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PSYCHOLOGICAL REACTIONS OF DRIVERS
AS RELATED TO HIGHWAY SAFETY

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FOREWORD

The following report contains a comprehensive discussion of those factors which affect, either directly or indirectly, the psychological reactions of the driver. Many of the factors considered nominally belong in the field of engineering and, at first glance, appear to have no connection with the subject under consideration. Thus, the designing of a highway intersection is basically an engineering problem. However, the feelings of the motorist as he approaches the intersection are definitely psychological and, along with the physical characteristics of the intersection, help determine its safety.

Unfortunately, the exact relationship between physical characteristics and psychological response is quite often unknown. While, for example, it is common knowledge that the accident rate for a slippery pavement is much higher than that for a dry road, no one has as yet determined what portion of the increase is caused by the actual road conditions and what portion by the feelings of nervousness and tension which these conditions engender in the motorist.

It is thus apparent that much work remains to be done before our understanding of the role played by psychological factors can be considered as reasonably complete.

This report summarizes much of what is known concerning the psychological factors in highway safety. The paper opens with a consideration of fatigue and its causes. Following this is a comprehensive discussion of highway design, construction, and maintenance, and vehicle design and operation, with special attention given to those factors which promote undesirable psychological responses in drivers. Included in this section of the report are numerous specific recommendations for minimizing or eliminating such responses. The last section of the paper deals briefly with federal proposals for a nationwide inter-regional highway system and for uniform traffic laws.

FATIGUE: CAUSES AND GENERAL EFFECTS

Anyone attempting to make a study of fatigue in relation to highway safety is immediately confronted with the difficulty that the exact nature of fatigue is still unknown and there is as yet no precise way of measuring it.

In general, three aspects of fatigue have been distinguished: (1) a decrease in the individual's capacity for work (2) physiological changes in the organism, due to the production of various chemical products, and (3) feelings of ennui, tenseness, and tiredness.¹ Unfortunately, there is no very high correlation among these phenomena. A decrease in work output is not necessarily accompanied by a feeling of tiredness; in fact, the worker may feel unusually alert. On the other hand, an individual faced with a difficult task may become very tired before ever beginning to work. Such facts indicate that attitudes and motivation play a central role in the production of fatigue, and have led some investigators to suggest that the word "fatigue" be applied only to those "subjective feelings of bodily discomfort arising in a conflict situation".² Specific changes in bodily condition and in the capacity to do work would be designated respectively, by the terms "impairment" and "work output", or similar expressions.³ For the purposes of this paper fatigue will be regarded as embracing both impairment and work output, since these are undoubtedly related in some manner to subjective fatigue.

It is difficult if not impossible to determine the extent to which fatigue is responsible for highway accidents. Table I, which is compiled from Michigan State Police accident records for 1951, shows fatigue and sleepiness to be a factor in only 3 percent of those accidents resulting in death or injury. Such a figure, however, is highly questionable. The use

TABLE I
MOTOR VEHICLE TRAFFIC ACCIDENTS
IN MICHIGAN 1951

Circumstances and Conditions Involved in Accidents	Percentage of Accidents in Which Circumstances or Conditions Occur	
	Fatal Accidents	Fatal and Injury Accidents
Speeding	31	28
Driver Fatigued or Asleep	3	3
Driver Vision Obscured	14	10
Vehicle Defects	10	9
Road Defects	6	9
Night	57	46
Wet, Icy or Snowy Pavement Surfaces	39	35
Cloudy, Rainy, Foggy or Snowy Weather	30	40
Curves, Hills and Grades	28	32
Intersections	27	29

of the expression "fatigued or asleep" indicates a tendency to regard driver fatigue as synonymous with sleeplessness or tiredness, while ignoring its other manifestations. The number and importance of these other manifestations is pointed up by an investigation of the effect of length of driving times upon driver efficiency, conducted by the United States Public Health Service.⁴ This study included measurements both of bodily states over which the individual has little control and of muscular reactions resulting directly from a mental stimulus. From the results obtained, a driver fatigue complex was built up, which included the following indicating factors: (1) reduction in speed of tapping, (2) lengthening of time required to make a coordinated movement, (3) increase in body sway, (4) decreased speed of action, (5) decreased steadiness of the hands, (6) decrease in vigilance as measured by driving tests, (7) decrease in ability to perceive flicker and, probably (8) decrease in ability to distinguish objects in the presence of glare, (9) reduced speed of eye movement, (10) reduced accuracy in aiming, (11) reduced efficiency in steering, (12) decreased heart rate, (13) increased white cell count, (14) lengthened brake-reaction time, (15) increase in blood pressure, and (perhaps) (16) slight increase in strength of grip. It was concluded that when any number of the above changes occur in combination and an individual has been driving for some time, he may be said to exhibit driver fatigue.

Similarly, excessive or insufficient light, obscured vision, noise and vibration, unsafe roadway conditions, poorly designed highways, and many other commonly encountered conditions have a detrimental effect upon driver performance. The motorist operating his vehicle under such conditions finds himself in a conflict situation similar to that created by any other disagreeable task. The same feelings of frustration and fear

are aroused, the driver becomes tense, his reaction time is slowed down and his judgment impaired, all of which increases his chances of becoming involved in accidents.

If all the various manifestations of fatigue and the many factors which contribute to it are taken into account, it becomes apparent that fatigue could be a much more important factor in highway accidents than is generally realized even among law-enforcement officials.

Fatigue has many causes. It may be brought on by both over and under exertion. The blood, in over-exertion, lactates, secreting an acid called lactic acid, which promotes fatigue. In idleness the muscles deteriorate, resulting in greater fatigue for a given amount of effort. In addition to over and under-exertion, such specific factors as excessive or insufficient light; noise and vibration; certain personality traits and mental states; lack of sleep; and hot, humid weather also contribute to the development of fatigue. These specific causes will now be discussed in some detail.

Vision

Vision has long been recognized as playing a major role in driver performance, and many investigations have been conducted to determine the influence of the various individual eye conditions. These investigations indicated that binocular coordination, muscular unbalance, and foveal and peripheral reaction time have little or no effect upon driver performance, since there was no significant difference in these factors between accident and non-accident drivers. However, such defects as myopia, inequality of acuity between eyes, narrowed field of vision ("tunnel vision"), astigmatism, color-blindness, uncompensated blind spots, and glare susceptibilities, are all more prevalent in the high-accident group.⁵

Of all the visual factors related to accidents, glare has probably received the most consideration. It is a momentary blindness caused by an

over-abundance of light entering an eye which is unprepared to receive it. There are two categories of glare - direct and reflected. Direct glare results when the offending brightness is directly in the viewer's field of vision; reflected glare occurs when the brightness is reflected from a glossy surface into the field of vision. An individual who is glare blind is especially susceptible to accidents since he requires a much longer time to recover from the effects of glare than does a person with normal vision. In research conducted by the Public Health Service⁶ to determine the effect of direct glare upon the reaction time of drivers, it was found that those who had not driven since a major sleep (6 hours) had a shorter brake reaction than those who had. In the presence of glare, men who had driven since a major sleep needed more light for distinguishing objects than those who hadn't.

Flicker may be defined as a series of rapid variations in the brightness of a light. One of the characteristic properties of the eye is its ability to fuse these variations in such a manner as to give the appearance of a steady light. The minimum rate of flicker at which this fusion occurs is called the critical frequency of flicker. The Public Health Service⁷ has tested the eyes of truck drivers to determine the relationship between fatigue and the critical frequency of flicker. Measurements were made using lights of both low and high brightness. It was found that for low brightness, there is a decline in the mean critical frequency with increasing hours of driving. For high brightness, the men who have driven have a lower mean critical frequency than those who have not driven, but there is little difference between the mean critical frequencies for those drivers who drove from 0 to 9.9 hours and those who drove 10 hours or over. In general, there is a tendency toward lower critical frequency with an increase of driving hours and of fatigue.

Sound

Sounds can be divided into two classes: those of transient nature and those which are steady while they persist. Transient sounds start suddenly and die away quickly, while persistent sounds are those of a musical nature or others produced and maintained for a relatively long period of time.

The average person can perceive sounds with a range of frequencies of from 20 to 20,000 cycles per second, the upper limit declining with increasing age. In the normal individual the range of audibility is from 0 to about 140 decibels, a decibel representing approximately the least change in sound level which an individual is able to distinguish.

There is no rigid definition of noise. It is usually called "sound out of place" and is composed of sounds of many different frequencies and amplitudes, any of which might predominate. When the pattern provides continuous coverage of a wide range of frequencies, we speak of "white noise".

The standard instrument for measuring sound is the audiometer. This instrument measures the loudness threshold at several frequencies. Under laboratory conditions, it has been found that the correlation between scores obtained for two administrations of the same test range from 0.70 to 0.87. Even when tests are administered by operators with a minimum of training an accuracy of 5 decibels can be obtained; with experienced operators the variation is between 2 and 3 decibels.⁸

In the ear, sound variations are analyzed and converted into nerve impulses and are then conducted from the ear to that part of the brain which serves as the hearing center. This hearing center communicates, directly or indirectly, with all other parts of the brain. Noise, therefore, may affect not only the ear itself but other portions of the body

beyond the ear, to which the vibrations, albeit in a different form, penetrate. The effects of noise can thus be studied from two points of view: its effects on the ear itself and its effect upon the brain and other organs of the body.

Dr. Charles Warren, an eminent British ear specialist, has stated⁹ that continuous noise causes a thickening of the ear drum. There is also a stiffening of the small bones within the ear and a loss of their ability to move. Thus noise can cause a gradual loss of hearing and even result in total deafness.

Today New York cab drivers who ply in the most congested areas of the city where there is a constant blare of auto horns, are becoming hard of hearing. Occupational deafness is becoming more and more common, and as our cities are becoming more noisy, there is an increase in occupational deafness among printers, bus drivers, road makers, and traffic policemen.¹⁰

Besides damaging the ear itself, noise causes mental and emotional upsets, interferes with various bodily functions, and impairs working efficiency.

At Colgate University, an experiment was conducted to determine what effects noise and vibration have upon the sleeping individual.¹¹ The nine male students who were used as subjects slept in beds with small electric motors hung underneath. The noise and vibration were found to cause headaches and circles under the eyes; the students were unsteady and wobbly on their feet, heard buzzing noises during the day, were irritated by ordinary things, and laughed at common occurrences. They wanted to be alone, time dragged for them, and they had to exert unusual effort to do routine work. It was also found that noise and vibration led to increased blood pressure and muscular tension even during sleep. The effects of the second week of sleeping under such conditions were more severe than those of the first week.

Brain specialist Dr. Foster Kennedy has shown that noise has a definite, detrimental effect upon the mind.¹² In experiments conducted at Bellevue Hospital in New York, he discovered that bursting a blown-up paper bag raised the pressure of the brain of a nearby patient to a point four times above normal for a period of one second. This increase is greater than that produced by morphine or nitroglycerine; the two most powerful known drugs for increasing brain pressure.

Dr. Walter B. Cannon of Harvard has stated that noise may affect digestion, and loud noise may even halt it.¹³ A noise level of 60 decibels was found to have a decided effect in deranging digestion. The digestive upset results because the noise decreases the flow of salive in the mouth and gastric juice in the stomach.

All experts agree that a loud, sudden noise causes about the same reaction in a person as does a great fright. If the reaction is severe enough it may be followed by shock, a general feeling of depression, and a loss of vitality. And shock, from a medical standpoint, often is more dangerous than various bodily injuries which produce shock.¹⁴

Not only loud noises, but continuing noises, even little ones, can cause great nervous strain and may lead to neurasthenia and other types of mental illness.

It is not an exaggeration to say that quite a few cases of insanity are caused by nervous systems that cannot adjust themselves to the constant bombardment of noise. People with emotional imbalances, or who are forced to carry heavier mental loads than they are capable of carrying, are pushed more rapidly into insanity by noise.¹⁵

Numerous measurements have been made of the loudness levels of noises from a variety of sources. The results of a number of such measurements are presented in Table II. These results indicate clearly that many of the street noises encountered by pedestrians and motorists are at a high enough level to have adverse effects upon the hearer.

Figure 1¹⁶ shows the variations in noise meter readings from instant to instant in late afternoon observations on a residential street. It can

TABLE II

TYPICAL NOISE LEVELS COMMONLY
ENCOUNTERED IN EVERYDAY LIFE*

<u>Source of Noise</u>	<u>Noise Level in Decibels</u>
quiet residence	30
quiet radio	35
noisy residence	45
quiet street	50
quiet auto	50
<hr/>	
automobile (V-12)	65
modern pullman sleeper	70
busy traffic (15-75 ft.)	70
loud radio in home	80
very heavy traffic	80
interior of auto (55mph)	80
sports car	90
railroad car	100
subway	105

* Data taken from Handbook of Human Engineering Data, Part IV,
Ch. IV, Sect. II, pp 2-3.

be seen that the noise level does not remain constant, but constantly fluctuates, sometimes by as much as 20 decibels.

