining the methods of demonstrating perceptual and stopping distances and how changes in one affected the other. The same problem persisted while serving as an expert witness in litigation and when making talks to public groups. As a result, the visual aid device described was devised. However, no attempt has been made to have the aid admitted into the court records as a method of explanation to a jury. Precedence frequently may nullify the advantage of such a gesture.

The apparatus can be described as one whereby the data from scientific experiments may be reduced to graphic representation in showing to laymen the dangers of excessive night driving speeds. This application of the principle involved has been upheld by a unanimous decision of the Iowa Supreme Court.

ACKNOWLEDGMENTS

The study reported herein was made possible through a grant from the Allstate Insurance Company on driving research, and done under the direction of A. R. Lauer of the Driving Research Laboratory, Iowa State College.

REFERENCES

1. Matson, M. M., Smith, S. S., and Hurd, F. W., "Traffic Engineering," p. 259, McGraw-Hill Book Co., New York, N. Y. (1955).

2. Roper, Val, and Howard, E. A., "Seeing with Motor Car Headlamps," Illum. Eng. Soc. Proc., 33: 422, (1938).

Discussion

K. A. STONEX, Assistant Director, and P. C. SKEELS, Head, Experimental Engineering Department, General Motors Proving Ground—The profession is indebted to Mr. Swanson for his comments on the controversial subject of what is a proper and safe night driving speed. This subject is a matter of great interest, and while the author's principal objective was the description of a graphic device for demonstrating safe speeds under a variety of conditions, it is felt that a primary contribution is made by bringing this subject into the open in a simple manner.

Mr. Swanson has treated the derivation of what is a safe night driving speed in a much oversimplified form. Although this may be intended merely as an example of the use of the device, the safe maximum stated is at such variance with common experience that the conclusion stimulates thought, and it is hoped that it will stimulate a program to develop a realistic body of evidence.

There is no particular object in dwelling on the points attempted to be shown that the maximum safe night driving speed of 1937 automobiles is 50 mph, that the author has seemingly misinterpreted Roper's data and used numbers referring to the 2 percent reflectance dummy rather than the 7 percent reflectance dummy as stated, or that one can show as convincingly with equally realistic values of coefficient of friction, stopping distance, and visibility distance from Roper's paper, that some higher speed is safe. However, it is appropriate to suggest that there are available more recent data on visibility distance in the Rassweiler-Doane paper in Bulletin 127 of the Highway Research Board, and that there are data on stopping distances in Normann's paper in the Proceedings of the 32nd Annual Meeting of the Highway Research Board which are certainly much more realistic than the calculated distances from the National Safety Council formula of 1937 or earlier.

The issuance of night driving regulations based on computed stopping distances, and the estimates of the visibility provided by 40,000 candle power should be discouraged; these computations can hardly be more accurate than the estimate of how many ducks one can shoot with a 12-gage shot gun and number 4 shot. Roper indicated, in his 1937 paper, that the distribution of the light from the headlights is a matter of primary importance. In the Rassweiler-Doane paper, the contribution of light distribution from more recent headlamps is given in terms of effective night visibility.

Even the data in the Rassweiler-Doane paper need interpretation, in the sense that the observers were instructed not to avail themselves of silhouette seeing, but to make certain that the objects were visible in the direct light of the headlights. Thus, while their data show that the average visibility distance of six observers falls to a minimum of approximately 230 ft at the moment before passing, it must be considered that the test imposed a special restriction where the observers were not availing themselves of silhouette seeing. It should be pointed out further that these tests were conducted with headlamps which are now obsolete; they would show better visibility is they were repeated with headlamps with the improved passing beam, and even a further gain if they were repeated with cars equipped with the four headlamp system. The figure of 50 mph as a safe night driving speed, which Mr. Swanson derived, is hardly representative even of passenger cars of 1937; it should be considered as merely as example of the use of the graphic device and not at all representative of values which should be applied to passenger cars with the current improved headlighting equipment and modern sensitive braking systems.

