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The Development of Speed Limits:
A Review of the Literature

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16. Abstract

This report contains the literature review conducted as a part of the project "A Study for the Selection of Maximum Speed Limits." Five aspects of speed and speed control are discussed. These topics include: the history of speed limits; the relationship of speed and speed limits; driver speed behavior and variables, other than speed limits, which influence it; the relationship of speed, speed limits, and accidents; and, methods for establishing speed limits. An extensive list of references and bibliography follow the report.

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ABSTRACT

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1.0 INTRODUCTION

This report presents a review of selected literature dealing with the subject of speed and speed control in the context of highway safety. The literature review is part of a study (FH-11-7275) funded by the National Highway Safety Bureau of the U. S. Department of Transportation to develop methods and methodologies for the establishment of speed limits.

The research was conducted by the staff of the Institute for Research in Public Safety of Indiana University, Bloomington, Indiana.

1.1 Purpose

The purpose of this report is to bring together in one document as much of the existing information concerning speed and speed control as is possible.

1.2 Scope and Approach

For the purpose of study, the literature search for this project was divided into five topic areas. The section titles of this report reflect these areas. They are: 1) The History of Speed Limits; 2) The Relationship of Speed and Speed Limits; 3) Driver Speed Behavior and Variables, Other Than Speed Limits, Which Influence It; 4) The Relationship of Speed, Speed Limits, and Accidents; and 5) Methods for Establishing Speed Limits.

Four facilities were used in conducting the search. The first and main facility was the Indiana University Library

System. In addition, bibliographies were prepared through the Safety Research Information Service of the National Safety Council, the Highway Research Information Service of the Highway Research Board, and the Transportation Center Library of Northwestern University.

The nature of the search was not analytical, and thus, this report presents only a content review of the literature for informational purposes. The basic design was to bring together in a logical manner written materials concerning speed limits from the historical to the technical. This type of report is a useful preliminary approach to give the reader an overview of the topic and to provide direction for further study.

Because of the wide variety of materials presented, many of the works are cited individually to preserve their uniqueness. From this, the reader himself can judge their worth within the total context of existing literature.

All materials that are cited in the text of the report can be found in the list of references. Publications that have been considered and reviewed, but are not referred to in the text can be found in the bibliography. A glossary of commonly used definitions is also included.

1.3 Summary

The following chronology of highlights in the history of speed control in America illustrates the progress that has been made in this area.

The history of speed limits in the United States dates back to 1678 when speed restrictions were imposed on horses in Newport, Rhode Island (4). European speed control had its effect on American policy, and in 1901 the first speed limit for automobiles in the U. S. was enacted in Connecticut (6).

Early speed control campaigns were colorful and dramatic. But in addition to the radical denunciations of speed and "speed mania" came more rational arguments supporting the adjustment of driving speed and speed regulations to existing conditions and condemning reckless driving rather than speed, *per se*.

Along with speed restriction legislation came technological developments for speed measurement, and by the 1920s a need had developed for minimum speed limits in addition to maximum limits.

"...By the 1930's efforts were begun to study speed control and take a more realistic approach to it..." (31). The organized traffic safety movement began in the mid-'30s, causing both cities and states to institute rigid accident reduction campaigns, the most notable being in Providence, Rhode Island (63, 65). Already in the late 1930s such western states as Colorado had speed limits as high as 60 mph (65).

During World War II an effort to conserve gasoline and rubber brought the entire nation under a 35 mph limit (74),

and in 1948 radar became a part of the traffic control system (80).

Tracing the development of the present day speed limit, it can be seen that many of the ideas which generate controversy today were proposed quite early in the history of automobile regulation.

A study conducted at the University of Illinois in 1947-48 concluded that traffic ignored speed limits and ran at speeds which drivers considered safe and that most posted speed limits were ineffective because they were unreasonable (79).

J. Edward Johnston suggested in 1956 that the 85th percentile was reasonable and encouraged uniform speeds (85).

Since the 1950s several major concepts have prevailed in the controversy over the effects of speed limits on driving speeds. The first is that speed limits have little or no effect upon driver behavior; that drivers ignore them and drive at speeds which they consider reasonable and safe (95, 96, 98, 104, 105, 109). An opposing view states that speed limits do have an effect (101, 107); however, different studies have shown varying effects, including decreased pace (97), reduction of excessively fast or slow speeds causing vehicles to travel closer to the same speed (77, 114, 175), and a random effect (99).

A 1955 book on *Traffic Engineering* explained:

> "For any given road there is an optimum speed limit which will have the greatest effect on spot speed. This value is usually between the 80 and

90 percentile of the free-flowing speed as plotted on a cumulative-frequency curve" (77).

Other articles seem to concur that the 85th or 90th percentile is a reasonable guide for setting speed limits (98, 99, 113).

It has been stated that absolute speed limits receive the highest observance, while advisory limits are exceeded more often than either absolute or regulatory limits (90). Urban limits appear to be violated more often than rural limits (105, 109).

The study of driver speed behavior has illustrated a number of interesting findings.

A 1954 study found that about a third of all drivers exceeded the 85th percentile of the spot speed distribution. If a set of drivers was observed as many as seven times, more than half could be expected to exceed the 85th percentile speed at least once (116).

A study to investigate drivers' speed perception involved the ability of eight subjects to halve or double their speed on command. In this study, drivers seemed to underestimate their speeds when decelerating and to overestimate them when accelerating (119).

A Los Angeles study conducted to assess the effectiveness of written warnings as compared to citations involved the stopping of motorists who exceeded 40 mph in a 25 mph zone.

By following these drivers after citations or warnings were issued, the study found that:

(1) Where a citation was issued, accompanied by no conversation between driver and officer, 32 of 100 cases recorded exceeded the limit again within 5 miles.

(2) Where a safety message accompanied the citation, 33 of 100 cases exceeded the posted speed within the next 5 miles.

(3) Where a written warning and safety message were issued in place of a citation, 43 of 100 motorists had exceeded the limit within 2 miles and 22 more within 5 miles, for a total of 65 (122).

Numerous publications discuss the factors which affect speeds. The following factors and relationships have been identified:

Studies of driver variables found that speed increased with trip distance (126, 136, 138); non-local vehicles traveled faster than local vehicles (138, 139, 143, 144, 145); male drivers drove slightly faster than female drivers (136, 137, 143, 145); and, drivers with passengers in the car drove slightly slower than those without passengers (137, 143, 145). Other driver variables which influenced speeds were expected arrival time (146), frequency of road use (146), opinion of the speed limit (146), and amount of driving connected with the driver's work (146).

Vehicle variables showed that vehicle type (137, 138, 139, 143, 145) and age affected speeds with newer cars traveling faster than older ones (126, 136).

Among the roadway variables cited were: functional classification of road type (137), surface type and condition (137, 138, 140, 142, 147), number of lanes and lane width (129, 137, 138, 140, 142), lane position (137), median type (139, 147), access control (137, 139, 142), frequency of intersections (137, 139, 140, 147), shoulder width and condition (140, 142, 147), and design speed (147). Other factors identified include geographic location (137), sight distance (137, 138, 139, 140, 142, 143), curvature (137, 138, 140), gradient (137), length of grade (137, 140), lateral clearance (137, 142), horizontal and vertical resistance (138, 143), marginal friction (138), vertical and horizontal alinement (142), traffic signals and control devices (140, 142, 147), parking (140, 147), and presence of pedestrians (140, 147).

Traffic variables shown to affect speeds were volume (129, 130, 138, 140, 142, 147), passing maneuvers (137), opposing traffic (137), and percentage of commercial vehicles (137, 142, 147). A study also indicated that vehicles in each lane tended to adjust their speeds to the speed of the slower parallel lane (107).

A study of environmental factors which affected speeds found that objects on the road shoulders demonstrated little effect on speeds unless the lane widths were less than 20 feet (132). Other environmental factors include weather (137, 142, 146), time (133, 137, 142), and roadside establishment (138, 139, 140, 142, 147).

It can be seen that a number of studies have been conducted to identify the above mentioned variables and that there is considerable agreement in this area.

Although discussions of the speed-accident relationship date back to the early use of the automobile, serious research in this area seems to have begun in the 1930s. From 1930 to 1939, the speed capability of the average vehicle sold rose from 55 mph to 84 (126).

A number of the early studies in this area attributed the occurrence of accidents to speed (70, 151, 153), while others did not find a relationship to exist between high driving speeds and accidents (126, 152). One author even went so far as to say that all traffic problems were grounded in highway design. He wrote:

> "It is as essential to spend effort to improve the speed of transportation as it is to spend it to reduce accidents. The automobile was not manufactured to save lives, or the roadway built to prevent injuries" (154).

Since the 1950s several ideas have predominated the discussions of the speed-accident relationship.

One concept generally accepted by experts in this area is that accident severity increases with speed.

But opinions are polarized on the questions of speed as a cause of accident occurrence and speed limits as an effective means of accident reduction.

There are those who believe that speed is the prime cause of accidents (4) and others who indicate that accidents increase with increased speeds (157, 162).

M. Earl Campbell presents an interesting approach to speed-accident comparisons. A May 30, 1964 news release from the California Division of Highways stated that although only 19 persons have been killed at the Indianapolis 500 since 1911, this is a fatality rate of 3,930 per 100 million vehicle miles as compared to a fatality rate of 3 per 100 million vehicle miles on California freeways. This 133,424 percent increase at 140 mph on the race track shows how accident frequency increases above 65 mph.

> "Traffic records and physics indicate that not only the hazard of severity but also the hazard of frequency of hitting another vehicle or fixed object increases with speed, and these hazards become specially notable in the higher ranges. Speed and accidents cannot be related to each other simply as a two-dimensional relationship: the relationship is always multi-dimensional and may include one hundred other factors...the third dimension of traffic density must always be included if any valid relationship is to come out of the analysis" (183).

> "The hazard of frequency...is related to these conditions: (1) the speed of the subject car related to the density, frequency distribution of speeds of all the cars in the total traffic stream and, (2) fixed objects and other roadside hazards. There are other factors, but these appear to be most important. It appears also that the hazard rate above and below the average speed of traffic flow increases faster than the change in rate of speed" (183).

> "One of the best confirmations of the increases in hazard of frequency of involvement with increase

> in speed is found in the 1959-64 records of the single-vehicle accident...This type of accident constitutes more than one-third of the accidents resulting in fatalities, and it is increasing at a rate significantly faster than the average rate of increase of fatal accidents, especially in urban areas" (183).

A 1956 study stated:

> "[f]aster drivers have more accidents than slower drivers, especially when judged by their speeds in the afternoon. The individual speeds of the drivers with accident records are slightly higher than those for the drivers without accident records; while in the morning, it is the drivers without accident records whose speeds are slightly higher" (158).

Another idea having several proponents is that low-speed drivers are more likely to be involved in accidents than high-speed drivers (159, 165, 190). The chance of being involved in an accident is lowest at about 65 mph, and highest for low-speed drivers, and it increases at over 65 mph (163).

> "...[O]nly eight per cent of all fatal motor vehicle accidents are reported to have happened at speeds above 60 mph in 1962. On the other hand, more than half of all fatal accidents in urban areas reportedly occurred at speeds under 30 mph, that same year" (178).

A very rational stand taken by several authors is that speed is a causal factor in accidents, but it is one of a number of causes and not necessarily the most important (156).

> "Speeding is outrageously overrated as a CAUSE of accidents. The fact is that it is inattentiveness or errors in judgment or lack of driving skill which contribute most heavily to the causes of accidents. Seldom does a single deficiency cause an accident" (178).

The *Proceedings of National Highway Safety Bureau Priorities Seminar* gives the following explanation:

"Does speed cause accidents and produce casualties? Obviously, considering speed of itself, the answer is often no. As a matter of fact there are occasions when the capacity for speed may even aid in the avoidance of a crash or the mitigation of its results (The capacity to pass quickly in a suddenly developing tight situation and the minimizing of speed differentials in rear-end collisions, for example). On the other hand speed can very often compound the task of accident avoidance if not precipitate a crash. Further, and without question, speed aggravates the consequences of the crash.

"In discussing speed in relation to accidents it is well to delineate the several senses in which the term might be used. It is useful to think of speed in the following contexts:

"a) very [*sic*] high speed - speeds approaching and exceeding 100 mph. Under these conditions, the speed factor dominates as a causative agent, since few if any of the elements of the overall vehicle-driver-highway system have been designed to accomodate travel at this speed.

"b) Excessive speed for conditions - speeds ranging anywhere from zero to design speeds. This category of speeding encompasses many of the speeding citations issued in connection with accidents.

"c) Differential speed or speed gradients in the traffic stream - in part, an overlapping set with excessive speed but also includes inadequate speed. Differential speed and the related variable "acceleration noise" figure prominently in the safe and efficient flow of traffic. Large speed differentials are seldom if ever cited as a contributing cause, the factor being implicit in other improper driving categories such as following too close and reckless driving.

"With these connotations of speed in mind it can be appreciated that speed is very often not a singular or an explicit variable in the accident equation. Thus, efforts to treat speed as an accident

cause are often reduced to treating symptoms arising from the synergy of speed and many other system factors" (179).

There are differing views as to the effect of speed zoning on accidents. Some studies have shown that speed limits reduce accidents either in number or in severity (114, 155, 164, 168, 170, 172, 174, 176).

In 1960 John Baerwald wrote: "No evidence exists to indicate that accidents are increased when speed zones are raised and by the same token, there is no evidence that accidents are materially reduced by establishing zones, although a downward trend is indicated" (96).

Other studies have shown that speed limit practices were ineffective at reducing accidents of any type (177).

One of the newer theories in the area of speed and accidents is that accidents are related to speed differences (189, 191). Probably the most noted study to support this theory was conducted by David Solomon. He concluded:

1. "The accident-involvement, injury, and property-damage rates were highest at very low speeds, lowest at about the average speed of all traffic, and increased at the very high speeds, particularly at night. Thus, the greater the variation in speed of any vehicle from the average speed of all traffic, the greater its chance of being involved in an accident."

2. "The severity of accidents increased as speed increased, especially at speeds exceeding 60 miles per hour."

3. "The fatality rate was highest at very high speeds and lowest at about the average speed."

4. "Pairs of passenger car drivers involved in two-car, rear-end collisions were much more likely to be traveling at speed differences greatly in excess of those observed for pairs of cars in normal traffic..."

5. "Drivers of passenger cars having low horsepower had higher involvement rates than drivers of cars having higher horsepower,...This may be related to the relatively poor acceleration capability at highway speeds of cars having low horsepower."

6. "Nearly half of all accident involvements were either rear-end collision or same-direction sideswipes. However, the proportion of these accident involvements decreased as travel speed increased. Single vehicle, noncollision accident involvements contributed an increasingly greater proportion of all accident involvements as speed increased, particularly at speeds of more than 70 miles per hour. At speeds of 80 miles per hour, non-collision accidents constituted half of all involvements. Although angle collisions usually were less than 15 percent of the total, at speeds of less than 25 miles per hour they constituted more than one-third of all accident involvements. The proportion of head-on collisions or opposite-direction sideswipes increased as speed increased; but this type of accident involvement always was less than 20 percent of the total regardless of speed and day or night conditions" (167).

A recent study by RTI - IRPS indicated "a 'U'-shaped relationship between involvement rate and speed deviation.... These results confirm the hypothesis that slow driving as well as fast driving increases the likelihood of being involved in an accident. However, the curvature of this U-shaped relationship is not as pronounced as that given by Solomon...."

The RTI - IRPS study also gave support to the use of the 85th percentile criterion stating:

> "The standard deviation of the speed distribution is from 5 to 7 mph. Approximately 85% of the drivers drive below the mean plus one standard deviation. The drivers having speeds between the mean and one standard deviation above the mean are definitely in a low involvement group. The region between one and two standard deviations above the mean speed encompasses approximately 10 percent of the drivers and does not have a significantly greater involvement rate than at mean speed. This region from the end of the first to the end of the second standard deviation is approximately the tolerance level allowed by police agencies" (191).

A 1966 article showed that on the five sections of freeway studied "...more than half of the violations contributing to accidents...were directly related to speed differential or to stream friction between vehicles moving in the same direction" (188).

As with the other areas of speed regulation and control, a number of factors have been suggested as criteria upon which speed limits should be based (193, 194, 195, 196, 198, 199). These factors are quite adequately summarized into four main categories in the article "An Informational Report on Speed Zoning." This article suggests that speed limits should be based on prevailing vehicle speeds, physical features, accident experience, and traffic characteristics and control (197).

Again we find a great amount of support in the literature for the 85th percentile criterion (85, 140, 191, 203, 205, 206, 208, 209).

Warren Kessler gives the following justification for the 85th percentile as a basis for setting speed limits:

"The 85th percentile speed is based upon the theory that the majority of motorists traveling upon a city street or highway are competent drivers and possess the ability to determine and judge the speed at which they may operate safely; further, that motorists are responsible and prudent persons who do not want to become involved in an accident and desire to reach their destinations in the shortest possible time" (204).

A 1969 "Resolution of the annual meeting of the American Association of State Highway Officials" states:

"The review of existing practice revealed that most of the member departments use, primarily, the 85th percentile speed. Some agencies use the 90th percentile speed, and of secondary consideration are such factors as design speed, geometric characteristics, accident experience, test run speed, pace, traffic volumes, development along the roadway, frequency of intersections, etc.