Figure 2¹⁷ shows the relationship between noise level and traffic volume. It will be noted that when the noise level reaches about 130 units its rate of increase diminishes sharply, and when the level reaches 145 units, there is no further increase. This leveling-off is probably due to the fact that when the traffic volume increases the average distance of the vehicle from the listener also increases.

The deafening effect of varying amounts of traffic in New York City is presented in Figure 3.¹⁸ In order to be heard in heavy traffic, a sound would have to have a level of more than sixty decibels, an intensity sufficient to cause feelings of discomfort and irritation in the hearer.

Within recent years, city officials have come to realize that excessive noise means lowered health and efficiency. In New York City the Mayor's Noise Abatement Commission, as a result of its studies, reported in brief that the continual pressure of the strident noises to which New Yorkers were subjected tended to produce impairment of hearing, introduce harmful strains upon the nervous system leading to neurasthenic and psychosthenic states, and interfere with sleep to the point that rest was difficult and in some cases impossible.¹⁹

A number of cities have taken steps to curb noise. San Francisco, for example, has cut street noises greatly by replacing old-fashioned streetcars with modern streamlined trolley coaches. Commenting on this changeover, San Francisco's Health Director, J.C. Geiger said:

Already we have received enthusiastic reports from hospitals where noise formerly created by the old streetcars has disappeared with the advent of trolley coaches. Moreover, the public should notice a difference in the air as more and more gasoline buses are replaced.²⁰

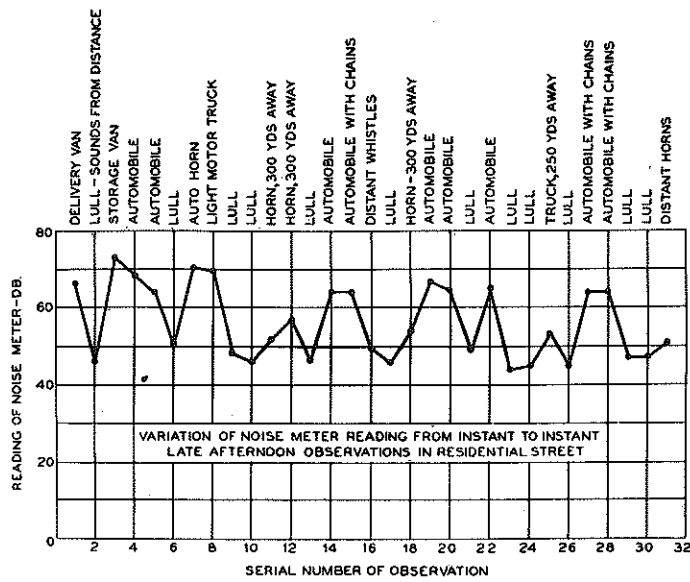


Figure 1: Fluctuation in the Level of Various Outdoor Noises.

Figure 2: Noise Intensity Vs. Passenger Automobile Traffic Volume.

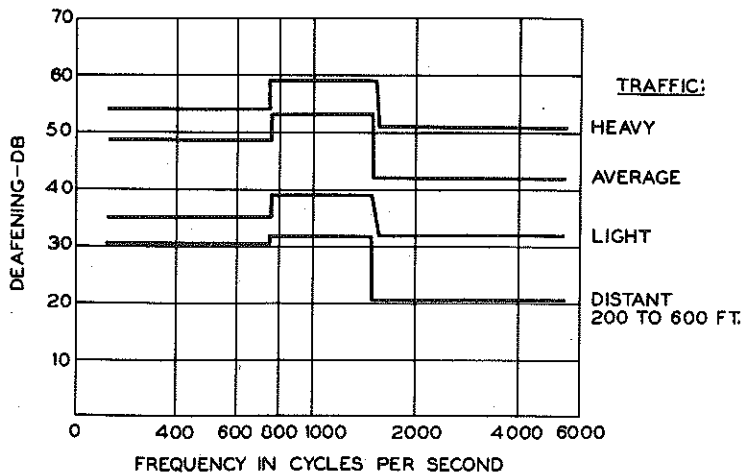
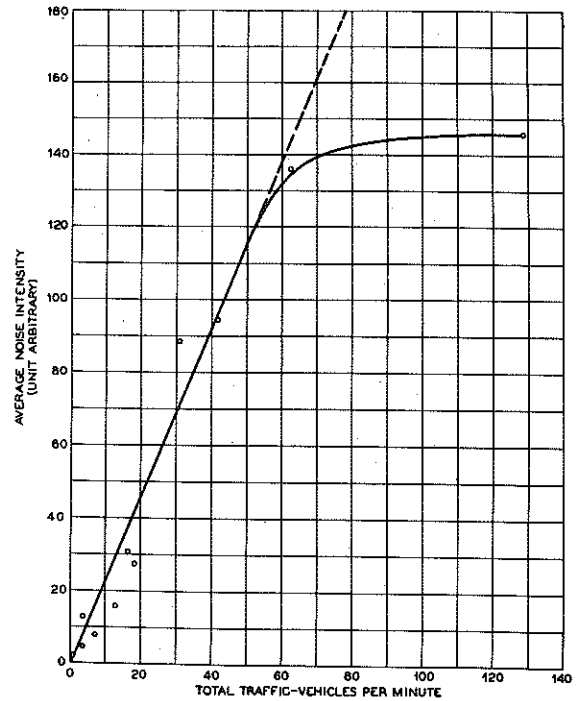


Figure 3: Deafening Effect of Traffic Noises.

Vibration

Sound and vibration differ from each other chiefly by the manner in which they are transmitted. Whereas noise is airborne, vibration is transmitted through solid structures. Because of the importance of the vibration problem in the automobile industry a number of studies of the effects of vibration upon humans have been made.

At Purdue University Professor H. M. Jacklin²¹ conducted tests designed to arrive at some sort of conclusions as to which type of vibration-vertical, longitudinal, or transverse - could be tolerated by human beings with the least discomfort. In these experiments the subject was seated on a rattan-covered street car seat, mounted on a vibrating platform or "shake table". Frequency varied from 1 to 17 CPS and amplitude from 0 to $2\frac{1}{2}$ inches. Observations were confined to three easily distinguishable reactions - perceptible, disturbing, and uncomfortable - which have been defined as follows:

- (1) perceptible - you feel that you are moving or that distant objects are moving slightly.
- (2) disturbing - you note that certain organs or parts of your body have greater vibration than you yourself and you try to prevent this condition by tightening certain muscles.
- (3) uncomfortable - you want very little of this treatment.

The results of the investigation showed that humans will tolerate considerably greater vibration, as represented by a combination of acceleration and frequency, in the vertical direction than in the other directions and that they can stand relatively little in the transverse direction when sitting on a relatively hard and rigid seat.

Reiher and Meister²² conducted a series of tests designed to measure the human response to sinusoidal vertical and horizontal vibrations applied with and transverse to body axis with subjects in both standing and prone positions. The frequency range was from 3 to 70 cycles per second, a range commonly met with in traffic and industrial vibrations. The subjects indi-

cated thresholds of sensation to vibratory stimulation be reporting sensations as: (1) not perceptible, (2) weakly perceptible, (3) easily perceptible, (4) strongly perceptible, (5) unpleasant, (6) very unpleasant. Standing subjects proved to be more sensitive to vertical than to horizontal vibrations, while prone subjects were more sensitive to horizontal vibrations transverse to body axis.

R.N. Janeway's²³ investigation of human tolerance to vertical simple harmonic motion is probably the most comprehensive of the human vibration studies. On the basis of a study of all available experimental data, he found that the entire frequency range of vehicle vibration from 0 to 60 cps could be divided into three zones. The low frequency range included vibration of from 1 to 6 cps, the middle frequency range vibrations from 6 to 20 cps, and the high frequency range vibrations of from 20 to 60 cps. Perhaps the most interesting conclusion that emerges from this study is that the comfort reaction in all three zones is determined basically by acceleration rather than by frequency of vibration. In the low frequency zone the critical factor is the rate of change of acceleration, or "Jerk"; in the middle frequency range it is the rate of acceleration; and in the high frequency range it is the velocity. The safe working limits for the three zones were found to be:

"Jerk": low frequency range - 40 ft./sec.³
Acceleration: middle frequency range - 3.3g.
Velocity: high frequency range - 0.105 in/sec.

Posture

Posture has a great deal of influence upon the performance of drivers. The undesirable effects of poor posture are numerous. When an individual is in a slouched position the heart's action is impeded, with a consequent diminution in both quantity and quality of blood supply and a decrease in

the elimination of carbon dioxide. Deprived of a normal supply of properly oxygenated blood, the brain becomes much more rapidly fatigued than it otherwise would, resulting in inattention and lack of alertness and increasing the possibilities for accidents.

Poor posture is probably the most easily remedied of the factors causing fatigue. For a driver to have correct posture, he should be seated in a position which will demand a minimum of mental, nervous, and muscular exertion. Substantial support should be provided for the lumbar region of the spine, since it is in this area that weariness is first noted. There must of necessity be flexion at the hip and knee, and the position of the head and trunk should correspond as nearly as possible to the position maintained when the driver is standing. If these conditions are complied with, the onset of fatigue will be delayed and its severity considerably lessened.

Weather

The human body maintains its temperature equilibrium through a dual control of heat producing and heat loss factors. The ability of the individual to adapt to environmental changes affecting this heat balance will determine his degree of comfort, efficiency in work, and, in extreme cases, his survival. The basic environmental factors affecting body heat balance are three: air temperature, humidity, and ventilation. These three factors are lumped together under the generalized heading of "Weather".

The average person at rest is most comfortable at a temperature of between 70 and 80°F and a relative humidity of about 45 percent. With a rise in the temperature of the air, the body adjusts through the skin as the blood vessels dilate and more blood flows, raising the skin temperature and increasing heat loss. If this is insufficient for maintaining thermal balance, the sweat glands become active.

Humidity has little effect on thermal balance within the temperature range 70°-80°F but is a vital factor in comfort and tolerance when temperatures are extremely high or low. At extremely high temperatures, with relative humidity also high, the perspiration is not evaporated but simply drips from the skin, hence heat loss is not speeded up. If the humidity of either hot or cold air is very low, the air has a drying effect on mucous membranes, making them irritated and more susceptible to colds and infection.

At high temperatures, air movement aids the loss of heat by evaporative cooling. Since air lying next to the skin soon becomes nearly saturated, rapid air movement causes rapid replacement by drier air and results in an increase in evaporation rate from the skin. An increase in air velocity also raises the dry-bulb temperature that can be tolerated before perspiration becomes necessary to maintain heat balance.²⁴

Investigations of the effects of high temperatures upon the efficiency with which work is performed²⁵ have shown that performance begins to deteriorate at about 87.5° to 92° effective temperature,²⁶ and deteriorates with increasing rapidity until at 97° effective temperature the number of mistakes is ten times normal. It can probably be safely assumed that the performance of drivers exposed to these same conditions would likewise suffer in a similar manner.

Personality and Mental States

Driving skill is the product of two factors - ability and training. The degree of driving skill should be a valid indication of traffic performance but unfortunately it is not. The mental state and personality traits of the driver also play an important role in his performance behind the wheel. Driving²⁷ requires the complete concentration of the mind and relaxation of the body, but such personal problems as illness, the loss of a job, family quarrels, or financial difficulties can cause the motorist

to become tense and divert his mind from the business at hand. Under such conditions, his driving skill is adversely affected, and his possibilities of having an accident greatly increased. Individuals who suffer from an inferiority complex are also often poor drivers, since they sometimes try to compensate for their inferiority by driving recklessly and showing off.

In their ability to drive, individuals range from the extremely able to the totally incompetent. There can be no doubt that there exists one large group of persons who are more accident prone than others. An accident prone driver may be skillful, experienced, healthy (so far as can be determined) and have a pleasant personality. Yet, whenever he gets behind the wheel, things happen to him.²⁸ Since accident proneness, at least in some instances, is the result of deeply buried subconscious attitudes, the condition is difficult if not impossible to correct.

Moffis²⁹ and his colleagues have attempted to show the relationship between scores obtained on certain aptitude and personality tests and driver performance. This study has succeeded in showing some relationship between psychological traits and driver performance, and has pointed up the personality of the driver as a factor in safety. The results obtained show that the more proficient drivers have a better understanding of general mechanical principles than those having poorer accident records. On the other hand, accident-prone drivers scored higher on computational interest tests. In general, safe drivers tended to be more tense,* less self-sufficient, and less dominant than others.

As one approach to the problem of accident proneness, the Industrial Health Research Board (British) has devised a series of tests to be uniformly applied to drivers of public vehicles as well as workers in certain

* This result is just the opposite of what might have been expected.

other occupations. These tests measure accuracy and hand-and-eye coordination. They have as their ultimate objective the elimination of the most accident-prone individuals from occupations where this tendency might be dangerous.

One investigator, Dr. Charles S. Myers,³⁰ has recommended that a psychological investigation of all the factors having a bearing on driving be undertaken. For example, in connection with traffic signals the psychologist would ascertain their best form, height, etc., in relation to the human factor in their viewers. In his investigation of the lights of roads and cars, he would take into consideration the dangers of contrast, shadows, and glare, as well as individual differences in the speed of adaptation to sudden great changes in illumination.

