Synthesis of Safety Research Related to Speed and Speed Management

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ABSTRACT

This report presents a synthesis of research findings on the safety effects of speed, speed limits, enforcement, and engineering measures to manage speed.

The report updates a similar synthesis published in 1982. A great deal of speed related research has been carried out since that time. This synthesis highlights the results of significant safety research related to speed completed since the last update. Some of the earlier benchmark studies are incorporated where appropriate.

The report is a product of the FHWA–NHTSA Speed Management Team.

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INTRODUCTION

This document provides a review of safety research related to speed and speed management. This review builds upon a similar synthesis prepared in 1982. This synthesis highlights the relationships among vehicle speed and safety; factors influencing speeds; and the effects on speed and crashes of speed limits, speed enforcement, traffic calming and other engineering measures intended to manage speed.

Despite the substantial social and technological changes that have occurred since the original speed synthesis was published, vehicle speed remains an important public policy, engineering, and traffic safety issue. Speed is cited as a related factor in 30 percent of fatal crashes and 12 percent of all crashes (Bowie and Walz, 1994). Based on on–scene investigations of over 2,000 crashes in Indiana by teams of trained technicians, excessive speed for conditions was identified as the second most frequent causal factor out of approximately 50 driver, vehicle, and environmental factors (Treat et al., 1977).

Excessive vehicle speed reduces a driver's ability to negotiate curves or maneuver around obstacles in the roadway, extends the distance necessary for a vehicle to stop, and increases the distance a vehicle travels while the driver reacts to a hazard.

The following pages present the results of a systematic review of the literature concerning safety research related to speed and speed management. Initial listings of citations were generated using multiple keyword filters on several bibliographic databases. The most productive databases were those of the National Technical Information Service (NTIS), the Knight–Ridder Transportation Resources Index, and the Transportation Research Information Service (TRIS). The initial inventory of approximately 700 citations was supplemented by searches of the Institute of Transportation Engineers (ITE) index and more than 100 items that either predated the on–line data bases or otherwise were known to be pertinent.

SPEED–SAFETY RELATIONSHIPS

Speed is the quintessential traffic safety issue, probably due to the clearly perceived relationship between vehicle velocity and human capabilities and limitations. Even inexperienced drivers usually recognize the merit of reducing their speed in uncertain or hazardous conditions to provide additional time for decision–making and action; driving experience affirms this natural tendency for self–preservation. Good judgment, however, is not uniformly applied by the operators of motor vehicles, nor are skills and abilities possessed in equal measure by all drivers. For these reasons, vehicle speed could be related to traffic safety in two ways: (1) the greater a vehicle's velocity the less time available for the operator to react to a hazard or for other motorists, bicyclists, or pedestrians to react to the vehicle; and (2) the physical relationship of mass and speed to energy. If the first relationship exists, it would be expressed in the relative incidence of crashes at different speeds. If the second relationship exists, it would be expressed in the relative severity of crashes at different speeds. Research concerning these relationships is reviewed in the following paragraphs.

Speed and the Incidence of Crashes

In a landmark study of speed and crashes involving 10,000 drivers on 600 miles (970 kilometers) of rural highways, Solomon (1964) found a relationship between vehicle speed and crash incidence that is illustrated by a U–shaped curve. Crash rates were lowest for travel speeds near the mean speed of traffic, and increased with greater deviations above and below the mean. The estimated travel speed from the accident records were compared to the speeds measured at representative sites within each study

section. The comparisons showed that crash–involved drivers were over–represented in both high– and low– speed categories of the speed distribution.

Crash–involvement rates decreased with increasing speeds up to 65 mi/h (105 km/h), then increased at higher speeds. Further, Solomon reported that the results of his study showed that "low speed drivers are more likely to be involved in accidents than relatively high speed drivers." Cirillo (1968) in a similar analysis of 2,000 vehicles involved in daytime crashes on interstate freeways confirmed Solomon's results, extending the U–shaped curve to interstate freeways, as illustrated in figure 1. The analysis was limited to crashes involving two or more vehicles traveling in the same direction.
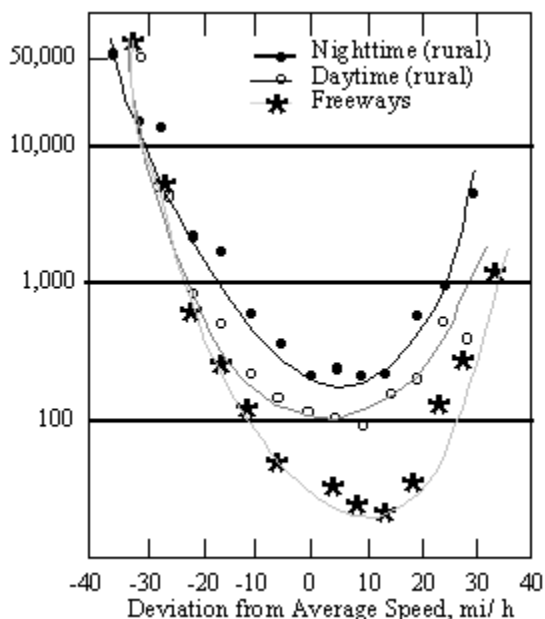
Figure 1. Crash involvement rate by deviation from average travel speed (from Solomon, 1964, and Cirillo, 1968).

In these studies, the speeds of crashed vehicles were obtained from police reports, driver's reports, or third party estimates – sources that are subject to error and unknown reliability. Another serious challenge to the internal validity of results is that many of the crashes involving slow speed likely involved vehicles that were stopping or slowing to turn or just entering the road. Whereas, the speed data were collected at locations within the study sections that were representative of the average speed for the entire section but away from intersections, driveways, and other locations having a major effect on speed. These problems would tend to overstate the risk of vehicles traveling at slower speeds.

To address these concerns, the Research Triangle Institute (1970) used a combination of trained on–scene crash investigators and a system of automated continuous speed monitoring stations using sensors embedded in the roadway pavement to obtain the speed of crash–involved vehicles and accurate measurements of traffic speeds at the time of the crash. Detailed data were collected on 114 crashes involving 216 vehicles on a state highway in Indiana with speed limits of 40 to 65 mi/h (65 – 105km/h). In about nine cases, speeds could be linked to specific vehicles involved in crashes and matched well with the estimates of the professional investigators. More importantly, the investigators recognized that vehicles slowing to negotiate a turn should be treated differently in the analysis than vehicles moving

slowly in the flow of traffic. The former involves a required slow speed to safely complete an intended maneuver, while the later is more likely to reflect driver choice or limited ability.

Figure 2. Relationship between speed and crash involvement (from West and Dunn, 1971).

West and Dunn (1971) reported the results of the Research Triangle Institute studies. Crashes involving turning vehicles accounted for 44 percent of all crashes observed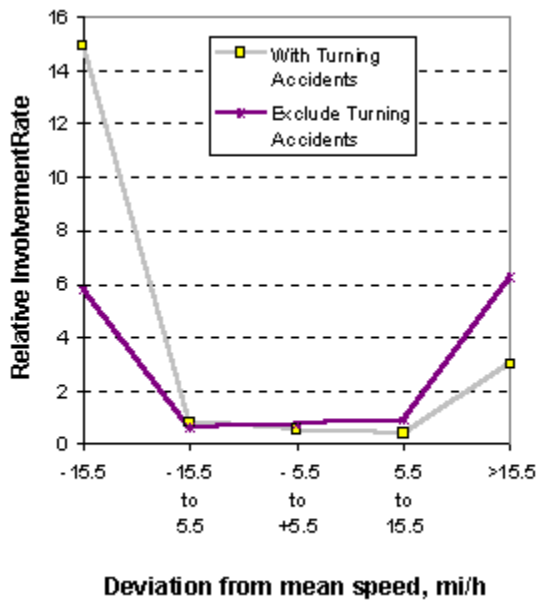 in the study. Excluding these crashes from the analysis greatly attenuated the factors that created the U–shaped curve characteristic of the earlier studies. Without vehicles slowing to turn, or turning across traffic, the investigators found the risk of traveling much slower than average was much less pronounced. Crash risk was greatest for vehicles traveling more than two standard deviation above the mean speed. As illustrated in figure 2, the likelihood of being involved in a crash was extremely flat, with little difference in crash risk for vehicles traveling within 15 mi/h (25 km/h) of the mean speed of traffic. Even excluding turning crashes, the crash risk for vehicles traveling much faster or slower was six times the average rate.

