THOUGHTS ON HIGHWAY DESIGN RESEARCH AS RELATED TO SAFETY OF VEHICLE OPERATION

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SYNOPSIS

Possibilities of research are outlined for the purpose of establishing definitely the basic causes of motor accidents and the relation of highway design to accidents The point is stressed that if those basic underlying causes can be known which originate in some subtle defect in the design of the highway and in the psychology of the driver, engineers can surely devise effective means to reduce such accidents as are chargeable to the highway itself, and at the same time correct and prevent many errors of the motorist Before highway designers can design for basic safety, enough of driver psychology must become known to enable the designer to arrange conditions in such a manner that the driver will instinctively choose the safe act The striking results of research, education and enforcement in the reduction of industrial accidents is cited and the analogy existing between that effort and the present motor accident situation is noted

In the field of technical design of those highway elements effecting safety of operation, the uncertainty of design features is treated and suggestions made relative to the desirability of research for the purpose of definitely establishing design practice The features mentioned include the width and detailed treatment of the center safety dividing space of dual highways, the lack of knowledge on permissible safe speeds for particular designs, lack of knowledge with respect to shoulder widths, spiral curves and distance between reverse curves, and the effect of vertical curves on headlamp visibility and entrance and exit facilities

The effect of the time element on design of modern highways because of the advancing speed of motor cars is outlined, elementary examples are given illustrating the thought that design features should be located at distances from the driver expressed in seconds of time, and necessary research is suggested to establish the data needed for designing with confidence

With some notable exceptions the bulk of past highway research has been in the field of the physical properties of the materials of construction, and little attention has been directed toward ascertaining the basic requirements of highway design as related to the safe and efficient operation of motor vehicles, with the result that great progress has been made in physical design and construction while insufficient knowledge is available in the realm of design affecting safe operation Thus, a challenge is offered the research worker, and fertile ground is available to organizations with sufficient financial and technical means to cultivate this form of investigation

The appalling accident and death rates indicate that many problems in highway design are unsolved The proper solution of these problems is vital, for the ease and comfort with which a modern motor car can be operated at high speed has revolutionized the requirements of design to such an extent that a national emergency exists One need only mention that more persons are killed in motor accidents in one month than have perished in all the floods in the United States within the past ten years, to indicate the magnitude and seriousness of the situation

Before it will be possible to establish confidently the fundamental principles of safe highway design, it will be necessary to ascertain the basic causes of accidents, to establish the relation and effect of highway design on accidents and to uncover the mysteries of driver psychology The conventional method of studying police accident reports, reveals only the most obvious accident causes, and frequently a wholly misleading picture may be obtained, for often the real and fundamental causes are so obscure and subtle that they will require the talents of a particularly trained and endowed investigator to uncover [1] All too frequently blame is attached to one or both drivers with no attempt being made to ascertain whether highway conditions created the circumstances which caused the accident This attitude on the part of the police is understandable when it is remembered that it is more natural to blame an individual than an inanimate facility, particularly since the participants may appear in a court of law to recover damages, and, since it is not possible to recover damages from an inanimate highway, the emphasis has been to search out the human error involved rather than to look back of the human error and find out what caused that error, for many times a particular set of inanimate components of the highway combine to cause the motorist to commit an error It is the search for such fundamental causes that concerns the investigator and from which will emerge a clearer conception of the relation of highway design to accidents

It may be of assistance in grasping the writer's meaning, to realize that almost never is an accident deliberate Seldom does a driver deliberately set out to cause an accident In other words a motor accident is truly an accident This suggests that it is very possible for highway or street conditions to be the fundamental originating cause of many accidents, conditions which at present are not recognized as hazards, things so subtle that they are not even suspected Unraveling this mystery will require a high type of detective work The situation is somewhat analogous to the condition existing in industry a number of years ago when the industrial accident rate was quite high At that time accidents were assumed to be an unavoidable evil and part of the risks of manufacturing, little effort being made to improve the situation Then, as today in the motor field, the operator of the machine was assumed to be at fault in case of injury, the assumption being that he was inept or careless Fortunately, men of vision believed that many accidents could be avoided by a study of causes, by education and by regulations forcing operators to conform to safe practices, and these methods have been so successful that all industrial accidents have declined materially, in spite of increased production, while in certain industries the accident rate has fallen to miraculously low levels Thousands of men and women are alive and well today who would be dead or permanently disabled had it not been for that effort This is a remarkable tribute to the men and organizations responsible for these results, particularly when it is remembered that in the beginning the very persons benefited most vitally, the workers, were almost entirely indifferent, and in many cases refused to cooperate