The psychologist would also study the combined total effect of the various traffic regulation, in respect to direction, speed, and signals, upon the motorist. A special effort would be made to ascertain whether or not they were so numerous as to impose excessive strain upon the driver, thus increasing his distraction and enhancing his liability to accidents.

Another important aspect of the psychologist's work would be the determination of the mental and physical abilities and the temperamental qualities required for a safe driver. With such information at hand, he could then advise the prospective or inefficient driver as to those defects which might be improved by special training.

Finally, the psychologist's help would be invoked in determining the treatment to be accorded the individual who violates a regulation; whether he should be partially or wholly excused from punishment or should receive any form of treatment. In order to arrive at a fair decision, the psychologist would have to inquire into the conscious and unconscious mental and bodily make-up of the offender and investigate both the remote and direct

causes of the accident, including the effects of strain, fatigue, worry, and such drugs as alcohol. Were such a program adopted on a comprehensive scale in the United States, significant decreases in the number of highway accidents occurring might result.

HIGHWAY AND ROADSIDE DESIGN

Various factors, including traffic density, assumed design speed, character of traffic, and weight of traffic, influence the type of highway constructed in any particular locality.

The most important factor to be considered in designing a highway is traffic density, ie, the amount of traffic that the highway will bear. Data gathered prior to 1939, including speeds of 300,000 vehicles on 2-, 3-, and 4- lane highways have been analyzed with a view to determining practical highway capacities for any highway condition.³¹ As a basis for determining practical highway capacities, possible capacities, or the traffic densities at that time when all vehicles must begin traveling at the same speed as the preceding vehicle, were established. The following possible capacities were found: about 2,000 vehicles per hour for both lanes of a 2-lane highway; 4,000 vehicles per hour for two lanes of a 4-lane highway; and up to 3,600 vehicles per hour for the best 3-lane highways. The total possible capacity of a 4-lane highway depends upon the distribution of traffic between the two directions, but normally is 6,000 vehicles per hour. Practical highway capacities depend upon such factors as type of traffic using the highway, congestion tolerated by the drivers, and various economic considerations - for example, the funds available for highway construction. Under certain conditions, practical highway capacities will approach the theoretical capacities; however, on rural highways or sections designed for high speed operations, undesirable conditions will exist when the total hourly traffic volume exceeds 800, 1,400 and 2,800 vehicles on 2, 3, and 4-lane highways with good alignment.

The assumed design speed of a highway is considered to be the maximum approximately uniform speed which probably will be adopted by the faster

group of drivers, but not necessarily by the small percentage of reckless drivers. The design speed selected is determined by consideration of the topography traversed, the traffic volume, cost of right-of-way, and other pertinent factors, such as aesthetic considerations. In effect it is the common denominator to which all design factors are related to provide a balance in design and to give the motorist a highway that encourages safe and uniform vehicle operation.

The type of traffic that a road will carry also has an important bearing on its design. Roads are designated by the letters "P", "T", and "M", according to their type of traffic. "P" signifies that the traffic will be primarily passenger vehicles, with a small number of trucks having little influence on the overall traffic picture; truck routes are designated by the letter "T"; while "M" signifies a road carrying a mixed traffic of both passenger vehicles and trucks. Most highways are in the "M" class.

The weight of traffic chiefly affects the design of the pavement and subsurface for weight-carrying capacity. If the percentage of heavy vehicles is high, geometric design details such as grades and widths of lane may be affected because of the probability that many of the heavy vehicles will travel slowly.³²

Some consideration will now be given to the many specific factors entering into highway and roadside design and construction which have an influence upon driver fatigue.

Number and Width of Traffic Lanes

Several studies have been made recently in order to determine the relative safety of 2, 3, and 4-lane highways, with rather inconclusive results.

Indiana rural accident records revealed that 4-lane divided highways had the lowest accident rate per vehicle mile, followed by 2-lane roads, and 4-lane undivided highways. Three lane highways appeared least safe of all.

On the other hand, New Jersey and California studies showed 3-lane highways to have a lower accident rate than 2-lane highways. Massachusetts also found 3-lane highways to be safer than 2-lane, but when traffic volume increased to $2\frac{1}{2}$ million vehicles per year, the accident rate rose sharply in relation to the 2-lane accident rate. New Jersey experience indicates clearly that 4-lane divided highways are much safer than similar undivided roads. In a two year period following conversion of a 4-lane undivided highway to a divided highway, fatal accidents decreased by 83.3 percent, personal injury accidents by 48.5 percent, and property damage accidents by 17.6 percent. Separation of the opposing traffic streams is thought to be responsible for the improvement.³³

The traffic density of a highway is directly related to the width of lane necessary for safe driving. As traffic increases, more frequent passing occurs, and wider traffic lanes become necessary.³⁴

Observations conducted by J.T. Thompson and Norman Hebden³⁵ indicate that 2-lane 20 ft.-wide roads are inadequate for heavy mixed traffic, but that 22 ft.-wide roads are adequate for modern mixed traffic. These conclusions were based upon observations of vehicle behavior when passing. Speeds generally were within 40 miles per hour, and some of the observations confirmed the general belief that wider lanes are desirable as speed increases. In the observations on 22 ft. pavements, the distance between the right edge of the pavement and the center of the right tire was measured when the vehicle was being passed. The average distance varied from 2.5 feet at 15 miles per hour to 3.5 feet at 40 miles per hour.

Steinbaugh observed traffic on a straight stretch of US-10 in Michigan. His study shows that the average distance of the right front wheel from the edge of the pavement ranged from 4.8 to 6.4 feet for vehicles traveling 40 to 60 miles per hour. For cars traveling in excess of 60 miles per hour the dis-

tance was found to be 8.6 feet. Steinbaugh concluded that the higher the driver speed, the more the driver crowds the centerline.

Steinbaugh also observed the positions of automobiles on a seven degree curve. He found the average front wheel distance from the pavement edge to be 5.5 feet for vehicles traveling less than 30 miles per hour and 8.9 feet for vehicles traveling from 30 to 50 miles per hour. He further observed that over 15 percent of the vehicles using the outside of the curve and traveling at a speed greater than 50 miles per hour use the wrong side of the road. He also states that traffic will tend to hug the inside of the pavement regardless of the direction of travel. Steinbaugh advocates a minimum roadway width of 23.5 feet in either direction. The inside lane should be 13.5 feet in width and the outside lane 10 feet wide.

Curbs and culverts tend to decrease the effectual width of the highway.³⁶ The motorist recognizes that his vehicle cannot climb a 3 - 4 inch curb, so, to give himself a margin of safety he drives clear of them, usually by a distance of 4 - 6 feet. Obstructions in the outside lane, such as parked cars have the same effect Traffic thus becomes crowded toward the center of the road, driver tension increases, and the result is an increase in the number of accidents, particularly sideswipe accidents.

Curves

Curves are dangerous for two reasons. In the first place they frequently restrict the driver's sight distance and thereby increase his chances of having an accident. Secondly, the driver runs the risk of overturning or running off the road in attempting to negotiate them at high speed.

Comparisons of the accident rates for curved and non-curved sections of highways have proven conclusively that curves are more dangerous. A South Carolina study showed that 1.57 accidents per mile occurred on curves as compared with 0.98 accidents per mile on straight sections of road. The sections

compared had similar traffic conditions. An Ohio study produced similar results. Curves of over 4 degrees curvature, though comprising only 6 percent of the total rural mileage, accounted for 15 percent of all accidents. The dangers of curves can be lessened in several ways. Signs and pavement markings can be used to warn the motorist that a curve lies ahead. The curve itself can be banked, and constructed with a non-skid surface and uniform degree of curvature. Sight distance may be improved by removing obstacles to vision, or by redesigning the road to eliminate curves of over three degrees.³⁷

Hills, Intersections

Hills and intersections also account for a disproportionately large number of all highway accidents. In Ohio, for example, hills with a grade of over 7 percent accounted for 8 percent of all accidents, although they comprise only 2 percent of all rural highway mileage in that state. Intersections constitute an even greater hazard. In both Ohio and South Carolina, up to twenty-five times as many accidents occurred at intersections as on straight sections of road.

Most hill accidents are caused by drivers of fast-moving vehicles attempting to pass vehicles which have been forced to slow down because of steep grades. Such accidents may be reduced by eliminating grades of over 3 percent, thus permitting most vehicles to proceed at normal or near normal speeds, or by widening the highway to four lanes to permit safe passing.

Intersection accidents can be reduced by means of grade separations, "Cloverleaf" type intersections, and traffic circles. The first two methods, though extremely effective, are also very costly and can only be used in a limited number of instances. Traffic circles are also expensive and furthermore of little help when traffic is heavy. In the majority of cases, such devices as traffic lights and signs must be relied upon to combat intersection driving hazards.³⁸

Surfaces

The road surface itself has an important bearing on highway safety. A too-smooth pavement will cause vehicles to skid in wet weather while a rough surface creates excessive noise and vibration, forcing drivers to reduce their speed and sometimes even causing them to lose control of their vehicles. Riding over rough roads is much more exhausting and irritating to the motorist than riding over surfaces that are relatively smooth. All the vibration and noise are transmitted from the road surface into the vehicle and absorbed by the motorist. This continuous absorption results in irritation, discomfort, and rapid onset of fatigue.

Faulty construction practices account for a great deal of the surface irregularities encountered in concrete pavement.³⁹ When concrete is dumped in heaps in front of the distributor, the position of these heaps can be detected by a profilometer on the finished road, even though they had been leveled by the distributor before being compacted. Similarly, improper setting and bedding of forms, and failure to securely fix and fishplate the rails on which the paving machines travel can result in pavement irregularities of at least 1/4 inch. These irregularities can be eliminated through controlled spreading of the concrete, and by exercising special care in the assembling of paving forms.

The glare produced by the road surface itself handicaps the motorist and eventually results in driver fatigue. It is, therefore, important that pavement surfaces be such that their ability to reflect light is rather low. The reflection of light from wet pavement surfaces is, in the main, a function of the texture of the surface, and the color or kind of material has only a relatively minor effect upon the amount of reflection. The least glare is produced by surfaces which are so deeply indented or grooved that water can drain away rapidly. Such rapid drainage prevents flooding of the road surface and the consequent formation of a film of water which acts as a mirror and re-

flects the light of approaching vehicles.

The pavement surfaces which give the least glare and most nearly approach an even distribution of light reflection are the wire-broomed portland cement concrete surfaces, the open-type asphaltic concrete surfaces which drain internally as well as laterally, and the bituminous macadam surfaces. The superiority of portland cement concretes grooved by wire brooms over those grooved by fiber brooms arises from the fact that the stiff wire brooms cut a more continuous groove and hence provide better drainage than the fiber brooms. Ribbed portland cement concrete surfaces have light absorption characteristics equal to the deeply-broomed surfaces but are not as practical from an operating standpoint.⁴⁰

The skidding properties of a pavement, as well as its tendency to produce glare, are definitely linked to its surface characteristics. Pavements whose surfaces have a sandpaper-like texture due to the presence of gritty particles have high coefficients of friction, and vehicles operating upon them show relatively little tendency to skid. Conversely, where the highway surface is glazed or polished the coefficient of friction is low and there is a greater tendency toward skidding accidents.

The importance of skidding as a cause of accidents is underscored by studies which show that in 1933 skidding was the direct cause of 7.5 percent of all highway accidents occurring in Connecticut and a contributing factor in 24 percent.⁴¹

In 1932 the Iowa Engineering Experiment Station undertook a comprehensive study of the skidding characteristics of tires on road surfaces in an effort to determine the true significance of skidding.⁴² Tests were run upon asphalt, tar, road oil, portland cement concrete, and gravel surfaces, as well as upon mud, snow and ice-covered surfaces with and without tire chains. Many tests were conducted to show the effects of tire pressure, wheel loads, types of

tire tread, and temperature. On the basis of the frictional requirements when braking and the results of braking effort tests of 2,134 cars, minimum safe stopping distances and clear sight distances were established. It was shown that the skid coefficient at 40 miles an hour should be 0.4 or higher if an automobile is to be free from the dangers of skidding when braking on wet surfaces.

The relative resistance to skidding offered by the various wet surfaces tested, starting with the surfaces having the highest resistance, was as follows: high type asphaltic pavements; tar macadams; asphalt retread and oiled gravel; untreated gravel; portland cement concrete; asphalt penetration macadam with soft seal coat; mud on concrete or other surface; and snow, sleet, and ice-covered surfaces. With vehicles having new tires, the coefficient of friction obtained in straight-ahead skidding were well above the recommended 0.4 at 40 miles per hour for all surfaces except the asphalt penetration macadam with soft seal coat, and the mud-and-ice-covered surfaces. With worn tire treads, the coefficients obtained were much lower; most of the bituminous and concrete surfaces which were satisfactory when tested with new tires, now had coefficients well below the minimum safe value of 0.4.⁴³

The Michigan State Highway Department has investigated slipperiness in pavements constructed using stone sand as fine aggregate.⁴⁴ It was found that the average coefficient of friction for these pavements when wet was 0.28, as compared to 0.50 for natural sand-aggregate pavement. Because of the large numbers of accidents occurring on such pavements, it was necessary to resurface them with bituminous material.

