

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

Safety is an essential component of transportation engineering. The safety of road transportation involves many factors including driver skills, roadway characteristics, vehicle conditions, and weather. In addition to crash causation, the identification of hazards that may increase severity in the event of a crash is important. Among all contributing elements, speed is considered to be one of the most critical. Statistics show that speed is a factor in one-third of all motor vehicle fatalities (NHTSA, 2002).

One mechanism of addressing roadway safety is the implementation of road safety audits. This chapter presents the road safety audit concept, its origin, and expansion. This section provides the background information regarding this concept and strategies used or implementation for an existing roadway focusing on speed issues.

Perhaps the most common attempt to control driving speed is imposing speed limits. In the second part of this chapter, the speed topic is reviewed. The review includes speed-related statistics and an examination of the relationship between speed and crash risk as well as a discussion about speed limits based on the 85th percentile speed. Literature about the effects of changing speed limits on all types of roads is also reviewed.

2.2 ROAD SAFETY AUDITS AND REVIEWS

2.2.1 Road Safety Audits

In the last decade, some countries have introduced the practice of auditing new or existing roadways to assist in building safety into the road network. This practice is known as the road safety audit. A road safety audit is a formal and proactive process to complete a comprehensive traffic safety study. The Austroads guidelines define a road safety audit as a “formal examination of a future road or traffic project, an existing road, or any project which interacts with road users, in which an independent, qualified team assesses the crash potential and safety performance” (Austroads, 2002).

These formal safety-focused analyses started during the early 1980's in the United Kingdom, moved to Australia and New Zealand in the early 1990's, and gradually have spread to many other countries (Navin et al., 1999). Road safety audits were introduced to the United States in the mid 1990's and various reasons justify the need for implementing them. The first and most powerful reason is the social and economic need to improve safety. In the United States, each year more than 40,000 people are killed and more than three million are injured on traffic

crashes. The estimated social cost of traffic crashes in 2000 was more than US\$230 billion (NHTSA, 2002).

Experiences with road safety audits in Australia, New Zealand and United Kingdom were successful. In October of 1996, the Federal Highway Administration (FHWA) sponsored a scanning team consisting of state, local, federal and academia representatives to travel to New Zealand and Australia to review their road safety audit process. The study tour concluded that road safety audits hold promise for maximizing safety of roadway design and operations, and they should be promoted in the United States (Trentacoste et al., 1997).

2.2.1.1 The Purpose

Road safety audits attempt to identify features of the highway–operating environment that could be potentially dangerous to road users and others affected by a road project and to ensure that measures to eliminate or reduce the problems are fully considered. The road safety audit focuses on evaluating safety in the context of all users, including pedestrians and cyclists, under the full range of environmental circumstances such as inclement weather and nighttime conditions.

The Austroads guide provides guidance about what a road safety audit is not. Specifically, a road safety audit is not the following (Austroads, 2002):

- A way of assessing or rating a project, is not a means of ranking projects;
- A way of rating one option against another;
- A check of compliance with standards;
- A crash investigation;
- A redesign of project;
- Something to be applied only to high cost projects or only projects involving safety problems; and
- The name to use for informal checks, inspections or consultations.

The main objective of a road safety audit is to address the safe operation of a roadway and to ensure a high level of safety for all users. Road safety audits foment safer roads by promoting elimination or mitigation of safety hazards (such as inappropriate intersection layouts) and by encouraging incorporation of suitable crash-reducing features (such as guard fencing, traffic control devices and delineation). A road safety audit should enclose two complementary approaches, crash reduction and crash prevention. A RSA has to develop corrective measures for sites where crashes occur frequently but also modify existing roads or design safer new ones to prevent crashes (Ogden et al., 1995).

Road safety audits aim to minimize the risk and severity of road crashes, minimize the need for remedial works after construction, and reduce the whole-of-life costs of the project. In addition, this practice can ultimately enhance the awareness of safe design practices by everyone involved in the planning, design, construction, and maintenance of roads (Austroads, 2002).

2.2.1.2 The Stages

Initially, road safety audit guidelines numbered five stages of audit: feasibility, preliminary design, detailed design, pre-opening and existing roads. This definition was changed in May 1998 during the Austroads International Road Safety Forum because different numbers and names were used in the United Kingdom, Australia, and New Zealand and introduced confusion. In the last edition of the Austroads guide, four stages are defined but not numbered. The fifth stage, when the road is operating, is considered at a different level of the process and called a road safety review (Austroads, 2002).

The four stages at which to audit during the design and development of new projects are illustrated in Figure 2-1.

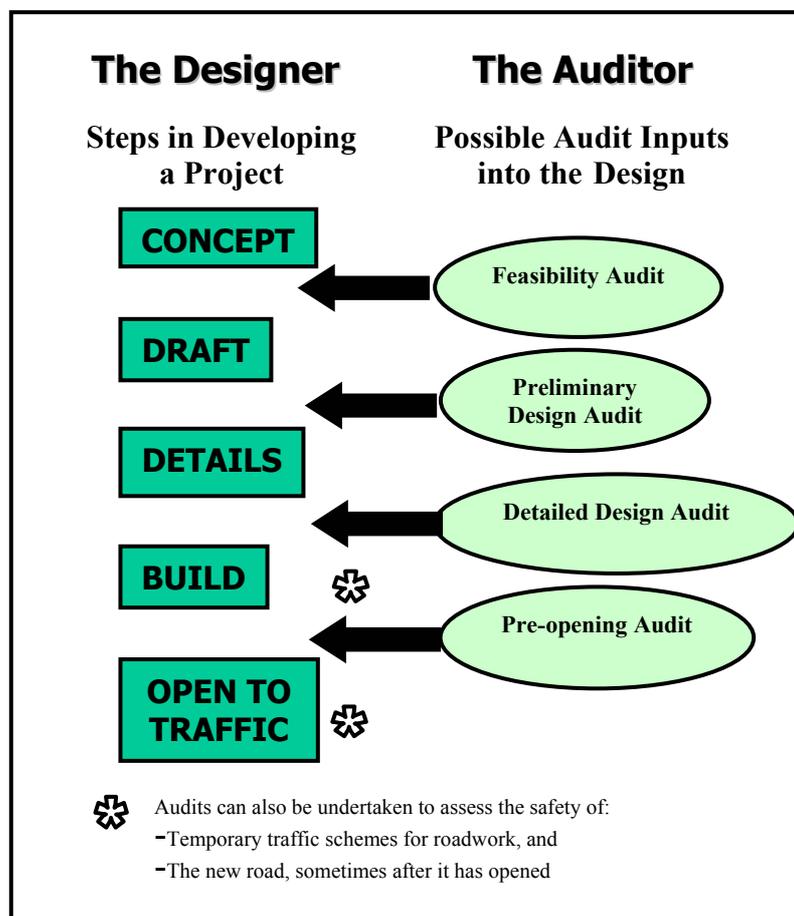


FIGURE 2-1 *How Audits Fit into the Design Process (Austroads, 2002).*

Feasibility stage audits consider the nature and extent of the scheme and determine the starting points for the actual design such as route options, layout options and/or treatment options. They allow an assessment of the relative safety performance of each option and identify the specific safety needs of various road users. During this stage, changes or improvements to enhance and promote safety are highly cost effective and relatively inexpensive.