Munden (1967), following a different approach, reported similar results for drivers in the United Kingdom who habitually drive at deviant speeds. The speed of selected drivers were observed and compared to the four preceding and four following vehicles. For drivers observed more than once, those traveling more than 1.8 standard deviations above or below the mean traffic speed had significantly higher crash rates. However, drivers observed only once did not exhibit a U–shape relationship.

More recently, Australian researchers, Fildes, Rumbold, and Leening (1991), used self–reported crash data collected at roadside from motorists whose driving speed had been unobtrusively measured. The researchers found a trend of increasing crash involvement for speeds above the mean speed in both rural and urban conditions – similar to the correlations reported in the early studies. However, no relationship between slower speeds and increased crash involvement was found. In fact, Fildes and Lee (1993) report that the researchers, "...failed to observe any vehicles traveling at the very slow speeds reported by Solomon on rural highways."

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Figure 3 illustrates the speed–crash relationships identified by Fildes et al, for the two rural and two urban sites used in their study. The relationships are presented along with the U–shaped curves derived from the early research on this topic. Some of the difference between the results can be attributed to changes in driver behavior (e.g., far less "drinking and driving" now than in the 1950s and 1960s) and safety improvements in road and vehicle design during the nearly half–century since the early data were collected.

Harkey, Robertson, and Davis (1990)recently replicated the U–shape relationship between speed and crashes on urban roads. The researcher compared the police–estimated travel speed of 532 vehicles involved in crashes over a 3–year period to 24–hr speed data collected on the same section of non–55–mi/h roads in mostly built–up areas of Colorado and North Carolina. To partial address the concerns of earlier studies and make the crash and speed data more comparable, their analysis was limited to non–intersection, non–alcohol, and weekday crashes. However, the estimated travel speeds of the vehicles before the crash are questionable.
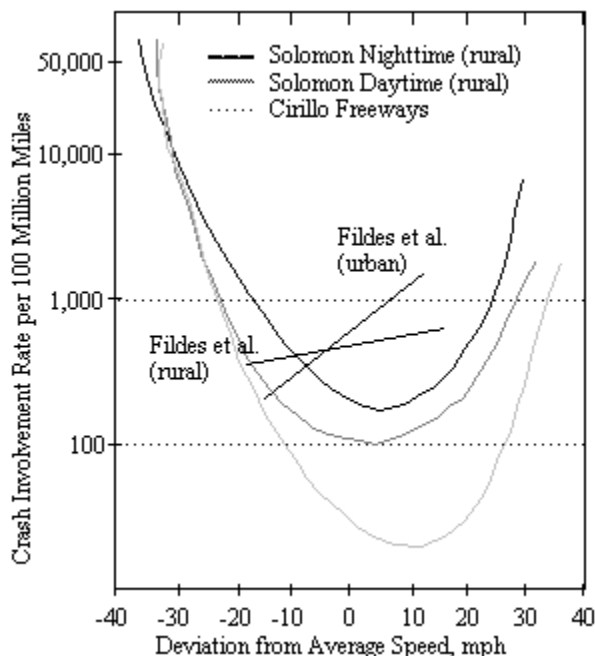

Figure 3. Crash involvement rate by variation from average traffic speed (from Solomon, 1964, Cirillo, 1968, and, Fildes et al., 1991).

In defense of the early studies, it is important to note that the researchers emphasized speed variance, rather than absolute speed, as the primary culprit in the incidence of crashes; speed variation is defined as a vehicle's deviation from the mean speed of free–flowing traffic. Hauer's (1971) theoretical analysis of overtakings demonstrated that the number vehicle interactions in terms of passing or being passed is a U–shaped curve with a minimum at the median speed. The number of vehicles that a driver catches up with and overtakes increases with speed and the number of times a driver is passed by others decreases with speed. Thus, the increased risk of crash involvement is a result of potential conflicts from faster traffic catching up with and passing slower vehicles. The slower motorists go relative to the median speed, the more overtakings and potential inter–vehicle conflicts encountered. This is illustrated in figure 4, which compares the relative overtaking rates for a 100–km/h road with a standard deviation of 10 percent with the crash risk form various studies. Hauer claimed "the indiscriminate public crusade against speeding should be replaced by a balanced approach emphasizing the dangers of both fast and slow driving."

If conflicts created by large differences in travel speeds were a major factor in the likelihood of crashes, then one might expect to find a large number of crashes involving two or more vehicles traveling in the same direction. Cerrilli (1997) found less than one–third of all crashes and 5 percent of all fatal crashes in 1996 involved two or more vehicle traveling in the same direction. Many of these likely occurred as a consequence of a vehicle slowing or stopping for cause (i.e., to make an intended maneuver or avoid striking a stopped vehicle or other hazard) and being struck from behind by a vehicle following too closely or going too fast for the driver to stop in time to avoid the collision. By far, the predominant crash type on rural roads is a single vehicle running off the road.

In a review of the issues associated with speed and traffic safety, Fildes and Lee (1993) reported that little research was conducted concerning the relationship between speed and crash involvement during the

1970s and 1980s. Lave (1985) revived the issue of speed variance as a contributor to crashes, suggesting that raising the speed limit would result in fewer crashes in situations where variance was reduced by the higher limit. Lave concluded that "speed limits designed to reduce the fatality rate should concentrate on reducing variance. This means taking action against slow drivers as well as fast ones."
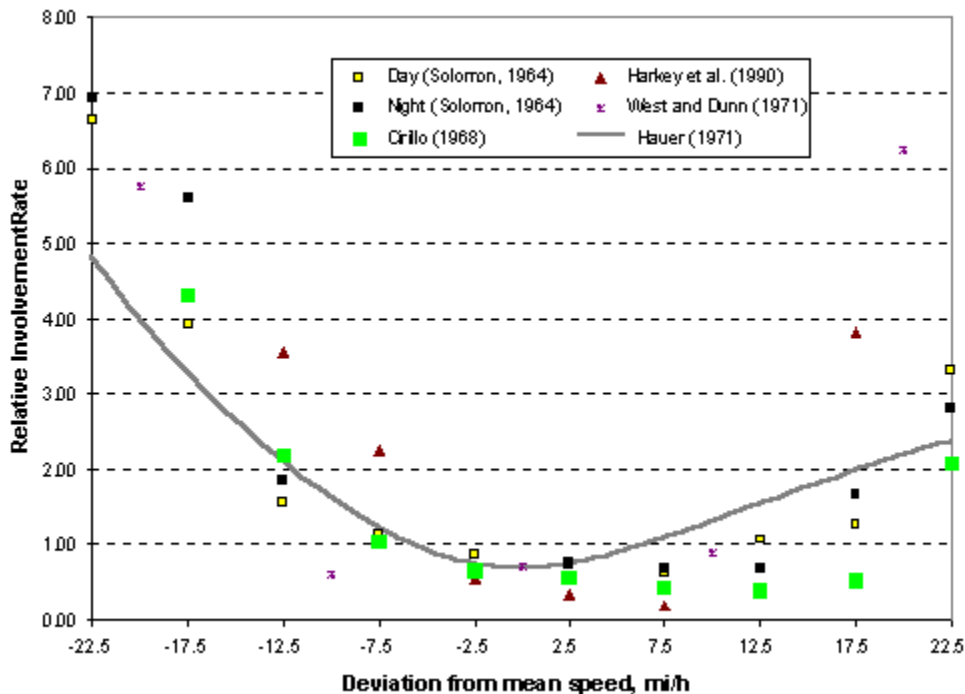
Figure 4. Crash involvement and overtaking rates relative to average rate and speed.