It is apparent that driving on pavements which are slippery and have a tendency to produce glare will result in the rapid development of driver fatigue. Indirect glare, like direct glare, temporarily blinds the motorist and causes an increase in the length of his reaction time. The motorist who

drives upon a slippery surface must keep constantly on guard against the possibility of skidding. The extra strain entailed results in tenseness and nervousness, thus further aggravating an already unsafe condition.

Sight Distances

Because the ability to see ahead is vitally important to the safe and efficient operation of a highway system, a great deal of attention has been devoted to the determination of safe sight distances.⁴⁵ Sight distance may be defined as the length of highway ahead which is visible to a driver. When not long enough to permit safe passing of overtaken vehicles, it is termed non-passing sight distance. The minimum non-passing sight distance is the distance traversed by an automobile from the instant a stationary object is sighted in the same lane to the instant the car comes to a complete stop. It must of course, be long enough to permit the car to stop before the object is reached. This distance depends upon such factors as vehicle speed, perception and brake reaction times, and characteristics and condition of automobile brakes and tires.

A sight distance which is long enough to permit safe passing of overtaken automobiles is called passing sight distance. The minimum passing sight distance for 2-lane highways is the sum of three distances: (a) distance traversed during perception time, (b) distance traversed by passing vehicle while passing, and (c) distance traversed by an opposing vehicle during the operation of passing. In determining the minimum passing sight distance for 3-lane highways only distance (a) and (b) need be considered. Distance (c) can be disregarded because the chances of collisions between opposing vehicles on 3-lane highways are much less than the chances for similar collisions on 2-lane highways.

The American Association of State Highway Officials has established the following minimum sight distances for highways.

Assumed Design Speed of Highway	Minimum Non-Passing Sight Distance	Minimum Passing Sight Distance		Minimum Passing Sight Distance	
		2 Lane Highway		3 Lane Highway	
		Desirable	Acceptable	Desirable	Acceptable
	feet	feet	feet	feet	feet
30	200	600	500	---	---
40	275	1100	900	---	---
50	330	1600	1400	1100	900
60	475	2300	2100	1500	1300
70	600	3200	2900	2000	1800

The driver, no matter how careful he may be, who remains behind a slow vehicle or train of vehicles for curve after curve without encountering opposing traffic is likely to become irritated. In such a mood, he may be inclined to take chances on passing, which in turn increases the possibilities for accidents.

Roadside Monotony

The condition of the roadside itself can have a profound influence upon the development of driver fatigue. Roadside scars, ugly surface configurations, and monotonous landscapes can lead to feelings of irritation in the motorist, hence to fatigue and an increase in accident proneness.

In the past, many long, straight highways were constructed. Such highways presented no particular danger to the drivers of the slower moving vehicles of that time, since the eyes were not focused on any one point, but were able to take in not only objects on the highway itself but also those in adjacent fields.

As vehicle speeds increased, however, the eyes' range of focus narrowed to the point where side views disappeared. Operators of modern, high-speed automobiles are likely to find themselves growing unduly sleepy when driving

long distances. The fixation of attention, the lulling sound of the motor going at a steady pace, and the monotonous "bump-bump" of tires on the pavement combine to produce an effect not unlike the hypnosis which psychologists induce in patients by similar means. The result is an increase in the number of accidents, especially those caused by side-swiping or head-on collisions.

⁴⁶

Gubbels⁴⁷ has coined the term "road focus" to define the focal point at which eye strain so frequently develops. He suggests that in constructing new roads engineers make use of some of the extraordinary features of the landscape to add variety to the road. If a highway were made to lead directly toward a grove of trees, a hill, or a village and then curve easily to the left or right, the landscape would become prominent, and the variety of interesting vistas presented to the motorist would aid him materially in maintaining his alertness. To combat the effects of road focus, group plantings are often made along old, straight roads which are not to be replaced for a number of years. These plantings narrow the horizon and give the eye vertical objects to rest upon, thus reducing eye strain, and lessening the risk of accidents.

Roadside Plantings and Glare

Highway plantings, although primarily intended to beautify the roadside or to act as snow barriers, may also increase driver safety in other ways. For example, experiments carried out by the New Jersey Turnpike Authority in cooperation with the General Electric Company⁴⁸ revealed that trees or shrubs on the median strips of divided highways materially reduce the glare which motorists encounter in night driving. In these experiments glare was supplied by the headlights of vehicles parked on the shoulder of the lane opposite that used by the test drivers. It was found that the dis-

tance at which drivers were able to see an obstacle averaged 14 percent greater in planted than in non-planted areas. The increase for individuals ranged from a low of 6 percent to a high of 34 percent, or 214 feet.

Roadside Plantings as Crash Barriers

In California,⁴⁹ tests have been conducted to determine the ability of marginal or median plantings to stop a vehicle without injuring its occupants. Vehicles were driven into plantings at 30 miles per hour, the drivers being unprotected by crash helmets or safety belts. The study revealed that the growth stopped the vehicles relatively quickly and generated no forces which the average motorist could not tolerate. These conclusions suggest that roadside plantings at locations where vehicles are likely to go out of control may serve as an effective means of bringing them quickly and safely to a halt. If sufficiently publicized, these results should also serve to reduce the number of collisions occurring on planted highways. The motorist who knows that he runs much less risk of injury by driving his automobile into a roadside planting than by "riding out" a collision is more likely to avoid an accident in this manner than one not aware of this fact.

Roadside Distractions

Many persons have expressed the opinion that roadside advertising and businesses are contributing factors in highway accidents, but until recently no attempt was made to determine the truth or falsity of the charge. In 1948, however, the Highway Research Board, with the help of the Iowa State Highway Commission and the Iowa Safety Council, began a study of roadside business and advertising as related to accident type and frequency. Highways observed included the immediate approaches to 24 Iowa cities of over 5,000 population. It was found that where businesses and advertising occupied a large portion of the private property adjoining the roadside,

accidents classified as being due to inattention predominated over all other classifications. Segments of highways with equal or nearly equal traffic density but little or no roadside business showed lower accident rates.⁵⁰

The following year (1949) the state of Minnesota, at the request of the Highway Research Board and the Bureau of Public Roads, conducted a similar investigation. A preliminary study of about 170 miles of the 500 miles of roadway to be checked revealed no apparent relationship between accident occurrence and advertising-sign type or location.⁵¹

The differing results obtained in these two investigations indicates clearly that further studies are necessary before any valid conclusions can be reached concerning the accident-advertising relationship.

Correcting Old Pavement

In the preceding sections on highway design, numerous design features which make for safer driving were discussed. By redesigning old pavements so as to incorporate these features, they too can be made safer. For example, if pavement lanes are too narrow, they can be widened. Undesirable driving conditions caused by an excessive volume of traffic may be eliminated by increasing the number of pavement lanes, while widening the roadway shoulders and eliminating unnecessary curbs and narrow culverts will help prevent traffic from crowding the center of the roadway. Curves may be made less sharp and steep grades flattened out, while obstacles which decrease the driver's sight distance can be removed. Such improvements will reduce both those accidents caused wholly by physical inadequacies of the pavement and those in which irritation and fatigue caused by improper driving conditions are contributory factor.

HIGHWAY MAINTENANCE

One of the purposes of an adequate, well-designed highway system is the promotion of highway safety. Unfortunately, no system, however excellent, can long fulfill this purpose without proper attention. From the moment a highway project is completed, it begins to deteriorate, and unless prompt measures are undertaken to counteract the process, dangerous conditions soon develop which lead to increases in driver tension and fatigue, and to an increase in automobile accidents.

Of the many types of maintenance problems, those created by snowfall have received a major share of attention in the literature. Summer maintenance operations, however, are also very important, and must be taken into account in any discussion of maintenance in relation to safety.

Summer Maintenance

One frequently-encountered dangerous condition is shoulder ruts adjacent to paved surfaces.⁵² These ruts are generally found along roadways which are inadequate for the amount of traffic using them. Vehicles using these crowded roads are forced at times to drive partially on the roadway shoulder, and their wheels cut ruts in it. The proper method of repairing the damage is to haul in suitable material and fill in the ruts before they become a serious menace. The ruts should not be filled with material removed from the outer edge of the shoulder, since this practice lowers the shoulder and eventually makes more drastic measures necessary.

When the pavement surface fails in a relatively small area, it is repaired by patching with bituminous material or cement concrete. If, however, the work is done carelessly, so that patches are left too high or too low, or are improperly compacted, or loose repair material is left lying around the area of the patching, a danger spot is created which is often a

more serious traffic hazard than was the original pit.

When pavement surfaces become slippery, the condition may be remedied by applying a surface treatment of bituminous material and covering it with aggregate. Where slipperiness is especially bad, the defective section, usually caused by an excess of bituminous material, is removed and replaced or the excess bitumen removed by burning. Nearly all grades of asphalt or tar can be used for seal coats although some highway officials think that the lighter grades are more satisfactory for this purpose. One weakness of this method lies in the fact that improvement often is not permanent - in time the slippery condition returns.⁵³

Winter Maintenance

If highways are to function efficiently during winter months, it is vitally necessary that they be kept as free as possible from ice and snow. Failure to do so not only results in extremely unsafe driving conditions, but may lead to a complete breakdown of the highway system during and after severe storms.

Several methods may be used to combat ice and snow. It is possible to design a road in such a manner as to minimize the amount of snow that can drift across it. Snow fences and snow barriers can also be used to prevent the drifting snow. When snow has become compacted or ice formed on highways it can be removed through use of chemicals or by means of radiant heating.

Work done in a number of states shows clearly the value of design methods as a means of reducing snowdrifting on the highways. The special design features that may be employed include raising the grade line to a definite position above the adjacent ground line; avoiding cut sections wherever possible; providing wide shoulders, flat backslopes, and shallow ditches; eliminating guardrails; and locating the road where drifts are least likely to occur.

Snow fences are an effective and economical means of controlling the drifting of snow. They work by breaking the wind velocity and causing the snow to be deposited from fast-moving air currents. Snow fences should be erected on the windward side of rights-of-way. They should be placed about 15 times the height of the top of the fence from the roadway; thus, a fence having its top 5 feet above the ground should be placed at least 75 feet beyond the point where drifting is to be prevented.⁵⁴ The most common type of snow fence consists of 4 ft. wooden slats or pickets spaced 2 inches apart and woven together with galvanized wire. Another snow fence, the railroad type, consists of horizontal boards, 1 in. by 6 in., in sections placed on supporting frames. Recently, the State of Michigan has been experimenting with a new type of snow fence consisting of two parallel strips of paper 12 inches wide, fastened to steel posts spaced 8 feet apart. Tests indicate that this type of fence gives excellent protection against snow drifts. It survives normal winter weather in excellent condition, and the paper, with proper installation and handling, may be used a second season.⁵⁵ A natural snow barrier consists of trees or shrubs planted in rows in such a way as to slow down the normal velocity of the wind and cause a drift. While coniferous trees, such as pines, firs, spruces and cedars are best adapted for this type of planting, deciduous trees and shrubs may be used where the conifers will not grow. There are two basic methods of tree planting: (1) Wide planting in multiple rows, employed when it is desired to trap snow within the barrier, and (2) narrow planting, consisting of double rows of trees, which will cause a drift to form between the barrier and the traveled way. The rows may either be staggered or lined up with each other. The effective area of the windbreak on the lee side is approximately 15 to 20 times the height of the barrier.⁵⁶

When the pavement surface becomes coated with ice or compacted snow, steps must be taken to remove this material and to correct the unsafe driving conditions which it creates. This may be done either by spreading abrasives on the pavement surface, or by the direct application of sodium or calcium chloride. The most commonly used abrasives are sand, washed stone screenings, and cinders. To prevent the abrasives from freezing during storage, and to insure that they will not be blown off the road, sodium or calcium chloride are often added to them, either in dry form or as a brine made by dissolving the chloride in water.

While treated abrasives are usually used to combat slippery pavements, there are situations in which the chlorides themselves give more satisfactory results. For example, coarse commercial sodium chloride is very effective in preventing wet snow from compacting and adhering to the pavement. When snow is of normal dryness, however, sodium chloride should not be used, since under these conditions it causes the snow to partially melt and compact. When a layer of ice forms on the pavement and the temperature then drops to around 0°F or lower, another condition is produced which requires the use of the straight chloride. Under such circumstances, a 1:3 mixture of calcium and sodium chlorides removes the ice successfully.⁵⁷

Within recent years, the use of snow-melting systems as a means of keeping roads free from ice and snow has become widespread. These installations consist essentially of a system of pipes or electric wires imbedded in the pavement. Hot water, steam, or an electric current is passed through the system, heating the pavement and melting the snow. Except in the comparatively rare instances where a natural supply of hot water is available, installations are not operated continuously. Rather, they are operated only during periods of storms. Investigations⁵⁸ have shown that where provision has been made for the system to go into operation before actual snowfall

begins, there is no difficulty in keeping the roadway surface free from snow or ice. If, however, it is not turned on until after precipitation has started, several hours may be required to warm the pavement and melt the accumulated snow.