. . .

"On the basis of the foregoing review, the Subcommittee on Speed Zoning recommends to the AASHO Operating Committee on Traffic for consideration as an AASHO Policy on Speed Zoning that:

"The 85th percentile speed is to be given primary consideration in speed zones below 50 miles per hour, and the 90th percentile speed is to be given primary consideration in establishing speed zones of 50 miles per hour or above. To achieve the optimum in safety, it is desirable to secure a speed distribution with a skewness index approaching unity" (207).

A California publication, "Speed Zoning - Why and How," discusses the results that realistic speed zoning may produce.

"A. Reduce the speed differential in a traffic stream when there is a large variation of speeds. This makes driving easier, increases capacity and reduces the liklihood [*sic*] of accidents by encouraging most drivers to travel at about the same speed.

B. Give enforcement officials a good guide as to what a reasonable and prudent speed is under normal conditions and permits concentration of enforcement against real traffic violators.
C. Give motorists a speed limit which they can respect and obey. When drivers respect speed limits in areas with which they are familiar, they are more likely to pay attention to limits in unfamiliar areas.
D. Assist traffic courts by providing a realistic guide as to normal, reasonable and prudent speeds.
E. Give local residents a realistic picture of the actual speed of most traffic. There is no safety in blind reliance on a speed limit inconsistent with speeds actually traveled by traffic.
F. Insure that all speed zones satisfy the requirements of state law" (208).

More recently developed areas of discussion concern the uniformity of speeds or the speed distribution (85, 214). William Taylor has said that assuming that variation of speed distribution and high accident rates on certain sections of highway are a result of the drivers' inabilities to properly evaluate the driving situation, it seems that the speed distribution would be helpful in determining where speed zoning might be effective. Mean speed and 85th percentile may not be influenced by each driver's inability to make a proper evaluation of conditions in the way that skewness and kurtosis of the speed distribution are (210).

Taylor's theory states that a relationship exists between the rate of occurrence of accidents and the distribution of speeds on a section of rural highway, and that the effectiveness of speed zoning in reducing accidents depends on the speed distribution before and after zoning (211). His study concluded:

"1. There is a strong relationship between the rate of occurrence of accidents and the speed distribution on rural state highways.
2. The best parameter to use in determining non-normality is the skewness of the distribution.
3. Changing the speed distribution from non-normal to normal results in an accident rate reduction which is about twice that found under any other set of before and after conditions.
4. Warrants for speed zoning should be established which include the speed distribution as a factor.
5. The 'Before' speed distribution alone is not adequate as a warrant for speed zoning" (177).

A Tennessee Department of Highways Study based on Taylor's theory concluded that speed limits below 50 mph are best represented by the 85th percentile, while limits of 50 mph and above are best represented by the 90th percentile (212).

J. C. Oppenlander proposed a cost-based method of establishing speed controls. His theory entails:

1. The selection of an optimal speed that minimizes the cost of highway transportation, taking into consideration monetary, time, safety, and comfort factors.
2. An adjusted speed is derived from the optimal speed by subtracting the reduction in speed occasioned by driver, vehicle, roadway, traffic, and environmental variables that modify vehicular speeds.
3. Statistical relationships between upper and lower speed limits and adjusted speed produce the posted speed regulation (200).

Jack C. Marcellis attempted to apply part of Oppenlander's theory, calculating the total cost of traffic movement as the sum of operation cost, time cost, and accident cost. The optimal speed for urban streets was scaled according to frequency of stops. For passenger cars, optimal urban speed ranged from

42 mph for 0 stops per mile to 27 mph for 16 stops per mile during the day. Night optimum is slightly lower. Commercial vehicles would move at an optimum speed of 37.5 mph at 0 stops per mile, and at 8 stops per mile the optimum would be 25 mph (215).

Thus, it can be seen that there are three major approaches to establishing speed limits, one based on measures of prevailing vehicle speeds, another based on characteristics of the speed distribution, and a third based on cost.

In summarizing the body of literature concerning speed and speed control, the reader can probably be certain of only one thing -- the controversial nature of many of the findings in this area. However, in considering the most rational and best supported approaches to various aspects of the speed problem, the following conclusions would seem reasonable.

1. Many of the basic premises concerning speed behavior and its control are not new; they appear early in the history of speed regulation and the automobile.

2. Numerous factors relating to the driver, the vehicle, the roadway, and the environment have a determining effect on driving speeds.

3. The main element in determining whether drivers observe a speed limit is their perception of the reasonableness of the limit.

4. Speed limits, taken as a whole, are beneficial, or at least appear to have no detrimental effect on accident occurrence.

5. Speed may play a large role in the severity of accidents, but is merely one of many factors in accident causation.

6. At present the most widely supported criterion on which to base a speed limit is the 85th percentile speed.

7. The theory that accidents increase as the value of the standard deviation increases, i.e., that speed differences play a causative role in accident occurrence, is a promising one, as evidenced by a high accident rate at both low and very high speeds and a lower accident rate around the average or normal driving speed.

2.0 A SURVEY OF THE EXISTING LITERATURE

This section consists of a summary of publications reviewed under each of the five mentioned topic areas.

2.1 The History of Speed Limits

The history of speed limits is international in scope, rather than being localized. However, since we are primarily concerned with speed control and its role in the traffic system of the United States, we will only briefly discuss early speed control in Europe to show its impact on the development of speed limits in the U.S.

As early as 1824, steam carriages were used on highroads in Great Britain. They were eventually thought dangerous, and in 1865 legislation was passed restricting speed to 4 mph and requiring that every road locomotive be preceded by a man with a red flag. This act was replaced in 1896 by another law which abolished the red flag and increased the speed limit to 14 mph (1).

In France, no red flag law existed and road racing was possible by permit (1). By 1906 France had a general speed limit of 18 1/2 mph, 12 1/2 mph in inhabited areas, and 4 mph in narrow or crowded places (2).

A Royal Decree allowed 18 1/2 mph outside towns and villages in Belgium in 1899 (1). And by 1906 Austria had changed from no speed regulation to 28 mph in open country, 9 mph for

inhabited areas, and 5 mph on narrow roads, while Germany recommended a no-limit policy in open country and 9 mph in inhabited areas (2).

One illustration of the early impact of European speed policies on American traffic regulation is found in the following passage: "Owing to the number of arrests which have been recently made in Paris for the fast driving of automobiles, attention has been called to a method which will determine the speed exactly, and not leave this to the judgment of the police officer" (3).

But the history of speed limits in the United States had a much earlier beginning. Even before the appearance of the automobile on American streets, an incident in Newport, Rhode Island in 1678 resulted in the first known speed law. After a child had been run down by a horseman, the following regulation and accompanying fine were imposed:

> "...if any person or persons shall presume to ride on either horse, mare or gelding, a gallop or to run speed, in the streets of Newport, said person shall for his offense pay into the treasurer of said towne 5 shillings of money on demand, 2 shillings of which shall be paid to any person or persons that shall give information thereof and the other 3 shillings to remain for the use of said towne" (4).

In 1757, Boston churchgoers were protected by a limit of a "foot pace" for carriages on Sunday (4).

Speed was also linked to public safety in the high death toll from the electric trolley. "The damage suits resulting

from these accidents made it a matter of equal concern to the company to protect life; hence, the rate of slowness...was presently what it had been when patient horses went jingling up and down the town..." (5).

The first speed limit imposed on automobiles in the United States was enacted in Connecticut in 1901 and provided for speeds of 12 mph and 8 mph in cities (6).

Soon after the appearance of the motor vehicle on American streets, the people of the nation became involved in a great debate over speed control. The strong advocates of regulating the automobile waged a colorful and highly emotional campaign to encourage its restriction. They termed it "The latest encroachment upon the liberty of the highway" (7) and began their battle against the epidemic of "speed mania" (8, 9). Vivid descriptions such as the following were used to present the issue:

> "The children must be shut up. The halt and maimed must stay in bed. The motorist must have his rush, and if he does not kill anyone he claims positive moral credit for lifesaving" (10).

In 1906 the Commissioners of the District of Columbia reported:

> "The most serious objection to the automobile is the speed at which it is frequently driven on the public thoroughfares. The abatement of this evil is intrusted to a detail of bicycle policemen. The activity of this force is shown by the fact that during the calendar year 1905 there were between 400 and 500 arrests for infractions of the automobile regulations, of which 246 were prosecutions based upon violations of the speed limit. An analysis of these latter cases shows that 15 persons

were twice, 4 persons were three times, and 2 persons were four times arrested and convicted of violating the speed regulations.

"The amount of fines collected during the year from these 246 violators of the speed law was $2,268. It is, perhaps, proper to remark at this point that although the regulations provide a maximum fine of $40 this sum was assessed only once during the year, the average fine being less than $10. The repetition of the offense did not, apparently, determine the amount of the fine. The general practice seems to have been to impose a penalty of $5 for the first offense, $10 for the second, and $20 for the third. In more than one instance, however, the first offense was penalized more heavily than the second, while the operator who was arrested four times was made to pay $40 for the first offense and only $5 for the second. It is evident, therefore, that the police court takes cognizance of the circumstances surrounding the offense rather than the repetition of the violation.

"Although the Commissioners believe that a rigorous enforcement of the penalty provided by the regulations would go far toward restraining the fast running of automobiles, they appreciate that occasion might arise wherein the imposition of a fine for overspeeding would be totally inadequate as a punishment. Several of the States have already recognized this fact and provide imprisonment as an alternative. The laws of these States, briefly stated are as follows:

"Alabama, $25 to $100 for first offense; $50 to $200 for subsequent offense, or thirty days to six months' imprisonment.

"Connecticut, $200 or under, or thirty days in jail.

"Illinois, $25 to $200, or three months' imprisonment, or both.

"Maine, $50, or ten days' imprisonment.

"Missouri, $100 to $1,000, or imprisonment from thirty days to six months, or both.

"New York, first offense, not over $100; second offense, $50 to $100, or imprisonment not exceeding thirty days, or both; third offense, $100 to $250 and imprisonment not exceeding thirty days.

"Pennsylvania, $10 to $100, or thirty days' imprisonment.

"Rhode Island, not exceeding $20, or three months' imprisonment.

"Vermont, not exceeding $100, or fifteen days' imprisonment, or both.

"The Commissioners are informed that sentences of imprisonment are rarely or ever imposed in these States, which indicates that would-be reckless automobilists have a wholesome fear of involuntary confinement. The Commissioners believe that an imprisonment law ought to be enacted for the District of Columbia, but suggest that the mandatory language of the proposed measure might well be amended so as to conform with the statutes of the States mentioned. With the posibility of imprisonment constantly menacing violators of the speed regulations, it is believed that the tendency to overspeeding will be effectually checked.

"It will be observed that the proposed bill of the commissioners includes horse-drawn vehicles. This inclusion is not only for the purpose of avoiding any charge of discrimination against owners and operators of automobiles, which charge might be made the basis of a legal effort to overthrow wise and necessary legislation, but is also based upon the facts shown by an examination of the police records. During the calendar year 1905 there were 275 arrests and convictions for fast driving. This is an evil which is unquestionably on the increase in the District of Columbia, and the Commissioners are of the opinion that careless and reckless drivers ought also to suffer adequate penalty.

"The Commissioners also request that they be given authority to revoke the license or permit granted to any owner or operator of an automobile after said owner or operator shall have been twice convicted in the police court of violating the speed regulations, provided such revocation shall be deemed necessary for public safety" (11).

A popular magazine article in 1907 defined two classes of "criminaloid" drivers:

"The type of man who motors at dangerous speed is the same type that speculates in more stocks than he is able to carry, eats and drinks more than he can assimilate, covers himself with gaudy jewels, makes an objectionable exhibition of himself on every possible occasion. The strong arm of the law is the only effective curb for this species; for it is a notorious fact that the logical conclusion of such disordered lives as these is in state's prison or the electric chair.

> "Yet most of the motoring accidents, especially about large cities, are due not so much to criminaloid owners of cars as to reckless hired chauffeurs...Saloons have sprung up in the neighborhood of all big garages and they are often too well patronized for the safety of the public. Chauffeurs after a hard day's run drop in and take a drink or two...And that is why I say that a great source of danger to life and limb is the tired motorist who drinks" (9).

During this time there was not only concern for the harm caused by the speeding driver, but also for a method of handling the speed violator. Henry Underwood, the author of the article quoted above, supported the revoking of the driver's license over other forms of punishment, saying:

> "And your speed maniac who laughs at a fine and boasts of it among his fellow maniacs would tremble with fear at the prospect of having his license revoked for a month, or six months, or a year" (9).

A 1909 article gave the following account of dealing with the violator:

> "In New York City in two days last week over 90 cases of chauffeurs and owners of automobiles accused of violating the speed regulations were tried in the court of Special Sessions, and fines ranging from five dollars to one thousand dollars were imposed; and the courts are acting with unprecedented promptness and severity" (8).

A second approach to speed control was more rational. Proponents of less rigid restrictions supported the adjustment of driving speed and speed regulations to existing conditions, condemning reckless driving rather than speed, *per se*. Automobiles were compared to other modes of transportation, and driver skill was taken into account. Such writers recognized

the fact that unreasonably low speed limits were being ignored. By 1906, 75,000 automobiles were in use in the U.S. and reasonable regulations were being demanded (12, 13, 14, 15, 16).

Another phase of early speed regulation was the development of mechanical instruments for speed measurement and speed control. As early as 1904, a speed indicator had been manufactured to accurately register speed from 2 mph to 45 mph (17). Later the speedometer was considered essential and the driver with a speedometer was thought to have no excuse for speeding (18).

Throughout the history of the automobile, speed governors were repeatedly suggested and fought as a means of limiting speed (14, 19, 20, 21, 22, 23). And in 1910 a double camera equipped with a timer was used to detect speeding violations. "A motorist who has been stopped does not have to rely on...the speed claimed by officers operating a trap by means of stop watch and signals" (24). (Note that by this time we can also see indications of the familiar speed trap.)

Another author, Montgomery Rollins, explained: "The regulation of traffic is still in its early stage, and the police find it a problem hard to deal with, they are criticized rather for omission than commission. The newspapers teem with complaints in this regard" (25).

The above author related an anecdote illustrating the extent to which communities would go in regulating drivers' speed:

"A rather amusing attempt to bring the automobile speed within reason occurred in California. Outside of one of the large cities, many efforts had been made by the use of warning signs, to slow the cars down, but still an endless procession of automobiles moved along in total disregard of the wishes of the community. Finally, in desperation, someone, thinking to appeal to the motorists' good nature, hung a tremendous canvas sign across the highway, reading....AUTOMOBILES WILL PLEASE SLOW DOWN TO SEVENTY MILES AN HOUR" (25).

In 1909, this author suggested that speed limits for the sake of public safety would soon be surpassed by the question of taxation for road repair (25).

In 1910 the legislatures of all but eleven states had motor-car legislation and a movement was on to make the state regulations uniform (26).

The supporters of the automobile cause recognized that laws were more strongly enforced against automobiles than other forms of transportation. "The automobile is new and blamed for everything." They pushed for equal rights on the road (27).

Arguments for fewer restrictions on the automobile became more numerous (28, 29, 30). The Automobile Club of America made the following recommendation:

"We advise that all speed limitations should be omitted from the law. In our experience a legal speed limit merely increases the number of offenders, because no matter what the limit is, the majority of drivers will try to exceed it" (28).

Governor Draper of Massachusetts stated that:

"Speed limits were unnecessary, because a machine may be driven recklessly at five miles an hour as

> well as at fifty, but in the present development of the industry I believe it is necessary to have a proper speed limit established as *prima facie* evidence of lawbreaking. As he pointed out, the real danger is not velocity, *per se*, but recklessness...Yet, it is not easy to determine recklessness, and thus it is convenient to have a speed limit, not as a rigid thing, but as *prima facie* evidence of reckless driving" (30).

It is interesting and important to note that "[s]peeding was about the only driving violation recognized in the early days. It is significant that when Chicago in 1912 established the country's first court to handle traffic cases exclusively, it was called Speeder's Court, not Traffic Court..." (31).

Each state adopted its own motor vehicle regulations and speed limits varied greatly from state to state and community to community (32, 33, 34, 35, 36, 37, 38). States often left the question of speed up to the driver with the qualification that it be "reasonable and proper" and special speed limits were often set for hazardous areas such as bridges, curves, etc.

The many facets of the speed problem were all considered and discussed in the popular magazines of the time. H. S. Whiting argued against the manufacturer's limitation of the speed capabilities of the vehicle, saying that the regulations should be put on the driver. "It is the driver who causes the car to speed or to be excessively noisy due to lack of care. Thus, evil is not inherent in the machine but in the man." This writer also pointed out the concern of boards of health

over the "unhealthful proportion of carbon monoxide produced by automobiles" (39).

In 1913 the following relationship was believed to exist between speed and severity of collisions: "...the destructive effects of an overturn or a collision are increased, not in proportion to the speed, but to the square of the speed" (40).

Automobile clubs in Maryland, Indiana, and Detroit began to engage in self-regulating activities. A club member would report any violator to the club headquarters which would, in turn, send a letter urging compliance (41).

