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MANAGING THE SPEED CRASH RISK

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ABSTRACT

The driving error of improper speed has been identified as a leading cause of traffic crashes and associated losses. Excessive speed is particularly prevalent in fatal and other serious crashes. Society has taken formal action to control the crash risk posed by speeding; the earliest such response and the one most used today is the legal approach that rests on the concept of deterrence. In most jurisdictions criminal or criminal-like procedures are used to enforce speeding laws: police officers are deployed to observe for speeders; suspected violators are pursued and apprehended; and offenders are referred to judicial or administrative tribunals to determine guilt or innocence. A variety of patrol configurations, vehicles, and speed-measuring devices (chiefly radar) are used by police agencies to enforce speeding laws. Speed enforcement as currently carried out is labor intensive and costly, principally because legal requirements stemming from the use of criminal law and procedures must be followed. For traditional enforcement procedures to effectively deter speeding, large increases in funds and personnel would be required. Therefore, strategies other than the legal approach for managing the speed crash risk should be considered.

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MANAGING THE SPEED CRASH RISK

INTRODUCTION

The familiar expression, "speed kills," reflects society's common knowledge that speed is one of the major factors that produces highway crashes and associated losses such as casualties and property damage. The speeder has been the target of societal action almost as long as the automobile has been in use. Speeding continues to be the leading category of traffic offenses cited by the police; an estimated 10 to 20 million speeding citations are issued annually. Speeding has gained even wider attention in recent years, now that the national 55-mph speed limit has achieved relative permanence and speed enforcement efforts have become increasingly visible.

Despite the attention that speeding has received, thousands of deaths and millions of traffic crashes—accounting for social costs totaling billions of dollars--still result from speeding. The purpose of this paper is to define the relationship between inappropriate speed and traffic crashes; describe society's response to the crash risk created by speeding; evaluate current approaches to managing the speed-crash risk; and offer suggestions to improve the management of this risk.

THE RELATIONSHIP BETWEEN SPEED AND TRAFFIC CRASHES

A recent clinical study of traffic crash causation, conducted by a research team at Indiana University and reported by Treat and associates in 1977, found that human factors play at least a possible role in causing more than 90 percent of all traffic crashes. Their analyses showed that excessive speed was one of the most frequent of specific errors, and that inappropriate speed may have played a part in other specific driving errors. Statistical studies comparing crashed and noncrashed drivers likewise link improper speeds and traffic crashes: the more a vehicle's speed differs from the average speed of traffic on a road, the more likely it is that it will be involved in a crash.

Speed can be measured objectively by external observers; thus society can intervene in the form of laws and other actions designed to influence drivers not to drive at unsafe speeds. One requirement for social action directed at speeding is to know what kind of speeding is most often associated with crashes in general, what kind produces the greatest crash losses, and what drivers most often speed. Effective efforts to control speed and reduce crashes must be based on a sound understanding of the relationship between speed and crashes. Both clinical and statistical studies define the relationship between speed and the risk of having a traffic crash.

Statistical Studies Relating Speed and Crash Risk

A statistical study of the relationship between speed and crash risk typically involves comparing the speeds of crashed vehicles with the speeds of a sample of noncrashed vehicles using the same road under like circumstances.

Perhaps the most comprehensive statistical study was conducted by Solomon in the late 1950s and reported in 1964. In Solomon's study, speed and crash data were collected for 600 miles of main rural highways at 35 sites in eleven states. Solomon's measure of risk was the number of crash involvements per 100 million miles of travel at a given speed. Vehicle speeds were measured with respect to the mean travel speed of all traffic on the selected highway segment; for example, if the mean speed was 60 miles per hour and a given vehicle was found to be traveling at 70 miles per hour, the 10 mph positive differential was the relevant statistic. For noncrashed vehicles, speeds were determined through spot speed checks; for crashed vehicles, speeds were determined by examining police accident reports. The locations at which Solomon measured the speeds of noncrashed vehicles were selected to correspond to those locations where crashes occurred.