Weather Forecasting for Highway Safety

While it is common knowledge that driving during bad weather is more dangerous than driving when conditions are good, few people realize just how much more hazardous it is. Pennsylvania Turnpike Commission records show that almost half the accidents on that road occur when the pavement is coated with ice or snow, or is wet, and that one third occur when driver vision is obscured by fog, rain, or snow.⁵⁹ National Safety Council figures for the period 1941-1945 reveal that between 17 to 25 percent of all fatal accidents occurred when the road surface was wet, muddy, or covered with snow or ice.⁶⁰

In spite of the high accident rate for bad weather, it is only recently that any attempts have been made to supply drivers with up-to-the-minute weather information. Present service is handicapped through lack of a central agency for gathering, evaluating, and disseminating information in time for it to be of use to drivers, and by a lack of knowledge of the precise effects of different weather conditions upon traffic volume and flow.

A successful weather reporting service would probably operate in somewhat the following manner: original information would be supplied by state police; buses and trucks with two-way radios; automobile clubs; and all-night garages and service stations. A central agency preferably the local branch of the United States Weather Bureau, would collect and process this information, and broadcast the completed report over all commercial radio wavelengths. In compiling the report, a standardized set of terms describing various road conditions would be employed. Such a system would probably result in a marked reduction in accidents, since the motorist's decision to make or to postpone a

trip would be based on information only a few minutes old at the time he received it.⁶¹

Weather sensing signs represent another method of warning motorists of the driving conditions which lie ahead of them. One such sign, $7\frac{1}{2}$ by 11 ft. in size, has been installed on an experimental basis on the Pennsylvania Turnpike. Automatically operated, it translates instantly unknown advance driving conditions into illuminated warning displays. Five different word combinations, in letters 1 ft. high and legible for 200 yards, are possible: "Danger-Fog"; "Slow-Roadway Wet"; "Danger-Snow"; "Clear Roadway"; and "Danger-Roadway Freezing". Automatic operation is attained by a master weather-sensing device which controls the word combination appearing on the sign.⁶²

VEHICLE DESIGN

Night Visibility

The ability of the driver to see at night has an important bearing on highway safety. As daylight wanes, this ability decreases markedly and the chances of becoming involved in an accident consequently increase.

One of the most important factors affecting night visibility is the glare emitted by the headlights of oncoming automobiles. The magnitude of its effect is pointed up by experiments⁶³ which show that a 1000 candlepower light directed toward the eyes of an approaching driver reduces perception distance by approximately one-third, and a 7000 candlepower light can reduce it by two-thirds. Although the amount of glare encountered in night driving has been considerably reduced by the introduction of sealed beam headlights, much work must still be done before the problem can be considered solved.

Headlight glare will probably eventually be taken care of by polarized glass or some similar substance. At the present time, the technical evolution of a polarized headlight system has been completed.⁶⁴ The system consists of polarizing filters on two 125-watt headlamps and a viewer-filter before the driver's eyes. With such a system the driver is able to see at least as well as with the upper beam of a sealed-beam lamp, and at the same time approaching cars appear to be driving on the lower beam of a sealed beam which has been cut to one-seventh of its normal brightness. Besides eliminating glare, the polarized headlight provides a greater visibility distance than the sealed-beam light. With the former, approaching automobiles 200 feet apart have 400 ft. visibility distance; with the latter, the greatest possible visibility distance is 200 ft. Furthermore, with the polaroid system, blind driving zones are eliminated. Once agreement had been reached among legislators, law enforcement officials, and automobile manu-

facturers on equipping new automobiles with the polaroid system, there would begin a transition period similar to that from presealed to sealed-beam lamps during which cars with both polaroid and non-polaroid system would be on the road. This period should present no special hazards not found in the earlier transition period. The driver with polarizing equipment would need to remember only one simple rule: "Depress your lights for approaching white headlights". For polarized headlights, which have a distinctive blue color, nothing would have to be done. It is impossible to predict accurately just how long this transition period would last. Assuming a normal 10 percent retirement of old cars each year, within eight years over 95% of the cars on the road would have polaroid equipment, and the transition period would be substantially over. When that time arrived, headlight glare would be a thing of the past.

A successful attempt has recently been made to combat glare by means of an automatic headlamp-control device, the Guide "Autronic Eye".⁶⁵ This device automatically switches the headlights to the lower beam when another car approaches and back to the upper beam after it passes; it retains the lower beam when the approaching driver dims; and is not affected by extraneous roadside lights, variations in the reflectivity of road surfaces, or adverse weather conditions. It is thought that this device also offers real possibilities for solving the glare problem.

Roper and Howard⁶⁶ conducted a series of tests designed to show the relationship between headlight candlepower, vehicle speed, and visibility distance. With the subjects in cars traveling at 20, 35, 50 and 60 miles per hour, measurements were made of their perception distances for unexpected and expected life-sized dummies in dark clothing. The results showed that 75,000 beam candlepower was needed for bare seeing at distances great enough to insure safety: there was about 20 feet loss in perception distance for each increment of 10 MPH in car speed, irrespective of beam candlepower and reflection

values; unexpected objects were perceived only half as far away as expected ones; and the perception distance increased rapidly for the first few thousand candlepower but more slowly at higher values. The perception distance for a car traveling 50 MPH with 20,000 beam candle-power was about 75 feet less than the distance required for stopping.

Recently, the use of green-tinted glass in automobile windshields has become widespread. The glass acts as a filter, cutting out the red and infrared rays in sunlight, and preventing the interior of the automobile from becoming too heated. In an effort to determine the effect of tinted windshields upon night-visibility distances, Heath and Finch⁶⁷ compared green-tinted and clear windshields in a series of tests carried out under different conditions of moonlight. In general, tinted glass appeared to cause a reduction in visibility distances, although sometimes it gave higher readings. In some instances the difference in seeing distance between the two types amounted to as much as 70 feet. Similar experiments by Roper⁶⁸ showed that tinted windshields caused an average reduction in visibility of not quite 6 percent with no approaching vehicles and 2 percent when approaching another vehicle on a straight, level road over a distance of almost a mile.

Miles⁶⁹ states that this reduction in visibility occurs because two-thirds of the energy from an automobile headlamp is concentrated at the red end of the spectrum while only one third is in the range to which the windshield is most transparent. As a result, the windshield filters out much of the light from automobile headlamps, cutting visual acuity to a marked degree.

Investigations have been conducted to determine whether or not exposure of the eye to sunlight has an adverse effect upon night visibility, and if it has, whether sunglasses can counteract the effect. The results of one such investigation⁷⁰ showed that sunlight reduced visual performance in the evening, that the reduction can be expressed as a fraction of the measured illumination

provided by artificial light, and that this effect can be prevented by the use of sunglasses. The investigator recommends that the driver purchase the darkest sunglasses he can, since these give the best nighttime results while reducing daytime visual performance by only a negligible degree. The color of the glasses is immaterial.

Daytime Visibility

The problem of daytime visibility, while seemingly simple in comparison to that of night visibility, is actually complicated and an important consideration in the design of automobiles.

With respect to visibility the modern automobile designer has two choices.⁷¹ He can provide good visibility by raising the top of the car and the driver's seat, but by doing so he likewise raises the car's center of gravity and increases its chances of overturning on curves. As an alternative, he can provide a safer center of gravity by lowering the car top and the driver's seat. This procedure, however, restricts the driver's visibility and exposes him to more glare from oncoming headlights. At present the trend is toward the lower center of gravity.

Within recent years automobile manufacturers have greatly increased the window areas in motor vehicles, and thus reducing or even eliminating a number of blind spots, caused by windshield center posts, front corner posts, framing, and other supporting elements of the body, which are potential sources of accidents. Illustrating this trend toward the more extensive use of glass, one manufacturer used more than 4850 sq. inches of glass in his postwar auto as compared to 3200 inches in the prewar model. The biggest change was in the area of the rear windows which was increased by over 700 sq. inches.⁷² Hunt⁷³ has expressed the opinion that too much emphasis is sometimes placed upon such improvement in visibility. He contends that the alert motorist

driving at ordinary speed will see a potential driving hazard long before he gets close enough for it to be cut off from view by solid parts of his car. In commenting on Hunt's view, De Silva⁷⁴ points out that he has failed to consider the situation in which a vehicle is approaching from the side and at just the wrong speed. Such a vehicle, DeSilva says, may be hidden by blind spots until it is too late to avoid a collision. Similarly, blind spots in the rear of an automobile constitute a safety hazard, since they prevent its driver from observing the vehicles following him.

The driver's ability to see what lies ahead is greatly influenced by his height.⁷⁵ The short driver who must peer between the ~~wheel~~ and hood has a very restricted view of the roadway, while the tall driver has his view of signs, signals, and the like cut off by the top of the car. Since automobiles are not custom built to fit each driver, variations in height must be compensated for by means of adjustable seats. Although at present all automobiles are equipped with front seats that slide backward and forward, the visibility problems arising from differences in height are not yet completely solved. The tall person must still hunch over to see, while the short one must use a cushion. This situation could be remedied by providing driver seats having vertical as well as horizontal adjustments. By adjusting the seat height to fit his particular stature the driver would improve his visibility - eliminate the fatigue caused by sitting in an uncomfortable position, and hence lessen his chances of having an accident.

Noise and Vibration

It is extremely difficult to estimate what proportion of the fatigue resulting from a long automobile trip is due to noise and vibration as distinct from normal vehicle motion. There is no doubt, however, that noise and vibration are prime causes of fatigue and should be reduced as much as possible. Unfortunately, such is the relationship between the aural loud-

ness of a noise and the strength of the sound producing it that in order to reduce a noise to one-fourth its original volume, the sound power producing it must be reduced to one one-hundredth of its original value.⁷⁶

The chief sources of the vibration encountered in vehicles are (1) irregularities in road surfaces, (2) the wheel, tire, and tube assembly, (3) rotating engine parts, and (4) the transmission.

The vibration caused by uneven road surfaces occupies a special position since it, unlike vibration from the other sources, can be controlled by highway as well as vehicle design. There are several categories of road-surface vibrations. Among these are "ride" motions, which have frequencies of from 60 to 100 cycles per minute, and hence correspond to Janeway's low-frequency vibration group.⁷⁷ These are almost exclusively motions of the sprung masses on suspension springs, plus radical deflections of the tires. The discomfort caused by "ride" motions depends upon rate of change of acceleration, acceleration, and displacement in pitch or roll. Discomfort is not proportional to the magnitude of these three factors nor does it depend on any one of them alone. In fact, the only general comment which can be made is that discomfort is less with lower frequencies of motion. Investigations show that on the best-riding cars, free-ride frequencies lie between 60 and 75 per minute; on poorer-riding cars between 70 and 100 per minute. Still lower frequencies are desirable, but impractical for two reasons. (1) With lower spring rates, the standing spring height varies too much under different passenger loads, (2) lower frequencies cause too frequent striking through of the suspension unless ride clearances are increased considerably.

Motions of the next higher order are called "shakes". These are vertical oscillations of the unsprung masses between tires and suspension ("wheelhop") and are produced by road waves or by unbalance and runout of the wheels. "Shakes" have a frequency of between 450 and 1000 per minute, hence they correspond to Janeway's middle frequency group. Although wheelhop cannot be

suppressed, it is thought that an automobile chassis can be built such that this type of discomfort will hardly be noticeable to the vehicle's occupants.

When a vehicle runs on an irregular road surface, noises arise from its body.⁷⁸ These noises occur due to the fact that the body is not a rigid structure, but flexes as the wheels encounter road irregularities. There are two such sounds - rumbles and growls. Rumbles have a major frequency of 30 to 43 cycles per second with a few higher harmonics, while growls have a major frequency of 140 cycles per second, with a range of harmonics.

Rumble can be reduced by stiffening the front end of the bay around the dash as well as by adopting certain methods of mounting the battery and spare tire. Growl presents a somewhat special problem. It is transmitted through the springs in the form of wave transmission instead of mass vibration, hence is not adequately handled by the springs, which theoretically should be capable of taking care of such high frequencies. Growl is reduced by inserting rubber between the rear axle and the springs; the rubber changes the resonant combinations of the various reactions of chassis and thus breaks up resonant paths of transmission.

Bristow⁷⁹ thinks it probable that road excited body noise is due basically to the excitation of the air mass inside the body at its many air nodes, and that the energy causing it is largely structure borne. He, too, believes that such sound can be controlled by breaking its resonant paths of transmission.

The vibrations which are generated in the tire-wheel assembly of the automobile, as distinguished from those which the assembly merely transmits to other parts of the vehicle, are of two types.⁸⁰ Shimmy and tramp result from poorly balanced assemblies and from wheels having too much radial run-out, and may be corrected by redesigning the faulty elements. Certain design factors other than imbalance may also result in vibration. Tread vibration

occurs because of the tread design around the circumference rolling in and out of contact with the road surfaces. Although it is impossible to eliminate such vibration, the problem may be handled by designing a tread which gives pleasing sound characteristics.