Similarly, Garber and Gadiraju (1988) reported that crash rates increased with increasing variance on all types of roadways and that speeds were higher on roads with higher design speeds, irrespective of the posted speed limits. They reported minimal variance when the posted speed limit was fewer than 16 km/h (10 mi/h) below the design speed of the road. In the analysis, the researchers combined data from different road types (e.g., rural two–lane, urban freeway, and rural freeway) which could lead to spurious results.

Speed And The Severity Of Crashes

The relationship between vehicle speed and crash severity is unequivocal and based on the laws of physics. The kinetic energy of a moving vehicle is a function of its mass and velocity squared. Kinetic energy is dissipated in a collision by friction, heat, and the deformation of mass. Generally, the more kinetic energy to be dissipated in a collision, the greater the potential for injury to vehicle occupants. Because kinetic energy is determined by the square of the vehicle's speed, rather than by speed alone, the probability of injury, and the severity of injuries that occur in a crash, increase exponentially with vehicle speed. For example, a 30–percent increase in speed (e.g., from 50 to 65 mi/h [80 to 105 km/h]) results in a 69–percent increase in the kinetic energy of a vehicle.

The relationship between travel speed and the severity of injuries sustained in a crash was examined by Solomon (1964), who reported an increase in crash severity with increasing vehicle speeds on rural roads. From an analysis of 10,000 crashes, Solomon concluded that crash severity increased rapidly at

speeds in excess of 60 mi/h (96 km/h), and the probability of fatal injuries increased sharply above 70 mi/h (112 km/h).

Bowie and Waltz (1994), in an analysis of tow–away crashes reported in the National Accident Sampling System over a 7–year period, found that the chance of being injured in a crash depended on the change in speed at impact (delta V) . As shown in table 1, the risk of a moderate or more serious injury was less than 5 percent when delta V was less than 10 mi/h (16 km/h) and increased to more than 50 percent when delta V exceeds 30 mi/h (48 km/h).

Table 1. Injuries per 100 Occupants by Change in Speed (deltaV) at Impact

delta V mi/h	Moderate Injury AIS 2+	Serious Injury AIS 3+	delta V km/h
1–10	4.5	1.0	1–16
11–20	10.6	2.6	17–32
21–30	29.2	11.1	33–48
31–40	53.4	27.9	49–64
41–50	67.2	40.6	65–80
50+	69.3	54.3	80+
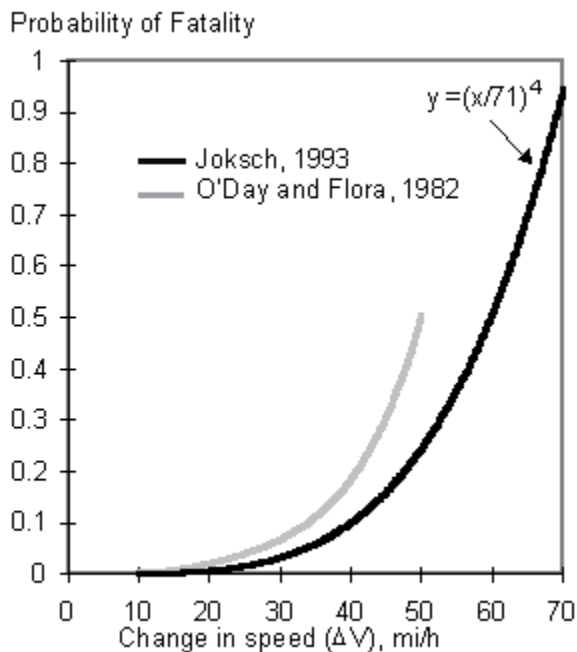
Figure 5. Effect of change in speed at impact on fatality risk.

Joksch (1993) found that the risk of a car driver being killed in a crash increased with the change in speed to the fourth power as shown in figure 5. The risk of a fatality begins to rise when the change in speed at moment of impact exceeds 30 mi/h (48 km/h) and is more than 50 percent likely to be fatal when the change exceeds 60 mi/h (96 km/h). The probability of death from an impact speed of 50 mi/h (80 km/h) is 15 times the probability of death from an impact speed of 25 mi/h (40 km/h).

The fatality risk curve from an earlier study by O'Day and Flora (1982) is also shown for comparison. The shift in the curve to the right can be explained in part by improvements in vehicle crashworthiness, seat–belt use, and emergency medical care over time. (See TRB, 184; Evans, 1991; Zador and Ciccone,1991; and FORS, 1992).

The relationship between impact speed and crash severity is particularly critical for pedestrians, the most vulnerable road users. In a recent review of the issues, the European Transport Safety Council (1995) report that only 5 percent of pedestrians died when struck by a vehicle traveling at 20 mi/h (32 km/h); however, the proportion of fatalities increased to 45 percent at 30 mi/h (48 km/h) and to 85 percent at 40 mi/h (64 km/h).
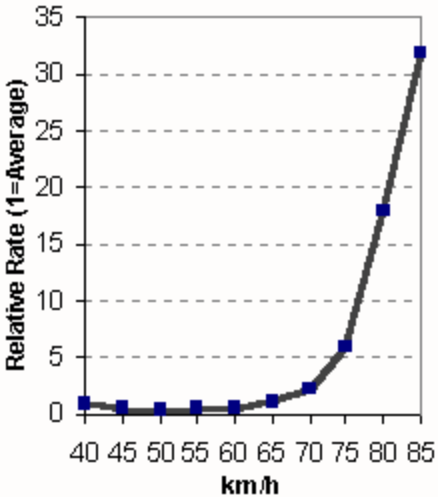
Figure 6. Injury crash involvement rate relative to average rate and travel speed (From Koeden et al., 1997).

Kloeden et al. (1997) compared the estimated speeds of over 150 cars involved in non–alcohol related injury crashes in 60 km/h speed zones in Australia with the free speed of cars measured at the same location at the same time of day and day of week. The pre–crash traveling speeds were based on detailed investigations of each crash scene and computer–aided crash reconstruction. The average and median speed of traffic was about 60 km/h (37 mi/h).

As shown in figure 6, the risk of being involved in an injury crash was lowest for vehicles traveling near or below the median speed and increased exponentially at higher speeds. Vehicles exceeding the 90th percentile speed or traveling more than 7 km/h faster (4 mi/h) than the speed limit and median speed had above average injury crash involvement rates. Nearly 25 percent of the cars involved in injury crashes were traveling faster than 72 km/h (45 mi/h) compared to only 2 percent of free flow traffic.

Clearly, a research or engineering approach to speed management that ignores the injury consequences of vehicle speed could lead to unintended results.

FACTORS INFLUENCING SPEED

In most of the crashes involving a slow–speed vehicle, the operator of the slow–speed vehicle is either preparing for or in the process of a maneuver that required a slow speed for safe execution (e.g., turning, crossing, entering, or exiting). The current discussion focuses on the conditions in which driving speed is a matter of individual choice.

Many different factors can influence the speed at which a motorist chooses to drive. Speed choice can be influenced by driver age, gender, attitude, and the perceived risks of law enforcement or crash. Speed choice also is influenced by situational factors, such as weather, road or vehicle characteristics, speed zoning, speed adaptation, impairment, or simply "running late." These and other factors are addressed in the following paragraphs.