A similar opportunity exists in the highway field, particularly as related to causation and to the psychology of the driver If it is possible to ascertain the basic originating cause of an accident and establish the fundamental concepts of driver psychology, then, and only then will it be possible to design the highway for basic operating safety insofar as physical and psychological conditions influence accidents Many of you are no doubt familiar with the psychological investigations conducted a number of years ago at Ohio State University [2] Those studies were made in an effort to dis-

[1] Tentative qualifications of the proper type of investigator (1) Practical experience in highway design and construction, (2) Thorough education in the physical sciences, (3) Extensive training in advanced mathematics, (4) Education in psychology, (5) The mental perception to realize that the above are only tools and are a means to an end, not the end itself, and, (6) Practical common sense

[2] Weiss and Laurer, "Psychological Principles of Automotive Driving," Ohio State University 1927-29

cover the suitability of the driver for the car and the highway. Furthermore the manufacturers of motor cars also regularly subject the vehicle to exhaustive tests to determine its suitability for the driver and the highway.

Tests are as urgently needed to determine the suitability of the road for the driver and the vehicle, for engineers will not be able to perfect the technique of safe highway design until all the basic facts of driver psychology and the physical effects of road conditions on accidents are known. Before highway designers can design for basic safety, enough of driver psychology must become known to enable the designer to arrange sets of conditions in such a manner that the vehicle operator will unconsciously choose the safe act rather than react in a way to lead up to an accident.

There are many who will contend that such results are impossible, but, since that particular state of mind has been proven incorrect in connection with almost every major accomplishment in the scientific and engineering fields during the past 100 years, the public has come to expect the impossible from science as a matter of course. To illustrate, not long ago foundation engineering was in a condition somewhat similar to the highway problem of today. Foundations were designed by rule of thumb, based on personal experience, and a scientific approach was considered unattainable until Dr. Terzaghi appeared and laid the foundations of soil mechanics. The complexities of the problem were so great, conditions so varied and intricate that the idea defied the imagination, and many practical engineers thought a solution impractical or impossible. But Terzaghi persisted, with the result that his principles have been enlarged and extended by other able investigators, practical design is utilizing soil mechanics and today he is acclaimed throughout the word as the father of a new science.

The accident problem is in urgent need of a similar type of fundamental analysis and research, for if engineers can but know what is causing accidents there can be little doubt that engineering ingenuity can surely devise means to combat them, with the result that thousands of lives will be saved and the tremendous economic loss occasioned by motor accidents will be materially reduced. The motor accident problem is more difficult and serious than any that engineers have ever been called upon to solve. Research into physical materials is simple in comparison, because engineering materials follow definite and constant laws, however obstruse, intricate and difficult of perception, but the accident problem involves human behavior and reaction in almost infinite variety and complexity. Yet there must be certain patterns, certain similarities and certain "laws" which will govern in many instances and of which use can be made in the design of highway facilities. It is, therefore, earnestly hoped that the opportunity will be seized and that searching and basic research will be undertaken and vigorously pursued until the fundamental principles of accident causation are definitely established.

Unfortunately the other tools effectively used by industry to reduce accidents, namely education and regulation, have not been as effective in the motor field as might be hoped (except in fleets of trucks and busses), for whereas industry has a certain amount of control over its employees and can force them to adopt safe practices, and may in addition weed out the accident prone, such a course has not yet proved practicable in the motor accident field. This may be attributed to the temperament of the American people, which is known to be impatient of regulation in any form, and since the public is not an employee the present means of education and enforcement have not been conspicuously successful.