"The number of deaths in 1919 was about 100 per million of population, and the estimate for 1920...is 110 per million, or a little less than 12,000" (42). Eight hundred was the projected death toll of automobile accidents for New York City in 1921 (43).

John H. Mackall, chairman and chief engineer of the Maryland Roads Commission stated in 1927 that archaic speed limits remained in force because "...two groups of people want to retain the old order -- the police and groups of individuals alarmed at the increase of fatalities" (44).

A "progressive" system of traffic controls was developed and used in such cities as Chicago and Detroit. "You're supposed to motor at the rate of twenty miles an hour. If you drive at this speed, you'll find the 'Go'...faster or slower, you'll see the 'stop'" (45).

The First National Conference on Street and Highway Safety held in 1924 made the following recommendation:

> "...In order to promote uniformity the speed limits should be subject to general control by the State law, which should prohibit any municipality from establishing a speed limit lower than 15 miles per hour, provided that municipalities and other political subdivisions of the State should be empowered to fix speed-limit zones according to local conditions, but should be required to mark the boundaries of such zones plainly. In rural areas, instead of an absolute speed limit, it should be provided that when any vehicle exceeds 30 miles per hour that speed shall be *prima facie* unreasonable, and it shall be incumbent upon the operator to prove affirmatively the reasonableness of such great speed" (46, 47).

Indicated speeds for special circumstances in the 1930 Uniform Vehicle Code were 15 mph for school or grade crossings, 20 mph for business districts and dangerous intersections, 25 mph in residential districts, and 45 mph for others (48, 49, 50).

By the 1920's a new problem had grown up within the old (50, 51).

> "With the growth of motor traffic and congestion the question of a minimum speed rate as well as a maximum deserves consideration...Already the police officers in a number of cities are urging cars to move at a more rapid pace, but in no place have they been given authority by ordinance to require a definite speed. It is suggested that for major streets, when the conditions of traffic permit, all vehicles should be required to move at not less than one-half of the legal maximum of the district" (20).

A *Traffic Officer's Training Manual* summarized the speed control theories developed up to 1930.

"There are two opposite views with regard to legislation on the subject of speed. One is that it is impossible to name any speed limit or limits that will be satisfactory under all conditions; and that there should be only a general rule making it unlawful to drive at any speed which may be dangerous. According to the other view such a rule is too vague, leaving too much to the judgment of the driver, and therefore a fixed limit is recommended...Out of these two views have grown the *prima facie* speed laws" (50).

"Another interesting theory has been developed, that speed limits should be based upon the clear space ahead. The idea is that the farther ahead to each side an operator can see, the faster he should be permitted to go, so long as he is able to stop his car in time to prevent a collision" (50).

"Thus far minimum speed limits are not in general use, but their utility is widely admitted" (50).

"...By the 1930's efforts were begun to study speed control and take a more realistic approach to it..." (31).

All aspects of speed were considered and reconsidered.

In 1930 cars capable of going 80 or 100 mph were being sold in states with a legal limit of from 20 to 40 mph. Connecticut and Kansas had no maximum, but most other states had a limit of 35 to 45 mph (52).

A two-year experiment in Rhode Island employed "reasonable speed" signs and found that "[b]esides aiding in keeping the high speed driver within limits, they have speeded up the slow driver, led to more uniform rates...to fewer accidents" (53).

A 1934 study observed and recorded speeds by using "mirror-boxes" and stopwatches. 674,945 vehicles were observed out of a total passing volume of 1,065,694. The overall average speed for all vehicles was 33.8 mph. The average speed was 34.5 mph for rural roads and 31.1 mph for suburban roads. Higher average speeds were observed on well paved and four-lane roads, and on those most used by "foreign cars" [i.e., out-of-state vehicles]. There was a noticeable decrease in speed on curves and a less marked effect on grades. Upgrade speeds were greater than downgrade speeds. A comparison of wet and dry pavements indicated that "the determining factor is apparently not the change from wet to dry, or vice versa, but whether the road actually became more or less slippery as a result of these changes." No general decrease in speed for vehicles approaching intersections was observed until the vehicles were within a quarter of a mile of the rotary traffic island marking the intersection. The study could establish no definite relationship between speed and accident frequency, but a high percentage of violation of posted speed limits was observed (54).

> "70 percent of the drivers who exceeded the speeds indicated by the limit signs restrained themselves sufficiently so as not to exceed that limit by more than 5 or 10 m.p.h. On the other hand, there were about 30 percent of the drivers who apparently disregarded the signs entirely and continued to drive at their own pace, which varies from 15 m.p.h. up to an indeterminate limit set only by their degree of recklessness. The fact

that there was such general violation of the speed limits, particularly in the lower ranges, tends to challenge the judgment used in locating the signs.

> "It should be noted in this connection that under the present system the signs are only advisory, that they are placed on the highways only from March to December, and some attempt has been made in the past to vary them from time to time to meet changing road or weather conditions" (54)

Thus it was recognized that "[i]n almost all cases where the low speed limit is in effect, the percentage of violations is high..." (55).

Night driving, as well as seasonal road and weather conditions, presented its problems.

> "With automobiles capable of high rates of speed and with a good many drivers operating them practically as fast during hours of darkness as during hours of daylight, it may be taken for granted that very little can be accomplished along the line of getting operators to reduce their speeds at night, unless, by chance, educational activities are multiplied many times...the thing to do is to start to improve highway illumination" (56).

Other sources indicate that as late as 1938 speed limits were not enforced at night (57).

During the mid-1930s the organized traffic safety movement in the U. S. was given its initial impetus by an aroused public opinion (58). "In 1936, the National Safety Council appointed a committee on speed, which surveyed the problem and came up with a set of recommendations that form the basis for realistic speed control today" (31). The importance of the use of traffic engineers was recognized (59).

Studies on speed as a cause of accidents gave the following statistics: of 1,056 accidents occurring on 22 of Detroit's main thoroughfares in January of 1931, only eleven drivers were listed as speeders, and of 10,822 accidents analyzed by the office of the Director of Traffic in Washington, D. C., only 1.5% were classed as "Exceeding the Speed Limit." However, an analysis of accidents in New York State for 5.75 years ranked "Exceeding the Speed Limit" as 3rd in the action of drivers involved in accidents, and it was tied for second in a similar study by the National Safety Council (60).

Miller McClintock described two methods of approaching the analysis of speed and its relation to accidents. The "sentimentalist" approach "envisions accidents as caused by reckless, foolhardy, anti-social or intoxicated drivers, who race over our street and highways at very high rates of speed, with utter disregard for public safety, until they kill or are killed." The "realistic" approach "does not visualize the traffic accident problem as resulting from the supper-speed of a few abnormals, but rather, from the daily operation of 28,000,000 motor vehicles by 40,000,000 reasonably average, normal individual citizens who become involved in accidents because a vehicle or vehicles, under a particular set of circumstances, are traveling at 'excessive speeds'" (61).

The safety approach was soon supplemented with an economic approach. It was realized that speed was expensive not

only in terms of safety but also in terms of money. Faster driving causes a car to use more gas, more oil, and causes more tire wear (62).

There was also concern expressed for adequately equipped enforcement agencies to implement a continuous, uniform enforcement policy (57).

During the late 1930s, safety campaigns were instituted by many cities and states. Among those cited in the popular literature of the time were Massachusetts, Iowa, North Dakota, Connecticut, Pennsylvania, and Kansas City and Wichita, Kansas (63, 64, 65), but the most noted example of an accident reduction campaign was in Providence, Rhode Island (63, 65). The safety campaign by the people of Providence gave the city a record of 111 days without a traffic fatality. This was accomplished by a highly publicized campaign coupled with strict enforcement and public support and compliance with a 25 mph speed limit in the city. "A monthly 'sampling' of speeds of 3,000 cars at 52 locations showed that the number of cars operating over 25 and up to and including 30 mph were reduced by about one-seventh; cars operating over 30 mph were reduced by a little more than three-quarters" (66).

At the same time that safety campaigns were using rigid speed reduction techniques to decrease the number of accidents, the following statement could be found in a book entitled *Seven Roads to Safety:*

"Speed in relation to safety is a complex subject, and we need to know more than we do before we make final pronouncements concerning its regulation. Generally speaking, speed does not seem to be a primary factor in a large number of accidents, but may greatly increase their intensity. England is filled with slow cars and has almost twice our accident rate. Speed is relative....

"An interesting fact about speed and safety has just been turned up in special studies made by the National Safety Council. This research shows that the speeding driver who figures in an accident was generally helped to have the accident by contributory negligence on the part of the other fellow" (67).

It is interesting to note that some of the advisory speed signs and speed zoning policies used in the late 1930s are still in use or are similar today. The Ohio Department of Highways, for example, used the same advisory speed sign for curves in 1938 that is used at present (68).

The following is from an article entitled "Municipal Traffic Problems on State Routes in Indiana":

"In order to establish uniformity of application of the various speed limits, the following definitions are applied to all proposed speed zones on the state highway system:

1. 20-mph zones shall be established when at least 50 per cent of the frontage (including both sides of the street) for a distance of 500 feet or more, measured along the centerline of the street is used for business.

2. 30-mph zones shall be established in locations outside of 20-mph zones where the total frontage on both sides of the street is occupied by residences or residences and business buildings under 100 feet apart....

3. 40-mph zones shall be established in locations not covered by 20- and 30-mph zones

when the total frontage on both sides of the street is occupied by residences or residences and business buildings more than 100 feet and less than 300 feet apart" (69).

"The following rules are also followed in the use of speed limit signs:

1. A 30-mph zone must always be preceded by a 40-mph zone at least 700 feet in length.

2. A 20-mph zone must always be preceded by a 30-mph zone at least 700 feet in length.

3. The signs for the beginning of a section of road or street zoned for a certain speed must have the word BEGIN at the top.

4. The numerals on all BEGIN signs shall be reflectorized.

5. At the end of each zoned area the signs shall have the word END at the top.

6. Intermediate signs shall be placed at sufficiently frequent intervals to keep the motorist informed and to secure obedience" (69).

Speed limits at this time (late 1930s) were as high as 60 mph in Colorado and other states. "Sixty still sounds like a lot of speed to many city folks in Eastern states, but it's commonplace in many other parts of the country" (65).

A 1937-38 study of "Vehicle Speeds on Connecticut Highways resulted in the following findings:

"A summary of the observations made during these periods...reveals the surprising fact that the average speeds of passenger cars and buses were highest in winter and lowest in summer, despite the fact that 25 percent of the winter observations were made in bad weather...It seems probable that the slower speed of passenger cars in summer results from the presence of numerous pleasure drivers."

"That passenger cars from outside the State are driven at markedly higher rates of speed than Connecticut cars was revealed by the study. The recorded speeds also show that the driver farthest from home drives the fastest."

"The observers recorded the license numbers as well as the speeds of these cars. A list of the license numbers was sent to the office of the Connecticut Department of Motor Vehicles, where the name of the owner of each car and his accident record since 1928 were ascertained. Because of duplications, the final figures included 981 cars observed at high speeds and 1,054 observed at moderate speeds.

"Results of these observations...show that 27.8 percent of the drivers observed traveling at high speeds had been involved in accidents, as compared with 21.3 percent of the drivers observed traveling at moderate speeds. In other words, 30 percent more of the fast drivers had been in accidents. Moreover, those fast drivers who had been involved in accidents, had had more of them and accounted for 45 percent more accidents" (70).

During this time there were also some technical advances in traffic control, for example, Maryland's use of "...a new traffic-signal system combining automatic speed control and traffic control at a highway intersection..." (71).

Once again innovation was called upon to tackle the community speed problem. In New Brighton, Pennsylvania, "[l]arge signs were posted at two main entrances to the town...advising the motoring public that they are entering New Brighton and that no speed-traps will be encountered. Instead, they are asked to please abide by the 35-mile limit, and are thanked in advance for their cooperation" (72).

World War II presented a new approach to the control of vehicle speeds.

> "In the war years the traffic safety program continued, although curtailed. A nation-wide appeal was made to save manpower by preventing accidents, and this, with gasoline rationing and a national speed limit of 35 miles an hour, greatly reduced the number of accidents" (4).

> "The wartime shortage of rubber following 1940 caused Federal authorities to lengthen the useful life of motor tires by making 35 MPH the maximum speed at which vehicles should be operated" (73)

> "Before World War II the basic rule of 'reasonable and prudent' speeds was in effect. On March 18, 1942 the Governor of Indiana established a 45 mph. limit to conserve rubber. On July 26, 1942, the limit was lowered to 40 mph. and on September 30, 1942, the entire nation was placed under a 35 mph. limit." Elimination of the war limit after the fall of 1945 brought back the 'reasonable and prudent' rule (74).

Speed rules were set up for special circumstances of wartime driving, such as moving under blackouts when no air raid signal had been given (75).

> "Joseph B. Eastman, Director of the Office of Defense Transportation, in a statement addressed to state and municipal authorities, said: 'The necessity for conserving vehicles, rubber and fuel, and the enormous expansion of war production in some areas, have created important changes in street traffic. Adjustments in traffic control methods have not kept pace...This is wasting rubber, gasoline and time.'" He asked for elimination of unnecessary traffic signals, flashing lights, use of traffic officers to decrease delay when necessary, and establishment of war routes for workers (76).

The following quote traces the average speed trends from the early years of the automobile through World War II:

> "Statistics of free-driving speeds on flat, level, two-lane rural tangents during fair daylight hours show that average driving speeds have increased over the years. Average speeds of 21 mph were reported as early as 1910 in Iowa. In 1925, average speeds of 25.6 mph ranging from 14 to 61 mph, were found in a statewide speed survey of Rhode Island. Speeds of 37 mph were reported in Iowa for the same year. By 1934, the average speed of motor vehicles in Connecticut had reached 39 mph. Just prior to World War II, in 1941, the averave free speed on rural roads was 47.1 mph. War conditions caused a drop in average speed to 36 mph by the end of 1942, but since that time it has climbed back to values above pre-war levels" (77).

Developments after the war included such practices as the reduction of the speed limit at night (78).

A study at the University of Illinois in 1947-1948 indicated the following: (1) Traffic ignores speed limits and runs at speeds which drivers consider safe for conditions; (2) Speeds vary little with traffic volumes up to the point where congestion begins; (3) Most posted speed limits are ineffective because they are unreasonable; and, (4) Sufficiently high, enforceable speed limits would expedite traffic and aid in enforcement (79).

In 1948 radar was introduced into the system of traffic control and became an important tool for police and traffic engineers (80). In the years that followed further technological developments including such devices as "speed-watches" and computerized photographic mechanisms were added (81, 82).

A 1949 periodical acknowledged the fact that "[t]he establishment of a uniform legal speed limit for rural and urban

areas is not a solution. Such a policy is unsound. A limit set at the maximum safe speed for the poorest section of highway is obviously an invitation to disregard the law...35 of the States now exercise the authority to post speed limits differing from the speed that has been set as a general maximum. The rural Statewide daytime limits range from 25 miles per hour in 1 State to no limit in 14 States" (83).

The nature of State speed regulations in the 1950s is also indicated in the literature (84).

> "Some states still have speed limits not exceeding 40 miles per hour on major highways, but higher speeds are in effect in most states. Except for Connecticut, Maine, and New Jersey, no state has a 40 mile limit on rural roads. The Merritt Parkway in Connecticut permits a speed of 55 miles per hour over a major portion of its length, while the Pennsylvania Turnpike between Harrisburg and Pittsburgh allows 70 miles" (6).

In March of 1953 the Indiana Legislature passed a 65 mph limit (74).

Higher speed limits were supported in order to help justify expenditures for better roads. Traffic laws at this time were not keeping up with the rapid rise in average speeds. Author J. Edward Johnston suggested in 1956 that the 85th percentile was reasonable and encouraged uniform speed. He also stated that many factors were more important than speed in accident causation (85).

A 1956 definition of "speed trap" stated:

> "Today we have another kind of speed trap. A speed trap may be defined as a street or road which is wide enough, straight and smooth enough, and sufficiently free of obstructions limiting visibility to permit driving at a certain speed but where the law nevertheless calls for a much lower speed" (86).

The National Safety Council Committee on Speed suggested certain policies which were embodied in the 1956 revision of the Uniform Vehicle Code. The recommended basic rule was a speed reasonable and prudent under existing conditions. It proposed absolute speed limits of 30 mph for urban districts and 60 mph day limits and 55 mph night limits for other roads. It also recommended that in speed zoning fixed numerical limits should be altered by appropriate authorities and based on engineering and traffic investigations (87, 88).

Recent work in the area of speed limits has been not only in technical and mechanical developments (89) but also in research. A survey of states' officials conducted in connection with the Vehicular Speed Regulation Research Project found that: (1) the "reasonable and prudent" statewide speed laws should be eliminated; (2) maximum speed limits should be 70 mph for rural controlled access highways and 55 to 65 mph for other main rural highways; and (3) a minimum limit around 40 to 45 mph should be used on rural controlled access highways (90).