During the preliminary design stage, issues such as intersection layout and the chosen design standards are addressed. Horizontal and vertical alignments and junction layout are broadly determined. At the completion of this stage, the design should be well enough established so that, if necessary, decisions can be made about land acquisition.

At the detailed design stage, the more specific design issues are addressed. For example, geometric design, signing schemes, roadside equipment such as lighting, and line marking plans are looked at in relation to operation of the safety and safety of all road users.

Before opening, a site inspection should be conducted to ensure previous concerns have been addressed and to identify any hazardous conditions that may not have been apparent from the plans. It is advisable to do this under different conditions such as darkness and bad weather and from the perspective of all road users, including pedestrians and cyclists (Austroads, 2002).

The safety audit of existing roads, referred as the road safety review, is different from the safety audit of projects or schemes and is treated separately (Appleton, 2001). The RSR process is discussed in further detail later in this report. The following section describes international experience with the RSA process.

2.2.2 International Experience

2.2.2.1 United Kingdom

The concept of the road safety audit was originated in the United Kingdom in the 1980's. In 1987, the Department of Transportation developed strategies to reduce road casualties by one-third by the year 2000. In 1988, legislation placed a responsibility on road controlling authorities to take action to reduce crashes. In response to this, the Institution of Highways and Transportation (IHT) prepared the "Guidelines for the Safety Audit of Highways", which was published in 1990. In April 1991, road safety audits were made mandatory for all national roads and freeways in the United Kingdom (Odgen et al., 1995). The last reviewed edition of the IHT guidelines was published in 1996.

2.2.2.2 Australia

Australia is undoubtedly the leader in the implementation of road safety audit processes. The states of New South Wales (NSW), Victoria and Queensland have published road safety audit guidelines.

The development of road safety audit manual for NSW began in 1990, and was published in July 1991. The Roads and Traffic Authority (RTA) in NSW carried out its first safety audit in 1990 on the Pacific Highway. The RTA requires in each year a concrete number of road safety audits within each of the RTA's regions plus road safety reviews on a certain percentage of the existing road system (Jordan-Appleton, 1994).

In the State of Victoria, safety audits are an integral part of a quality management process used by VicRoads (the state's road agency). All major projects undergo a safety audit, and there is also a scope for safety reviews, according to VicRoads procedures for investigating hazardous locations (Jordan-Appleton, 1994).

At the national level, Austroads (the national association of road and traffic agencies) set up a working party to develop road safety audit guidelines to provide a national focus for this work. In 1994, they published the first guidelines that become an international guiding principle in the road safety audit process. These guidelines were revised in the Austroads International Road Safety Forum held in Melbourne in May 1998 and a second edition of the Austroads guidelines was published in 2002. This improved edition reflects the knowledge and experience gained around the world in these last years and it is an essential tool in the road safety audit practice (Austroads, 2002).

2.2.2.3 New Zealand

Safety audits began in New Zealand with a series of post-construction safety audits in 1990. Helped by experienced safety auditors from the United Kingdom and Australia, some pilot safety audit projects were conducted in 1992 and 1993. A safety working party was set up with representatives of all sectors to develop safety audit policies and procedures. Transit New Zealand (TNZ), the national roads and public transport agency, adopted these policies and published them in 1993. From 1993, safety audit was mandatory for a 20 percent sample of state highway projects (Ogden et al., 1995).

2.2.2.4 United States

A FHWA report entitled "Management Approach to Highway Safety: A Compilation of Good Practice", published in 1991, recognized the need for a comprehensive and coordinated approach to highway safety, but did not translate the need into specific recommendations. Although safety audit as such was not mentioned, the main concept was introduced.

In 1994, the FHWA sponsored an international technology scanning review focused on Japan, Australia, and New Zealand with the purpose of reviewing safety management systems. One of the findings was that safety audits were an effective tool in improving highway safety. Based on the recommendation of the FHWA, a follow-up scanning review on road safety audits was undertaken from October 21 to 31, 1996.

Recognizing the value of this proactive safety strategy, the FHWA started piloting road safety audits in the United States, and agencies such as the Institute of Transportation Engineers (ITE) are further exploring the concept and expanding the knowledge base for the transportation profession. In May 1998, a workshop for pilot States and other interested agencies was conducted. In March 1999, the ITE carried out a very successful conference entitled "Enhancing Transportation Safety in the 21st Century: new Tools for Transportation Professionals". As part of this conference, a one-day seminar entitled, "An Introduction to Road Safety Audits" was conducted (Horne, 1999).

ITE with financial support from the FHWA, under a cooperation of both entities, has developed a web site intended to provide a clearinghouse of information exchange to expand road safety audit practices. The site provides an easy, centralized way to access a variety of resources related to safety audits including: references, full text documents, information about courses and conferences, contact information for experts in the field, links to other safety audit web sites and a convenient way to discuss issues with safety professionals.

2.2.3 Road Safety Reviews

The road safety audit process applied to the existing road network is given the name of road safety review or road safety assessment. Road safety reviews are completed to identify hazards and deficiencies affecting safety which may lead to future crashes, so that remedial treatment may be implemented.

Although the published guidelines included procedures to audit existing roads, road safety reviews have always been a minor element in road safety audit programs. This apparent lack of action may be because the investigation of high crash points, called blackspots, could appear a more effective treatment to improve safety. The difference is that blackspots work is reactive, rather than not proactive (Ogden et al., 1995).

In general, treating known crash sites is more cost-effective than treating sites where crashes are yet to occur. However, the most effective procedure is indeed complementing both approaches in the study.

The revised Austroads guidelines indicate that the aim of a review is to identify any existing safety deficiencies of design, layout, and road furniture and to check consistency of standards such as the road user's perception of local conditions assist safe behavior. Austroads states the value of conducting safety reviews, specifying that they adequately complement a program of accident blackspot treatment (Austroads, 2002).

2.2.4 Thematic Road Safety Audits

Thematic audits are an element of road safety audits that have been recently introduced by the Roads and Traffic Authority (RTA) in Australia. A thematic audit basically aims to focus on a specific aspect, facility or user in the road environment. The ultimate purpose is not only address concerning areas of in the network, but over time knowledge gained from them provide improved guidelines, training and practices, thereby promoting continuous improvement (Brisbane-Yee, 2002).