Therefore, since this form of accident prevention is equally as important as prevention by safe highway design, it is as fundamental that research be instituted for the purpose of discovering means whereby the public can be persuaded or forced to adopt safe driving practices This thought is not new to business, for sales and advertising groups have become expert in persuading the public to purchase their products and they have developed a reasonably efficient technic which is based on research as well as experience The identical methods used by business to persuade the public to buy their products may not be effective in the motor accident field but undoubtedly research will develop far more efficient methods than now employed for this purpose In addition, research for developing positive means of enforcement is urgently needed, for there is always a small group of individuals on whom the most efficient and scientific methods of persuasion and education would be wasted

Fortunately an attack has already been started at Harvard University on this phase of accident prevention, which shows great promise of success, and it is hoped that this work will be further encouraged and stimulated

If, then, research can uncover the fundamental causes of accidents and indicate the relation between highway design and accidents, while at the same time effective means of education, persuasion and enforcement of safe driving practices are developed, a great stride will have been made toward making motoring on American streets and highways safe

In addition to the subtle and psychological a number of unsolved problems relating to design are awaiting much needed research in the physical field For example, can anyone state with certainty the correct width and treatment of the safety dividing space for a dual highway to satisfy particular sets of conditions, and can anyone specify with certainty the maximum safe speed that vehicles can operate on any given type of design?

From a practical standpoint it must be admitted that financial and physical circumstances will limit the width of the space dividing dual highways On the other hand the average motorist, if questioned, would undoubtedly indicate a preference for a design without curbs, flanked with wide smooth stabilized shoulders Such a design is practical and safe, when a wide separating space is used, but as the width decreases it becomes evident to thinking engineers, that, at a certain limit, some type of design is required which will prevent impatient drivers from using the safety space as a means for passing (possibly simultaneously in opposite directions, resulting in head-on collisions), and as a means of a certain amount of protection to opposite direction traffic from cars out of control Studies are urgently needed to determine the limiting width when protective devices are required in the center, and to indicate the type of detailed design most suitable for certain widths For example, on an elevated structure where every increase in the width of the structure represents an appreciable increment to the capital outlay, the designer is faced with the choice of making the width as small as possible, which may take the form of a low wall one (1) foot wide, or the provision of a greater space of some arbitrary width If a greater width is used, the problem resolves itself into a choice of normal height vertical curbs, high vertical curbs and low sloping curbs, all types with or without a low wall in the middle At present there are no data on which to base a detailed design or to determine the minimum safe width

The type of curb is also a problem where conditions are such that the width need not be an absolute minimum It is recognized that a vertical curb over 3 or 4 in high will prevent motorists, pinched by traffic, from mounting the curb and thus it may be expected that sideswipe accidents will increase where high vertical curbs are used The motorist senses such hazards and instinctively drives clear of high vertical curbs, usually a distance of from 4 to 6 ft, thus causing an economic waste in the effective width of the highway If the designer wishes to use low or sloping curbs he has no certain knowledge of exactly what type to use for it is quite possible that he may use a type which might throw a vehicle completely out of control if mounted at even a moderate speed, or that vehicles may be unable to mount them when covered with ice Again, the type used may offer so little obstruction that drivers will at the least provocation mount the curb and use the space for passing, thus greatly increasing the hazards of operation

In determining the answers to all the above detailed problems, opinion is not of much value A canvass of one hundred engineers would, in all probability, result in one hundred different solutions Therefore, the only sure basis of determining the true facts is from a thorough-going investigation in which the accidents occurring on each type of design are analyzed and exhaustive practical tests are conducted simulating actual accidents and noting the resulting damage created by each type of design In this way, the ideal design which subjects passengers and cars to the least injury would soon be indicated

The question of the safe permissible speed which may be used with a particular design and width of separation is an entirely unexplored field and thus it will not be possible for engineers to design for over all economy or to post safe speeds until research provides the answer to this question Therefore, it is most urgent that such investigations be instituted before any considerable program of dual highway construction is undertaken