Comparison of speeds in the last 20-25 years shows the following increase:

"To the extent that high speed is shown to be detrimental, there is truly cause for concern. Since 1945, average rural speeds in the U.S. have been increasing approximately 0.5 miles per hour (MPH) each year. The percentage of vehicles exceeding 50 MPH on selected rural highways has increased from 40 to 80 percent in the period 1947-1967. On representative sections of rural Interstate highways, 19 percent of all traffic exceeds 70 MPH" (91).

Annotations to the *Uniform Vehicle Code* of 1967 stated that 20 states were in substantial conformity with the basic speed rule. Compliance with recommended maximum limits is high, and 34 states are in substantial agreement with recommended minimum speed regulations. Twenty-three jurisdictions require speed zone alterations to be based on engineering and traffic investigations, and twenty-four states make some provision for administrative alterations (92).

In July of 1968 the "basic speed rule" of the *Uniform Vehicle Code* was changed to read:

"Sec. 11-801 -- Basic rule

No person shall drive a vehicle on a highway at a speed greater than is reasonable and prudent under the conditions and having regard to the actual and potential hazards then existing. Consistent with the foregoing, every vehicle shall be driven at a safe and appropriate speed when approaching and crossing an intersection or railway grade crossing, when approaching and going around a curve, when approaching a hill crest, when traveling upon any narrow or winding roadway, and when special hazards exist with respect to pedestrian or other traffic or by reason of weather or highway conditions" (93).

An interesting addendum to the history of speed limits abroad is a recent practice in France.

> "Those under 20 years of age, and all drivers who have held a license for less than a year, are expected to conform to a speed limit of 90 kph (56 mph). Special stickers must be affixed..." (94).

The preceding pages of this section have traced speed limits from their applications before the development of the automobile to their present-day status. This historical tracing leads to several important conclusions.

First, there is evidence of distinct stages in the history of speed limits. Their first applications were to horse-drawn vehicles. Their early application to the motorized vehicle in Europe was carried over with the introduction of the automobile in the United States. Immediately there was a dramatic period of exaggerated concern over restricting the automobile. This concern was based not only on safety and the reduction of accidents but also on economic interests. Little attempt was made to determine the effect of speed regulations. The country then settled down to take a more rational look at the speed problem, and a period of legislation ensued. The middle and late 1930's brought the organized safety movement, which again was followed by a period of legislation, technical developments, and research which has extended up to the present.

The second point of importance is the fact that many of the present ideas about speed and speed regulation were espoused very early in the history of the automobile's regulation. It was recognized that speed limits must be reasonable

to obtain driver compliance and that speed excessive for conditions, rather than speed, per se, was the basic problem. Other early points of discussion were over economic aspects of fast driving, air pollution, and taxation for road repair. That such amazing insight was evidenced so early in the history of the automobile in America says little for the "progress" that has been made to date.

2.2 The Relationship of Speed and Speed Limits

Several research studies conducted in the 1950s concerned the relationship of speed and speed limits.

Professor C. C. Wiley of the University of Illinois observed traffic speeds under 20 mph limits, 25 mph limits, 35 mph limits, and no limits. He found that traffic moved at the same speed regardless of what the signs said, or even without signs. On well-paved streets traffic moved at about 40 mph, while on a poorer surface travel speed was about 30 mph. In both cases the posted speed was 25 (95).

Wiley, *et al.*, concluded that traffic consistently ignored posted speed limits, and even the absence of speed limit signs, and ran at speeds drivers considered reasonable, convenient and safe for existing conditions. Drivers operated by conditions rather than by their speedometers. And the general public paid little attention to what limits were posted (96).

A before-and-after study to assess the effectiveness of speed zoning in Wisconsin covered six high-accident locations.

After the zones went into effect, frequency and severity of accidents decreased and the pace decreased by 5 mph (97).

A 1955 book by T. M. Matson, W. S. Smith, and F. W. Hurd includes the following explanation:

> "For any given road there is an optimum speed limit which will have the greatest effect on spot speed. This value is usually between the 80 and 90 percentile of the free-flowing speed as plotted on a cumulative-frequency curve.
>
> "The effect of speed regulations on the maximum speed of single vehicles is influenced by the degree of enforcement, but the number of vehicles traveling at excessive speeds is sharply reduced when optimum speed limits are adopted. Furthermore, proper speed regulation causes vehicles in the lowest 10 to 25 per cent of the range to increase in speed, as road users tend to accelerate, on the realization that they are traveling far below the stated safe allowable speed.
>
> "The over-all effect of proper speed regulation is that a greater number of vehicles travel closer to the average speed..." (77).

A 1956 study in Nashville, Tennessee, concerned driver compliance with unusual speed limit signs, for example 34 mph and 39 mph. It was concluded that: (1) Night traffic averaged 1 mph slower than day traffic; (2) Peak hour traffic averaged 2 mph slower than off peak traffic, and peak hour traffic was more uniform; (3) Posted speed limits had little, if any, effect on traffic speed, regardless of whether the posted limit was set at multiples of 5 mph or not; (4) 85th or 90th percentile speed provides a guide to reasonable and prudent speeds (98).

A study conducted in St. Paul in 1956, 1957, and 1958, studied the effects of raising the 30 mph speed limits to 35 mph or 40 mph. The 30 mph limits on these streets were apparently considered to be unreasonably low, as there was a high percentage of violations. Conclusions drawn from the study were: (1) The 85th percentile is an adequate method of determining speed limits on urban arterial streets as far as its effect on travel speeds; (2) When speed limits are justifiably raised 5 to 10 mph according to the 85th percentile method, there is a tendency for mean, median, modal, and 85th percentile speeds after the change to remain near those before the change. Changes tend to be small and unrelated to the change in the limit; (3) Such changes in speed limit will produce more uniformity in some cases, less in others, and no change at all in still other instances (99).

A later St. Paul study conducted in 1960, also investigated the effects of changing the speed limit on urban streets. In this study, "[r]aising the speed limit had no consistent effect on the standard deviation" and "[a]t every lowered speed limit test location the standard deviation of the normal speed curve increased after the limit was lowered" (100).

The effects of implementing a 35 mph speed restriction were studied in Pennsylvania. The erecting of 35 mph speed signs in a previously designated 50 mph zone has a marked effect on the speed of traffic, although a sizable proportion of the drivers violated the new limit (101).

A comparative speed study carried out over a five-year period on four-lane Pennsylvania highways showed that in 1955 speeds were 3 to 5 mph slower than in 1950, despite the fact that the posted maximum was raised from 50 mph to 60. Average speed was found to be inversely proportional to traffic volume, and average speed decreased 3.5 mph for each 100 vehicles per hour increase in volume (101).

A 1957 study which measured the effect of slow and stop signs on drivers found that slow signs in themselves were generally not effective. They should not be used without additional signs stating the nature of the danger, and even then should not be used unless there is a great need to decrease speed (102).

An early study of speed limits observed 60,000 drivers to determine the percentage of operators who violated the legal speed limit while approaching intersections. Sixty and nine-tenths percent approached the intersection at speeds exceeding the limit. Mid-block studies showed 62% over the 25 mph limit and over 1% of the drivers exceeded the limit by at least 20 mph (103).

A study by Elmburg and Michael recorded spot speeds for 31,573 vehicles (20,552 during the day and 11,021 at night) before and after the posting of speed limits.

> "The study revealed that the drivers paid little, if any, attention to posted speed limits. They seemed to choose a speed which they themselves considered appropriate for prevailing conditions..." (104).

"A new Highway Research Board bulletin (341) on the speeding habits of urban drivers reports findings which confirm the surmises of many experienced traffic officers. Among the findings are these:

1. Speed regulations have no significant influence on how fast city motorists drive at any one spot.

2. Chronic speeding apparently is not widespread.

3. City speed regulations are violated more frequently than rural limits..." (105).

Gerald J. Driscoll, Chief of the Traffic Safety Service of the New Jersey Division of Motor Vehicles, was quoted as saying:

"Ridiculously low speed limit signs only give a false sense of security, afford no protection, are a waste of money, and create a disrespect for all other control devices" (106).

The Illinois Division of Highways found that:

"1. The physical changing of the numbers of speed limits signs upward will not, of itself, generate higher speed proportional to high postings.

"2. The physical changing of the numbers on speed limit signs does not materially alter a speed limit pattern based on normal operation within a zone. When speed limits are raised, in many instances, the speed patterns are lowered..." (96).

A study of two freeways in Texas indicated that vehicle speeds were influenced by posted legal limits (107).

Another aspect of freeway control was studied by the California Division of Highways.

"The objective of this study was to determine the feasibility of establishing minimum speed limits on multiple lane highways, on a lane to lane basis...

"From the analysis of individual vehicle speeds several things were learned: (1) There was little evidence of increased average speeds due to signing. In fact, most study sites showed a decrease. (2) With the average speed in the range of 67 mph for the left lane of high speed freeways and the variation in speeds in the range of four to six mph, it was found that a vehicle traveling at the posted minimum speed (60 mph) would often be impeding traffic...

"The most unexpected result of the minimum speed signing was a shift of traffic to the left; i.e., for a given traffic volume, more cars drove in the left lane. It was originally anticipated that the signs would cause slow drivers to move to the right. This shift to the left lanes resulted in the above mentioned reduction in mean speeds. It also resulted in increased violation of the minimum speeds; increased passing on the right; and increased instead of reduced travel time..." (108).

A 1963 report in connection with the Vehicular Speed Regulation Research Project presents the findings of a study to ascertain driver observance of reasonable speed regulations on a relatively homogeneous highway. It was concluded that: (1) the presence of speed regulations in urban areas had no significant influence on the central tendency and variability of spot speed characteristics; (2) individual drivers have variable speed habits; (3) at any one check point 15% of the drivers exceeded the speed limit, but 50% of the drivers violated the limit at at least one check point, making apprehension of the fastest 15% unrealistic; (4) chronic speeding was not evident, for only 20% of the drivers exceeded more than 2 out of 9 speed limits; and, (5) more drivers violated urban limits than rural limits (109).

Another part of the Vehicular Speed Regulation Research Project employed experimental and standard advisory speed signs to study the effects of advisory speed limits on drivers (110, 111).

> "The variance analysis showed that the drivers did not differentiate between the two types of advisory speed signs tested, and that the speed at which the drivers negotiated the centers of the curves does not correlate with the posted advisory speed. A special study...indicated that posted advisory speed does influence the rate of deceleration of drivers entering the curve.
>
> "There is a tendency for the highest mean speeds to occur when high advisory speed limits were posted and for the lowest mean speeds to occur for the lower advisory speed indications...
>
> "The 85th percentile speeds tended to be higher for advisory speed signs of higher magnitudes. There was a correlation between safe operating speeds and the 85th percentile speeds" (110).

A third portion of the Illinois study concerned the practicability of using posted speed limits to obtain conformity between average speed of the traffic stream and the adjusted optimal speed. This is based on the theory that there is a speed at which the cost of highway transportation is minimized and this speed can be adjusted to conditions less than ideal.

> "It was found that in the majority of cases the mean speed observed at each site was within 5 m.p.h. of the recommended modified speed. There were many locations, however, at which the mean speed of the traffic stream would have to be reduced by more than 5 m.p.h. if the desired objective of minimizing costs was to be achieved. The results of previous studies indicate that changes of this magnitude have been accomplished by means of a reduction

in the speed limit but these results have generally been obtained in areas where special speed restrictions have not previously been in effect" (112).

The Illinois study also found that absolute speed limits received the highest observance, while advisory limits were exceeded more frequently than either absolute or regulatory speed limits (90).

In 1967, R. R. Roberts arrived at the following conclusions concerning speeds on urban arterial streets:

"(1) The mean speed of the vehicles was not changed significantly by increasing the posted speed limit from 35 MPH to 40 MPH.

"(2) A reasonable posted speed limit based on the 85th percentile speed appears to stabilize traffic to allow the speed distribution to more closely approximate a normal distribution.

"(3) It would seem to appear that motorist [*sic*] observe and respect a reasonable speed limit more so than [*sic*] unreasonable one as indicated by the 85th percentile speeds.

"(4) The stability of traffic flow on an urban arterial seems to be improved as indicated by the reduction in the standard deviation and the standard error of the mean.

"(5) The posted speed limits on an urban arterial street has [*sic*] little or no effect on the inclusive speeds within the 10 MPH pace or the percentage of the total vehicles within this range.

"(6) The task of the police in enforcement of speed limits can be greatly simplified by establishing reasonable speed limits based on the 85th percentile speed together with the other necessary considerations" (113).

The Road Research Laboratory in England summarizes speed restriction experience with the following:

> "Measurements of speeds before and after the imposition of speed limits in France, Great Britain, Northern Ireland, the Netherlands and the U. S. A. have shown that a large proportion of vehicles are driven at speeds in excess of the limit but that the number of vehicles driven at high speed is usually considerably reduced after a speed limit is imposed" (114).

The variety of studies reviewed in this section present the following conclusions concerning the relationship of speed and speed limits.

A number of studies conclude that traffic moves at similar speeds regardless of speed limit signs; thus, drivers ignore speed limits. A similar finding states that posted speed limits have *little*, if any, effect on traffic speeds. Speed regulations are said to have no significant influence on how fast city motorists drive at any one spot. Several studies which altered speed limits found no consistent changes in driving speeds, and the raising of the limit did not generate higher speeds proportional to the posting.

Studies whose conclusions are contrary to the above found that although speeds observed at the centers of curves were not correlated with posted advisory speeds, the posted limit did influence the rate of deceleration on entering the curve. Speed zoning in a Wisconsin study produced a 5 mph decrease in the pace, and the lowering of a 50 mph zone to 35 mph had

a marked effect on traffic speeds. Such findings would support the conclusion that the number of vehicles driven at a high speed is usually considerably reduced after a speed limit is imposed. Another conclusion states that proper speed regulation causes a greater number of vehicles to travel closer to the average speed.

Absolute speed limits are said to receive the highest observance, while advisory limits are exceeded more often than either absolute or regulatory.

Thus, the studies cited in this section illustrate two opposite views regarding the effects of speed limits; and these views are connected by a number of intermediate conclusions relating to specific conditions.

2.3 Driver Speed Behavior and Variables, Other Than Speed Limits, Which Influence It

A variety of aspects of driver speed behavior have been considered in numerous research studies. Some of these will be discussed below.

An early study conducted in 1948 by the Eno Foundation compared accident-repeater groups and accident-free groups in Michigan and Connecticut. Among the topics covered by the interview were attitude and speed habits. Connecticut repeaters showed a significant preference for higher speeds. This was not confirmed in Michigan except for night driving (115).

A 1954 report concerned the study of a commuter route to determine whether or not some individuals consistently eexceeded the average speed. About a third of all drivers exceeded the 85th percentile of the spot speed distribution. It was found that if a set of drivers were observed as many as seven times, more than half of them could be expected to exceed the 85th percentile speed at least once. Speed was also found to be significantly higher for younger drivers (116).

A study by Michaels and Solomon proposed to determine whether advance information of speed change through a visual signal would markedly affect following behavior. Results indicated a significant reduction in mean headway when advance speed change information was presented, and that headway was at a minimum when the advance information was presented 1 to 3 seconds before the onset of change. This significantly reduced the variability in headway (117).

The authors of a study concerning forward velocity and lateral acceleration propose that the perception of lateral force resulting from a change in the direction of motions is an important driving skill. Drivers choose the speed at which they will negotiate a curve before they enter the curve. Thus, the authors have hypothesized that: "1. When the driver chooses a speed he is predicting the lateral force which he will feel in the curve and 2. the lateral force produced will be an inverse function of the speed" (118).

A study to investigate drivers' speed perception involved the ability of eight subjects to halve or double their speed on command. Over the range of speed tested, it seemed that drivers underestimate their speed when decelerating and overestimate it when accelerating (119).

The summary of research which related intelligence and socioeconomic status to driving records states:

> "Official driving records of educable mentally retarded individuals were compared with records of individuals with normal or above intelligence to study the relationship of intelligence and economic status to driving ability and driving habits. Generally, intelligence and socioeconomic status did appear to be influencing factors in the total number of violation points accumulated over a five year period. However, inspection and analysis of driving records indicated that subjects from high socioeconomic groups received more speeding violations than the low groups, and that low intelligence subjects had more points for violations, other than speeding, than the average and above intelligence groups. The low intelligence group differed significantly from an average group on the factors of combined accidents and violations. However, the low intelligence group did not differ significantly from the high intelligence groups on these same factors" (120).

Another article presented the following statistics:

> "Average speed of cars, trucks, and buses rose to a record high of 53.8 m.p.h. during 1962 in an annual study of speed on level sections of main rural highways during periods of relatively low traffic densities when most drivers could travel their desired speed. Twenty-seven states reported the results of 1,006 speed studies.
>
> "The 58.8 m.p.h. average speed was 1.2 m.p.h. above the 1961 speed. Average speed for passenger cars was 55.1 m.p.h.; trucks 49.5 m.p.h. and buses, 56.8 m.p.h." (121).

A Los Angeles study to assess the effectiveness of written warnings as compared to citations involved the stopping of motorists who exceeded 40 mph in a 25 mph zone. By following these drivers after citations or warnings were issued, the study found that:

(1) Where a citation was issued, accompanied by no conversation between driver and officer, 32 of 100 cases recorded exceeded the limit again within 5 miles.

(2) Where a safety message accompanied the citation, 33 of 100 cases exceeded the posted speed within the next 5 miles.