Within the last few years a new low-pressure tire for passenger cars has been put on the market.⁸¹ This new tire is 8 to 12 percent larger in cross-section, contains 12 to 25 percent greater air volume, and operates at an air pressure 14 percent less than in older types. The most noticeable difference between the new tire and older ones is the softer ride characteristics of the former. The new tire's ability to surround or to deflect locally around roadway irregularities permits it to negotiate many bumps with little or no vertical deflection of the wheel. Further, body shake is reduced 16 to 19 percent. Certain disadvantages result from the use of the new tire. Steering and parking require more effort, wheel weight is greater, and brake blanketing is increased. These disadvantages, however, are more than offset by the gain in riding comfort.

When an engine is fastened to a vehicle chassis it forces vibrations into that structure, and may create unpleasant shaking and noise. If shock-absorbing devices, such as springs or rubber mounts are not employed, vibration is directly proportional to the engine's running speed. With suitably mounted assemblies, however, the relationship is such that if the resonant frequency of the mounted assembly is $1/3$ of the engine running speed, vibration force is reduced to $1/8$ that of a solidly mounted assembly. By using springs of such a stiffness that the resonant frequency of the mounted automobile engine is 600 cpm, vibration is reduced to the point where it is not objectionable.

A problem arises, when the engine must be operated at 600 cpm for extended periods. The engine is now operating at the resonant frequency of the

system, and the assembly behaves as if it were rigidly belted to the chassis. At such time, the amplitude of vibration can increase to the point where spring mounts break. This type of vibration can be reduced by employing damping in the form of dash pots, rubbing friction, or materials having a high internal friction.⁸²

Riding Comfort, Seats

The function of the automobile seat is to provide a comfortable ride over long or short distances with a minimum of fatigue. The ideal seat cushion, therefore, should support the passenger in a comfortable position and absorb vibration energy with as little disturbance as possible to the passenger.⁸³

The pioneer investigation of riding comfort as related to automobile cushions was begun in 1935 by the Department of Engineering Research of the University of Michigan, and was soon followed by others.

These investigations revealed that in order for the automobile passenger to enjoy the maximum in comfort with the least amount of fatigue, the automobile cushion should support the passenger over a large area, thus keeping unit pressure on the skin at a minimum. The cushion should also be designed so that variations in pressure, except those dictated by body contours, are avoided.⁸⁴ Unit pressures should depend principally upon the character of the spring coils rather than the character and tightness of the cloth covers. This may be accomplished by designing spring coils which are freely compressible without undue restrictions from adjacent coils, rigid coil rims, or bracing, and by the use of padding which is not excessively coarse or stiff.⁸⁵ The free contours of a seat proved to be of little importance compared to its actual contours with a passenger in it, and quite often seats having satisfactory showroom "softness" proved extremely uncomfortable under actual driving conditions.⁸⁶ The mean unit pressure in a comfortable seat cushion was

found to be 0.55 lbs per sq. in. and the corresponding back pressure 0.15 lbs per sq. in. For maximum comfort, the angular position of the seat with reference to the floor should be $10-18^{\circ}$ from the horizontal for a cushion approximately 15 inches above the floor, and the included angle approximately 100° .⁸⁷

Air Conditioning

Within the past few years, automobile manufacturers have devoted a great deal of attention to the development of practical air conditioning systems. Such systems are now being offered as standard equipment on many makes and models of automobiles, and it seems only a question of time until all new vehicles are so equipped.

The systems developed by all three major automobile companies are basically mechanical refrigeration systems consisting of a refrigerant, a compressor and a series of cooling coils. Air is drawn into the vehicle through special air intakes, cooled by being passed over the cooling coils, and discharged into the interior of the vehicle. One system now in use is capable of reducing car temperature from 130° F (after parking in the sun) to 85° F within two minutes. Another will maintain an inside air temperature of 72° F even with the outside temperature at 104° F, and will hold a relative humidity of 45-55 percent for outside temperatures of $80-100^{\circ}$ F and relative humidities of 20-85 percent.⁸⁸

When air conditioning systems are part of the equipment of every new automobile, fatigue resulting from improper temperature - humidity conditions will no longer be a driving hazard.

Design Recommendations

Although automobile manufacturers have striven to make automobiles as safe as possible, there is still room for a great deal of improvement.

Halsey⁸⁹ has suggested that design engineers improve vision by minimizing the front pillars and the no-draft vertical strips. He states that the windshield wiper now employed on cars is essentially the same as that used in 1926, and advocates the development of a more efficient model which would clear a larger area of windshield. Brakes should be redesigned so that they require less maintenance and maintenance is easier. Halsey believes that the automobile manufacturer places too much emphasis upon high speeds. As a counter-measure, he suggests that the two speed figures, 25 mph (the legal speed limit in almost all American cities) and 50 mph (the ceiling legal speed limit on highways in many states), be given special prominence on the speedometer by means of size, design, or illumination of the figures. In this way, the driver would be made speed-limit, rather than just speed, conscious.

Woodward⁹⁰ has made similar recommendations for improving automobile safety. He advocates a two-door model car with windows large enough to be used for escape hatches but high enough to discourage passengers from letting their arms protrude. The door latches should be operable from both front and rear seats, with the safety lock on the front latch. All protruding handles, knobs, or buttons, both on the inside and outside of the vehicle, should be eliminated. Windshields and headlight lenses should be made of plastic and both polarized, to eliminate glare. Crash pads of sponge rubber on the back of the seat and on the dashboard, steering columns with "give", and safety belts would, in Dr. Woodward's opinion, materially reduce the number of traffic injuries and deaths occurring each year in this country.

Halsey believes that the safety engineer should assume dumbness, laziness, forgetfulness, and unskillfulness on the part of the motorist, and resolve to think up safety features that will work no matter how bad the driver may be in these respects.⁹¹ Such an attitude would help the engineer to recognize possibilities for improvement that might otherwise escape his attention, and would pay dividends in the form of safer automobiles and fewer accidents.

VEHICLE OPERATION

Traffic Signs

Motorists rely to a great extent upon signs for information as to their location, permissible speeds, and the existence of various driving hazards. When, because of inadequate posting of signs, such information is not supplied, the motorist develops feelings of nervousness, anxiety, and irritation, and his susceptibility to driver fatigue and accidents is thus increased.

Because of the great importance of traffic signs, both their design and location have been the subject of much study. In 1932 the American Association of State Highway Officials, in cooperation with the Bureau of Public Roads and the Bureau of Standards, undertook an extensive investigation of the comparative visibility of different types of highway signs.⁹² As part of this investigation an attempt was made to evaluate the relative visibility of standard signs having different background-legend color combinations. The investigators concluded that signs with the standard yellow background and black letters or design were much superior to either black on white or white on black signs for all conditions that can reasonably be expected in either urban or rural driving. Besides being more readable, the signs were more eye-arresting and conspicuous, because of the greater signal value of the yellow background as compared to ordinary natural or artificial backgrounds.

Recently, a joint committee of the American Association of State Highway Officials, the Institute of Traffic Engineers, and the National Conference of Street and Highway Safety has approved the use of either black letters on a white background or white letters on a black background for all signs of an informational nature, such as directional and distance signs. Studies showed that signs with white letters on a black background have considerably greater

legibility than signs with the reverse combination. Signs with a black background do not have quite the attention getting value of those with light background and generally they are more difficult to locate. Once spotted, however, they are very legible.⁹³

One of the most important recent developments in sign design is the substitution of rounded letters for the former standard block letters. Studies established the fact that signs with words made up of rounded letters have generally a greater legibility than the same words made up of the same-sized block letters. The studies showed also that with both block and rounded letters wide spacing increased legibility, the improvement being greater with block than with rounded letters.⁹⁴

The state of California⁹⁵ has recently made a comparison of the effectiveness of lower case and capital letters for highway signs. It was found that when recognition distance was expressed in terms of letter height, lower-case letters appeared at a disadvantage, probably because they were narrower. On the basis of width, the lower-case words could be seen further than the capital words, presumably because they were higher. This means that where length of sign is the controlling factor, lower-case letters would have the advantage.

A great deal of attention has also been given to the size of signs and sign lettering. It has been calculated that a driver should have at least ten seconds in which to react to the information on a sign and to prepare to execute the necessary maneuver. At a speed of 50 mph, ten seconds means 733 feet. Sign makers estimate that each inch of letter height has a legibility distance of 50 feet. For night visibility, this distance is reduced by 15 percent. Based on a distance of 750 feet which is required for a 10-second warning at 50 mph, a sign would require 18-inch letters to adequately serve night drivers.

The Institute of Traffic Engineers has listed the following basic minimum dimensions for signs as follows: ⁹⁶

Stop signs - 30 by 30 inches, except that in locations where speeds and traffic volumes are low, a 24 inch sign is permissible.

Other regulatory signs - 18 by 24 inches, or on important highways, 24 by 30 inches.

Warning signs - 24 by 24 inches, except where the length of the message requires a plate 30 by 30 inches for equivalent legibility.

Investigations have been undertaken⁹⁷ to determine the relative effectiveness of symbols, words, and sign shape for warning the motorist. The time required for the motorist to read the sign was used as the criterion for effectiveness. Results indicated that a large symbol on any shape sign is more effective than any combination of words and symbols. The shape of the sign itself was of no value, because most motorists were not familiar with special meanings of shapes.

The State of Alabama has designed an interesting map sign utilizing both words and symbols which convey a great deal of information to drivers of motor vehicles. It gives location, towns near by, time to next town, speed limit, and the number of miles to the next sign. It has been found that these map signs slow down the faster drivers and speed up the slower, thus facilitating the flow of traffic. Traffic violations are reduced and safety enhanced.

Numerous investigations of the various types of reflectorized signs have also been carried out. In 1932, as part of its study of highway signs, the American Association of State Highway Officials conducted night observations on signs made with three sizes of reflector buttons - 0.95 in., 0.76 in., and 0.58 in. - under conditions simulating both rural and city driving. It was found that colorless buttons having a diameter of 0.76 in. and a minimum spacing of 1 in., center to center, were generally the most efficient.⁹⁸ Recently, it has been shown⁹⁹ that rounded letters containing

reflector buttons are over 5 percent more effective by day and over 10 percent more effective at night than correspondingly reflectorized block letters. Comparisons were also made of the relative effectiveness of black letters on a white reflectorized background and white reflectorized coating letters on a black background. It was found that 4-inch white reflectorized-coating rounded letters were 20 percent more legible by night than similar black letters on a white reflectorized background.

It is well known that the improper placement of traffic signs is almost as bad as having no signs at all. Too often, unfortunately, location of signs has been based upon the results of haphazard experimentation by persons without proper training or experience, or even upon sheer guesswork. One result of this loose control has been a tendency to over-sign. So many warning signs have been placed that the average motorist tends to lose respect for all of them.¹⁰⁰

These comments on the tendency of motorists to ignore signs take on added significance in the light of a Rhode Island study¹⁰¹ of driver reaction to signs and signals. It was found that 42 percent of the motorists observed failed to slow down to 15 miles per hour when a flashing amber light was encountered and that from 22 to 66 percent of the motorists failed to make a complete halt at a standard stop. Illinois studies¹⁰² also show that drivers constantly ignore posted speed limits and travel at speeds which they consider reasonable and safe for prevailing highway conditions.

Some years ago, Wiley¹⁰³ carried out an investigation concerning the placement of non-reflectorized signs for maximum value at night. He found that for signs having vertical dimensions of 24 to 26 inches, the distance from the crown of the road to the middle of the sign should be about 3 feet. When signs are 15 to 20 feet from the road centerline, they should be turned toward the road at an angle of from 50 to 60 degrees with its centerline.

Adequate safety from glare can be obtained by tilting the sign forward about 3 degrees.

Michigan highway sign specifications¹⁰⁴ require, with few exceptions, that warning, regulatory, and guide signs erected in rural areas be located 10 feet to the right of and 5 feet above the edge of the pavement or roadway. With oversized signs, the height may be somewhat less. In urban areas, most signs are to be placed 1 foot to the right of the face and 7 feet above the top of a standard curb. Here again, oversized signs may be somewhat lower. Junction signs are to be 300 feet ahead of intersections in rural areas and 1000 feet ahead in urban areas. The corresponding distances for signs denoting curves are 250 and 750 feet.

The City of Boston is experimenting with a new overhead sign location for all signs on its new James J. Storrow Memorial Parkway. These signs, mounted on supporting structures of tubular steel, can be seen from a greater distance than conventional roadside signs of the same size, can not be blocked from the view of one vehicle by another vehicle, and may be placed directly over the lane to which they refer. Signs are equipped with 10-inch reflectorized letters and numerals and are visible from at least 600 feet under normal night driving conditions. No accident rate statistics have as yet been compiled for the new signs, but police report a minimum of driver hesitation and confusion, and many motorists have commented favorably on their attractiveness and legibility.¹⁰⁵

Delineators and Surface Markings

Road delineators consist of reflective heads approximately 2 inches wide and 6 inches high, mounted on suitable supports. The reflecting element may be either reflector buttons or a reflective coating. Such markers are very effective aids for night driving. They are used on long continuous stretches of highway or through short stretches where there are changes in vertical or

horizontal alignment which might be confusing. Properly placed, delineators will remain visible in any type of terrain under all adverse weather conditions. Under normal atmospheric conditions, they should be clearly visible for 1000 feet when illuminated by standard automobile headlamps.¹⁰⁶

Judging by the lack of published results, no studies have as yet been made of the effect of delineators upon automobile accident rates. Since, however, delineators enable the driver to detect both horizontal and vertical curves more quickly than he otherwise would, there can be little doubt that they are effective in decreasing the number of accidents occurring on such stretches.