Driver Attitudes and Behavior

Solomon (1964) identified the driver and vehicle characteristics associated with speeding on rural highways during the late 1950s. He reported higher mean speeds for young drivers, out of state vehicles, buses, and late model passenger vehicles, especially high–performance models. Other early studies linked driving speed to age, trip length, and presence or absence of passengers. More recently, Fildes et al. (1991) unobtrusively measured the speeds of vehicles on urban and rural road segments in Victoria, Australia, then stopped a sample of the vehicles to interview the drivers. The researchers found that younger drivers, drivers without passengers, drivers of newer cars, drivers traveling for business purposes, and high mileage drivers were more likely to drive faster than average and exceed the speed limit.

Mustyn and Sheppard (1980) found more than 75 percent of drivers claiming they drive at a speed that traffic and road conditions permit, regardless of the posted speed limit. Although the motorists who were interviewed tended to consider speeding to be one of the primary causes of crashes, they did not consider driving 10 mi/h (16 km/h) over the limit to be particularly wrong. However, most of those interviewed considered driving 20 mi/h (32 km/h) over the limit to be a serious offense.

Of all drivers involved in fatal crashes, young males are the most likely to have speed as a collision factor. In 1995, nearly 40 percent of the fatal crashing involving male drivers 15 to 20 years old were speed related (NHTSA 1995). The relative proportion of speed–related crashes to all crashes decreases with increasing driver age.

A recent study of the behavioral cues associated with driving while intoxicated (DWI) found that drivers who were exceeding speed limits by 10 mi/h (16 km/h) or more were DWI (BAC>0.08) only in 9 percent of all nighttime enforcement stops, but those driving more than 10 mi/h (16 km/h) under the limit were found to be DWI in 48 percent of the stops (Stuster, 1997); driving under the speed limit does not include maneuvers that require slow speed. A previous study of motorcyclist DWI detection found that 10 percent of speeding motorcyclists have BACs of 0.08 or greater (Stuster, 1993). These probabilities of DWI are low compared to other behaviors, such as weaving, turning with a wide radius, or drifting during a curve (all with probabilities of DWI greater than 50 percent).

Driving with excessive speed is a risk–taking behavior that often is found in association with other risk–taking behaviors. For example, in 1995, only 37 percent of passenger vehicle drivers under 21 years old who were involved in fatal crashes related to speed were wearing safety belts at the time of the crash. In contrast, 56 percent of drivers in the same age group were properly restrained when speed was not a factor. For drivers 21 years and older, the percentage of drivers involved in speed–related fatal crashes who were using restraints at the time of the crash was 34 percent, but 62 percent of drivers were restrained in fatal crashes that were not speed related.

Road Characteristics

Road characteristics contribute to the speeds at which drivers operate their vehicles. Warren (1982) reported the most significant characteristics to be curvature, grade, length of grade, number of lanes, surface condition, sight distance, lateral clearance, number of intersections, and built–up areas near the roadway. Tignor and Warren (1990) reported that the number of access points and nearby commercial development are the factors that have the greatest influence on vehicle speeds. In contrast, Fildes et al. (1987, 1989) found road width and number of lanes to have the greatest influence on speed choice.

More recently, the European Transport Safety Council (1995) reported that width, gradient, alignment, and layout, and the consistency of these variables, are the determinants of speed choice on a particular stretch of road. Road characteristics determine what is physically possible for a vehicle, but they also influence "...what seems appropriate to a driver." In this regard, individual perceptions of appropriate

speed are influenced by the maintenance condition of the road. For example, Cooper et al. (1980) found that average vehicle speeds increased by 1.6 mi/h (2 km/h) after resurfacing major roads in the United Kingdom; no change in traffic speed was found in locations where surface unevenness remained the same after resurfacing. Parker (1997) found no change in speeds on two rural highways and a 3 mi/h (5 km/h) increase on two urban streets that were resurfaced and had the speed limit raised. It was not possible to determine if the speed change was due to the higher speed limit or the resurfacing.

Roadway surroundings, especially proximity of tall objects to the road, also can influence the speeds at which motorists choose to drive. Designing roadway features to influence driver perceptions of appropriate speeds is a subject that will be addressed briefly in a subsequent section of this report.

The theory of speed adaptation predicts that apparent vehicle speed is influenced by the speed and duration of recent travel in the vehicle. This adaptation to vehicular speed is the combined result of the visual, auditory, and proprioceptive feedback associated with various rates of travel. Speed adaptation is a commonly experienced phenomenon that results in an under estimation of speed after encountering a reduced–speed zone (Schmidt and Tiffin, 1969; Mathews, 1978). In short, according to the speed adaptation hypothesis, the perceived speed of one's own vehicle will be lower than the actual speed if the driver has recently been operating the vehicle at a higher speed.

Several studies have explored the speed adaptation hypothesis. For example, Denton (1976) found that drivers who had traveled at 70 mi/h (113 km/h) for three minutes tended to drive 5 to 15 mi/h (8 to 24 km/h) faster in a 30 mi/h (48 km/h) zone than drivers who had not previously driven at the faster speed. Casey and Lund (1987) found a lesser, but more persistent, effect when drivers made the transition from 55 mi/h to 35 mi/h zones (88.5 to 56.3 km/h). Vehicle speeds on streets and roadways leading from highways and freeways were greater than the speeds approaching the highways and freeways, even though the posted speed limits are the same.

The review of speed–related issues prepared by Fildes and Lee (1993) for the Australian Federal Office of Road Safety describes the cognitive aspects of speed perception. In particular, the authors summarize how the visual pattern that is presented to a moving observer creates a blur of increasing magnitude at greater deviations from the fixation point. This "retinal streaming" provides cues that are used to help estimate speed. Human capabilities, however, are limited in this regard. Most research on the topic has found that drivers underestimate their speeds, especially at the medium and high speed ranges. Further, research has found perceptual limitations that contribute to drivers underestimating the curvature of an approaching bend (Shinar, 1977). Brummelaar (1983) and Fildes (1986) identified road curve features that influence a driver's perception of curvature.

Environmental Conditions

Weather conditions influence the vehicle speed selected by most drivers. For example, reduced visibility due to fog caused a 6 mi/h (10 km/h) decline in mean speeds on a freeway in Minnesota (CRC, 1995). Greater reductions in speed can be observed under extreme conditions (Schwab, 1992). Although drivers reduce their speeds during poor environmental conditions, this reduction is often accompanied by higher variation in speeds. Liang et al. (1998) in an analysis of speeds on a rural freeway in Idaho found the standard deviation of speed doubles during fog events and triples during snow. The researchers also found that drivers reduce their speeds an average of 0.7 mi/h for every mi/h that the wind speed exceeds 25 mi/h or 0.4 km/h for every 1 km/h that wind speed exceeds 40 km/h.

Although wet road surfaces will affect traction when attempting to stop, pass, or negotiate a curve or turn, most drivers do not reduce their speeds very much when traveling on wet roads. Olson et al. (1984) compared speed data collected during daylight hours on wet and dry days at 22 sites in Illinois and found no practical differences. The maximum difference in speed was less than 2.5 mi/h (4km/h). Similarly, Lamm et al. (1990) found no differences in operating speeds on dry and wet pavements for 11 curves

studied on two–lane rural roads in New York. Although light rain had little effect on speeds, Ibrahim and Hall (1994) observed 3 to 6 mi/h (5 to 10 km/h) reductions during periods of heavy rain.

SPEED LIMITS AND SPEEDS

In a survey of speed zoning practices, Parker (1985) found that all states and most local agencies consider the speed of traffic in setting speed limits. The primary factors considered in engineering studies to set speed limits were, in order of their importance:

- 85th percentile speed.
- Type and amount of roadside development.
- Accident experience.
- Adjacent Limits.
- 10 mi/h pace (i.e., speed range that contains the largest percentage of vehicles).
- Horizontal and vertical alignment.
- Design speed.
- Average test run speed.
- Pedestrians.

Criteria and procedures for setting appropriate speed limits in Australia (Fildes and Lee, 1993) and Canada (Knowles et al., 1997) are remarkably similar to the methods followed in the United States.