(3) Where a written warning and safety message were issued in place of a citation, 43 of 100 motorists had exceeded the limit within 2 miles and 22 more within 5 miles, for a total of 65 (122).

A report analyzing Indiana spot speed observations from June and July of 1968, showed the overall average speed for passenger cars to be 64.5 mph and the average for trucks to be 56.5 mph. A regression analysis of data for eleven years showed an annual increase of .85 mph for cars and .87 mph for heavy trucks. No large increase in truck speeds followed a 15 mph speed limit increase for trucks on Indiana highways. Trucks seem to travel at speeds which their drivers consider safe regardless of maximum speed limits, and the growing percentage of automobiles violating the speed limit indicates the same (123).

A November 1969 follow-up to this report analyzed speeds observed during the months of July and August 1968.

> "Analysis of the speeds showed the over-all average speed for passenger cars was 67.9 miles per hour. The over-all average speeds for trucks on the three types of highways was 59.5 miles per hour.
>
> "A regression analysis on the available results of the past eleven years showed an annual increase of 1.03 miles per hour for the over-all average speed of passenger cars and 0.97 miles per hour for the over-all average speed of heavy trucks" (124).

The variables which have an effect on driving speed are numerous, and a rather extensive amount of research has been done in this area. Several early studies were conducted in the 1930s.

A 1934 study determined average and maximum travel speeds on various surface types and found the fastest speed on concrete, with decreasing speeds on oil mat and gravel (125).

A study of factors which influence driving speed found the following in 1939:

(1) speed increased with trip distance

(2) new cars traveled faster than old

(3) driver sex and number of passengers had little effect except in a study of racial difference in South Carolina where colored drivers showed a sharp increase with passengers (126).

The New York State Department of Public Works in 1953 made a study of speed characteristics at vertical curves with restrictive stopping-sight distance in order to determine the relation between sight distance and driver speed. Drivers were found to reduce their speeds far less than required for safe operating conditions. No consistent relation was found

between operating speeds at the crest and minimum sight distance. Neither did a relationship exist between driver operating speeds and safe speed standards (127).

A 1954 study recorded driver performance and passenger car speeds on horizontal curves with minimum sight distances from 200 to 655 feet. Four conclusions were drawn: (1) Drivers don't significantly alter their speeds after entering a curve; the adjustment is made on the approach; (2) Outside and inside lane speeds are about equal despite a 20% greater sight distance in the outside lane; (3) Drivers drive under the high speed permitted by easy curves, but exceed the design limit on sharp curves; (4) When minimum sight distance is 400 feet or longer, few drivers exceed what can be considered a safe speed (128).

A study of two freeways in Texas indicated that vehicle speeds were influenced by posted legal limits and by volume levels.

> "...The minimum speed limit was 40 mph and the maximum speed limit was 50 mph. The average speed of the vehicles using the inside lane was 45 mph during periods when the volume level was less than 1,500 vehicles per hour. The average speeds based on 5-min. periods for the inside lane were within a band width of 5 mph. This held true up to a 5-min. volume of 125, which is equivalent to a level of 1,500 vehicles per hour. When this volume level was exceeded, the average speeds became erratic and varied from 30 mph to 45 mph" (107).

> "Five minute average speeds of 40 to 50 mph are maintained in the middle and inside lanes when the 5-min. lane volumes are below 150 or an equivalent hourly volume level of 1,800 vph" (107).

"On the two freeways studied, the vehicles in each lane tended to adjust to the speed of the slower parallel lane. This sympathy of speed between lanes appears to exist regardless of volume" (107).

A study in a Michigan county found that at the five study sites:

"1. The average speeds among the several station-operations differed significantly. Number of lanes and posted speeds did affect average driver speed.

"2. The average speeds among the several hourly traffic volume groups differed significantly. Size of hourly traffic volume did affect average speeds.

"3. The effect of number of lanes and posted speeds is probably significantly greater than that of hourly traffic volume.

"4. There was significant interaction in the speeds between station-operation and hourly traffic volume group. Driver response to changes in hourly traffic volume was not the same at all station-operations. Or, what is the same thing, driver response to changes in number of lanes and posted speed (changes in station-operation) was not the same in different hourly traffic volume groups.

"5. There is a definite trend toward reducing speed as hourly traffic volumes increase up to about 500 vehicles per hour. Beyond this there is no decrease shown" (129).

The study found that "the faster driver changed his speed less frequently and by a lesser amount due to speed zones, number of lanes of roadway and hourly traffic volumes than did the slower driver" (129).

Results of another volume study by T. W. Forbes state:

> "Analysis of speeds by volume groups was carried out using each five-minute sample to estimate volumes and including all cars measured. A trend was found toward a reduction of speed as lane volume increased from approximately 600 to 1800 or 1900 vehicles per lane per hour. This trend, however, was relatively slight.
>
> "Contrary to findings on two and four lane highways reported by others, no maximum volume point was reached, and the faster lanes (toward the center of the highway) showed less tendency to approach a maximum volume than did the slowest outer lane. The three lanes, furthermore, showed different average speeds for the same volume, and the center-most lane actually carried the highest volume at the highest average speed. This is contrary to the often reported relationship of higher speed with lower volume" (130).

In 1939, O. K. Normann concluded that:

> "With light traffic on a rural highway, the speed of each individual vehicle is not governed by the speed of the vehicle immediately ahead, and there is a relatively high mean difference in speed between successive vehicles. As the volume increases, there is an increasing tendency for the speed of the individual vehicles to be governed by the speed of the preceeding vehicles. This causes a marked decrease in the mean difference in speed between successive vehicles, although the decrease in average speed may be slight" (131).

In a study of the effects of objects on the road shoulder, Asriel Taragin found that the presence of a passenger car, maintenance truck, or barricade, 3 to 6 feet from the edge of the pavement, had little effect on vehicle speed for two- and four-lane highways. Speeds did, however, average 3 mph lower on two-lane highways with a lane width of less than 20 feet (132).

A one-month study of "Hourly and Daily Variation in Vehic

Speeds on a rural Highway" in 1951 arrived at these conclusion

> "There is definitely a time-speed variation during the 24 hours of the day.
>
> "The greatest single factor in causing a variation under normal and favorable operating circumstances is apparently the light condition.
>
> "Daylight mean speeds are appropriately 5 miles per hour higher than mean speeds during the hours of darkness.
>
> . . .
>
> "After the daylight level is reached there is very little fluctuation during the remainder of the daylight hours...
>
> "In regard to daily variation, there appears to be no significant difference between various days of the week, with the exception of the morning hours on Tuesdays...
>
> "Speeds on Sunday do not follow the pattern set by weekdays. After the peak mean is reached between 8 and 9 A.M. the means begin to decline throughout the remainder of the day" (133).

In a 1954 a study of horsepower and speeds was undertaken

Robert E. Schmidt reported:

> "[H]orsepower is not the only factor involved in the determination of vehicular speeds. It is true that where speed characteristics or capabilities on level highway sections are to be considered, horsepower is all-important."
>
> "1. The highest powered vehicles, while driven more frequently in the high speed ranges, are not driven at any greater maximum speeds than the lower-powered cars, except perhaps for those under 100 horsepower.
>
> "2. As the percentage of higher-powered vehicles on the highway increases, the average speed of traffic may be slightly increased.
>
> "3. The high-powered vehicles are better able to maintain desired speeds on steep grades and,

because of their lower weight to horsepower ratio, have greater acceleration ability.

"4. The vehicles with from 100 to 130 horsepower appear to be driven as fast as any vehicles of any horsepower.

"5. Inasmuch as vehicles of 100 to 130 horsepower are generally capable of maximum speeds in the range of 85 to 100 miles per hour it would appear that the critical factor in determining highway speeds is still the driver and not the vehicle" (134).

Burton M. Rudy studied signal spacing and suggested 4000-4600 feet as maximum signal spacing for achievement of adequate headings and speed characteristics (135).

A 1940 research study identified a number of relationships between speeds and several different variables. Many of these findings have been supported by more recent research.

"[T]he speeds of 608 drivers on the open highway were obtained without their knowledge together with the vehicle license number, the number of occupants, the sex of the drivers, the time of day and the day of the week. Through the cooperation of state authorities the license number was used to determine the place of residence of the owner, his sex, age, and the weight and age of his car...

"In general, the findings would seem to support the following conclusions:

"1. Prevailing speeds varied on the two highways studied.

"2. Speeds on Wednesday were slower than those on any other week day at the one location where data were available.

"3. There were no differences in speeds by hours of the day between 10:00 A.M. and 5:00 P.M.

"4. Drivers between the ages of 40 and 49 drove faster than any other group and faster than all other groups combined.

"5. Drivers in the younger age brackets drove no faster than did drivers in the older group.

"6. Those drivers having rural route addresses and those residing within 25 miles of the place of observation drove more slowly respectively than did those with street addresses and those who reside more than 25 miles away.

"7. When these rural-urban and near-far groups were examined for possible overlappings, the same relationships were found to obtain except when drivers residing more than 25 miles away were segregated into rural and urban groups. The difference here was quite small and was not statistically significant, thus indicating that those rural people who were farther away from home did not differ from urban people insofar as speed is concerned.

"8. The women observed drove more slowly than did the men. This was true in the case of all secondary comparisons except when men and women residing more than 25 miles from the place of observation were compared. Here no difference existed; those women who were farther away from home did not differ from men in their speed practices.

"9. Lone drivers drove faster than those who were accompanied by one or more persons.

"10. Drivers of new cars drove faster than did drivers of old cars and heavy-car drivers drove faster than drivers of light cars.

"11. The hypothesis is advanced that speed differences appearing between the sex groups, the rural-urban groups, and the near-far residence groups might be explained on the basis of amount of driving experience, as might the differences existing between lone drivers and the drivers who are accompanied by other occupants" (136).

The 1960s brought an increased amount of materials concerning the variables which influence speeds. A number of

studies within the Vehicular Speed Regulation Research Project of the University of Illinois dealt with this area.

In his review of the literature, J. C. Oppenlander divided the variables which influence spot-speed characteristics into five categories: driver, vehicle, roadway, traffic and environmental variables.

> "In summarizing driver variables, trip distance has the most significant influence on spot-speed characteristics, whereas passengers in the car and the sex of the driver are of less importance. From the discontinuities evident in the literature on driver characteristics, it is reasonable to assume that driver variables influence vehicular speeds to different degrees in various parts of the country. Vehicle type (passenger car, single-unit truck, combination truck, or bus) and vehicle age appear to have predominant effects on spot speeds of highway motor vehicles...In a recapitulation of roadway characteristics, vehicular spot speeds are most significantly influenced by functional classification, curvature, gradient, length of grade, number of lanes, and surface type. Other elements are geographic location, sight distance, lane position, lateral clearance, and frequency of intersections. Vehicle volume and traffic density exert pronounced influences on spot-speed characteristics. Percentage of commercial vehicles, passing maneuvers, opposing traffic, and access control and [sic.] also important in evaluation of traffic-stream characteristics. Environmental variables such as time and weather are to be considered in evaluation of spot-speed characteristics" (137).

A study by Oppenlander concerning the statistical estimation of the functional relationships between various variables and mean speeds found that five factors largely determined the rate of traffic flow: horizontal resistance, long-distance travel, marginal friction, vertical resistance, and obsolete pavement. Eight variables were found to explain variations

in mean spot speeds: out-of-state car, truck combination, degree of curve gradient, minimum sight distance, lane width, roadside establishment, and total volume. The two most influential variables in these groups were horizontal resistance and degree of curve (138).

Robert Wortman measured 38 variables at 83 study sites and concluded that mean spot-speeds on four-lane and rural highways could be estimated with reasonable accuracy by using a mathematical model. He found that variation in mean spot-speed could be explained by the following factors: out-of-state passenger cars, minimum sight distance, posted speed limit, and the number of roadside establishments. When the posted speed limit was excluded from the analysis, the following variables were used: combination trucks, out-of-state passenger cars, minimum sight distance, median type, presence of access control, the number of roadside establishments, and the number of access points (139).

James E. Wilson includes the following elements in the development of speed limits: alignment, grade, vertical curves, sight distance, width of traveled way, width of shoulde parking, speed patterns, traffic volumes, pedestrian travel, type of pavement surface, accident picture, roadside culture, and frequency of grade intersections and traffic signals (140).

Mohamed Onsi considered three methods for determining significant variables for spot-speed prediction: (1) the

DuBois method for eliminating insignificant variables; (2) the addition of variables to a simple regression equation; and, (3) a factor analysis indicating pattern of vehicular speed. Onsi favors the second method for use in further research (141).

The following groups of variables which may have an effect on motor vehicle speeds are listed by William Bunte: (A) Physical features of the site: lane width, shoulder width, road roughness, access control, roadside development, lateral clearance, horizontal alinement, vertical alinement, and sight distance; (B) Presence and action of traffic: vehicle volume, commercial vehicles, and driver variables; (C) Controls: type of enforcement, degree of enforcement, and traffic control devices; (D) Variable factors: weather, pavement conditions, seasonal, daily, and hourly variations, and day-night variations (142).

The effects of horizontal resistance (degree of curve, total central angle, superelevation, and minimum sight distance) for two-lane rural highways were studied by Horkay. He found that:

(1) Horizontal-resistance variables influenced driver and vehicle types in the same manner but to varying degrees.

(2) Mean speeds of male passenger car drivers were 1.8 mph greater than of female drivers.

(3) Out-of-state drivers traveled 1.3 mph faster than in-state drivers, when judging on the basis of mean speeds for all values of degree of curve, values of total central angle greater than 18 degrees, and values of sight distance less than 2500 feet.

(4) Mean speeds of drivers with passengers were 1.5 mph slower than cars without passengers.

(5) A significant difference of 1.9 mph existed between mean speeds of combination and light and single-unit trucks with the combination truck traveling faster in all three considerations.

(6) A significant difference of 1.8 mph existed between mean speeds of all three types of trucks and passenger cars although car speed was highly variable.

(7) Superelevation had almost no bearing on speed (143).

J. C. Oppenlander also found that out-of-state cars traveled at higher average speeds on two-lane highways, but residence had little effect on speed characteristics of four-lane highways (144).

Two additional studies connected with the Vehicular Speed Regulation Research Project present the following findings: Drivers' speed was not significantly influenced by posted advisory speed limit signs. Male drivers drove 3 to 4 mph faste than females, and drivers of new cars drove faster than those with old cars. Non-local drivers operated at higher speeds than local drivers on the flattest curves, and drivers with passengers drove slightly slower on sharp curves than those without passengers. Geometric design of curves was found to have a significant effect on driver speed (145).

Speeds of drivers at 12 rural sites in Illinois were measured by camouflaged radar units, and later questionnaires which revealed attitudes and opinions on speed were administer

to the drivers. The results of 1,440 interviews indicated that drivers' choice of speeds are influenced by expected arrival time, frequency of road use, opinion of speed limit, vehicle type, amount of driving connected with their work, and traffic, weather, and road conditions. Most drivers liked to drive and were aware of both the speed limit and the speed they were driving (146).

In addition to the Illinois study, various other sources have contributed to this area.

A periodical "New Brief" states that:

> "...researchers conducted considerable research to determine what factors cause a motorist to reduce his speed. Major factors were curves or grades which reduced sight distances; and urban development such as curbs and gutters, buildings and trees. However, in the first case drivers reduced their speed only in developed areas, not in rural areas. And, in the second case, they did not reduce their speed nearly so much when approaching residential as commercial development" (105)

The *Traffic Engineering Handbook* presents the following elements as factors to consider in speed zoning:

1. Physical features
   a. Design speed
   b. Measurable physical features
      (1) Maximum comfortable speed on curves
      (2) Spacing of intersections
      (3) Number of roadside businesses per mile
   c. Roadway surface characteristics and conditions
      (1) Slipperiness of pavement
      (2) Roughness of pavement
      (3) Presence of transverse dips and bumps
      (4) Presence and condition of shoulders
      (5) Presence and width of median
2. Accident experience

3. Traffic characteristics and control
   a. Traffic volume
   b. Parking and loading of vehicles
   c. Commercial vehicles
   d. Turn movement and control
   e. Traffic signals and other traffic control devices that effect or are affected by vehicle speeds
   f. Vehicle-pedestrian conflicts (147)

A slightly different influence on speed behavior concerns the effect of stop signs. Studies at five locations on a collector-type street of 6,000 vehicles per day showed that the 85th percentile speed is 20 mph only 50 feet after leaving the stop sign. The effect of a stop sign is nearly completely dispersed after 100 feet. When these stop signs were removed after the study, spot speeds decreased from 3 to 5 mph (148).

A 1963 article states that radar enforcement causes motorists to reduce their speeds considerably, but this influence extends only four miles on each side of the radar post (105).

Several foreign studies have brought out additional points of interest.

T. M. Coburn has written:

> "The existence of clearly defined relations between the mean speeds of different classes of goods vehicles and the mean speed of cars has been demonstrated by Charlesworth and Coburn and confirmed by Almond. These relations indicate that on roads on which speeds are low, there is little difference between the mean speeds of different classes of vehicles, but as conditions improve to permit higher speeds, the differences in mean speed between vehicle classes become greater" (149).