Thematic audits can be applied to various situations in the road environment. They can focus on different themes such as clear zones or roadside fixed objects. Thematic audits can also adopted the perspective of a given road user group such as pedestrians, cyclists or heavy vehicles. The purpose of this research is to focus the safety audit review on speed issues.

2.3 SPEED AND SPEED LIMITS

Imposing a speed limit is a recognized strategy to control driving speeds. Setting speed limits is not an exact science since speeds driven are strongly influenced by some basic principles of human behavior. This section provides a large overview of speed and speed limits, from the relationship between speed and crash causation to the effects of changing speed limits.

2.3.1 Speeding on Different Roadways

Local and collector roads, providing access to residential or business areas, compose the majority of road miles in the United States. These categories of roadways have posted speed limits ranging from 32 to 88 km/h (20 to 55 mph). Arterials include important roadways that connect urban areas, but exclude Interstate highways, and are usually posted between 80 and 113 km/h (50 and 70 mph). The highest class of roadway in the United States is the Interstate system, with speed limits between 88 and 121 km/h (55 and 75 mph). While Interstates account for less than 14 percent of all speeding-related crashes, almost half of the speeding fatalities occur on local and collector roads. In fact, the speeding-related fatality rate for low-speed roads is three times higher than the rate for Interstates (US DOT, 2000).

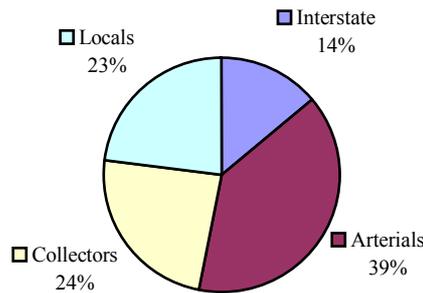


FIGURE 2-2 *Distribution of Speeding-Related Fatalities by Road Class, 1999 (US DOT, 2000).*

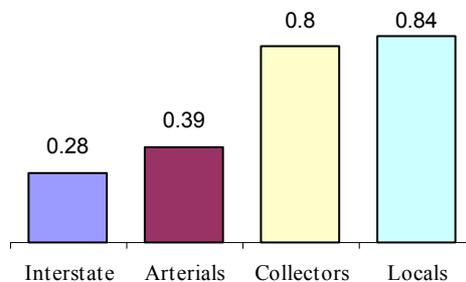


FIGURE 2-3 *Rate of Speeding-Related Fatalities by Road Class (fatalities per 100 million vehicle miles traveled, VMT), 1999 (US DOT, 2000).*

2.3.2 Relationship between Speed and Risk of Crash Involvement

The earliest significant research using an approach that demonstrates a relationship between vehicle speed and crash risk was conducted in the U.S. by Solomon in 1964. Solomon examined 10,000 crash reports from main rural roads with speed limits of 55 to 70 mph. As a control speed, the average speed was calculated for 290,000 vehicles not involved in crashes. Solomon then found the degree to which the estimated pre-crash speed of vehicles deviated from the average speed of the control vehicles and plotted these deviations versus the crash involvement rate per hundred million vehicle-miles of travel. The result was a U-shaped curve. That is, when speeds deviated greatly from the average speed, either faster or slower, the risk to be involved in a crash was high, whereas speeds close to the average speed present low crash risk (Stuster et al., 1998).

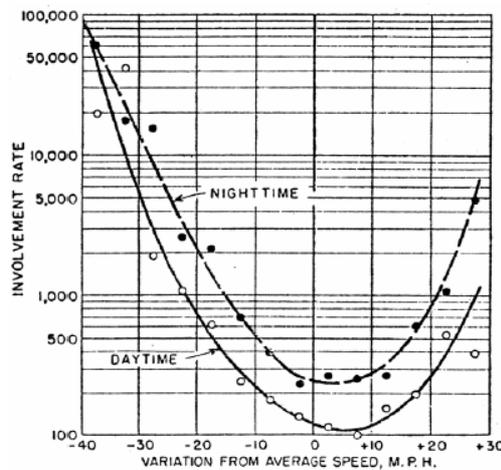


FIGURE 2-4 *Crash Involvement Rate by Variation from Average Travel Speed, Day and Night (TRB, 1998).*

The U-shaped relationship between deviation from average traffic speed and crash involvement rate was also found by Munden in 1967 using a different analytic method on main rural roads in the United Kingdom and by Cirillo in 1968 in a similar analysis of 2,000 vehicles involved in daytime crashes on U.S. Interstate highways (Stuster et al., 1998).

Most of these studies have been criticized as inaccurate because they estimate speeds of crash-involved vehicles and mix crashes of free flowing with slowing vehicles, which could explain high crash involvement rates at slow speeds.

As cited by Stuster et al. in their *Synthesis of Safety Research Related to Speed and Speed Management*, in 1970, the Research Triangle Institute (RTI), and one year later, in 1971, West and Dunn attempted to support Solomon's approach using more reliable speed data. Because turning vehicles tend to slow down or stop in order to turn, they were considered not representative and thus removed from the database. Although a U-shaped pattern was found, the curve was considerably weakened, showing more symmetric crash involvement rates above and below average traffic speeds.

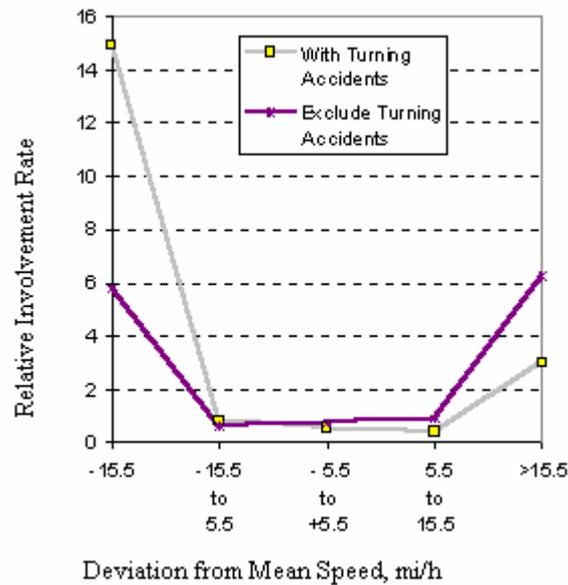


FIGURE 2-5 Relationship between Speed and Crash Involvement (Stuster et al., 1998).

The results obtained by West and Dunn showed that four percent of drivers operate their vehicles at excessive speeds that create a hazard to themselves and others that share the road. This risky group of drivers have a crash involvement rate which is more that six times that of the remaining 96 percent.