The safe speed that a vehicle may travel is influenced to a considerable extent by the width and condition of the shoulder adjacent to the pavement, but as yet there is no definite method of evaluating in concrete terms its effect on motor safety In other words, because of lack of knowledge, the value of the shoulder is an unknown intangible, and it is generally conceded that engineers dislike dealing with intangibles It is therefore evident that more knowledge is required to establish the facts relative to the effect of the shoulder on safety and on safe speeds To illustrate, if the highway had no shoulder, with an abrupt drop at the pavement edge, the average motorist would feel quite unsafe and it would be readily admitted that the safe speed should be quite low, cars stopping for any purpose, such as changing a tire, must of necessity remain on the pavement, thus completely blocking the lane, and all drivers must observe extreme care not to run off the edge of the pavement, for such a course would immediately result in a serious accident Suppose an increment of one foot is added, making a shoulder one foot wide, the question awaiting an answer is, how much has this increment added to vehicle safety and what may be the safe speed? It is probable that as increment after increment is added to the shoulder width, the locus of a curve on a diagram representing benefits would continue to ascend until a certain width has been reached after which the curve will droop over and start to descend, indicating that after reaching a certain width any further increase of the shoulder follows the law of diminishing returns

To the writer's knowledge no start has been made on this problem, and yet it is quite as vital as many other highway problems which have been exhaustively investigated It must be admitted that the problem is not simple but highly complex, yet, intelligent, careful and patient research is certain in the end to provide the engineer with tangible facts on which to base a design for the various types and classifications of highways he is called upon to construct

Considerable discussion has been directed to the problem of setting up a proper criterion of the length of spiral curves A recent method of approach has been on the basis of the rate of change of centrifugal acceleration, but there is some question as to whether this method will really lead to a proper solution for it is quite possible that the rate of superelevation and the friction value assumed in the formula for superelevation may have as important an influence on the spiral length as the rate of change of centrifugal acceleration A statement of the case may make the issues clearer

In order for the motorist to feel the effect of centrifugal force and the rate of change of centrifugal acceleration, the curve must not be superelevated, or the vehicle must be travelling at a higher rate than the speed for which the curve is banked In other words, if a vehicle is travelling around a curve at the exact speed for which it is banked, the operator will not be affected by centrifugal force since the force of gravity introduced by the tilt in the roadway cancels centrifugal force, and if a spiral is utilized which at every point is banked for the given speed and radius at that point there will still be a balancing of forces even if the spiral is only one foot long However, a rotational force is introduced by the transition from the ordinary crown to the superelevated section and if the spiral were only one foot long this rotation would be too rapid for comfort or safety In the case where the vehicle is travelling at a faster rate than the speed for which the curve is superelevated, then the forces introduced will amount only to the difference in speed between the superelevated speed and the actual speed, and since the speed is cubed in arriving at the rate of change of centrifugal acceleration, the difference in the forces is appreciable A numerical case will illustrate

$$L_s = 1\ 58\ \frac{V^3}{r},$$

in which L_s = length of spiral, v = velocity in M P H , and r = radius in feet

(The formula is based on a rate of change of centrifugal acceleration of 2 ft per sec per sec per sec , and assuming no superelevation) If it is assumed that the rate of banking E is 05 ft per foot of width, permissible friction F 03 and speed 60 M P H then from the formula $E+F=\frac{067V^2}{r}$, r = 3000 ft (in round numbers) Substituting these values of speed and radius in the spiral formula, L_s = 113 ft If, however, only the difference in the actual speed and the superelevation speed, which amounts to 13 M P H , is introduced into the spiral formula, L_s = 1 ft Thus, it is evident that if the actual unbalanced force is used, an entirely inadequate spiral is indicated, while,,on the other hand if the full force is used (balanced plus unbalanced) there is serious question if consistent riding qualities will be produced with different friction values and different rates of superelevation