Also, a report from Finland states: "The high mean speeds of the week-end traffic flow cannot be explained except by the

passenger car percentage...the reason for this evidently lies in the different driving population and the different driving habits" (150).

The topic driver speed behavior is multifaceted, and it can be seen from this section that several research studies have been conducted in this broad area. These studies, however, have been very limited in scope, and thus, their findings are applicable only to very specific circumstances.

A limited amount of research has been conducted in the area of drivers' attitudes toward speed and speed control. Several studies have considered various types of curves and speed adjustments to these curves. Researchers have also concerned themselves with such areas as the amount of violation of speed limits, the effect of enforcement on compliance with speed limits, and drivers' perception of speed and speed changes.

Thus, the literature illustrates that relatively little is known in the area of driver speed behavior, and what we do know has limited applicability.

Research concerning the variables which affect speed has been rather extensive and numerous pertinent variables have been identified. Since there is a considerable amount of consistency in the variables identified by the various authors, it would appear that research in this area has more reliability than in some other areas.

Mathematical techniques have utilized various combinations of these variables to predict speeds for particular circumstances. Such research has shown that mathematical models are adequate tools for speed prediction.

Several studies have gone beyond mere identification in pointing out the most significant variables in relation to speed. Since this type of conclusion is applicable only when considering a given set of variables, further study is necessary.

It would seem, though, that this area contains some of the most extensive and least controversial research that has been conducted in connection with speed control. This is probably due to the relevance of these variables to highway design and other aspects of highway safety. Extensive research would be necessary to determine the nature and relative importance of each variable's effect and to identify variables that are yet unknown.

2.4 The Relationship of Speed, Speed Limits, and Accidents

The concern over speed as a causal agent in accidents was probably the primary reason for the early development of speed limits for the automobile. Of course, discussions of this problem date back to the beginning of the automobile, but serious research in the area of speed and accidents seemed to have its beginning in the 1930s. One reason behind this is

the fact that speed capability of the average vehicle rose from 55 mph in 1930 to 84 mph in 1939 (126).

Some time before 1933 the Institute of Traffic Engineers sent a questionnaire to all motor-vehicle departments. Of the 29 replies received, less than half the respondents thought speed limits had an appreciable effect on speed, and more than half the respondents thought speed was the most frequent cause of accidents (151).

Another early study observed 67 locations in Dallas to help determine remedial measures in high accident locations. The study "...does not indicate that there is any direct connection between either high average speeds, or high maximum speeds...and high accident locations" (152).

During a 1937 study of average driving on Connecticut roads, the relationship between speed and accidents was studied. License numbers of a group of cars traveling at moderate speed and a group of cars traveling at higher speeds were recorded. The drivers' response to questionnaires showed that 28% of the drivers in the higher speed group had been involved in accidents, but only 21% in the moderate speed group (70).

A 1937 driver education text gave the following speed-death statistics: 1 in 61 deaths at speeds of 0 to 20 mph; 1 in 42 deaths at 20 to 29 mph; 1 in 35 deaths at 30 to 39 mph; 1 in 25 deaths at 40 to 49 mph; and 1 in 11 deaths at speeds of 50 and over (153).

A study of two groups of drivers, the first traveling over Connecticut's legal maximum of 50 mph, and the second selected from moderate operators in a speed survey, showed that the speeding group had 5 times as many speeding tickets, twice as many traffic violations, but half as many accidents as the moderate group (126).

A rather unique view of traffic safety is presented in a 1941 book by Maxwell Halsey. It states that the chief difficulty is probably not the driver's ability, education, or malice -- nor is it speed. The problems are all grounded in highway design. "It has been indicated that the basic underlying causes of accidents are identical with the causes of congestion." "It is as essential to spend effort to improve the speed of transportation as it is to spend it to reduce accidents. The automobile was not manufactured to save lives, or the roadway built to prevent injuries" (154).

One selection from a book published in 1949 includes the following:

> "A number of examples have shown that speed-zoning reduces accidents. Speed-zones through a village on Long Island reduced accidents 67 per cent. All curves on a 100-mile segment of highway in Indiana were speed-zoned with a resultant decrease of thirty-six accidents on curves in the year following the zoning. Fifty-three persons were injured and seven killed on curves in the year before installation as compared with eighteen injured and none killed on curves during the following year in spite of a 15 per cent increase in traffic" (155).

A study by Morton S. Raff in the early 1950s attempted to determine how rural traffic accident rates were influenced by various physical features of highways and usage characteristics. Traffic volume, degree of curvature, pavement and shoulder width on curves, percentage of cross traffic at intersections, and bridge width were found to contribute heavily. Raff concluded that speed is obviously a causal factor but does not deserve the blame it usually receives (156).

In 1953, D. M. Belmont conducted a study relating single-car, rear-end, and head-on collisions to speed and volume. Though the author recognized that available data were inadequate for making a satisfactory conclusion about the relationship between speed and accidents, he presented the following theories.

"1. The number of single-car accidents per vehicle mile varies with the average traffic speed, and is independent of traffic volume.

"2. The number of head-on collisions per vehicle mile increases directly with the traffic volume and with the average speed. The chance of collision between any pair of opposing vehicles is proportional to approximately the square of their approach speeds."

3. There are two types of rear-end collisions. Those occurring among vehicles travelling so close together that collision is inevitable if the lead vehicle stops suddenly, result in an accident rate that increases with traffic volume and average speed. Those rear-end collisions which occur due to a failure to stop where a safe stop could normally be made have rates which vary primarily with speed rather than volume.

"4. The over-all accident rate per vehicle mile for freely moving traffic is

$$Av_m = C_1 v^{1.5} + C_2 n + C_3 nv$$

where C_1, C_2 and C_3 are positive constants, v is the average speed, and n is the volume per unit time" (157).

A 1956 study found the following:

1. "It appears that faster drivers have more accidents than slower drivers, especially when judged by their speeds in the afternoon. The individual speeds of the drivers with accident records are slightly higher than those for the drivers without accident records; while in the morning, it is the drivers without accident records whose speeds are slightly higher."

2. "It appears that drivers who have very short headways in the morning have more accidents than those who do not. No relation was found between afternoon headways and accident rates. Higher accident rates are associated with younger drivers, larger amount of travel, and newer cars."

3. "The majority of the accidents of record for which information was available occurred on dry road surfaces during daylight, and involved other vehicles. Accidents with fixed objects usually occurred during hours of darkness" (158).

A 1956 article in *Traffic Engineering* stated that over-zealous attempts to insure safety frequently defeat themselve and hamper the driver. Although it is widely believed that speed is the cause of accidents, most accidents occur between 30 and 60 mph. Further, there is no correlation between acci dent rate and top speed regulations, and only 4% of fatalitie on rural highways, where speed is the apparent cause, are caused by vehicles exceeding 65 mph (159).

An attempt to reduce accidents on an exit ramp on the Ohio Turnpike employed a guard rail which gave a sight cue sufficient to slow driving speed without any need to alter the speed limit (160).

Another Ohio study examined single-car accidents (161).

> "About three out of 10 drivers in fatal traffic accidents during 1956 were violating a speed law. 32 per cent were exceeding stated speed limits and 10 per cent were exceeding safe speeds although traveling at less than the stated speed limits or on roads with no stated limits" (162).

Studies of 1959 included the following findings:

Using 600 miles of highway in 11 states and drawing on observations and interviews with 290,000 drivers using these highways, speeds representative of everyday traffic at typical locations on primary rural highways were obtained. Speeds for accident-involved drivers were determined on the basis of police investigation reports. Difference between observed and interviewed drivers and accident-involved drivers indicates that on main rural highways, low-speed drivers are more likely to be involved in accidents than high-speed drivers. Chance of being involved in an accident is lowest about 65 mph, highest for low-speed drivers, and increases over 65 mph (163).

Prior to June 10, 1959, a rural highway in Minnesota had a daytime *prima-facie* limit of 60 mph and a nighttime *prima-facie* limit of 50. All curves were marked with warning signs.

On June 10, 1959 a day-night *prima-facie* limit of 50 was installed. In addition, advisory speeds (determined by a ball-bank indicator) were posted at the curves. A "before and after" accident study showed a substantial reduction in accidents after the changed limit. "In the 18 months prior to th change, 14 accidents occurred while only 2 accidents occurred in the identical 18 months following the changes. It is believed that the traffic control measures made a considerable contribution to this accident reduction" (164).

A study of accident and injury data on 3,203 automobiles involved in injury-producing accidents determined that 74% of the cars in injury-producing accidents were traveling under 60 mph and 88% involved impact speeds under 60 mph. There is a statistically significant association between speed and frequency of dangerous or critical injury. Beyond the 59 mph speed of travel there is a sharp upturn in frequency of critical injury, and the risk of critical injury triples for occupants where speed exceeds 59 mph (165).

"Too much speed is the No. 1 cause of traffic accidents in a city -- speed in excess of the legal limits and speed within the legal limits but too fast for conditions." Selective enforcement and speed control are essential to accident reduction. Speed is not the only causative factor in accidents, but it increases the danger and severity of other violations. "Bringing the speed at which traffic moves down to

legal limits by continuous rigid enforcement will have an almost magic effect on the accident record" (4).

In a 1960 paper John E. Baerwald states that three measures of accident severity show that it increases up to speeds of about 60 mph and more rapidly at higher speeds. But merely placing a speed limit along a highway does not appreciably influence driver behavior. A realistic speed limit must be coupled with adequate enforcement to achieve maximum safety. "No evidence exists to indicate that accidents are increased when speed zones are raised and by the same token, there is no evidence that accidents are materially reduced by establishing zones, although a downward trend is indicated" (96).

A pilot study to determine whether future traffic records could be predicted for individuals indicated that associations between driver's speed as reported by the individual, prior traffic record and subsequent traffic records are much greater than would be expected by chance (166).

David Solomon combined data from 11 states to find the relationships between speed, driver, and vehicle characteristics and accidents on two- and four-lane highways. Concerning accidents, he found:

1. "The accident-involvement, injury, and property-damage rates were highest at very low speeds, lowest at about the average speed of all traffic, and increased at the very high speeds, particularly at night. Thus, the greater the variation in speed of any vehicle from the average speed of all traffic, the greater its chance of being involved in an accident."

2. "The severity of accidents increased as speed increased, especially at speeds exceeding 60 miles per hour."

3. "The fatality rate was highest at very high speeds and lowest at about the average speed."

4. "Pairs of passenger-car drivers involved in two-car, rear-end collisions were much more likely to be traveling at speed differences greatly in excess of those observed for pairs of cars in normal traffic..."

5. "Drivers of passenger cars having low horsepower had higher involvement rates than drivers of cars having higher horsepower,...This may be related to the relatively poor acceleration capability at highway speeds of cars having low horsepower."

6. "Nearly half of all accident involvements were either rear-end collisions or same-direction sideswipes. However, the proportion of these accident involvements decreased as travel speed increased. Single vehicle, noncollision accident involvements contributed an increasingly greater proportion of all accident involvements as speed increased, particularly at speeds of more than 70 miles per hour. At speeds of 80 miles per hour, non-collision accidents constituted half of all involvements. Although angle collisions usually were less than 15 percent of the total, at speeds of less than 25 miles per hour they constituted more than one-third of all accident involvements. The proportion of head-on collisions or opposite-direction sideswipes increased as speed increased; but this type of accident involvement always was less than 20 percent of the total regardless of speed and day or night conditions" (167).

Foreign research studies on speed and accidents include the introduction of a 30 mph limit in Northern Ireland areas and a 40 mph limit in London. The imposition of the 30 mph limit reduced accidents and reduced the proportion of drivers

traveling at high speeds. Removal of 30 mph limits in 17 cases produced about a 45% increase in accidents. The 40 mph limit in London also decreased accidents (114, 168).

An 80 km. per hour speed limit was in effect from December 22, 1960 to January 9, 1961, in rural areas of Sweden. The following results were obtained:

> "By collating the daily record of accidents with the foregoing rural data, we find that accidents, casualties and fatalities all declined in rural areas from Dec. 22, 1959 - Jan. 9, 1960 to the speed-limit period. It should be borne in mind, however, that the 1959/60 period was particularly unfavorable as far as serious accidents were concerned.
>
> "In urban areas, on the other hand, total accidents and casualties both increased from Dec. 22, 1959 - Jan. 9, 1960 to the speed-limit period, whereas the proportion of injuries remained roughly constant. However, a decline was recorded for fatalities..."
>
> "...the available facts do not enable us to determine how much of the observed decline in accident rates from 1959/60 to 1960/61 is attributable to the speed limit itself, how much to other safety measures -- increased enforcement, intensified education and propaganda -- or how much to changes in the volume and composition of traffic" (169).

Accident statistics collected in Sweden (1961) to compare a 38-day period during which a 90 k.p.h. speed limit was in effect and an 86-day period of no speed limit revealed a significant decline in the accident rate during the speed limit periods.

> "A twofold tendency can be observed...Firstly, during the speed-limit periods the 'fast' roads reduced their share of accidents in relation to other roads, and, secondly, this reduction is more pronounced where serious accidents are concerned."

"A study of the number of persons killed in accidents of different types...shows that the decline occurred mainly in head-on collisions, overtaking accidents, turning accidents and accidents involving the running over of pedestrians, while in other types of accidents the decline was negligible or nil."

"...[T]he decrease in the accident rate observed while the speed limit was in force was even more pronounced on those roads where high speeds are the most common."

"...[T]he Committee is of the opinion that there are weighty reasons for assuming that the improvement in accident trends during the speed-limit periods can be ascribed to the imposition of speed limits" (170).

"On January 1, 1963, the speed limit in urban areas in the State of Victoria was raised from 30 to 35 m.p.h. Studies of vehicle speeds in the Melbourne area were made before and after the change and each year since that time...Accident statistics for the year before and after the change have been analysed and no significant increase in accidents found. However, there was a significant increase in accidents in 1964, two years after the change, but this was not sustained in 1965. Accident rates for the Melbourne metropolitan area covering the years of the speed surveys have been calculated and these compared in the light of the form of the speed density function each year. This comparison suggests that the shape of the density function of vehicle speeds in an area may be a contributing factor in accident occurrence" (171).

A 1968 report concerning the influence of a general speed limit on accidents and driving speeds in Finland stated:

"It is obvious that a general speed limit has no influence on low speeds and no essential effect on medium speeds. The speed used by drivers accustomed to low speeds seems to be determined mainly by external driving conditions. On the other hand, the influence of a general speed limit on high speeds is highly remarkable" (172).

"A general speed limit has a decreasing influence, particularly on the number of serious accidents, as well as on conditions in which high speeds are possible when a speed limit is not in force, that is, on the group of passenger cars outside local speed limit areas" (172).

It was also found that the difference in speeds was smaller during the period with a speed limit than in the period of no speed limit (172).

In *The Effect of Conventionally Enforced Maximum Speed Limits on Motor Vehicle Accidents*, J. Wadsworth summarizes:

"There is sufficient extant literature, albeit somewhat controversial, to support the contention that a conventionally enforced maximum speed limit may have some beneficial effect upon motor vehicle accidents by reducing their severity but not their number" (173).

Two important international meetings have summarized the results of studies similar to those discussed above regarding the relationship between speed, speed limits, and accidents. These are the conclusions of the two summary reports:

"Data on the effects of speed limits from a number of countries have been analysed. It is found that: --

(i) A high proportion of drivers do not limit their speed as they should do in order to accord with legal requirements.

(ii) In nearly all cases for which we have satisfactory data, a speed limit had a marked effect in reducing the higher speeds.

(iii) In other cases, the distribution of the speeds was identical before and after the imposition of the limit. This may have been because of the unsatisfactory nature of the speed limits, of the signs indicating the speed limit or, in some cases, of the measurements of speed. In a few cases, it may have been due to the unsatisfactory nature of the speed limit.

(iv) Speed limits seems [*sic*] to have a marked effect in reducing fatal accidents in urban areas. They have much less on slight or damage-only accidents.

(v) There is some evidence that motor cyclist and pedal cyclist fatalities are especially affected by speed limits.

(vi) The imposition of speed limits on a number of main roads including motorways, seems to have had a favourable effect on road accidents" (174).

"1. The collective experience on motorway accidents and speed reported upon shows an irregular pattern of benefits to motorway operation resulting from speed posting. Clearly more investigation will be needed to produce reliable guidelines, as additional speed posting is contemplated.

"2. Differences or conflicts in results reported can be accounted for at least in part by the fact that speed limits have not had widespread application on extensive mileages of motorway in many countries, nor have they been applied uniformly to all types of vehicles.

"3. Where carefully controlled studies have been made, the most noticeable effect of speed posting has been to decrease the number of drivers operating at the extremes of the speed range.

"4. The motorway is a relatively recent design development and as these facilities are first opened to traffic there is a tendency for the initial accident experience to be unfavorable. This higher initial accident rate is commonly attributed to a learning experience on the part of motorway drivers and often is self-correcting. Increasing traffic volumes must nevertheless be reckoned with as a future accident generator. Available data also reveal that an increase occurs in the number of vehicles involved per accident as traffic volumes increase.

"5. Speeds and speed differences are found to be especially critical at night. Accident rates during darkness are two to three times higher than those in daylight for accidents resulting from collision with an object beside the roadway or another road user because of excessive speed, or as a result of vehicles moving at different speeds in the same lane and direction.