TABLE 2-1 Relationship between Involvement Rate and Speed Deviation not Including Turning Crashes (West-Dunn, 1971)

Speed Deviation Class Interval (mph)	Number Involvements	Total Vehicle Mileage (MVM)	Rate (Involvements per MVM)
< -15.5	12	1,890	6.3
-15.5 to -5.5	11	16,243	0.7
-5.5 to +5.5	32	39,976	0.8
+5.5 to +15.5	16	16,243	1.0
> 15.5	13	1,890	6.9

In an attempt to reduce the number of high and low deviations and consequently lower the crash rate, West and Dunn proposed setting and enforcing speed zoning with both maximum and minimum limits. For the upper limits they recommended the use of the standard 85th percentile providing enforcement at the 95th percentile. Likewise, for the lower side, the recommendation is setting the speed limit at the 15th percentile and the enforcement at the 5th percentile.

More recently, an Australian study performed in 1991 by Fildes, Rumbold and Leening, as cited by Stuster et al., challenged Solomon's theory when no evidence of the U-shaped relationship was found. While crash involvement rates rose as a

function of speed, no relationship between slower speeds and increased crash probability was found. The results of this research are summarized in a linear and positive association between risk of crash involvement and the speed driven.

A few years later, in 1997, Kloeden, McLean, Moore and Ponte conducted another study supporting some of the results found by Fildes et al. in 60 km/h (37 mph) speed zones in the Adelaide metropolitan area in Australia. Using a case-control study design, Kloeden et al. compared the speed of vehicles involved in casualty crashes (case vehicles) with the speeds of vehicles not involved in crashes (control vehicles) but traveling in the same direction, at the same location, time of day, day of week and time of year. Casualty crashes are defined as crashes that involve transport of at least one person from the crash scene by an ambulance. The authors found that the crash involved vehicles were traveling faster than the control vehicles. Specifically, the researchers indicated that, in a 60 km/h speed zone, 14 percent vehicles involved in casualty crash were traveling faster than 80 km/h, and only one percent of control vehicles were running at these speeds. Additionally, they stated that the risk of involvement in a casualty crash doubles with each 5km/h increase in traveling above 60 km/h.

Referring to speed lower than the speed limit, Kloeden et al. concluded that traveling speeds below 60 km/h do not have an associated crash risk statistically different from the risk at 60 km/h. This result, different from the U-shaped pattern, may be biased by the study design. First, the analysis only accounts for injury crashes, and crashes occurring at lower speeds tend to be less severe. Secondly, only the free-flowing vehicles were considered in the crash data, thus the speeds of slowing vehicles were excluded. Figure 2-6 represents Kloeden et al. findings.

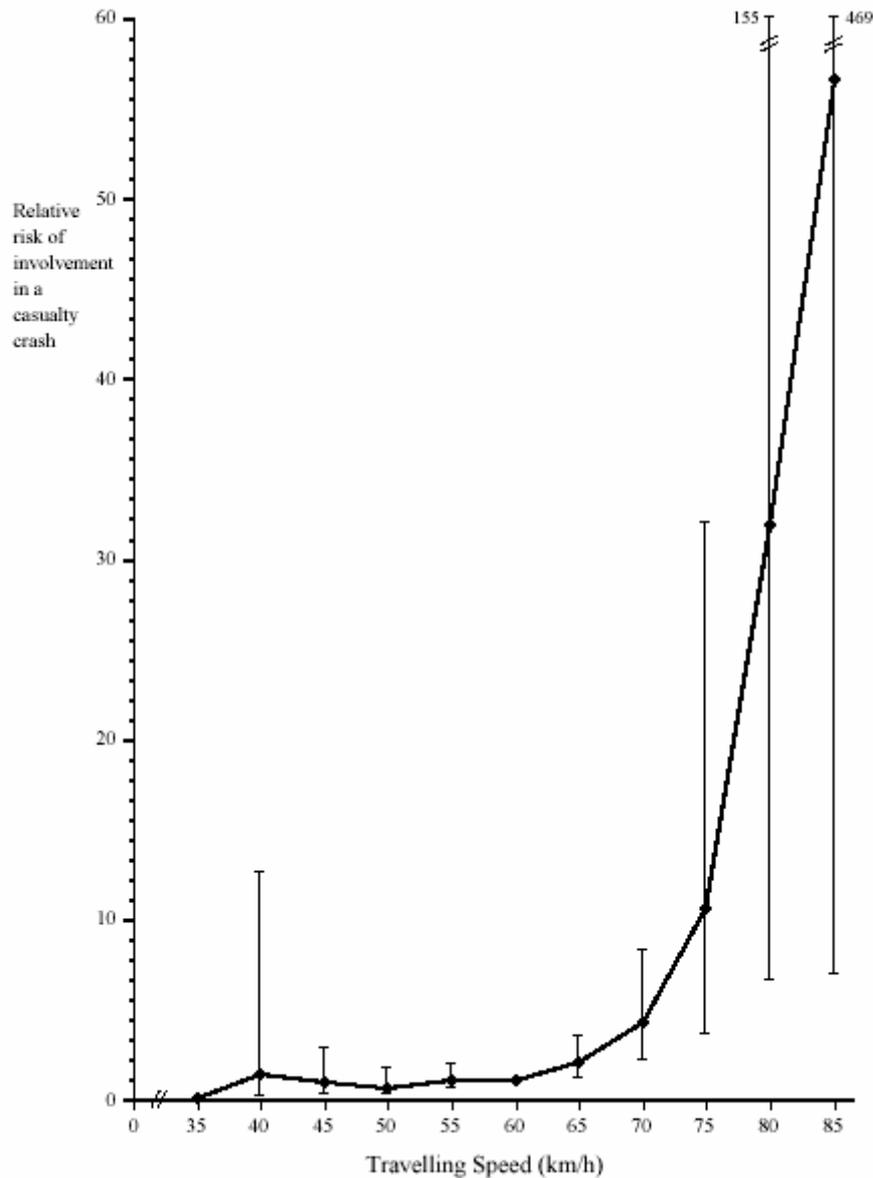


FIGURE 2-6 *Traveling Speed and the Risk of Involvement in a Casualty Crash Relative to Traveling at 60 km/h in a 60 km/h Speed Limit Zone^a (Kloeden et al., 1997).*

^a Relative risk at 60km/h set at 1.00; 95% confidence intervals are shown by the vertical lines.

Another safety related topic in the literature considers the variation in traffic speed as a determining factor of crash risk. This idea appears to be in large part derived from Solomon's work in 1964, particularly in terms of deviation from average speed. While Solomon's estimation of the crash risk associated with low speeds was deemed unreliable, the speed variation idea gained acceptance.