In general compliance with speed limits is poor. Harkey et al. (1990) found that 70 percent of the vehicles exceeded the speed limit on a representative sample of low and moderate speed roads in four States. Similar results are reported abroad by the European Transport Safety Council (1995) and in Canada by Knowles et al. (1997).

A number of studies have examined the effects of altering speed limits on speeds. Spitz (1984) reported that the 85th percentile speed of traffic increased less than 0.4 mi/h (0.6 km/h) in 40 zones where speed limits were raised in 10 California cities. This was less than the 0.7–mi/h (1.1–km/h) increase observed in the comparison sites which had no speed limit change. For the 10 zones where speed limits were lowered, speeds actually increased on average by 1.1 mi/h (1.8km/h).

Dudek and Ulman (1986) found no significant changes in speeds at six sites in the urban fringe where speed limits were lowered from 55 to 45 mi/h (89 to 72 mi/h).

Change in 85th Percentile Speed, mi/h
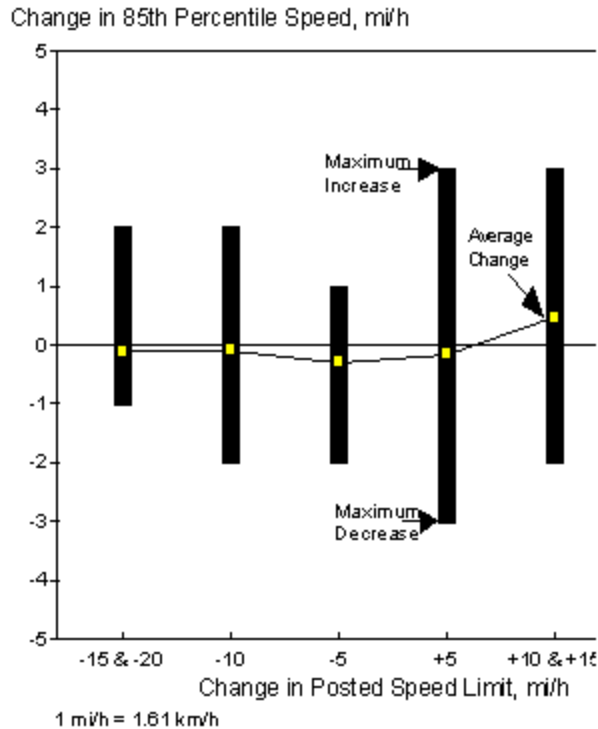
Figure 7. **Effects of altering speed limits by various amounts on non–freeways (Parker, 1997).**

Parker (1997) , taking advantage of routine speed zoning changes being made by State and local agencies, evaluated the effects of raising and lowering speed limits by various amounts at 98 non– freeway sites in 22 States.

Free–flow speeds were measured for a 24–hr period before the speed limit was altered and on the same day of the week about one year later. Before and after speeds were measured simultaneously at comparison sites where speed limits were not altered to control for time trends. As shown in figure 7, raising and lowering speed limits had little or no effect on speeds. Although maximum speed changes up to 3 mi/h (5 km/h) were observed at individual sites, the average change in the mean and 85th percentile speeds was less than 1 mi/h and similar to sites that were not changed.

However, studies in the USA and abroad generally show an increase in speeds when speed limits are raised on freeways. Changes in mean speeds ranging from 1 to 4 mi/h were observed when the speed limits in the United States were increased from 55 mi/h (89 km/h) to 65 mi/h (105 km/h) as shown in table 2.

Table 2. Speed increases observed from raising speed limit from 55 to 65 mi/h

	mi/h	km/h
Brown et al. (1990)	2.4	3.9
Freedman and Esterlitz (1990)	2.8	4.5
Mace and Heckard (1991)	3.5	5.6
Pfefer, Stenzel, and Lee (1991)	4–5	6–8
Parker (1997)	0.2–2.3	0.3–3.7

Finch et al. (1994) analyzed the changes in speeds from raising and lowering speed limits reported in a number of international studies and found that the change in mean traffic speed is roughly one–fourth of the change in the posted limit. Knowles et al.(1997) reported similar findings from observational before and after studies in Canada.

SPEED LIMITS AND SAFETY

Another way to examine the relationship between vehicle speed and traffic safety is to measure the effects of lowering or raising speed limits on the incidence and severity of crashes. Table 3 summarizes the results of studies of this type conducted in several countries. The table shows that crash–incidence or crash severity, or both measures, generally decline whenever speed limits have been reduced. Conversely, the number of crashes or crash severity generally increased when speed limits were raised, especially on freeways.

Table 3. Summary of the effects of raising or lowering speed limits.			
Reference	Country	Change	Results
Speed Limit Decreases			
Nilsson (1990)	Sweden	110 km/h to 90 km/h (68 mi/h to 56 mi/h)	Speeds declined by 14 km/h Fatal crashes declined by 21%
Engel (1990)	Denmark	60 km/h to 50 km/h (37 mi/h to 31 mi/h)	Fatal crashes declined by 24% Injury crashes declined by 9%
Peltola (1991)	UK	100 km/h to 80 km/h (62 mi/h to 50 mi/h)	Speeds declined by 4 km/h Crashes declined by 14%
Sliogeris (1992)	Australia	110 km/h to 100 km/h (68 mi/h to 62 mi/h)	Injury crashes declined by 19%
Finch et al. (1994)	Switzerland	130 km/h to 120 km/h (81 mi/h to 75 mi/h)	Speeds declined by 5 km/h Fatal crashes declined by 12%
Scharping (1994)	Germany	60 km/h to 50 km/h (37 mi/h to 31 mi/h)	Crashes declined by 20%

Newstead and Mullan (1996)	Australia	5–20 km/h decreases (3–12 mi/h decreases)	No significant change (4% increase relative to sites not changed)
Parker (1997)	USA 22 states	5–20 mi/h decreases (8–32 km/h decreases)	No significant changes
Speed Limit Increases			
NHTSA (1989)	USA	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Fatal crashes increased by 21%
McKnight, Kleinand Tippetts (1990),	USA	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Fatal crashes increased by 22% Speeding increased by 48%
Garber and Graham (1990)	USA (40 States)	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Fatalities increased by 15% Decrease or no effect in12 States
Streff and Schultz (1991)	USA (Michigan)	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Fatal and injury crashes increased significantly on rural freeways
Pant, Adhami and Niehaus (1992)	USA (Ohio)	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Injury and property damage crashes increased but not fatal crashes
Sliogeris (1992)	Australia	100 km/h to 110 km/h (62 mi/h to 68 mi/h)	Injury crashes increased by 25%
Lave and Elias (1994)	USA (40 states)	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Statewide fatality rates decreased 3–5% (Significant in 14 of 40 States)
Iowa Safety Task Force (1996)	USA (Iowa)	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Fatal crashes increased by 36%
Parker (1992)	USA (Michigan)	Various	No significant changes
Newstead and Mullan (1996)	Australia (Victoria)	5–20 km/h increases (3–12 mi/h increases)	Crashes increased overall by 8% 35% decline in zones raised from 60–80
Parker (1997)	USA 22 states	5–15 mi/h (8–24 km/h)	No significant changes

Parker (1992) found little change in crashes on low and moderate speed roads in Michigan where speed limits were altered under the State's normal speed zoning process. For the 21 sites where the speed limit was increased, crashes decreased about 3 percent compared to sites not changed. Crashes also decreased approximately 2 percent at the 47 sites where speed limits were lowered. Neither change was statistically significant.

Parker (1997) found no significant changes in total or injury crashes for the 98 sites where speed limits were altered in the 22 States. This should not be surprising since, as discussed in the previous section, there were little or no change in speed. Compared to sites not change, crashes increased on the average 7 percent at sites where the speed limits were lowered and decreased on the average 11 percent where the speed limits were increased.