"6. There is an indication that high speeds per se are associated with high accident rates. This correlation appears in the comparison of the overall upgrade and downgrade operating experience. For descending grades, both driving speeds and accident rates are higher than on upgrades...

"7. Significant reductions have been measured in the frequency of dangerously short headways in the left lane of a 4-lane motorway as a result of imposing a speed limit for cars. These conditions occur only when the one way volume is more than 100 to 120 vehicles in a 5-minute period. It is likely that the presence of a suitable speed limit would discourage the practice of following too closely even more effectively at higher traffic volumes. Headways in the shoulder lane show no appreciable change as a result of the speed limit posted. In the case of this finding, as with many others, it must be recognized that the precise criteria for selection of a particular speed limit for given environmental conditions are not well defined by any research so far conducted.

"8. To accomodate mounting traffic volumes and the increasing public call for safety, the motorway stands out as the optimum highway engineering solution for safe, rapid movement. Accident rates appear to be more strongly associated with the type of design and traffic volume than with speed limits or speed differences alone. Speed controls in most situations must be largely self-enforcing because of the sheer size or the task of providing close surveillance over motorway drivers. Lacking this, new technology must be developed for an event, so long as the choice of speed is under the driver's foot, the limiting of speed on motorways must be a circumspective approach, never discrediting the value of an appeal to man's reason" (175).

The Automotive Safety Foundation also summarizes several American studies concerning speed zoning and its effect on accidents. Michigan and Arizona studies as early as the 1930s showed significant reductions in accidents, and later studies with similar findings were conducted in Nebraska, Illinois, and Wisconsin (176).

On the other hand, the Ohio Department of Highways studied the effect of speed zoning on accidents and found that the speed zoning practices used at that time were ineffective as means of reducing accidents of any type (177).

Drivers have many misconceptions about their driving abilities, the causes of accidents, and drivers who have accidents. Most people believe that speeding is responsible for a great majority of accidents.

> "From the traffic safety point of view there is no such thing as a speeder -- only people who drive too fast for the condition of the highway" (178).
>
> "...[O]nly eight per cent of all fatal motor vehicle accidents are reported to have happened at speeds above 60 m.p.h. in 1962. On the other hand, more than half of all fatal accidents in urban areas reportedly occurred at speeds under 30 m.p.h., that same year" (178).
>
> "Speeding is outrageously overrated as a CAUSE of accidents. The fact is that it is inattentiveness or errors in judgment or lack of driving skill which contribute most heavily to the causes of accidents. Seldom does a single deficiency cause an accident" (178).

Proceedings of National Highway Safety Bureau Priorities Seminar gives the following explanation.

"Does speed cause accidents and produce casualties? Obviously, considering speed of itself, the answer is often no. As a matter of fact there are occasions when the capacity for speed may even aid in the avoidance of a crash or the mitigation of its results (The capacity to pass quickly in a suddenly developing tight situation and the minimizing of speed differentials in rear-end collisions, for example). On the other hand speed can very often compound the task of accident avoidance if not precipitate a crash. Further, and without question, speed aggravates the consequences of the crash.

"In discussing speed in relation to accidents it is well to delineate the several senses in which the term might be used. It is useful to think of speed in the following contexts:

"a) very [*sic*] high speed - speeds approaching and exceeding 100 mph. Under these conditions, the speed factor dominates as a causative agent, since few if any of the elements of the overall vehicle-driver-highway system have been designed to accomodate travel at this speed.

"b) Excessive speed for conditions - speeds ranging anywhere from zero to design speeds. This category of speeding encompasses many of the speeding citations issued in connection with accidents.

"c) Differential speed or speed gradients in the traffic stream - in part, an overlapping set with excessive speed but also includes inadequate speed. Differential speed and the related variable 'acceleration noise' figure prominently in the safe and efficient flow of traffic. Large speed differentials are seldom if ever cited as a contributing cause, the factor being implicit in other improper driving categories such as following too close and reckless driving.

"With these connotations of speed in mind it can be appreciated that speed is very often not a singular or an explicit variable in the accident equation. Thus, efforts to treat speed as an accident cause are often reduced to treating symptoms arising from the synergy of speed and many other system factors" (179).

In 1960 D. P. Moynihan reported results of a survey by the U. S. Federal Bureau of Public Roads, which showed that cars traveling at 35 mph were involved in 600 accidents per 100 miles traveled compared to 100 accidents at 65 mph. The rate began to rise about 65 but at 80 it was still only 1/4 the rate at 35 mph. This may be biased by the fact that drivers often state that they were traveling 30 mph in court. Teenagers had 4 times as many accidents at 35 mph as at 65 (180)

In 1964 J. Stannard Baker stated that the roles of speed, speed limits, and enforcement in accident causation and reduction are still a matter of guesswork. The research that has been done on the relationship between speed and accidents is mainly statistical inference from primitive investigations. It is not a convincing basis for forming policy regarding speed limits and their enforcement (181).

Dr. Irwin Bross at Roswell Park Memorial Institute, Buffalo, New York, reached the following conclusion by using a mathematical model and computer program developed by J. C. Tanner: "A driver attempting to travel at 80 m.p.h. cannot raise his average speed above that of the traffic stream if the traffic is moderately heavy (nine cars per minute) and moving at or below the legal limit (65 m.p.h.) except by taking dangerous chances in passing." By using computer simulation Dr. Bross found that a driver trying to go 80 mph could achieve

a 13% saving in time on a low-density highway, but such activity increases his chances of getting killed by at least 400% (182).

M. Earl Campbell presents a unique approach to speed-accident comparisons. A May 30, 1964, news release from the California Division of Highways stated that although only 19 persons have been killed at the Indianapolis 500 since 1911, this is a fatality rate of 3,930 per 100 million vehicle miles as compared to a fatality rate of 3 per 100 million vehicle miles on California freeways. This 133,424% increase at 140 mph on the race track shows how accident frequency increases above 65 mph.

> "Traffic records and physics indicate that not only the hazard of severity but also the hazard of frequency of hitting another vehicle or fixed object increases with speed, and these hazards become specially notable in the higher ranges. Speed and accidents cannot be related to each other simply as a two-dimensional relationship: the relationship is always multi-dimensional and may include one hundred other factors...the third dimension of traffic density must always be included if any valid relationship is to come out of the analysis...
>
> "The hazard of frequency...is related to these conditions: (1) the speed of the subject car related to the density, frequency distribution of speeds of all the cars in the total traffic stream, and (2) fixed objects and other roadside hazards. There are other factors, but these appear to be most important. It appears also that the hazard rate above and below the average speed of traffic flow increases faster than the change in rate of speed...
>
> "One of the best confirmations of the increase in hazard of frequency of involvement with increase

> in speed is found in the 1959-64 records of the single-vehicle accident...This type of accident constitutes more than one-third of the accidents resulting in fatalities, and it is increasing at a rate significantly faster than the average rate of increase of fatal accidents, especially in urban areas" (183).

Authors R. L. Goen and R. G. Poulsen have recently suggested some rather harsh measures for reducing accidents. Among other alternatives, Goen suggests a 20% reduction in speed limits and poses this question: "Do we prefer to have 25,600 people killed each year and the other associated accident costs, rather than increase driving time by an average of 11 minutes per day per person" (184, 185)?

Poulsen proposes a steeply graduated tax on automobiles according to their high acceleration ability. (186)

The National Highway Safety Board Staff states that the factors clearly belonging to the speed-accident relation include vehicle stopping capability, tire limitations, head-ligh limitations, acceleration and maneuvering capability, driver skill and behavior, alcohol, and roadway and roadside factors. The BPR-Solomon report based on data collected in 1954-59 shows that about 29% of fatalities are associated with vehicle speeds of 63 mph and higher. At 62 mph there is a sharp inflection upward in fatalities per vehicle involvement. California data also indicate that 27% of the fatalities occur at speeds above 60 mph (187).

A 1966 article by H. Richard Mitchell, was concerned with accident rates, severity, types, and contributing violations on five sections of freeway. It showed that "...more than half of the violations contributing to accidents on the freeway sections studies were directly related to speed differential or to stream friction between vehicles moving in the same direction" (188).

The Interstate System Accident Research Study was conducted to determine whether speed variance contributed to accident involvement on the Interstate System. Results of the analysis indicated that a reduction in the variation of speed among vehicles should significantly reduce accidents. The lowest accident involvement rate occurred at approximately 12 mph above the mean speed of a study unit. As the magnitude of the variation increased, either above or below the mean speed, the involvement rate increased. The author concluded:

> "It appears, however, that with respect to accident involvement on freeways, as well as on conventional rural highways, both very high and very low speeds are dangerous, and it is differences in speed among vehicles that cause 'hazardous situations'" (189).

Statistics from "Traffic Accident Facts, 1969 Edition" state:

> "Of the 64,800 fatal accidents which occurred in 1968, speed was a factor in about 14,700 -- 4,500 in urban places and 10,200 in rural areas.
>
> "Speed does not always mean 70 mph. For example, more than half of the fatal accidents in urban areas occurred at speeds under 30 mph" (190).

A recently completed research project summarized its investigations as follows:

> "Over a thirteen month period, 200 accidents, involving 353 vehicles were investigated on the state roads of Monroe County, Indiana. In addition, 94 accidents which occurred on county roads were investigated...The results of this study indicate a "U"-shaped relationship between involvement rate and speed deviation...These results confirm the hypothesis that slow driving as well as fast driving increases the likelihood of being involved in an accident. However, the curvature of this U-shaped relationship is not as pronounced as that given by Solomon...in a previous study" (191).

It is well recognized that speed plays an important determining role in accident severity, but its role as a causal agent is still quite controversial. While some conclusions state that speed is the most important and most frequent cause of traffic accidents, the more recent viewpoint is that although speed is a factor in accidents, it is one of many factors and not necessarily the most significant.

Paralleling the controversy over speed as a cause of accidents is the question of whether or not speed limits reduce accidents. Both foreign and American studies show that speed limits have a variety of effects, generally favorable, on the accident picture.

A number of authors have pointed out that many accidents occur in both the low and excessively high speed ranges, while accident experience is at a minimum at the average driving speed.

A newer concept in the study of speed and accidents is the theory that accidents occur with deviations from the average speed of traffic. Thus, it is proposed that the speed distribution is the most important factor for consideration.

The wide variety of publications supporting the different approaches to the speed-accident relationship illustrate the turmoil found in this facet of the speed problem.

2.5 Methods for Establishing Speed Limits

"Methods" for establishing speed regulations were cited as early as 1932. Critical speeds for curves and street corners with obstructions were to be posted where simple "curve" and "slow" signs were inadequate. A simple method for determining critical speeds at obstructed intersections was provided so that a higher speed on a given street was the determinant of the appropriate speed on the intersecting street (192).

At the proceedings of the First California Institute on Street and Highway Problems, F. M. Carter gave the following guides to setting speed limits.

> "In no case should the speed posted be lower than the limit of the pace speed; the pace speed being the ten-mile increment of the speed curve in which the majority of the vehicles are traveling."

> "Traffic engineers have found that this curve is fairly uniform until it reaches the 85 per cent point, and this is generally called the critical speed. Somewhere along the curve the majority of vehicles checked are traveling and a 10-mile section of the curve is found that contains more vehicles than any other 10-mile range and this 10-mile range is called the pace speed.

"Inasmuch as many of the vehicles are traveling within this pace speed, a zone established within this 10-mile increment should be recognized as reasonable by the motorist because he has determined that as the speed at which he feels safe in traveling. This selected speed should not be much lower than the critical speed."

"When the accident rating is much higher than the average for other highways, the estimated safe speed should be nearer the lower limit of the speed range" (193).

In 1957 a study of Winnipeg, Canada, cited type of highway, physical dimensions, and abutting land use as principles for decision making regarding the setting of speed limits (194)

A 1957 article by John E. Baerwald cited the following warrants for speed zoning:

"The warrants, as presently proposed, require knowledge of certain conditions such as design speed, minimum length of zone (if proposed zone is lower than adjacent zone), minimum distances between access points, and the frequency of roadside businesses per mile. Consideration is also given to such items as the upper and lower limits of the pace, the 85th percentile speed, the accident rate per million vehicle miles, and the results of test runs" (195).

The Ohio Department of Highways designated division engineers as responsible for requesting alterations for *prima facie* speed limits in construction zones. The Engineer of Traffic analyzes requests for changes of the *prima facie* speed limits and makes his recommendations on the basis of warrants including the following: pace, 85th percentile, consideration of total accidents, consideration of driveway or intersection accidents, and highway design (196).

An article entitled "An Informational Report on Speed Zoning" gives much the same explanation citing four factors to be considered: 1. Prevailing vehicle speeds; 2. Physical features; 3. Accident experience; and, 4. Traffic characteristics and control. "The prevailing speeds of traffic on the section of highway involved are the most important, though not necessarily the determinative factor in speed zoning" (197).

A similar recommendation is given by other sources (198, 199).

Dr. J. C. Oppenlander cites two present methods of setting speed limits: (1) an arbitrary selection of speeds, for example, statewide speed limits; and (2) speed limits set according to some measure of existing traffic speeds, including 85th percentile and 10 mile per hour pace (200).

Several authors consider the first method in their works, Donigan and Fisher say that most states delegate some authority to establish speed limits to administrative agencies.

> "There is a definite tendency in the more modern cases to grant broader authority to administrative officers and agencies in regulation of traffic. Adequate provision for the protection of the traveling public makes it necessary that administrative discretionary authority be provided to deal with specific situations which cannot be included within laws of general statewide application...
>
> "Administrative authority to alter speed limits and established zones, however, is not without limit. In the language of the usual statute it is limited to 'any intersection or other place' where the maximum limit is greater or less than is reasonable or safe under conditions found to exist thereat" (198).

John Baerwald suggests that to remedy deficiencies: (1) Legislative bodies are not competent to set specific speed limits; (2) Area speed limits for general types of conditions should be established by state legislatures with authority for warranted revision delegated to competent and appropriate jurisdictions; and (3) The State Highway Commission should be given authority to establish a minimum speed limit (201).

Speed rezoning in Indiana is initiated by statutory change, residential and commercial developments, and roadway construction. The State Highway Commission sets the maximum speed limit. For an urban district this is 30 mph, interstates 70 mph, and 65 mph for others unless altered by special investigations to absolute speed limits. These limits must fall within a certain range and the investigation takes 300 vehicles or two hours sampling time, whichever comes first. The sample should be analyzed for 85th percentile speed and pace. In no case should the speed limit arrived at be more than 7 mph below or 5 mph above 85th percentile speed. There are also standard procedures for establishing night and minimum speed limits (202).

In 1956, J. Edward Johnston stated that:

> "A reasonable speed limit is one that will include the speed of all but a few of the fastest drivers.
>
> "Many traffic authorities agree that a limit which includes 85 per cent of the drivers is reasonable. A speed limit should seem too high to the majority of drivers.

"If this is not the drivers' reaction, the limit is not maximum. The limit should apply only to those who are grossly negligent, taking into account allowances necessary for variables in speedometers and arresting techniques -- and this tolerance does not need to be ten to 15 miles an hour as is often the case" (85).

Warren H. Brandt states that "It is the intention of all speed surveys to determine the actual operating speeds of a representative sample of motorists. Usually the results are interpreted in terms of the 85th percentile speed" (203).

James E. Wilson also cites this method of setting speed limits, indicating that the preferred speed is near the 85th percentile and that permissible ranges extend from the lower limit of the pace speed to the 85th percentile (140).

In attempting to justify the 85th percentile method for speed zoning, Warren L. Kessler of the Illinois Division of Highways states:

"The 85-percentile speed is based upon the theory that the majority of motorists traveling upon a city street or highway are competent drivers and possess the ability to determine and judge the speed at which they may operate safely; further, that motorists are responsible and prudent persons who do not want to become involved in an accident and desire to reach their destinations in the shortest possible time" (204).

An article in a 1959 issue of Traffic Engineering summarizes:

"In view of the foregoing considerations, namely, that
(1) numerical limits are not satisfactory because of variations in driving conditions; and
(2) even if they were satisfactory, drivers, as a rule, pay no attention to them;
it would appear that logic would dictate the removal

of all speed signs. However, if all speed signs were removed, a police officer would be left to his own devices to determine whether a driver was driving at a reasonable and prudent speed and a conviction for speeding would be difficult to make even though the accused might have been driving at a very excessive rate.

"Posted speed limits then can serve a useful purpose if set sufficiently high to separate the large majority of alert and careful drivers from the few flagrant violators of traffic regulations.

"The 85 or 90 percentile speed seems to be the logical speed at which to set the speed limit for any given section of road" (205).

A survey of traffic engineering officials throughout the country conducted by the Tennessee Department of Highways found:

"The 85th percentile speed is generally accepted as that speed which is most often used as a basis for establishing speed zones. Of the reporting 34 states 28 use the 85th percentile speed to some extent reporting that this percentile appears to be that speed limit at which drivers most favorably respond and that it appears to be reasonable from a law enforcement standpoint. This consensus has been based upon experience and little research has been presented to substantiate this conclusion" (206).

The following statement is from a 1969 "Resolution of the annual meeting of the American Association of State Highway Officials."