A method suggested by Elmer R Haile, Jr ,[3] which utilizes the rate of rotation as a measure of spiral length may yield more consistent results This method requires the substitution of two values to be derived from tests

In view of the uncertainties outlined it appears desirable that experimental spirals be constructed, embodying the different conditions encountered in practice, and that they be subjected to scientifically controlled tests to the end that

[3] *Proceedings,* American Society of Civil Engineers, December 1936, p 1650

a real and satisfying criterion of spiral length may be set up It is also important that it be determined if very long spirals are detrimental, or are desirable

To the mathematically inclined, there is opportunity for service in the invention of a mathematically simple spiral for special use on elevated viaducts and in tunnel construction, in order that concentric curves and radial lines may be accurately determined for the purpose of shop fabrication of steel

In the past, the minimum distance between reversed curves has been established more or less arbitrarily, but with advancing speeds it becomes necessary to replace past methods, based on judgment alone, with definitely known facts founded on scientifically conducted tests The minimum distance between reversed curves depends on the reaction time required for the operator to emerge properly from one curve and become prepared to enter the following one The reaction time in seconds multiplied by the vehicle velocity in feet per second at the design speed will give the minimum distance in feet between the curves It is quite possible that the friction assumed as permissible in the superelevation of particular curves will have an important bearing on the reaction time and that the use of spirals will still further affect the time, due to the fact that steering (or slippage) angles are released gradually on passing out of the first curve and developed gradually on entering the reversal

Since the basic facts concerning the reaction time required between reversed curves for the various design assumptions of friction and spiral length are unknown, it would seem fundamental that authoritative data be accumulated based on tests in order that this detail of design may pass from the field of uncertainty into the realm of definite knowledge

The lengths of vertical curves affect visibility and sight distance This has generally been recognized and taken into consideration in design in relation to sight distance during daylight, but little thought has been given to the problem as related to sight distance with headlamps during the hours of darkness Indeed, at the present time, it is not possible to set up the minimum length of a vertical curve for a given algebraic change in grade which will assure full visibility with headlamps while at the same time not result in a curve of a greater length than actually required to fulfill practical requirements A mathematical solution may quite readily be developed, provided certain facts relating to lamp characteristics are known, as for example, the height of the lamp above the road, the vertical angle of the upper rays of the beam and the length of visibility on a level road, but the value of a mathematical approach is questioned because of the extreme length of curves that are indicated

Until recently, the length of visibility with a headlamp was unknown but fortunately certain facts have been made available by W C Giessler[4] as a result of a series of tests conducted by the Illinois Division of Highways The striking fact was disclosed that it is possible with properly adjusted headlamps, in good condition, to see a white object at a distance as great as 715 ft from the car

The vertical curve problem is divided into two parts (1) At sags, and, (2) at summits If it is desired to utilize vertical curves which will not restrict headlamp visibility for a distance of 715 ft, assuming the height of the lamp to be 3 ft, the upper aiming to conform to legal requirements (Pennsylvania, 2° 40′) and

[4] "The Relationship of Headlamps to Road Speeds"—by W C Giessler, Mechanical Engineer, Illinois Division of Highways (February 1937)

"What is the Night Accident Problem Like"—by W C Giessler (May 1937) the algebraic difference in the highway profile to be 8 per cent, then a mathematical solution indicates that at a sag a vertical curve 560 ft long is necessary, while at a summit a vertical curve 6800 ft long is required The length of the latter curve is so great that serious doubt exists as to whether curves of such length are really required to assure full headlamp visibility A further analysis of both cases may indicate the general features of the problem