Based on the investigations of 50 separate speed limit changes on urban and rural roads in Sweden, Nilsson (1981) derived a series of mathematical functions that explain the relationship between changes in a speed limit and traffic safety. Figure 8 illustrates Nilsson's calculations, which predict increases in fatal crashes as the change in vehicle velocity by a factor of 4, severe injury crashes by a factor of 3, and all injury crashes by a factor of 2.
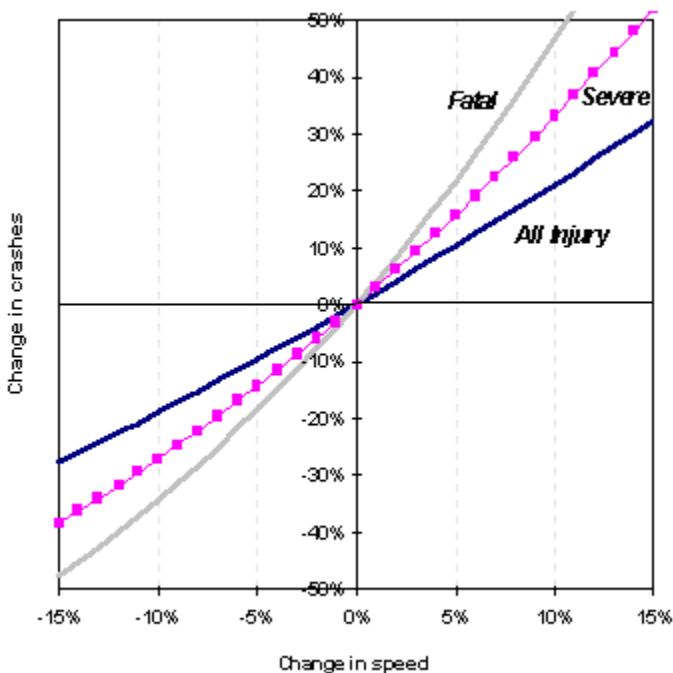
Figure 8. Effects of changes on injury and fatal crashes (from Nilsson, 1981).

Based on the effects of speed limits reported in various international studies, Finch et al. (1994) developed a model of the relationship between the change in mean speed and the change in crashes. The results suggest that for every 1 mi/h change in speed, the number of injury crashes increases 5 percent or a 3–percent increase in injury crashes for every 1–km/h increase in speed.

ENFORCEMENT

The following paragraphs have been limited to summaries of quasi–experiments that have been conducted to assess the effects of speed enforcement.

Mobile Patrol Vehicles

Raub (1985) reported on an Illinois State Police experiment in which the overhead lights on patrol cars in an experimental group were removed. This group and a control group (more than 200 cars in all) logged more than 5.5 million rural patrol miles in the course of the experiment. All participating officers had similar driving records before the study was conducted. Officers driving vehicles without roof–mounted lights improved their fuel mileage by 7 percent, were 25 percent more productive in speed enforcement, and were involved in 65 percent fewer crashes. The experiment lasted nearly two years and all results are statistically significant. Interestingly, while the group without overhead lights was more productive in enforcing speed regulations, overall productivity was not affected.

Shinar and Stiebel (1986) demonstrated the relationship between perceived risk of receiving a citation and driving in excess of speed limits. The researchers found compliance with speed limits to be greatest in the vicinity of police vehicles and diminish with increasing distance; the distance halo effect was greater for mobile than stationary police vehicles. Benekohal et al. (1992) evaluated the impact of mobile patrol vehicle speed enforcement on car and truck speeds through a highway construction zone. They found that the presence of a marked patrol car reduced average car and truck speeds while no reduction occurred in an unpatrolled control condition. Additionally, the proportion of cars traveling faster than conditions permitted in the work zone was reduced by 14 percent, and trucks traveling faster by 32 percent, when the patrol car was present. A time halo effect on average truck speeds lasted for about 1 hour after patrols ended. Average car speeds increased immediately after patrols ended. In contrast, Vaa (1997) found that intensive enforcement (an average of 9 hours of police presence per day) resulted in reductions in vehicle speed that lasted up to 8 weeks.

Stationary Patrol Vehicles

Hauer et al. (1982) conducted several experiments to measure the impact of stationary patrol vehicle enforcement on traffic speeds before, at, and after the site of enforcement, and during and after the enforcement period (the time halo). The researchers detected a pronounced decrease in average traffic speed to the posted speed limit at the location of the patrol vehicle. By identifying vehicles passing through the enforcement area, the researchers also were able to determine that repeated exposure of the enforcement to drivers had no significant effect in speed reduction after the first encounter with the stationary patrol vehicle. Speeds returned to their pre–enforcement level within 3 days after a single dose of stationary enforcement whereas exposure to a stationary patrol vehicle over a 5–day period had the greatest effect in suppressing speeds after enforcement ended.

Armour (1986) examined the impact on traffic speeds of parking a marked patrol car along an urban street. The presence of the patrol car was associated with (1) a 2/3 drop in the number of vehicles violating the speed limit; (2) an increase in community awareness of police enforcement in the surrounding area; and (3) a measurable decrease in speed at the site of enforcement. Based on these findings, Armour recommends the use of the stationary patrol car enforcement technique for localized speed problems.

Stuster (1995) evaluated the effects of municipal speed enforcement programs on several dependent measures. Three communities were selected to participate in the study on the basis of comparability and isolation from each other. Two of the communities' police departments implemented special speed enforcement programs focused on six special enforcement zones within each community. Four of the zones in each community were selected on the basis of speed–involved crash statistics and two in each

community on the basis of chronic citizen complaints of speeding. Police departments in the two experimental communities devoted an average of 8 hours of officer time each week to each of the zones. The department in the third community refrained from implementing any special traffic enforcement effort for the 6–month duration of the study. The study found significant declines in unobtrusive measures of vehicle speed and speed–related crashes in the special enforcement zones of the experimental communities. In addition, time series analyses found 112 fewer crashes than expected.

Aerial Enforcement

Research has demonstrated that aerial speed enforcement programs have a generally positive effect in reducing highway speeds. In western Australia, researchers compared the impact of changing the levels of aerial enforcement on several roadway sites maintaining aerial programs (Saunders, 1979). The removal of aerial enforcement in one site increased the percentage of cars violating the posted speed limit by 6.1 percent and the number of trucks by 6.2 percent. An increase in aerial enforcement at another site reduced the percentage of trucks violating the speed limit, but had no impact on the percentage of cars traveling above the limit. In a later Australian study, eleven months of aerial speed enforcement in New South Wales was investigated (Kearns and Webster, 1988). The aerial program resulted in a vehicle crash reduction of 22 percent.

Blackburn, Moran and Glauz (1989) evaluated alternative methods of enforcing New York's then 55 mi/h (89 km/h) speed limit. Aerial enforcement was found to be significantly more effective than radar in detecting and apprehending drivers who used radar detectors and CB radios to avoid being caught exceeding the speed limit.

Radar and Laser Speed Monitoring Equipment

Teed and Lund (1991) studied the relative effectiveness of police radar and laser speed monitoring equipment in a brief field trial; the researchers used the same four locations, alternating use of radar and laser speed guns over a 2–week study period. They found that laser guns were significantly more effective in identifying speeding motorists (41 citations per 1,000 vehicles, compared to 33 per 1,000 for radar). Perhaps more important, it was found that speeders identified under the laser enforcement condition were four times more likely to have a radar detector in their vehicles than those ticketed under the radar condition. In fact, most of the additional speeders caught by the laser guns were using radar detectors, and those vehicles tended to be traveling at the most extreme speeds.

Automated Enforcement

Automated enforcement systems combine radar or laser speed–measuring technology and video or photographic identification to automatically detect and record speed limit violations. Radar or infrared laser instruments detect a speeding vehicle and trigger a pre–positioned camera to photograph the vehicle's license plate and the driver. The time of the violation and recorded speed of the vehicle are superimposed on the photograph. If the license plate number and driver can be clearly identified in the photograph, a citation is issued and mailed to the registered owner.