"The review of existing practice revealed that most of the member departments use, primarily, the 85th percentile speed. Some agencies use the 90th percentile speed, and of secondary consideration are such factors as design speed, geometric characteristics, accident experience, test run speed, pace, traffic volumes, development along the roadway, frequency of intersections, etc...

On the basis of the foregoing review, the Subcommittee on Speed Zoning recommends to the AASHO Operating Committee on Traffic for consideration as an AASHO Policy on Speed Zoning that:

> The 85th percentile speed is to be given primary consideration in speed zones below 50 miles per hour, and the 90th percentile speed is to be given primary consideration in establishing speed zones of 50 miles per hour or above. To achieve the optimum in safety, it is desirable to secure a speed distribution with a skewness index approaching unity" (207).

A 1970 research report from Research Triangle Institute concludes:

> "There was not sufficient data available to allow a full analysis but it appears that this study reinforces the setting of speeds [*sic*] limits at the 85th percentile speed. The standard deviation of the speed distribution is from 5 to 7 mph. Approximately 85% of the drivers drive below the mean plus one standard deviation. The drivers having speeds between the mean and one standard deviation above the mean are definitely in a low involvement group. The region between one and two standard deviations above the mean speed encompasses approximately 10 percent of the drivers and does not have a significantly greater involvement rate than at mean speed. This region from the end of the first to the end of the second standard deviation is approximately the tolerance level allowed by police agencies.
>
> "If minimum speed limits are set a similar argument would lead to the conjective that the limit should be placed at about the 15th percentile speed with enforcement at about the 5th percentile" (191).

"Speed Zoning - Why and How" describes the 85th percentile as the critical speed.

> "This is the speed at or below which 85 percent of the traffic is moving. Experience has shown that this is the one characteristic of traffic

speeds which most nearly conforms to a reasonable limit. Speed limits set higher than the critical speed will make very few additional drivers 'legal' for each five mile per hour increment of speed increased. Speed limits set lower than the critical speed will make a large number of reasonable drivers 'illegal' for each five mile per hour increment by which the speed is reduced" (208).

This paper also discusses what results realistic speed zoning may have.

"A. Reduce the speed differential in a traffic stream when there is a large variation of speeds. This makes driving easier, increases capacity and reduces the liklihood [*sic*] of accidents by encouraging most drivers to travel at about the same speed.
B. Give enforcement officials a good guide as to what a reasonable and prudent speed is under normal conditions and permits concentration of enforcement against real traffic violators.
C. Give motorists a speed limit which they can respect and obey. When drivers respect speed limits in areas with which they are familiar, they are more likely to pay attention to limits in unfamiliar areas.
D. Assist traffic courts by providing a realistic guide as to normal, reasonable and prudent speeds.
E. Give local residents a realistic picture of the actual speed of most traffic. There is no safety in blind reliance on a speed limit inconsistent with speeds actually traveled by traffic.
F. Insure that all speed zones satisfy the requirements of state law" (208).

In 1965, J. Edward Johnston presented a rather comprehensive summary of speed control information to the Institute of Traffic Engineers.

"There is nothing wrong with many of our speed limits but there are not enough of that kind. The bad ones are unrealistic; they make law violators out of normally law abiding citizens; they create a fearful

driver; they subject drivers to unreasonable and punitive traffic laws; they are misleading and do not accomplish the safety that the public thinks they do; and they do not recognize the inherent desire of the public for mobility."

"The following premises have been used successfully in the education of the public about speed and are offered as a guide for your own conclusions in the matter of speed control and regulation.

"1. The majority of drivers drive properly most of the time.
"2. Most drivers drive as fast as they feel safe and are capable of recognizing driving conditions that require greater driving caution.
"3. Drivers have little respect for and rarely conform to unreasonable speed limits.
"4. Reasonable speed limits will have the greatest effect in slowing the faster driver, speeding up the slow drivers, and increasing the number traveling at or near the same speed.
"5. A speed limit should seem too fast to at least 85 per cent of the drivers or it is not a maximum limit. There is still plenty of room for enforcement speed tolerances.
"6. Unreasonable speed limits cannot be enforced with reasonable enforcement. Many arrests is no measure of enforcement. Speed limits should be in a large measure self-enforcing.
"7. Forcing traffic to drive more slowly does not mean that it is driving more safely.
"8. Safety campaigns are effective only to the degree that they impress the drivers with need for caution. This may or may not result in his driving more slowly.
"9. There is no such thing as a safe speed limit. Traffic accidents occur at all speeds and more have occurred at speeds not normally considered excessive.
"10. No speed limit adapts itself effectively to any extended length of street or highway, or for even limited extent under all driving conditions.
"11. Radar and other speed measuring devices would be effective tools for making speeding arrests if reasonable speed limits were used -- established, recognizing the many

variable conditions, with the precise accuracy with which the devices are capable of operating.

"12. Our concern is not so much with speed as with 'speed too fast for conditions or circumstances.' It may be that 'haste' is the real aggressor.

"13. There are many other factors than speed that are more important in the causation of accidents: inattention, aggressiveness, pride of power, revenge, haste, condemnation, recklessness, daring and many others. These are reflected in 'driving on the wrong side of the road,' 'cutting in,' 'failure to yield right of way,' 'following too close,' 'weaving from one lane to another,' 'stopping too quickly,' yes, and 'driving too fast for conditions.'

"14. Speed limits aimed at regulating the few grossly reckless drivers only make law violators out of most of the normally good drivers and has [*sic*] questionable value in accomplishing the purpose for which they are intended.

"15. The 'slow' drivers are a greater menace on our streets and highways today than are the 'fast' drivers" (209).

Another topic discussed in the literature is the uniformity of speeds or the speed distribution. According to William Taylor, assuming that variation of speed distribution and high accident rates on certain sections of highway are the result of the drivers' inability to properly evaluate the situation, it seems that speed distribution would be helpful in determining where speed zoning might be effective. Mean speed and 85th percentile may not be influenced by each individual driver inability to make a proper evaluation of conditions in the way that skewness and kurtosis of speed distribution are (210).

Taylor's theory states that a relationship exists between the rate of occurrence of accidents and the distribution of speeds on a section of rural highway, and that the effectiveness of speed zoning in reducing accidents is dependent on the speed distribution before and after zoning (211). His study concluded that:

"1. There is a strong relationship between the rate of occurrence of accidents and the speed distribution on rural state highways.

2. The best parameter to use in determining non-normality is the skewness of the distribution.

3. Changing the speed distribution from non-normal to normal results in an accident rate reduction which is about twice that found under any other set of before and after conditions.

4. Warrants for speed zoning should be established which include the speed distribution as a factor.

5. The 'Before' speed distribution alone is not adequate as a warrant for speed zoning" (178).

The Tennessee Department of Highways based a study on the assumption that Taylor's theory was true. In this study a speed limit was said to be "effective" if the index of skewness of the resulting speed distribution was close to 1. Speed distributions were measured at 834 locations and 189 locations were found for which the speed limit was said to be "effective." The 189 locations were grouped according to the value of the speed zone and for each speed limit the average values of 85th percentile, 90th percentile, mean, median, mode, mean deviation,

and standard deviation were calculated. From these characteristics the one with the smallest "average deviation from posted speed limit" was selected as that characteristic which best represented the speed limit. It was concluded that speed limits below 50 mph are best represented by the 85th percentile while limits of 50 mph and above are best represented by the 90th percentile (212).

Baerwald indicates that the safest and most efficient vehicle operating conditions occur when all traffic is traveling at or near the same speed, thereby minimizing the need for overtaking and passing. To achieve speed uniformity he recommends that traffic engineers establish maximum and minimum speeds according to roadway and traffic conditions in order to minimize excessively fast and excessively slow-moving vehicles (243).

Publications agreeing with Baerwald's view state:

> "The principal objective in speed control is to achieve as uniform a movement on a given roadway as possible. This means "speeding-up" the slow driver as well as "slowing-down" the fast ones" (214).
>
> "Speed Limits should encourage uniform speeds.
>
> "If all traffic moved at the same speed, there would be no overtaking and passing -- which results in a large number of fatalities and injuries. The greatest tendency toward uniformity is achieved when no more than 15 percent of the drivers exceed the clearly posted speed limit" (85).

J. C. Oppenlander states that existing techniques are not scientifically based and presents the following theory as an alternative method for the establishment of speed controls:

(1) Optimal speed that minimizes the cost of highway transportation is selected considering monetary, time, safety, and comfort factors.

(2) An adjusted speed is derived from the optimal speed by subtracting the reduction in speed occasioned by driver, vehicle, roadway, traffic, and environmental variables that modify vehicular speeds.

(3) Statistical relationships between upper and lower speed limits and adjusted speed produce the posted speed regulation (200).

Jack C. Marcellis attempted to apply part of this theory, calculating the total cost of traffic movement as the sum of operation cost, time cost, and accident cost. The optimal speed for urban streets was scaled according to frequency of stops. For passenger cars, optimal urban speed ranged from 42 mph for 0 stops per mile to 27 mph for 16 stops per mile during the day. Night optimum is slightly lower. Commercial vehicles would move at an optimal speed of 37.5 mph at 0 stops per mile, and at 8 stops per mile the optimal would be 25 mph. A possible application of these limits would be to statewide or areawide maximum and minimum speed limits (215).

A completely different view of speed limits if presented by Charles W. Prisk, deputy director of the Office of Highway Safety. Prisk feels that the posting of advisory speeds, determined by prevailing engineering and traffic conditions, might be more appropriate than arbitrary speed limits. He states:

> "The driver wants and deserves intelligent aids to his choice of proper speeds...Rather than try ineffectually to limit his speed, we might better look for new ways to let the driver know what speeds are satisfactory, comfortable and safe...I think the public is becoming suspicious of the safety value of speed limits based solely on arbitration by legislators. Perhaps it is time to face up to the fact that drivers respond better to advice than to regulation" (216).

The *Traffic Engineering Handbook* states that the criteria for safe speed regulation are based upon the need to give the driver adequate time to reduce speed, make decisions, and react when he encounters hazards. Some indicators of the effectiveness of a speed regulation are increased safety, smoother traffic flow, and healthy driver attitudes toward speed limits (147

There exists a considerable amount of agreement as to the factors which should be considered when setting speed limits. Generally included are: 1) a measure of prevailing vehicle speeds, 2) roadway characteristics, 3) accident experience, 4) traffic characteristics, and 5) the nature of existing control measures.

The most frequently advocated method for establishing speed limits today is the 85th percentile or some other measure of existing traffic speeds such as 10-mph pace or average test run speed. However, little empirical justification for this method can be found in the literature. Two bases that have been presented are first, that the 85th percentile stems from

the idea that drivers are capable of judging a safe and reasonable speed, and second, that something peculiar starts to happen to the speed distribution curve at the 85th percentile point.

A newer line of thinking has proposed that the speed distribution is the prime consideration, and thus, that the object of a speed limit should be to have some desired effect on this distribution. It is at this point that further research must continue.

Three questions present themselves: 1) What are the objectives of speed control? 2) Can speed limits meet these objectives?. 3) If so, what methods should be employed to establish effective speed limits?

3.0 CONCLUSION

From a historical perspective it can be seen that relatively few new ideas have been added in the area of speed limits since the early days of the automobile in America. Although this says much for the insight of the men who worked in this area in the early 1900s, it also illustrates the weak level of effort ascribed to speed control research since that time.

Little real progress has been made either in theory or in practice regarding modern speed regulation. Relatively few new concepts have been introduced, and most aspects of the speed problem remain highly unsettled.

The type of effect which speed limits have is questionable, and there is still no consensus as to whether they do or do not have an effect at all. It appears, however, that speed limits may have a favorable effect, or at least no unfavorable effects have been shown. The main characteristic of a speed limit is its reasonableness.

Studies in the area of driver speed behavior seem to relate only to particular situations and thus, cannot be generalized. The small amount of research that has been conducted in this area does not begin to cover the complex topic.

Despite the amount of work that has been done concerning the speed-accident relationship, the conclusions have not been consistent. The later studies on this topic tend to place speed in a group of causal factors rather than labeling speed as the single or most important cause of accidents. The role

of speed in accident causation has received the greatest amount of serious attention and this interest has probably led to the present concern over speed control.

The most promising theory that has been proposed in this area states that accidents are a function of the speed distribution, i.e., that accidents are caused by deviations from the average driving speed.

Current methods for setting speed limits are often arbitrary and are not uniformly applied throughout the country. The 85th percentile is the most highly recommended criterion for setting speed limits, yet little empirical justification for this method can be found.

The inconsistencies, contradictions, and gaps in our current body of knowledge concerning speed and its control, indicate that a logical approach to the problem needs to answer these questions: First, is speed a problem? Second, does speed need to be controlled? Third, if speed should be regulated, are speed limits the best method for its control? And fourth, if speed limits are the best solution to the speed problem, how can they be most effectively implemented?

American society has already adjudged speed to be a problem and decided that it must be controlled. Now, it is the role of research to put the speed problem into perspective, to determine the role speed plays in accident causation, to prove that speed limits are an effective solution to the problem or to find a more adequate alternative, and to develop justified methods of implementing the solution.

4.0 GLOSSARY

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absolute speed limit: "a speed above which it is always illegal to drive." Also known as a maximum lawful limit. (I, p. 538)

advisory speed limit: the maximum safe speed that is posted below a warning sign. "In most states, the advisory speeds are not legally enforceable, but in some courts violation of the advisory speeds is admissible as evidence that the driver was operating in a reckless manner." (I, p. 541)

average overall speed: "The average of the overall speeds of all vehicles on a given roadway during a specified period of time." (II, p. 12)

average overall travel speed: "The sum of distances divided by the sum of overall travel times (a space-mean speed)." (I, p. 159)

average spot speed: "The arithmetic mean of the speeds of all traffic, or component thereof, at a specified point." (I, p. 159)

critical approach speed: "At an intersection, that speed above which a vehicle does not have sufficient distance to stop in time to avoid collision with another vehicle approaching the intersection on the cross street ." (II, p. 39)

critical speed (on curve): "The speed above which a vehicle will slide off the curve rather than follow around it." (II, p. 40)

design speed: (of highway): "A speed selected for purposes of design and correlation of those features of a highway, such as curvature, superelevation, and sight distance, upon which the safe operation of vehicles is dependent. It is the highest continuous speed at which individual vehicles can travel with safety upon a highway when weather conditions are favorable, traffic density is low, and the design features of the highway are the governing conditions for safety." (II, p. 48)

85th-percentile speed: "That speed at or below which 85 percent of vehicles travel." (II, p. 68) [The x^{th} percentile would also have a corresponding definition.]

free-moving vehicle: "One in which the driver is not restricted in selecting his speed by other vehicles...Some observers classify a free-moving vehicle as one which has not less than 6 - 9 sec. headway from the vehicle ahead of it and is making no apparent effort to overtake and pass the vehicle ahead of it." (I, p. 539)

headway: "The time interval between passages of consecutive vehicles measured from head to head, moving in the same direction as they pass a given point." (II, p. 91) or "The distance, measured front to front, between consecutive vehicles." (II, p. 92)

maximum lawful limit: "a speed above which it is always illegal to drive." Also known as an absolute speed limit. (I, p. 538)

median speed (of traffic): "That speed below which 50 percent and above which 50 percent of the speeds occurred." (II, p. 128) [the 50th percentile]

modal average: "that speed at which the greatest number of vehicles travel." (III, p. 51)

nominal speed (of traffic): "A running speed at which driver' operate on a given section of highway in the absence of traffic interference." (II, p. 140)

operating speed: "The highest overall speed exclusive of stops at which a driver can travel on a given highway under prevailing conditions without at any time exceeding the design speed." (II, p. 151)

optimum speed: "The average speed at which traffic must move when the volume is at a maximum on a given roadway. An average speed either appreciably higher or lower than the optimum will result in a reduction in volume." (II, p. 152)

overall travel speed: "The speed over a specified section of highway, being the distance divided by overall travel time..." (I, p. 159)

overall travel time: "The total time of travel, including stops and delays, except those off the traveled way..." (I, p. 159)

pace of traffic: "the range of speed which includes the greatest number of vehicles for some nominal increment in speed, usually 10 mph." (III, p. 5

prima facie speed limit: "a speed above which the driver is presumed to be driving unlawfully but if charged with exceeding it, a driver may show cause to prove that his speed was safe for conditions and, therefore, that he was not guilty of a speed violation." (I, p. 538)

running speed: "The speed over a specified section of highway, being the distance divided by running time ..." (I, pp. 159, 161)

running time: "The time the vehicle is in motion..." (I, p.

skew distribution: "A non-symmetrical distribution. A distribution is skewed to the left (right) if the longer tail is on the left (right) - also called negative (positive) skewness..." (IV, p. 126)

space-mean speed: "The speed corresponding to the average of overall travel times or running times over a specified section of highway." (I, p. 161)

spot speed: "The speed of a vehicle as it passes a spot or point on a street or highway." (I, p. 159)

ten-mile-per-hour pace: "The 10-mph speed range containing the largest percentage of vehicles in a sample of spot speeds." (I, p. 159)

time-mean speed: "The average of spot speeds of individual overall travel speed values." (I, p. 161)

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