One researcher who studied the issue of speed variance as a contributor to crashes was Charles Lave, a Professor of Economics at the University of California in Irvine. Lave was a committee member for the study of the benefits and costs of the 55 mph National Maximum Speed Limit, and contributed to the preparation of TRB

Special Report 55: *A Decade of Experience* (1994). Lave wrote the appendix *Speeding and Highway Fatalities*, where he presented the conclusion of a multiple regression analysis comparing fatality rates to measures of vehicle speeds. Lave found that the analysis data revealed no statistically significant relationship between average speed and fatality rate and that this was also true for other measures such as the 85th percentile speed. However, he found statistically significant relationship between speed variance and fatality rate. As cited in by Stuster et al. (1998), Lave's 1985 report concluded that speed limits intended to improve safety and reduce the fatality rate should focus on reducing speed variance, taking action against slow drivers as well as fast ones.

In 1988, a study to examine factors that influence speed variation and to quantify the relationship between speed variation and crash rates was conducted by Garber and Garidaju. Crash rates, speed variation and average speed were measured on 36 sections of Interstate highways in Virginia. Each section of highway had a posted speed limit of 55 mph, but the design speeds varied from 40 mph to 70 mph. Design speed is defined by the American Association of State Highway and Transportation Officials (AASHTO) as "the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern". It was used as a summary of the geometric characteristics of the road section. Garber and Garidaju (1999) found, for different types of highways, differences in average speeds and diverse variation in speed, despite all these highways were posted at the same speed limit. Particularly, the plot of speed variance against the difference between design speed and posted speed was found to be a U-shaped function, showing speed variance was least when this difference was five to ten mph.

Garber and Garidaju also found that crash rates increased with increasing speed variation and stated that the crash rate does not necessary increase with an increase in average speed. The researchers concluded that since crash rates increased with increasing speed variance, and since speed variance was minimum when posted speed limits were five to ten mph below the design speed, changing posted speed limits to within this band would minimize crash rates; that is, the speed limit set should be based on the design speed of the road.

2.3.3 Setting Speed Limits: the 85th Percentile Speed

Imposing speed limits is one of the oldest strategies of controlling driving speeds and improving traffic safety. Setting these speed limits is not an exact science since speeds driven are strongly influenced by some basic principles of human behavior. The matter of establishing a speed limit for a given roadway is a serious concern for traffic engineers. The following paragraphs detail some of the common practices of establishing speed limits.

The main objective of speed limits is to enhance safety, and they attempt to achieve this in two different ways. By limiting speeds, the probability and severity of crashes should theoretically be reduced. In addition, the speed limits must have a coordinated function and reduce dispersion in driving speeds; more uniform speeds are associated with fewer vehicle conflicts (TRB, 1998).

The Basic Speed Law in Massachusetts, which is similar to that of most other states, declares: “No person shall ‘run’ a motor vehicle at a rate of speed greater than is reasonable and proper, having regard to traffic and the use of the way and the safety of the public” (NHTSA, 1999).

Research has shown that the speed limit should be based in part upon the characteristics of the roadway and its associated design speed. The design speed defines the values used for the design of a road including elements of the roadway geometry such as curve radii, vertical and horizontal alignments, sight distance and lanes. The design speed also impacts elements of the roadside development such as sidewalks, parking lots, and driveways. Garber and Gadiraju (1999) concluded that drivers tend to drive regardless of the posted speed limit, increasing their speeds as roadway geometric characteristics improve, and the accident rate do not necessarily increase when average speed augments. Based on this premise, speed limits should also be established based in part on drivers themselves. For a speed limit to be effective, it must be reasonable to the driver.

In 1995, a study team from the FHWA conducted a scanning review tour in some European countries and Australia with the intent of obtaining knowledge about practices and policies concerning speed management and enforcement technologies. The report states that a prerequisite to developing any effective speed management program is to establish realistic speed limits to match roadway design and area characteristics. Specifically, the FHWA report states, “the relationship between speed limits and the roadway environment must be credible and consistent. If speeds limits are viewed as unrealistic for prevailing conditions by the majority of road users, they will not be obeyed”. From this point of view, establishing maximum speed limits based on the 85th percentile of travel speeds would be a reasonable practice.

Speed limits that reflect the behavior of the majority are determined by using the 85th percentile speed. The 85th percentile speed is defined as the speed at or below which 85 percent of the motorists travel. This method is based on the principle that the majority of motorists drive in a safe and reasonable manner and, in addition, these drivers tend to regulate the speeds of their vehicles relative to traffic, road and weather conditions. This 85th percentile rule identifies that the 85 percent of drivers are driving a reasonable and proper speed, given the conditions, and recognizes that the other 15 percent of drivers drive faster than is safe and reasonable.

Analytic support for setting speed limits near the 85th percentile comes from a series of traffic safety studies including in Solomon in 1964, Cirillo in 1968, RTI in 1970, and West and Dunn in 1971. These studies found that crash involvement rates on certain road classes were lower for vehicles traveling in a speed range whose upper bound was one standard deviation above traffic speeds, or approximately at the 85th percentile speed (TRB, 1998).

Some rational arguments supporting the use of the 85th percentile speed as a speed limit can be found in the *Speed Zone Guidelines* prepared by an ITE technical council committee.

The first reason given by the ITE committee is that several studies have demonstrated that drivers who travel either slower or faster than the 85th percentile

speed of the traffic stream have a higher crash involvement rate than those drivers who drive close to the 85th percentile speed. Therefore, posting the speed limit at the 85th percentile informs the motorists of the speed that is expected to minimize their risk of a crash (Taylor et al., 1993).

A second rationale for establishing rational speed limits is the desire for fair treatment of the drivers. ITE states that if speed limits are established artificially low, enforcement action cannot target all the violators and the police officer has too much discretion in picking out the motorists to be penalized. The cost of being selected can include both a fine and an increase in the cost of insurance. This non-uniform enforcement ultimately leads to poor public relations for both the traffic engineering agency and the enforcement agency. If speed limits are posted at the 85th percentile speed, police officers can then target their speed enforcement efforts at the remaining fifteen percent of drivers who are not in compliance with the speed limit.

A third reason supporting rational speed limits cited by the ITE committee is the need for consistency between the speed limit and other traffic control devices. The design of signal timing, traffic signal coordination, and sight distance requirements, must be based on operating speeds. If these values are based on a speed limit that does not reflect the real speed of traffic, safety may be compromised (Taylor et al., 1993).

Another argument could be added to this list: the need to reduce speed variance. As cited in Stuster et al. (1998), in his 1985 report, Lave suggested that speed limits should be set always regarding reducing speed variance. The more uniform the speeds of vehicles in a traffic stream, the less chance there is for conflict and crashes. Posting speed limits lower or higher than what the majority of drivers are traveling produces two distinct groups of drivers, those attempting to observe the limit and those driving at what they feel is reasonable and prudent. These differences in speeds may result in increased crashes due to tailgating, improper passing, reckless driving and waving from lane to lane.