Maekinen and Oei (1994) reviewed the effects of automatic enforcement on speeding, red–light violations, and crashes. They provide technical and tactical guidelines and stress that publicity and warning signs contribute significantly to the effectiveness of the technology.

Rogerson et al. (1994) examined the effect of a speed camera program in Melbourne on the speeds of motorists and on the incidence and severity of crashes. A statistically significant reduction was found in casualty crashes within 1 km of a speed camera. The effect was confined to "high alcohol hours" of the week on arterial roads; there was no evidence of a difference in crash severity. It was reported that, following the introduction of the speed camera, the percentage of vehicles exceeding the speed limit by

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more than 15 km/h decreased and remained at a lower level in both 60 km/h and 75 km/h speed zones. No significant change in the mean speed was detected, and the distribution of vehicle speeds recorded in 100 km/h speed zones did not change.

In a before and after study of photo radar in Norway, Elvik (1997) found a 26 percent reduction in injury crashes at sites that had high accident rates and density. For sites that did not conform to the warrants, the reduction was only 5 percent which was not statistically significant. The empirical Bayesian method was used to correct for regression to the mean effects and control for general trends. The results of a meta analysis that combined the effects of automated enforcement reported in Australia, England, Germany, Sweden, the Netherlands and Norway indicated a 17 percent reduction in injury crashes.

Drone Radar

Freedman, Teed and Migletz (1993) evaluated the impact of unattended radar transmitters deployed in a construction zone to spoof motorists with radar detectors. Drone radar was associated with a slight reduction in average vehicle speed—an average reduction of one mile per hour or less. However, the proportion of vehicles exceeding the speed limit by more than ten miles per hour through the zones was reduced by 30 to 50 percent during active drone radar enforcement.

A similar study by Streff, et al. (1995) examined the effectiveness of drone radar and police presence on the reduction of speeds at a high speed freeway location and in a freeway construction zone. They also found that speed reductions due to the drone radar deployment were of little practical significance. They did find that drone radar with police patrols can be an effective deterrent at locations where high speed trucks are a problem.

Speed Feedback Indicators

A speed feedback indicator displays the speeds of passing cars on a variable message display. The speed indicator is often trailer mounted below a speed limit sign. Speeds may be measure by an integrated radar or lidar unit or by sensors in the pavement for permanent installations. Speed indicators are intended to increase awareness of excessive speeds and to encourage drivers to slow down.

Casey and Lund (1990) found that the presence of a speed feedback indicator decreased speeds at a placement site and for a short distance past the site. No speed reduction was noted after the indicator was removed. Speed reduction decay rates downstream from the location of the indicator were significantly prolonged when minimal traffic enforcement activities were conducted in the area immediately surrounding the location of the indicator.

Perrillo (1997) observed speed reductions of 2–3 mi/h (3–5 km/h) in the vicinity of the speed feedback trailers for the two days they were in place on four residential streets in Texas. Speed returned to their previous level as soon as the indicator was removed.

Dart and Hunter (1976) evaluated the effects of four speed enforcement techniques, one of which was a speed indicator. The other techniques included a speed check zone, a stationary patrol car, and a simulated pullover. The speed indicator was not combined with any other enforcement technique. While all of the other techniques had a significant impact on reducing speeds at enforcement sites, the speed indicator had no significant effect on traffic speeds.

Hamalainen and Hassel (1990) describe a well–publicized speed indicator pro–gram carried out in Finland. Reduced speeds were noted while the indicator was pre–sent, and the speed halo effect lasted up to 10 km after the location of the display. The incidence of overtaking also was reduced. This reduction in passing behavior exhibited a time halo effect, continuing for a short period after the end of the

experiment. It is not clear from the report whether the speed indicator was combined with other speed enforcement techniques.

Public Information And Education (PI&E)

A large proportion of the citations reviewed concerning speed enforcement mention some form of public information or educational program, or publicity. None attributed a significant reduction in speed, speeding, crashes, or crash severity to any such campaign that was not closely tied to an enforcement or engineering program.

Traffic Enforcement Notification Signs

Another innovative means of speed enforcement that emphasizes increasing driver awareness of speed is the use of portable traffic enforcement warning signs. The signs are placed at each end of a targeted roadway just prior to an enforcement period. During the enforcement period, officers write citations for all traffic and vehicle violations occurring within the target area. There was a 17 percent reduction in injury crashes in Huntington Beach and fatal crashes had decreased by 100 percent between the introduction of the traffic enforcement and warning sign program and Stuster's (1995) survey.

The Racine, Wisconsin, Police Department established a program in 1983 to reduce crashes at the most dangerous intersections in the city (Stuster, 1995). The "EZ" pro–gram created enforcement zones around each of the ten most dangerous intersections.

All traffic safety laws within the zones (including speed limit laws) were strictly enforced. A unique feature of the EZ program was the use of pole wraps placed on every light pole within one block of a targeted intersection to remind drivers that intensified traffic enforcement was being conducted in the area. Traffic officers issued written warnings in the form of EZ "contact cards" (instead of citations) for minor traffic infractions within the zones. Each contact card listed the ten dangerous intersections and encouraged drivers to drive more safely in Racine. EZ contact cards also were issued to motorists who drove safely through the enforcement zones. These commendation contact cards were put into drawing for prizes supplied by the police department. The community realized a 30 percent reduction in traffic violations over the three–year duration of the program.

Traffic safety programs that include highly visible public information and education (PI&E) campaigns that accompany law enforcement efforts have proven to both increase positive public impressions toward police activities and result in safer driving habits. Sali (1983) evaluated the impact of a Selective Traffic Enforcement Program (STEP) initiated in Boise, Idaho, in 1979. The program combined an aggressive traffic enforcement effort with a strong PI&E program in order to reduce injury crashes in Boise. The STEP publicity program was designed to inform the driving public of hazardous road locations, the types of driver actions that made these locations unsafe, and the traffic enforcement that would be used to alleviate the problems at these locations. The PI&E program portrayed the Boise Police Department as genuinely interested in increasing public safety, as opposed to simply citing motorists and collecting fines. STEP advisory messages were broadcast twice a day over three local radio stations. The implementation of STEP in Boise was associated with a significant 17 percent reduction in the number of injury crashes; a non–STEP control area experienced no similar change. More important, the change in Boise was most dramatic following the delayed implementation of the STEP PI&E campaign (publicity began one month after the start of aggressive traffic enforcement). Besides the Boise STEP efforts, successful speed enforcement programs using speed indicators and photo–radar have been attributed to well–mounted PI&E pro–grams (Hamalainen and Hassel, 1990; Cameron, Cavallo and Gilbert, 1992).

The Impact of Speed Enforcement on Crime

The deterrent effects of police practices on crime have been a topic of research and debate for several years. The 1974 report describing the impact of the Kansas City Preventive Patrol Experiment (Kelling, et al., 1974) was an early evaluation of the effect on crime of in–creasing or decreasing police personnel. No significant differences in the incidence of crime, citizen fear of crime, or satisfaction with police services were found between Kansas City, Missouri, neighbor–hoods varying in levels of enforcement. The Kansas City study was criticized for only examining variations in force size and not taking into account the type of police strategies used in combating crime.

In response to the Kansas City study, Wilson and Boland (1978) developed a model predicting that police techniques that maximize the level of interaction between the police and the community (termed aggressive policing) will result in a reduction in crime. To support their model, they examined the historical incidence of robbery in 35 large American cities and found that robbery rates were lower in cities in which more traffic citations were written (their measure of aggressive policing). Despite criticism of the measure of aggressiveness used by Wilson and Boland (Jacob and Rich, 1981), similar historical research by Sampson and Cohen (1988) supports the model developed by Wilson and Boland. Weiss, et al. (1993) employed quasi–experimental methodology to directly manipulate the level of traffic enforcement and measure its impact on local area crime. Local crime levels in areas treated with traffic enforcement were compared to locations where no enforcement took place. No relationship was found between traffic enforcement levels and the prevalence of crime in the experimental sites. While the researchers postulate that traffic enforcement may indeed have no impact on crime, they also recognize several flaws in their research that may have made such an effect undetectable.