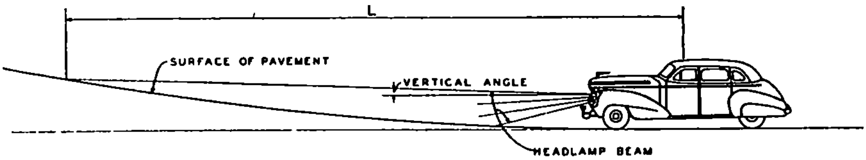

Figure 1 Condition at Sags

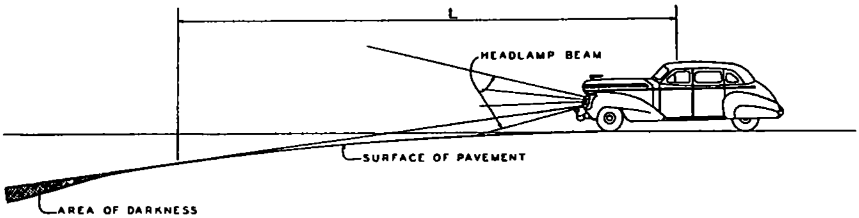

Figure 2 Condition at Summits

Figure 1 shows the conditions at a sag The mathematical solution mentioned assumes that the light is projected forward with equal intensity and that the top rays will reveal objects at as great a distance as the center or "hot spot" rays This does not conform to common observation, as it is known that the edges of the light rays become shadowy and that objects are not defined so clearly in the outer areas as those within the center of the intense rays at a corresponding distance from the car Thus, it can readily be seen that the vertical angle of the extreme upper rays should not be utilized, but that the vertical angle of the intense or "hot spot" rays should be used instead Mr Giessler found that maximum visibility was obtained with the top of the "hot spot" located 2 in above the horizontal axis of the lamp at a distance of 25 ft, which represents a vertical angle of 0° 23′ The result is that a longer vertical curve than indicated above is required to maintain the sight distance available with headlamps, the calculated length being 2640 ft

Figure 2 shows the conditions at a summit It is to be noted that the rounding curve intercepts the light rays and that the down curving pavement beyond the tangent point is in darkness In other words, there is a sliver of darkness below the bottom of light rays and the top of the pavement beyond the tangent point In the example given above it was assumed that the tangent point should be at the distance of maximum headlamp visibility from the car, namely 715 ft With a curve of this length, the rate of change or "rounding" of the curve is quite slight and thus the sliver of darkness beyond the tangent point is very thin, in fact at a distance of 100 ft beyond the tangent point the depth of the darkness is only three quarters of an inch In view

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of the fact that the "hot spot" must be aimed above the horizontal for maximum visibility, and that the lower fringes of the light are of lower efficiency, it is quite possible that the lower fringes of the light will be shadowy on level pavement at the maximum distance and thus the thin sliver of darkness for a curve of such great length may cease to govern visibility requirements after the vertical curve is increased beyond a certain magnitude This suggests that shorter vertical curves than indicated by a mathematical solution may possibly be used at summits without adversely affecting sight distance with headlamps

In view of the almost complete lack of definite knowledge on the subject, it appears only reasonable to assume that design standards must await the results of tests and it is to be hoped that such an investigation may be instituted in the near future

An important detail which is yet in the development stage is the design of entrance and exit ramps to and from high speed highways, particularly in urban regions where space is restricted It is important that these facilities function efficiently, while at the same time, assuring the maximum safety not only to the entering or leaving vehicle but particularly to the vehicles on the high speed highway where an accident is of a more serious nature because of the speed involved The fundamental principle of acceleration and deceleration lanes is being adopted in modern designs, but their length for particular situations and design speeds and the details of design are in the experimental stage It is to be hoped that studies will be instituted for the purpose of establishing basic principles and to indicate definitely bad or undesirable design Such principles cannot be established from opinion, but must be founded on facts deduced from accident analyses, congestion studies and habits of drivers obtained by investigating the various types of design in actual use today. In this connection, it would be helpful in determining natural travel paths if the natural radius which an operator utilizes of his own volition when making a turnout for passing on the open highway is established; and the rate of deceleration of passenger cars and trucks in gear with the throttle closed utilizing the compression in the engine as a braking force It must be realized that a traffic stream is similar to a flowing liquid, and abruptly introducing new streams of flow causes turbulence. An entrance or exit ramp causes such turbulence unless it is designed correctly An entrance ramp, for instance, suddenly reduces the number of main travel lanes each time a vehicle enters unless the vehicle is given an extra lane of its own for such a distance that it can accelerate to the travel speed of the other cars and mesh into traffic without turbulence In other words, the efficiency of the main highway is seriously impaired unless proper exits and entrances are provided, and thus it can be seen that improper design of these facilities adversely affect the functioning of the entire highway, and, therefore, they are of vital importance in maintaining balanced operation of the complete system as well as affecting the safety of the motorist