A study conducted by Fitzpatrick, Krammes and Fambro in 1995 examined concerns and difficulties about the relationship between design, operating and posted speed. Concerns arise at locations where the posted speed limit based on an 85th percentile speed exceeds the roadway's inferred design speed. Fitzpatrick et al. (1997) stated that this inconsistency is a result of the fact that roadways are designed for near worst-case conditions. The study concluded, stating as a guideline, that speed limits on all roadways should be set by an engineer based on spot studies and the 85th percentile operating speed. They considered the 85th percentile speed the appropriate posted speed limit even for those sections of roadway that have inferred design speed less than the 85th percentile speed. Fitzpatrick et al. (1997) added that arbitrarily setting lower speed limits at point locations due to a lower inferred design speed is neither effective nor good engineering practice.

Although many support using the 85th percentile as an optimal speed limit, there are a number of people that argue against it. The Insurance Institute for Highway Safety (IIHS) believes that the 85th percentile is not a stationary point but is rather a moving target that increases when speed limits are raised. They suggest that

if speed limits are raised to meet the 85th percentile speed, a higher 85th percentile will result (IIHS, 2000).

Another example is found in Book and Smigieslski. They conducted a speed study in the city of Glendale, Arizona, comparing travel speeds, crashes, access points and development intensity. The expected patterns were that with decreases in volume, access points and development, speeds would increase. In this analysis, even though the relationship between these factors was mostly as anticipated, some unpredicted results were found. They reported, “one third of drivers followed their own beliefs, not Traffic Engineers’, on how driving should be accomplished” (Book-Smigieslski, 1999). In light of these results, Book and Smigieslski concluded recommending that the 85th percentile could be lowered between the 50th and 75th percentiles.

2.3.4 85th Percentile Speed Recommendations

The use of the 85th percentile speed as a posted speed limit is a current recommended practice in most states. Support for this practice can be found in several traffic manuals, such as the one published by the California Department of Transportation (Caltrans) or the one written by the Center for Transportation Research and Education (CTRE) at Iowa State University in 2001. Both documents encourage setting speed limits at the 85th percentile speed. Caltrans suggest that establishing speed limits on the basis of the 85th percentile conform to the consensus of those who drive highways as to what speed is reasonable and prudent. CTRE indicates that setting realistic speed limits is important in inviting driver compliance, allowing effective enforcement, minimizing public antagonism, and reducing crash incidence.

Other states have launched informational campaigns and brochures to help understand speed limits, how they are set and how they affect traffic safety. One example is the Maryland State Highway Administration, which published in 1997 an informational brochure supporting the use of a speed limit based on the 85th percentile. Another example, both Kansas and Arizona published a booklet called *Establishing Speed Limits, a case of majority rule* supporting the use of realistic speed limits. This booklet also discredits some widely held misconceptions, such as the erroneous perception that raising the posted speed limit will cause an increase in the speed of traffic (ADOT and KDOT, 2002).

2.3.5 Effects on Changing Speed Limits

A common assumption is that increasing speed limits will necessarily lead to increased speeds and consequently a higher likelihood of being involved in a crash. The following sections describe the literature conducted around this issue, and indicate that the consequences of speed limit changes on safety are not that straightforward.

2.3.5.1 1974: The National Maximum Speed Limit

In 1974, Congress enacted a National Maximum Speed Limit (NMSL) of 55 mph in response to a severe fuel shortage. Before the introduction of the NMSL, states set their own speed limits, which were generally higher than 55mph. Several

studies examined the effect of this new speed limit on road safety. In 1984 The Transportation Research Board reviewed these studies in the Special Report 55: *A Decade of Experience* and found that the lower speed limit reduced both travel speeds and fatalities, but at the same time, compliance with the speed limit decreased over time. However, the findings of the report clarified that not all of the decrease in fatalities can be attributed to the 55mph speed limit. The report states that the total amount of driving was reduced because of the economic crisis and fuel shortages, and this fact contributed to part of the decrease in fatalities. Improvements in vehicle characteristics, safer highways, and better emergency medical services enhanced safety and also reduced fatalities (TRB, 1984).

2.3.5.2 1987: Rural Interstate Highways

Since the imposition of the NMSL, there have been two major changes in speed limits in the United States. In 1987, states were permitted to raise the limit to 65 mph on qualifying sections of rural Interstate highways. Following this change, most states raised their speed limits to the new maximum. The effect of the change was widely studied. These studies generally showed an increase in speeds when speed limits were raised on freeways, but at the same time, they did not find a significant increase in fatalities.

Pfefer, Stenzel and Lee examined the effect of the new 65 mph speed limit on rural Interstate highways in Illinois and found, at the 95 percent confidence level, an increase of four mph in the 85th percentile speed for cars. The reported findings related to safety were more assorted, following the speed limit change, the frequency of all crashes increased by 14 percent, but no statistically significant change was detected in the frequency of fatal and injury crashes. In addition, no change was found in the rate of all crashes. The report also states that significant reductions were found for both the rate of car-truck fatal and injury crashes and the proportion of car-truck fatal and injury crashes to all fatal and injury crashes (Pfefer et al., 1991).

The impact of the new speed limit was also studied on Virginia's Rural Interstate highways by Jernigan and Lynn. Virginia's 65 mph speed limit became effective for passenger cars on July 1, 1988. The findings of this study, summarizing 18 months of experience with the new speed limit in Virginia, showed an increase in fatal crashes and fatalities. The report states that fatal crashes increased from 40 in 1987 to 59 in 1989, and fatalities increased from 44 to 63. Thus, Virginia had a 47.5 percent increase in fatal crashes and a 43.2 percent increase in fatalities. However, Jernigan and Lynn concluded that, even though the speed limit increased, this change might not account for the increases in fatal crashes and fatalities. They specified that weather conditions, changes in traffic volume, trip type, or vehicle mix could account for some of the increase (Jernigan-Lynn, 1991).

As a summary of most of these studies, Stuster, Coffman and Warren indicated in their synthesis of safety research related to speed that, when the speed limits were increased from 55 to 65 mph in the U.S., average speeds changed ranging from one to four mph (Stuster et al., 1998).

A review of these studies was also conducted by the Transportation Research Board and can be found in the Special Report number 254 *Managing Speed*. The effects of changing speed limits, particularly on safety, were found to vary.

As cited in the TRB Special Report *Managing Speed* (1998), in 1989, Garber and Graham examined 40 states that had raised speed limits on rural Interstate highways and reported a 15 percent overall increase in fatalities. However, the data for individual states appeared to be heterogenic: fatalities increased in 28 states and either decreased or remained the same in 12 states.