Stuster's (1995) study of municipal speed enforcement examined the effects of municipal traffic enforcement methods on a variety of dependent measures. In addition to measures of traffic safety, reported previously, the incidence of crimes in the special zones was analyzed for a control and two experimental communities. Overall, serious crimes (e.g., murder, rape, robbery, assault, burglary, larceny, arson, and motor vehicle theft) declined by eight per–cent in the special enforcement zones of one of the experimental communities, and by one percent in the other experimental community. Less serious crimes (e.g. drug violations, vandalism, disorderly conduct, and prostitution) increased by four per–cent in the comparison community's control zones. None of the changes in serious crimes as a whole was statistically significant, but both experimental communities experienced significant declines in the incidence of the larceny and theft. This is the one type of crime equally likely to occur during nighttime as well as daylight hours (i.e., when the special enforcement was conducted). Analyses found the 11 and 12 per–cent declines in larceny and theft to be statistically significant and attributable to the deterrence effects of the special enforcement programs; larceny/theft declined less than 2 percent statewide and increased by 4 percent in the control zones of the comparison community .

ENGINEERING MEASURES

Traffic calming techniques are street design or regulatory features that cause motorists to be more attentive to their surroundings and to drive more slowly; some traffic calming techniques are designed to induce motorists to select an alternate route. Techniques range from the Woonerf concept whereby cars and pedestrians share the same space, at one extreme, to relatively unintrusive lane striping at the other. In their review of this subject, Fildes and Lee (1993) make it clear that the many traffic calming techniques have the common objective of transferring the costs associated with excessive speed from unprotected road users (i.e., death and injury of pedestrians and cyclists) to vehicle drivers and their passengers (i.e., discomfort, risk, damage to vehicle, longer travel time). Westerman (1990) describes the approach as usually applying a "friction factor" to physically restrict a vehicle and force a motorist to slow down. In contrast to simple traffic signs, most traffic calming techniques are continuously reinforcing. That is, a motorist incurs a penalty when ever a traffic calming device is encountered at excessive speed.

Few studies have been conducted of the type that could provide evidence to support the claims that traffic calming techniques reduce the incidence of motor vehicle injuries and fatalities. The hypothesis, however, is intuitively compelling and the rapidly–expanding literature on the topic is beginning to include a few for–mal evaluation studies that show clear, positive effects on measures of traffic safety.

The Effects of Traffic Calming

The current review found the most effective traffic calming measures to involve vertical shifts in the roadway, such as speed humps and speed tables. However, the effectiveness of these measures is dependent upon spacing. Greater reductions in vehicle speeds and crashes are achieved when combinations of measures are implemented and when traffic calming is implemented systematically over a wider area than a single neighborhood. Reductions in the incidence and severity of crashes of 50 percent or more are frequently reported, as summarized in table 4. However, most traffic calming projects result in reductions in traffic volume and many of the safety studies do not take this diversion into account. It is possible the crashes may be migrating to other roads.

Table 4. Summary of the effects of traffic calming measures			
Reference	Country	Measure	Results
Zidel et al. (1986)	UK	Rumble strips	Mean speeds reduced by 40%
Bowers(1986)	Germany	Speed tables, narrowing, chicanes, gateways	No change in crash rate Injuries reduced by 50%
Chua and Fisher (1991)	Australia	Various methods	Crashes reduced by 50% Through traffic reduced by 35% Vehicle speeds reduced by 25%
Herrstedt (1992)	Netherlands	Various methods (staggerings, gateways)	Vehicle speeds reduced 6 mi/h (10 km/h)
Kjemtrop andHerrstedt (1992)	Netherlands and France	Various methods (humps, staggerings)	Crashes reduced by 30 to 60%

Engel and Thomsen (1992)	Denmark	Various methods (humps, staggerings)	Speeds reduced by 7 mi/h (11 km/h) Injury rate reduced 72% in calmed areas Injury rate increased 96% on adjoining streets
Vis et al. (1992)	Netherlands	Humps, staggerings, islands	Speeds reduced by 20%; volumes reduced 5–30% Crashes reduced by 5%, injury crashes by 25%
Webster (1993)	UK	Speed humps	85th percentile speeds reduced 10 mi/h (16 km/h) Crashes reduced 71% on treated streets Crashes reduced 8% on surrounding roads
Dahlerbrach (1993)	USA	Speed humps	Speeds reduced by 14% (5 mi/h) Traffic volume reduced by 7%
Halbert et al. (1993)	USA	Speed humps Traffic circles	85th percentile speeds reduced by 30% 85th percentile speeds reduced by 22%
Bulpitt (1995)	UK	Humps and chicanes	Speeds reduced by 10 mi/h (16 km/h) Crashes reduced up to 80% and traffic by 30 to 50%
Wheeler and Taylor (1995)	UK	Gateway signing, marking, narrowing	Speeds reduced 0–12 mi (0–19 km/h) Injury accidents decreased 14%
Webster and Mackie (1996)	UK	Mostly humps and speed tables	Speeds reduced by 9 mi/h (14 km/h) Crashes reduced by 61 percent
Griffin and Reinhard (1996)	Japan UK	Chevron markings Transverse markings	Crashes reduced 25 to 50% Crashes reduced 5 to 50%
Ewing et al. (1998)	US	Speed humps Mini–circles	Crashes reduced 13%; speeds by 22% Crashes reduced 18%; speeds by 14%

SUMMARY

There is evidence that crash risk is lowest near the average speed of traffic and increases for vehicles traveling much faster or slower than average. The occurrence of a large number of crashes involving turning maneuver partly explains the increased risk for motorists traveling slower than average and confirms the importance of safety programs involving turn lanes, access control, grade separation, and other measures to reduce conflicts resulting from large differences in travel speeds.

When the consequences of crashes are taken into account, the risk of being involved in an injury crash is lowest for vehicles that travel near the median speed or slower and increases exponentially for motorists traveling much faster. One of the major concerns in all of the studies is the travel speed before the crash. Emerging technology used in mayday, vehicle tracking, and adaptive speed control systems provide the opportunity to accurately and continuously capture travel speed. This technology should be applied in improving our understanding of the relationship between speed, speed variation, and safety.

When a crash occurs, its severity depends on the change in speed of the vehicle at impact. The fatality risk increases with the change in speed to the fourth power. International research indicates the change in injury crashes will be twice the percentage change in speed squared, and fatal crashes will be four times the percentage change in speed. These relationships are based mainly on speed limit and speed changes on high–speed roads. More research is needed to assess their applicability to low–speed urban roads.

In general, changing speed limits on low and moderate speed roads appears to have little or no effect on speed and thus little or no effect on crashes. This suggests that drivers travel at speeds they feel are reasonable and safe for the road and traffic regardless of the posted limit. However, on freeways and other high–speed roads, speed limit increases generally lead to higher speeds and crashes. The change in speed is roughly one–fourth the change in speed limit. Results from international studies suggest that for every 1 mi/h change in speed, injury accidents will change by 5 percent (3 percent for every 1km/h). However there is limited evidence that suggests the net effect of speed limits may be positive on a system wide basis. More research is needed to evaluate the net safety effect of speed limit changes.

Most of the speed related crashes involve speed too fast for conditions. This would suggest that variable speed limits that adjust with traffic and environmental conditions could provide potential benefits.

Despite the large number of references concerning traffic calming, very few reports include results of a systematic evaluation. In many cases traffic volumes as well as speed are reduced. As a result of the traffic diversion, crashes may be migrating to other roads. More research is needed to assess the system wide impacts and permit comparisons to be made among individual as well as combinations of traffic calming measures.

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