The author states that "a road user with average reaction time and driving on a dry level concrete surface at 60 mph will be able to stop in a minimum of 306 ft." He does not give the values of the constants, but if a coefficient of friction of 0. 7 is assumed, it appears that he used a reaction time of 2 seconds. This value is very high; the generally accepted figure for perception time plus reaction time to apply brakes is 0. 75 seconds. If stopping distance is computed using a speed of 60 mph, coefficient of friction value of 0. 7, a level road, and 0. 75-second reaction time, the calculated stopping distance would be 238 ft. If this figure is combined with realistic perception distances and the gain obtained with silhouette seeing incorporated, a considerably higher safe night driving speed would be obtained. This brief example should serve to point out

the uncertainty of any computations of safe driving speeds, including the writers'.

The determination of a safe maximum night driving speed should take into account the wide variety of night driving conditions. To attempt to regulate speeds on the basis of only the worst possible condition is to invite general disrespect of the regulations and engender formidable enforcement problems. Drivers cooperate in the observance of speed regulations which they consider reasonable, and imposition of regulations which appear to be unduly restrictive is met with widespread non-observance. No regulation at all is better than one generally not observed.

The writers are familiar with the fact that nighttime accidents occur much more frequently than daytime accidents, but they are not convinced that this is necessarily so because nighttime limits are too high. This is a problem requiring more research, and there is no obvious simple solution.

Any regulation should take into account the fact that, on rural highways, traffic volumes are negligible during most of the hours at night and the upper beam is used a large proportion of the time. Under these circumstances, with modern headlighting systems the visibility distance is such that speeds considerably above 50 or 55 mph can be driven with relative safety. During the time and under the conditions of traffic such that the passing beams are used an appreciable part of the time, the driver has the advantage of silhouette seeing provided by the headlamps of approaching traffic, and he has the very considerable advantage of traffic ahead traveling in his direction.

It is common experience that the strain and uncertainty of night driving is eliminated when following a car at a distance of anywhere from a couple of hundred feet up to as far as it can be seen in the distance.

In the attempt to derive an estimate of a safe maximum night driving speed by calculation and oversimplified tests, no one has taken into account the real benefits which are given by silhouette seeing afforded by approaching headlamps and by the taillamps of vehicles ahead proceeding in the same direction, nor have the relative proportions of use of the upper beam and passing beam been considered.

Everyone is familiar with the glow from headlights that indicates the approach of a car over a crest vertical curve or from a side road; this gives more advance notice than a driver has during the day, and these conditions make night driving safer than day driving.

In Michigan, there has been approximately one year of experience with a 55-mph night driving speed on a statewide basis; it is the writers' understanding that the relative safety experience is favorable. On some parts of the rural road system, drivers find that this is faster than they want to drive because of the geometrical design of the road or other conditions; in other locations, this limit is below the safe capacity of the road, and there is a real possibility that the dangers of falling asleep may exceed the possible danger of overdriving the headlights at a higher speed.

There is as yet no clear evidence as to what constitutes a maximum safe night driving speed and so far no one has demonstrated a technique which will yield such data.

C. O. SWANSON, Closure—It was the primary purpose of this paper to describe a device of slide-rule type which could be used with any data to establish a safe stopping distance at night. Data from the National Safety Council (1956 Edition of "Accident Facts") on day and night accidents show at least three times as many fatalities at night. There seems no doubt but that a greater margin of safety should be allowed for stopping distance under nighttime conditions.

It is the author's impression that the discussers are arguing primarily for higher speeds rather than for a simplification of the paper under discussion. By using the least conservative set of constants it is possible to do this, but the author's purpose was to take a reasonable set of values which are realistic. Many cars on the road are of prewar type and no increase in headlight illumination standards has been accepted in Iowa.

It is agreed that the probelm is complex and no simple solution can be given which will fit all conditions. Likewise, drivers differ markedly and some states require only 20/70 vision for a driver's license. This fact emphasizes the need for conservative estimates with respect to a safe nighttime stopping distance.

Messrs. Stonex and Skeels have misinterpreted the data in referring to a stopping distance of 306 feet at 60 mph. A coefficient of friction of 0.5 was assumed, which is well below that given by authorities for a rolling speed.

It is further agreed that more experimental work should be done on the problem, preferably by research agencies unbiased with respect to the outcome.