In 1994, several years after the permitted increase on rural Interstate highways, Lave and Elias looked for secondary effects that could result in positive safety consequences of the change in the speed limit. They suggested that, when speed limits were increased, state highway patrols were able to reallocate from monitoring the rural Interstate highways where posted limits had been raised to patrolling other roads. As cited in the TRB Special Report *Managing Speed* (1998), the change resulted in increased flexibility in the deployment of police enforcement resources, as these highways did no longer required as much enforcement, permitting patrol at other less safe roads. A second effect was the diversion of some traffic from other roads to the qualifying rural Interstate highways with new posted limits. They found general support for their hypothesis and, using Garber and Graham data, Lave and Elias estimated that the new speed limit reduced statewide fatality rates by 3.4 to 5.1 percent.

2.3.5.3 1995: *The Repeal of the NMSL*

On November 28 of 1995, the National Highway System (NHS) Designation Act abolished the federal mandate for the NMSL and returned the authority of establishing speed limits to the states. Several states raised their speed limits almost immediately.

After the repeal, several studies tried to evaluate the effects of increasing the speed limits. In 1997, Retting and Greene sampled traffic speeds in five states: California, Texas, New Mexico, Montana and Nevada. In general, they found a slight increase in average speeds and in 85th percentile speeds after the new speed limit was posted. In addition to that, more worrying results were reported. One year after the speed limit was raised to 65 mph on some urban freeways in California, the percentage of drivers exceeding 70 mph had increased 12 percent. Similarly, they found that drivers exceeding 70 mph on urban freeways in Texas increases from 15 percent before the change, to 50 percent one year later (Retting-Greene, 1991).

In 1996, the State of New Mexico increased its speed limit to 75 mph on rural Interstate highways, and in most cases, this new speed limit was close to the existing 85th percentile speed. Two years later, in 1998, Davis conducted a study to evaluate the effects of the change on New Mexico roads. He found different results on different roads; higher speed limits on the rural Interstate have lead to higher rates of crashes and injuries on I-25 and I-40. But it does not appear that higher speed limits had much effect on crashes on I-10, nor is there much evidence that the higher limits are creating big problems on rural non-Interstate roads. Davis found a reason for these discrepancies based on changes in travel patterns, increased levels of vacation

travel, differences in seat belt usage, rigorous enforcement and percentage of heavy traffic (Davis, 1998).

A similar study was conducted on Kansas highways in 2000. In this case, a slight increase in 85th percentile speeds was noted, but no statistically significant increases in crash, fatal crash and fatality rates were detected during the after period on either rural or urban Interstate highway networks (Najjar et al., 2000).

The State of Georgia raised speed limits shortly after the repeal of the NMSL and also published a report where the safety effects of the increased speed limit were presented. In this study, Dougherty (2000) showed consistent findings with previous studies in terms of relationship between average speed and higher speed limits. Figure 2-7 reveals a clear increase in average speed on Georgia's Interstates since January 1996.

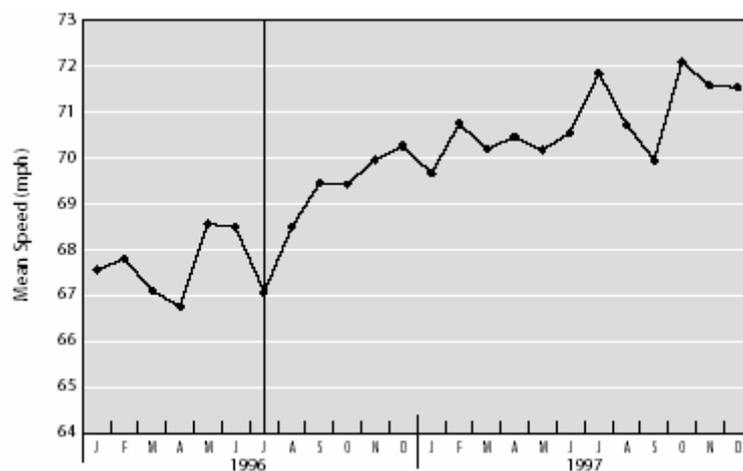


FIGURE 2-7 *Average Speed on Rural Interstates in Georgia, 1996–1997* (Dougherty, 2000).

Dougherty considered traditional measures of highway safety including the number of crashes, injuries, and fatalities on Georgia Interstate highways. It was anticipated that increasing the speed limit from 65 mph to 70 mph would lead to significantly more crashes, injuries, and fatalities; however, Interstate crashes did not show any increasing trend or seasonal pattern. Both injuries and fatalities exhibited slight increasing trends and some seasonality, especially in terms of the months with the highest and lowest numbers of injuries and fatalities. Dougherty (2000) concluded that none of the figures showed a step change in highway safety. The results of Dougherty's study for Interstate crashes, injuries and fatalities are presented in Figure 2-8, Figure 2-9 and, Figure 2-10, respectively.

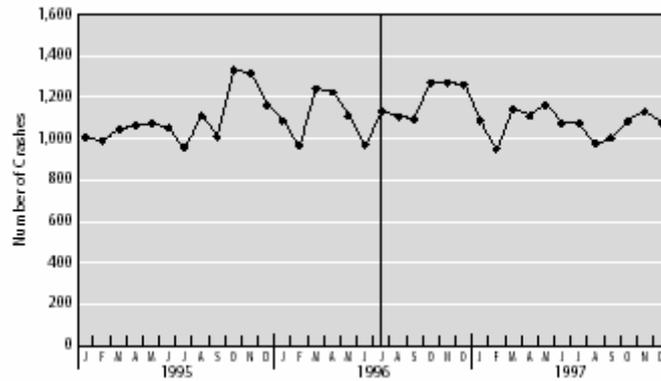


FIGURE 2-8 *Rural Interstate Highway Crashes in Georgia, 1995–1997* (Dougherty, 2000).

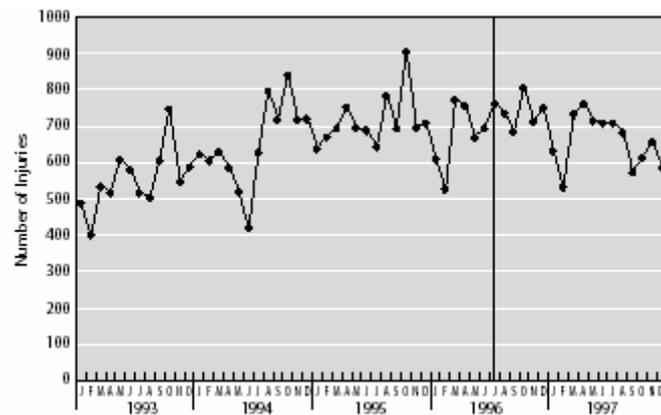


FIGURE 2-9 *Rural Interstate Highway Injuries in Georgia, 1993–1997* (Dougherty, 2000).