Pavement surface markings are used to facilitate the flow of traffic and reduce the possibility of accidents. They are of two types: (1) lines which divide the pavement into lanes and indicate such special areas as parking spaces and pedestrian crosswalks, and (2) words or symbols which supply information to the motorist or warn him of hazards which lie ahead. The prime requirement for traffic markings is visibility. During daylight, mere contrast in color with the pavement surface generally results in sufficient visibility. Color contrast by itself is, however, not adequate to insure good visibility at night. The slab must have the ability of reflecting part of the rays of the vehicle's headlights back to the eyes of the driver. It has been found¹⁰⁷ that glass beads increase the night visibility of painted traffic stripes to a greater degree than other available materials, with smaller beads offering a number of advantages in economy and service life over the larger sizes. Beads were originally applied by gravity to the fresh surface of the paint stripe. This so-called overlay method has been largely superseded by the premix method, in which the beads are mixed with the paint before it is applied to the pavement. Sometimes a combination of the above two methods is employed. Beads are retained in the

stripe more uniformly when the premix method is used, and the stripes retain a uniform and adequate degree of brightness throughout their life.

Traffic Signals

Highway traffic signals are power operated devices, other than signs, by which traffic is warned or permitted to take specific actions. Properly installed, these signals facilitate the flow of traffic, help to eliminate driver confusion, and reduce the rate of certain types of accidents.

In any adequate discussion of traffic lights, the problems raised by colorblindness must be taken into consideration. The retina of the eye may be divided into three zones: the central zone, in which so-called normal vision occurs; the medial zone, in which only blue and yellow are discernible; and the marginal zone, in which all color stimuli tend to appear as colorless. In the typical color-blind person, the central zone of the eye is analogous to the medial zone of the normal eye. It is apparent, therefore, that the ideal colors for traffic lights would be blue and yellow since even color-blind persons, with rare exceptions, could distinguish between them. However, tradition prevents their use. With present "red - green" traffic lights, it is desirable that the green be made as bluish as possible. A more satisfactory traffic signal than that currently in use could be obtained by replacing the standard red with an orange-red. Unfortunately, the necessity of providing for the yellow "caution" light makes such a change impossible. If yellow could be generally excluded as a signal color, the adoption of a more adequate "red" would then be in order.¹⁰⁸

In the past, traffic signal salesmen, capitalizing on their customer's desire for safety, labeled the stop-go signal as a safety device, and the public generally still accepts it as such. Actually, such signals are nothing more than regulator valves which, properly applied and operated, can produce orderly traffic flow, with traffic safety an important by-product.

Some years ago, the Michigan State Highway Department began to suspect that signal installations do not end traffic accidents; rather, they merely alter traffic behavior and produce a different accident pattern. In order to obtain more accurate information on this point, the department decided to conduct a study of accidents as related to traffic signals.¹⁰⁹ Although this study has only just begun, certain facts have already become known with regard to rural intersections. For example, in several instances it was found that the accident rate actually increased after installation of signals. Many of these accidents can be attributed to the isolated location of the signals. The motorist unexpectedly encounters the signal and is forced to apply his brakes suddenly, with the result that automobiles following behind his own are often unable to stop in time to avoid rear-end collisions.

Observations made by the Maryland State Highway Commission on the Pulaski Highway indicate that even when a signal is expected, accidents can still occur.¹¹⁰ For example, the driver who approaches an intersection when the light changes from green to yellow is faced with the problem of whether to stop or to go on and try to beat the red light. While he is trying to decide, the driver ahead may elect to stop, thus causing a collision.

In discussing methods of improving accident control on rural highways, McMonagle points out that the present stop-and-go signal has not been changed in any important way for at least twenty-five years. He suggests that the same form of the device may not be applicable to traffic conditions in both urban and rural areas, and that a specially-designed signal may be what is needed.¹¹¹

For a number of years an argument has raged regarding the relative merits of overhead and corner post traffic signals, with first one and then the other being preferred. At present, the trend appears to be toward overhead signals, especially those suspended directly over the traveled way.¹¹²

The mast arm type of signal appears to be gaining favor in Detroit and California. Two methods of increasing the visibility of signals are now being employed. The first of these consists of mounting the signal face in the center of a rectangular steel or aluminum plate which is from 10 to 16 inches greater overall dimensions than the face. The result is a target which is much more easily seen than the conventional unmounted signal. Increased visibility may be attained by using double red indicators on traffic signals. Not only is the signal more easily seen, but an additional safety factor is provided, since the burning out of one red lamp no longer leaves the intersection without any signal.

Flashing Beacons and Signals

A flashing beacon is a section of a standard highway traffic signal having a single red or yellow lens in each face, which is illuminated by rapid, intermittent flashes. Flashing signals are similar except that a standard traffic signal is used, one lens being flashed.

Flashing beacons and signals perform useful functions at locations where traffic or physical conditions do not justify a conventional type of stop-go installation. At other points of hazard - for example, a sharp curve hiding an intersection or a physical obstruction in the roadway - flashing beacons may be justified as advance warning devices. This type of installation is especially effective at intersections where approach speeds are in excess of that warranted by conditions and signs do not adequately impress the driver with the need for stopping.

Street Lighting

The amount of light available for seeing is constantly changing. As daylight wanes, driving continues but the driver's ability to see decreases markedly. Accident records clearly indicate that with lessened visibility

the driver's chances of becoming involved in an accident are much greater than they otherwise would be. It is highly desirable, therefore, that night driving conditions be improved through the design and utilization of adequate lighting equipment for both vehicles and roadways.

The salutary effects of adequate, glare-free street lighting are numerous. First, and most important, the number of deaths and injuries caused by accidents decreases sharply. Safe vehicle-operation speeds become higher, resulting in great savings of time. The daily traffic load on the highway tends to be more evenly distributed, thus partially relieving highway congestion and overloading. Finally, as a result of safer driving conditions, insurance rates drop.¹¹³

A good street lighting system must meet several requirements. To begin with, the system should as nearly as possible be uniform. When the motorist is forced to pass in quick succession through several zones having lights of varying color, intensity, and height, driving strain increases greatly. The levels of illumination should be such that the motorist, driving without headlights and at normal speeds, can proceed with as much confidence as he displays in the daytime. Backgrounds as well as road surfaces should be illuminated, while advertising and display lights which might interfere with driver visibility should be eliminated. Lastly, traffic signs should be illuminated and all road obstructions adequately lighted.¹¹⁴

In the past, street lighting problems have not received all the attention they deserve.¹¹⁵ In 1932, for example, the public spent \$1.30 per capita on street lighting as compared to \$0.99 per capita spent in 1944. Furthermore, in spite of the increased number of vehicles on the road and their greater speeds, as well as greater mileage of highways in use, the actual number of kilowatt hours used annually to light the streets declined from 2.3 in 1932 to 2.1 in 1942.

In recent years, however, highway engineers have devoted an increasing amount of attention to the adequate lighting of streets, with results that in some cases have been little less than astonishing. Detroit, Michigan, provides a dramatic example of the great effect which street lighting has on highway accident rates. A survey of automobile accidents in that city just prior to World War II indicated that 75 percent of all night accidents occurred on some 100 miles of streets which carried about 15 percent of the night traffic load. After a systematic study of the illumination of these roads, lights were added which tripled the illumination. Over the following two-year period, the number of night-time accidents on those same streets dropped sharply to about 26 percent of the total number in the city.¹¹⁶ As a result of an extensive modernization program, Detroit is now one of our best-lighted cities, with more than 350 miles of modern, safe lighting.¹¹⁷

As of 1952, about 60,000 mercury vapor lamps were in lighting service. Most of these were 15,000 lumen installations, but the number of 20,000 lumen lamps was increasing. About 15,000 sodium vapor lamps were also in use, mostly at short danger zones, such as bridges and railway crossings. Fluorescent lighting, despite such advantages as high efficiency of generation of light, low brightness, relatively long life of installation, and ability to provide glare-free lighting of wet pavement, was relatively uncommon.¹¹⁸

Numerous steps may be taken to alleviate the very poor seeing conditions which prevail on most rural highways at night.¹¹⁹ First, and most obviously, safety lighting can be provided on as many miles of highways as is physically possible. Known danger points can be illuminated by the use of lights of distinctive color. The visibility of roadside obstacles can be increased by the use of white concrete and white paint, and highway surfaces can be constructed with as high a reflection factor as possible. The adoption of all or even most of these recommendations would no doubt lead to a great decrease

in the amount of driver fatigue caused by night driving and hence to a decrease in the number of accidents occurring.

Speed

The speed at which people drive is important for several reasons. Speed makes automobiles useful, and anything which reduces driving speed takes away part of their usefulness; speeds are related to accidents, hence, safety engineers must pay attention to speed trends; and a knowledge of driving speeds is essential to the designers of new highways.

The earliest usable speed-trend information comes from Rhode Island, where the average speed showed a steady increase from 22 miles per hour in 1925 to 34 miles per hour in 1934. In 1952, twenty-six states reported the results of 681 speed studies on main rural highways.¹²⁰ These studies included observations on 274,810 vehicles. The average speed of all vehicles was 49.5 miles per hour, an increase of 0.6 miles per hour over the figure for 1951. The average speed for passenger cars, trucks, and busses was 50.8, 44.8, and 51.9 miles per hour respectively. Fifty-two percent of the passenger cars, 22 percent of the trucks, and 60 percent of the busses were traveling over 50 miles per hour, while 15 percent of the passenger cars exceeded 60 miles per hour.

The Institute of Traffic Engineers,¹²¹ in a questionnaire sent to the motor vehicle department or corresponding agency in each state, asked the question: "Do you believe that high speeds (over 45 miles per hour) alone are a frequent cause of accidents"? Fifteen "yes" and 14 "no" replies were received. To the question: "Do you believe that high speeds in combination with other actions and conditions are the most frequent cause of accidents"?, 21 replied "yes" and 7 said "no". The consensus thus appeared to be that speed is a basic factor in accidents; that if cars were operated at lower speeds, the ensuing better control might result in less accidents.

The problem of determining accurately the relationship between excessive speed and automobile accidents is more difficult than it appears at first glance. In addition to vehicle speeds, such other factors as traffic density and weather and visibility conditions must be taken into account, since they determine to a large extent whether a particular speed is safe or unsafe.

State motor vehicle accident reporting is, on the whole, quite inadequate. For example, although the combined accident reports from 34 states for 1940 listed speed violations as a contributing factor in one out of every three accidents, the figures for individual states ranged from a low of 7 percent to a high of 54 percent. Such a wide variation is due to differences in the completeness of reported information and to differences in definitions of speeding. By adopting a national standard definition of speeding and a standard system of reporting and summarizing vehicle accident information, the usefulness of such reports in determining the importance of speed in relationship to accidents would be greatly enhanced.¹²²

There is a great difference of opinion regarding the proper methods for controlling speed. At one extreme is a group favoring low speed limits and rigid enforcement of traffic laws. On the other hand there are those who oppose any speed limit other than that dictated by driving conditions. A more practical and less extreme speed control program than either of these calls for state-wide general speed limits, supplemented by speed zoning at locations where general limits do not fit road conditions. This middle-of-the-road approach is being favored by an increasing number of highway officials.

Many conditions may operate to render general speed limits inapplicable. For example, when numerous accidents have occurred on a particular stretch of highway because of hazards which cannot readily be corrected, speed zoning should be considered. Likewise, when physical and traffic conditions

are such that speeds must be lower, or may be higher, than the general limits, speed zoning is indicated. Changes in physical and traffic conditions encountered in passing from a rural to an urban area may also warrant the establishing of speed zones. Finally, it is often necessary to post special limits at dangerous curves or intersections.

Since speed limits should as nearly as possible be made to conform to road conditions existing when traffic is normal and weather is good, they should be selected only after an extensive investigation including field checks of motor vehicle speeds; spot map studies of accidents; studies of roadside development; and trial runs over the section being zoned. If more than 15 percent of the vehicles using a road exceed the established speed limit by 5 miles per hour or more, the zone should be restudied to determine what is responsible for the situation. Often, the fault will be found to be in inadequate posting of signs or laxty in enforcing speed regulations, rather than in incorrect speed limits.