The element of time is the new factor which has become increasingly important due to the advancing speed of the modern motor car Therefore, designers must begin to think in terms of highway elements being arranged or placed so many seconds away from the driver That is to say, if the time required for the driver to react to a given condition is known, then the required distance in feet for locating a design feature is obtained by multiplying the reaction time in seconds by the design speed in feet per second The difficulty at the moment, however, is that very little data are available in print on the reaction time required for many motoring situations, for although machines for measuring reaction time for various situations have been developed, it must be recognized that the subject operating such a machine is keyed up and alert, thus being able to perform a given function in a shorter period of time than is usual under actual operating conditions. In other words, the motorist under actual driving conditions is seldom ready to go into instantaneous action when an emergency arises and therefore requires a longer time to react than when being tested by a time measuring machine. This suggests that vital information is still required before engineers can confidently design to conform to the operating characteristics of motorists. The striking similarity of many serious accidents is the lightning like rapidity with which they occur. Many participants are unable afterwards to give a clear picture of the events which led up to the accident and often have not the faintest idea of what really happened. This is because the action took place in a split second and was completed before the driver's mental machinery could grasp what was happening. This imposes on the highway designer the task of lengthening out the perspective ahead of the driver and of arranging the highway elements so that time and space are provided in such a manner that it is possible for the motorist to correct an error in judgment or to recover from a minor mishap in time to avert catastrophe. A statement of a few of the more simple and obvious cases in which the time element affects design may be illuminating.

A not infrequent accident condition is the case where a passing vehicle cuts in ahead too quickly and contacts the front of the vehicle being passed sufficiently to cause momentary loss of steering, and if the pavement is flanked by a narrow 5 foot shoulder with ditches, trees, poles, headwalls, etc., at the shoulder edge, the driver must be able to recover control within approximately $\frac{1}{4}$ of a second (Speed 40 M. P. H.) in order to avert a major accident. In this case the shoulder may be said to be $\frac{1}{4}$ of a second wide. At the present moment it is not known what reaction time is required for a driver to recover control of steering under such circumstances or the time consumed by a car out of control in traversing lateral space.

The design, size of lettering and position of a direction sign depend on time.

Frequently a motorist passes a direction sign before being able to read it, or if the letters of the sign are of sufficient size to be read it may be placed improperly in such a position that the motorist has passed the turnout before he has had time to react to make the turn. For example, if the speed is assumed as 60 M. P. H. and the reading and understanding time 3 sec., the letters of the sign must be of such a size that they can be easily read at a distance of 264 ft. In this case the sign may be said to be 3 sec. from the motorist. The sign also should be set sufficiently in advance of the turnout for the motorist to make up his mind if he wishes to make the turn, for brake reaction time and for decelerating at a moderate rate to the speed required for the turn. If those functions require 5 sec. (440 ft. at 60 M. P. H.) the turnout may be said to be 5 sec. from the sign. The fact that many direction signs have letters of improper design and size to be read and understood at as moderate a speed as 40 M. P. H., and that they are placed an improper distance in advance of the turnout is an indication that the factors are either unknown or that they have not been widely disseminated.