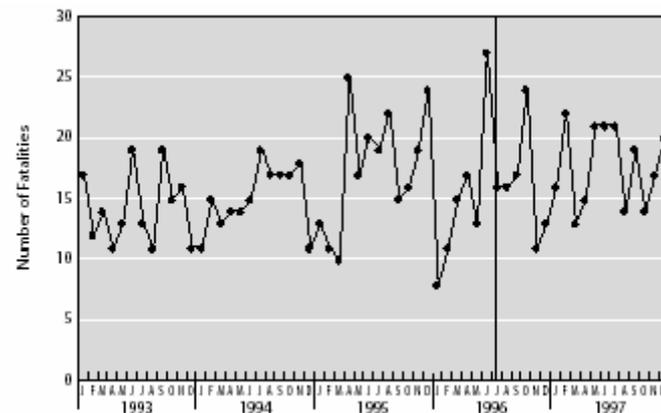


FIGURE 2-10 *Rural Interstate Highway Fatalities in Georgia, 1993–1997* (Dougherty, 2000).

2.3.6 Urban Roads

Most studies have focused on rural highways but a few researchers have examined the impacts of changing speeds on urban roads. In 1984, Spitz conducted a

study at ten California cities to provide a notion of speed trends on urban streets. He reported that the 85th percentile speed of traffic increased from 39.9 to 40.3 mph, less than 0.4 mph in 40 zones where the speed limits were raised. This was less than the 0.7 mph (from 40.1 to 40.8 mph) increase observed at the comparison sites that had no speed limit change. Moreover, in the 40 zones where speed limits were lowered, traffic speed also increased (Spitz, 1984).

As cited in Stuster et al. (1998), another study of urban speeds was conducted by Dudek and Ulman in 1986 on six sites on the urban fringe in Texas. In this case, the speed limit was lowered from 55 to 45 mph. They reported no significant changes on vehicle speeds and speed variance.

More recently, in 1997, Parker examined the consequences of raising and lowering speed limits in short speed zones on both urban and rural non-limited access highways. He evaluated 100 sites in 22 states using data collected before and after the speed limits were changed. Before and after speeds were also collected simultaneously at comparison sites where the speed limits were not altered. One of the findings showed that the majority of speed limits are posted below the average speed of traffic; however the most important finding was the conclusion that changing posted speed limits had little or no effect on driving speeds. The report reviewed before and after speed data at the selected sites and revealed that differences in average speeds, standard deviations of speeds, and 85th percentile speeds were generally less than two mph and were not related to the amount the posted speed limit was changed. Parker concluded that changing posted speed limits alone, without additional enforcement, educational programs, or other engineering measures, has only a minor effect on driver behavior (Parker, 1997).

With respect to safety, Parker (1997) found no significant changes in total crashes or fatal and injury crashes, which is consistent with the fact that no significant changes in speed were found.

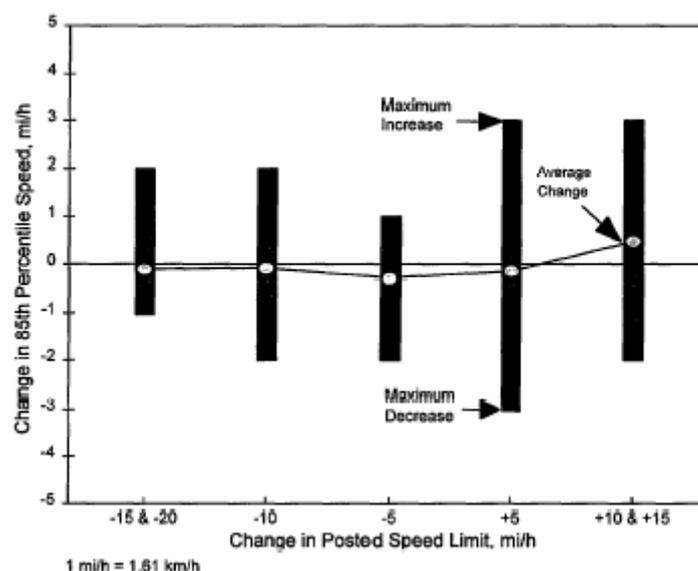


FIGURE 2-11 Maximum and Average Changes in the 85th Percentile Speeds at the Experimental Sites (Parker, 1997).

2.4 SUMMARY

The preceding sections have presented an overview of road safety audits, including its historical development and the different application stages. Furthermore, road safety reviews and thematic audits. Road safety reviews are intended to assess safety issues on existing roads and thematic audits allow focusing on a specific concern. The aim of this study is to focus a road safety review on speed issues. To provide additional background, the essential topics related to speed and speed limits have been considered.

As noted, the relation between speed and safety is complex. Although the evidence is not conclusive, speed seems to contribute to crash occurrence and deviation from average traffic speeds appears to be a crash risk factor. Evidence suggests that crash involvement risk is lowest near the average speed of traffic and increases when driving speeds are faster or slower than average. Speed variance appears to play the most important role in the relationship between speed and crash involvement rate. From this point of view, road safety campaigns and enforcement strategies should focus on reducing speed variance and conflicts resulting from large speed differences.

Speed management should look for the balance of engineering, enforcement and education to reduce speed-related crashes and promote the orderly movement of traffic. Speed limits are one of the most widely used tools in controlling speeds and are intended to improve safety. One important consideration when setting speed limits is that the relationship between speed limits and roadway geometry and roadside development must be consistent. Speed limits must be reasonable to the driver to be effective. Based on this premise and on the principle that the majority of drivers tend to regulate their speeds relative to traffic, road conditions and weather, speed limits should be established based in part on drivers themselves.

Setting the speed limit near the 85th percentile, the speed at or below which 85 percent of drivers operate their vehicles, assumes that most drivers are capable of judging the speed at which they operate safely. It has been shown that posting the speed limit at the 85th percentile minimizes crash risk, increases compliance with speed limits, helps police enforcement in the sense that officers can target a minor group of drivers, avoids inconsistencies between speed and other traffic devices and could reduce speed variance.

The effects of changing speed limits, particularly on safety, have been largely examined taking advantage of historical speed limit modifications. Several studies have reviewed some of these effects, showing that the consequences of changing speed limits are quite complicated. Research has demonstrated for all types of roads that the common assumption that higher speed limits lead to higher driving speeds is not always true. Moreover, it has also been revealed that increasing speed limits does not necessarily involve an increase in crashes, injuries or fatalities.

From this perspective, setting the speed limit at the 85th percentile speed, according to operating speeds, appears to increase driver compliance with speed limits, help enforcement to control speeders and improve consistency between speed and road environment, without endangering safety.