Where speed zoning has been based upon the results of engineering and traffic investigations and zones are adequately posted, marked decreases in the frequency of accidents result. For example, records for a 28 mile traf-
fic-control zone south of Detroit show that 44 fatalities occurred in the two-year period preceeding establishment of the speed zone as compared to 43 for the three-year period following zoning. This represents a 35 per-
cent decrease in the number of fatal accidents per year. Similar studies of zoned areas in New York and Arizona likewise showed zoning to be an ef-
fective means of reducing automobile accidents.¹²³

Speed zones should be posted at regular intervals in order that the motorist have no doubts concerning proper speed. The State of Michigan¹²⁴ provides that signs be placed approximately 1,000ft. in advance of the point of beginning of a speed control zone, informing the motorist that the zone

lies ahead. Approximately 500 feet ahead of the zone and at half-mile intervals throughout it, signs are installed indicating the speed limit which prevails. When speed zones are thus adequately posted, the motorist is able to proceed at a satisfactory speed, while remaining at ease both mentally and physically.

A program of education can go far toward making the public aware of the need for speed regulation. Such a program should include an explanation of speed laws, provide information on the interpreting of speed signs, and tell what is being done with regard to the enforcement of speed regulations.¹²⁵

In order to impress upon the driver the necessity for operating his vehicle at reasonable speed, information concerning the relationship between speed and such factors as vehicle energy and braking distance should be made readily available. The motorist who realizes that the destructive power of his vehicle increases as the square of the speed and that the average vehicle traveling at 50 mph requires 130 feet in which to stop¹²⁶ will very likely be less inclined to take chances than one ignorant of these facts.

Posted speed limits are meant to apply when traffic and weather conditions are normal, and no special driving hazards exist. Many times, however, such conditions do not obtain; therefore, a consideration of the effects of rain, snow, sleet, fog, traffic density and many other factors must also be included in any educational program. Educational material, in the form of safe driving manuals, pamphlets, and leaflets can be distributed in high-school driver-training courses and to individuals taking driver's-license examinations. A digest and explanation of the more important state traffic regulations might also be included on official road maps.

In March, 1954, the National Safety Council, the National Committee for Highway Safety, and the Inter-Industry Highway Safety Committee launched a program to increase driver courtesy. At the core of the program is a seven

point code of the road, which asks the motorist to (1) keep in the proper lane (2) allow ample clearance when passing (3) yield right of way to other motorists and pedestrians (4) signal when turning and stopping (5) dim headlights when meeting or following other vehicles (6) respect traffic laws and signals, and (7) adjust driving speed to road, traffic, and weather conditions. Dash stickers, with the rules painted upon them, will be used inside vehicles, and other material will be distributed through business and industrial organizations, schools, and churches. It is hoped that the highway safety problem can be greatly alleviated by making the driver courtesy-conscious.¹²⁷

While most motorists will voluntarily obey traffic regulations, these are always a few who must be held in line through force or the threat of force. Such persons not only endanger other motorists but also set a bad example for normally safe drivers, some of whom may be tempted to emulate them and violate traffic regulations. It is, therefore, necessary to back up any driver-education program with enforcement of speed regulations.

Information on enforcement practices in cities and states was first obtained in 1937 by the Committee on Speed Regulation of the National Safety Council. It was found that, because of the deficiencies in existing speed laws, very few police organizations made any attempts to enforce them rigidly. Instead, drivers were permitted to exceed legal speed limits by amounts ranging from 5 to 10 miles per hour. In a few places, police made arrests only when speed limits were exceeded by 20 miles per hour or more. In practice, the speed enforced in any particular locality was probably one which the majority regarded as reasonable for the prevailing conditions.¹²⁸

The experience of several states indicates that accident rates can often be materially reduced by establishing and rigidly enforcing speed limits. In Pennsylvania, for example, the Governor, as a result of the large number of accidents occurring in 1937, decreed a state-wide absolute speed limit of 50

miles per hour, effective Jan. 1, 1938. In the first year following the establishment of this limit, the number of accidents in rural areas declined 24.5 percent, and the number of injuries 29.4 percent. The number of fatalities for all highways both urban and rural, decreased by approximately 25 percent.¹²⁹

The state of California has attempted to determine the type of patrol set-up most effective in reducing speed violations and accident rates.¹³⁰ One group of experiments was conducted on two high-fatality sections of highway. At each end of the zone being investigated, a large sign bearing the words "Control Zone" was erected. Every half-mile throughout the zone a sign was placed indicating a maximum speed limit of 45 mph. Parked squad cars and officers standing beside parked motorcycles were stationed at several points, in full view of motorists. Speed counts showed that during the 10 day period in which these tests were conducted, 20 percent of all vehicles exceeded the legal speed limit, as compared to 46.3 percent with normal patrolling. There were no accidents of any kind. Patrolmen cruising through the area on motorcycles proved much less effective. Indeed, when this system was employed, 50.4 percent of all vehicles exceeded the legal speed limit, an increase of 4.1 percent over the normally prevailing rate of violation.

Care must be used in interpreting the above findings. For one thing, the validity of conclusions based on a 10-day period of observation is open to serious question. Furthermore, it is difficult to believe that motorists increase their speed in the presence of a patrolman on a moving motorcycle. To properly interpret the results of these investigations, information concerning traffic volume, traffic conditions, weather, and numerous other factors must be taken into account.

Traffic Congestion in Urban Areas

Although great advances have been made in the transportation of both people and goods in the last 30 years, and much money spent on wider streets, overpasses and underpasses, bridges, tunnels, and other highway improvements, urban traffic congestion is becoming worse, rather than better. Traffic jams are undesirable on several counts. The driver caught in a lane of slow-moving vehicles quickly becomes fatigued and irritable, hence more susceptible to accidents. Furthermore, the extra time consumed in traveling from place to place results in financial losses both to the operators of commercial vehicles and those they serve. It is estimated that New York merchants lose one million dollars a day because of street congestion,¹³¹ and the losses to trucking companies are probably of a comparable order.

There are three ways of relieving urban traffic congestion: (1) by improving and augmenting parking facilities, (2) by promoting the use of public carriers rather than private vehicles, and (3) by widening existing streets and constructing new ones.

Investigations have shown parking meters to be an effective means of reducing traffic congestion. One early study showed that installation of parking meters was followed by a decrease in the amount of parking, hence in the number of vehicles cruising about looking for parking spaces. As a result of the time limit on parking, there was an increased turnover of cars at the curb. In Portland, Oregon, the increase amounted to 54 percent on blocks observed by traffic engineers.¹³²

A recent survey,¹³³ conducted by the Highway Research Board, likewise revealed that parking meters greatly augmented curb turnover. Of 806 municipalities which participated, 24 percent reported a turnover increase of 100 percent or more; 21 percent a turnover increase of 75 to 99 percent; 18 percent an increase of 50 to 74 percent; and 26 percent "to a great extent".

The pattern of turnover increase apparently was not affected by municipality size.

Street traffic may also be reduced by providing public parking areas. Filled-in lake, waterfront, or canal areas, or space obtained by razing old buildings can be used for this purpose. In Midland, Michigan, an area along the river, formerly used as a dumping ground, has been converted into a municipal parking lot providing space for several hundred cars about two blocks from the main business district. In the same town, areas formerly occupied by a church and a tennis court have also been utilized as parking lots.

While the installation of parking meters and the provision of off-street parking facilities may help to alleviate traffic congestion, such measures will never entirely eliminate it. Wherever street parking -- metered or otherwise -- is permitted, the effective width of the road is reduced. In downtown areas, the traffic capacity of a 40-foot pavement on which parking is permitted is 45 percent less than the capacity of the same-width street on which parking is banned. Seventy-foot streets are deprived of 43 percent of their capacity. In each instance, the reduction in traffic capacity is greater than the reduction in space available for driving. It is the bottleneck caused by vehicles pulling into and out of parking spaces, as well as the actual space occupied by parked vehicles, which accounts for the reduced highway capacity.¹³⁴

The congestion problem is further complicated by the limited carrying capacity of streets. Whereas the maximum capacity of a single lane of an elevated highway is approximately 2,700 passengers per hour, a lane of busses can move 9,000 persons in the same time, a surface street car 13,000, and an express subway 60,000.¹³⁵ In New York City, it would take 12 to 15 six-lane grade separated parkways to provide the same passenger-carrying capacity as a four-track subway.¹³⁶ By persuading the public to make greater use of public transportation, a major step toward the solution of the urban traffic problem would be accomplished.

Where traffic congestion is particularly bad, it is sometimes necessary to redesign the street system. This may be done by widening existing streets, by building new arterial routes, or a combination of these methods. A great deal of care must be taken in planning the location of such routes. It is necessary to have a thorough knowledge of the existing street system, including the volume of traffic using each street, the hours of maximum traffic flow, and the bottlenecks in the system. In addition, expected population growth, direction of growth of city, shifts in centers of industrial employment, and possible future use of various sections of the city must also be considered.¹³⁷ A poorly planned system can result in more, rather than less, traffic congestion, especially if a new roadway discharges a great volume of traffic into a system unable to handle it. With proper attention to the above factors, however, a noticeable and lasting improvement in the urban traffic picture may be obtained.

FEDERAL PROPOSALS AND RECOMMENDATIONS

In this section an attempt will be made to summarize several federal proposals and recommendations which have as one of their aims the promotion of highway safety on a nationwide basis. Included in these proposals and recommendations are (1) a nationwide interregional highway system (2) a vehicle regulation code for states, and (3) a model traffic ordinance for cities.

Interregional Highways

The federal proposal for a system of interregional highways was transmitted to Congress by the President of the United States in January, 1944, and published as House Document No. 379, under the title A Report of the National Interregional Highway Committee Outlining and Recommending a National System of Interregional Highways. The committee recommended the establishment of a national system of rural and urban roads totaling approximately 34,000 miles and connecting the principal geographic regions of the country. It was proposed that the roads connect as many as possible of the large urban centers and as many as practicable of the cities having at least 10,000 population, even though inclusion of the latter might involve deviation from ideally direct routes between the larger cities.

All rural sections of the highway having a daily traffic volume of 3,000 vehicles or over would be divided highways, while rural sections with a daily traffic volume of 15,000 vehicles would be 6-lane divided highways. Pavement lanes would have width of 12 feet. All railway crossings and all urban crossroads would be separated, as well as all crossroads in rural sections having a daily traffic volume exceeding 5,000 vehicles. In addition, rural crossroads would be separated whenever feasible, regardless of traffic volume. All curves sharper than one degree would be super-

elevated, the maximum super-elevation for rural areas being 0.12 and for urban areas 0.10.

For 2-lane highways the minimum non-passing sight distance would be 400 feet at 50 mph, while passing distance would be 1,500 feet.

In determining the location of the roadway, an attempt would be made to bring the highway into view of lakes, rivers, wooded hills, or other pleasant vistas. Sufficient right-of-way would be acquired so that objectional and unpleasant features of the landscape could be screened from view. In urban areas, planting of trees and shrubs in formal arrangement along the roadway edge or in the median strip would be allowed, but in rural areas an attempt would be made to preserve or to recreate a natural foreground in harmony with distance views.

The system is designed to meet to an optimum degree the needs of interregional and intercity transportation. Of the now-existing rural highways, city streets, and bridges which conform approximately in location to the recommended system, only a very small percentage closely approaches the standards proposed. This being so, it is quite likely that safety-wise they also compare unfavorably with the proposed new system. Any improvements, therefore, which are designed to bring such existing roads up to the standards proposed for the new system would almost inevitably make them safer for motorists.

Uniform Vehicle Code, Model Traffic Ordinance

It has long been recognized that non-uniform traffic laws are a source both of inconvenience and hazard to motorists and pedestrians. They contribute to accident and traffic congestion, increase administrative and enforcement burdens, and interfere seriously with interstate travel and commerce. In 1926, in an effort to meet public demand for uniform traffic laws, a Uniform Vehicle Code was formulated by the National Conference on Street and

Highway Safety, in cooperation with The National Conference of Commissioners on Uniform State Laws and recommended as the basis for uniform state traffic regulations. At the present time, the code comprises five separate acts, each of which deals in great detail with a particular phase of vehicle regulation, as follows: Act I is concerned with motor vehicle registration, certification of title, and anti-theft legislation; Act II with licensing of operators and chauffeurs; Act III with the civil liability of owners and operators of motor vehicles; Act IV with the safety responsibility of drivers; and Act V with state traffic regulations. Along with the Uniform Vehicle Code, a Model Traffic Ordinance was adopted, which was designed for municipalities. Both standards are revised periodically to keep ahead of changing traffic conditions, the last such revision being in 1952. Revisions are made by the National Committee of Uniform Laws and Ordinances, which is part of the President's Highway Safety Conference. The committee includes more than 100 representatives of federal, state, and local law enforcement and legislative agencies; educational institutions; manufacturers; insurance companies; and business, professional, and social organizations.

While it is impossible to summarize concisely the many individual provisions contained in these recommendations, the brief description of their contents, given above, shows clearly that they cover every aspect of vehicle ownership and operation. Experience has shown that when all or part of these recommendations are adopted by a state or community, the result is an increase both in the safety and efficiency of highway transportation. Considering their scope, plus the fact that they represent the considered opinion of many individuals and organizations directly concerned with highway transportation problems, such results are not at all surprising.

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