Hazards such as wells separating turnout ramps from the main roadway should be properly located and the motorist protected from them by allowing adequate warning of their existence and then an allowance of sufficient time after the warning to enable the motorist time to avoid crashing into them This protection and warning may take the form of an island extending out in front of the wall for some distance, the end of the wall illumined with an indirect outdoor "billboard" type of light, the end of the island to be low so that it in turn may not be a hazard and with no form of fixed obstruction located in the island such as light standards, reflectors and signs The length of the island from the wall to the tip should be such that a motorist who straddles the island will have time either to come to a stop or swerve off before striking the wall If the island is low enough to permit swerving, the time required will be the sum of two reaction times, first a period to come to the realization that danger is ahead and that there is necessity for action, and second, a period sufficient to swerve out of danger If 3 sec are required (176 ft at 40 M P H) then the tip, or nose, of the island may be said to be 3 sec from the wall In the case where the sides of the island are designed with curbs of such height that it is not possible for a vehicle straddling the island to swerve off, the time required will be the sum of the reaction time for the motorist to come to the realization of the danger and of the necessity for action, the reaction time for brake application and the time required to bring the car to a stop before reaching the well If 7 sec are required (approximately 275 ft at 40 M P H), the tip of the island may be said to be 7 sec from the wall

The reaction times required for these conditions are unknown and in addition they may be different from similar reaction times occurring under favorable weather conditions, for the hazards imposed by walls and other obstructions operate during periods of darkness, fog, rain, sleet and snow when visibility is poor

It may be thought that many questions raised in this paper are only a matter of detail and are consequently subordinate to other features of highway design, but it must be realized that other elements of the highway, particularly those features involving strength of construction, have been receiving considerable attention over a period of years, while knowledge of the questions treated herein is quite vague and unsettled, yet such problems have a vital effect on motor safety Consequently the motorist will be appreciative of their solution since he is quick to sense any advancement in highway design which improves vehicle operation and safety

It is well to note that it has been stated in structural circles that close attention to details is the secret of success in structural design This thought is even more true in highway design, but the fact has only recently been recognized, particularly in relation to safety of operation Perfected highway design awaits definite and precise data concerning these details, and it is earnestly hoped that research will be undertaken to clear away the uncertainties in order that the engineer may proceed with certainty to design safe and efficient highways The results will be measured in lives saved and in a tremendous reduction of the economic loss due to accidents

DISCUSSION ON DESIGN RESEARCH

MR BURTON MARSH *American Automobile Association.* Mr Noble's paper deals with a feature of highway design which is bound to get a great deal of attention—the matter of the divided highway It was pointed out that much needs to be done about the design of the center strip, its curb, planting, etc These design features do need careful study

I had occasion about five years ago, in connection with a paper on traffic features of highway design, to interrogate highway engineers concerning their attitude toward divided highways, which I favored I found relatively little support for this design Recently in preparation for another paper on a somewhat similar subject, a similar inquiry was sent to the state highways departments Responses indicated an almost unanimous favor for this type of improvement In fact, there was only one negative response among the 42 replies received In light of this attitude of approval and despite the fact that at present there are now but 1,200 miles of non-urban divided highway in the country, it would seem that here is a type of improvement for highways four lanes in width or wider, which will be increasingly utilized

It is, therefore, particularly appropriate that such important questions which relate to highway use should be given attention by progressive engineers Demand for divided highways is certainly increasing and efficient designs should be developed Highway users will profit greatly if active discussion and research precede extensive construction involving this feature.

DR A R LAUER, *Iowa State College* Mr Noble mentioned reaction time Perhaps we are wrong in allowing for an average of one-quarter, one-half or even three-quarters of a second I believe we should think of such matters in terms of the maximum time that anyone is likely to take, then add still more as a margin of safety In designing a bridge we allow for the maximum load that will pass over the bridge, and a wide margin of safety in addition

I feel this is an important point in the matter of sight distance We should consider only the maximum time any individual is likely to take in perhaps but 1 out of 20 instances It is the exceptional individual at the inopportune time which causes all the trouble.

To attempt to build shoulders wide enough to protect the slow-reacting driver, when he finds himself headed for a ditch, would be utterly impossible You would need shoulders wider than the main road as some drivers may even "freeze" under conditions of fright and take 1, 2 or even 3 or more sec to regain control of themselves This is exceptional Perhaps one sec basic time would be sufficient in most cases This might be doubled to include an adequate safety factor