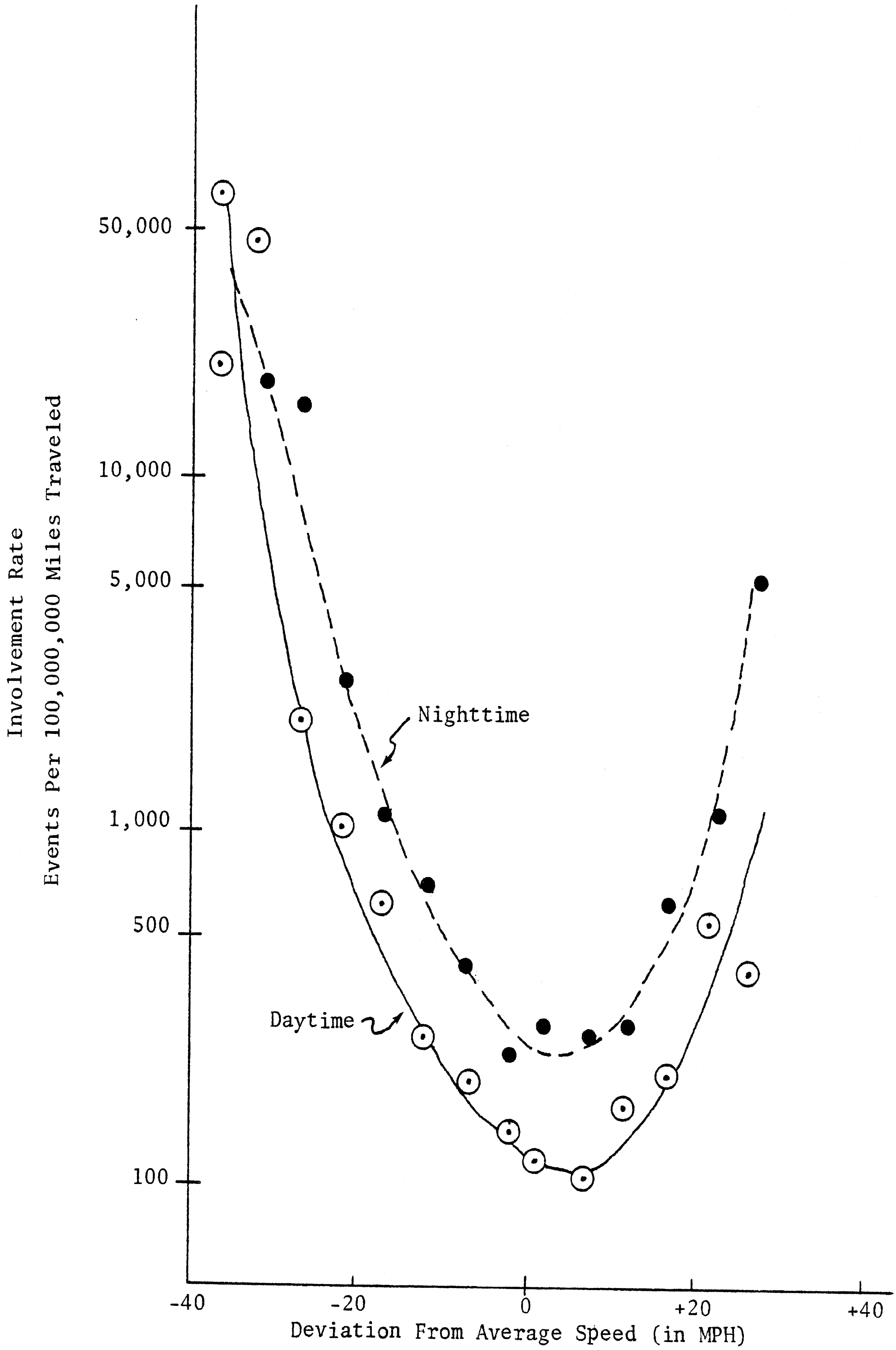
Solomon's major finding from these data was that the greater the differential between a vehicle's speed and the average speed of all traffic, the greater the chance of that vehicle's being involved in a crash. The lowest crash involvement rate occurred at the mean travel speed or slightly above it; as speeds departed from the mean in either direction, the crash involvement rate increased in a nearly symmetrical fashion. The U-shaped curves relating speed differential to crash frequency are depicted in Figures 1 and 2. From those curves, **it can be seen that the crash involvement rate increases very rapidly as deviations from the mean speed become large.** For example, the daytime crash involvement rate for vehicles traveling 37 miles per hour below the mean speed is about 500 times the rate for vehicles traveling at the daytime mean speed. Both daytime and nighttime data show increases in involvement rate as speed deviations from the mean increase.

From Solomon's data two findings are significant. First of all, **even though speeding is usually thought of only in terms of excessive speeds, too-slow driving is also identified as risky behavior.** The data indicate that negative deviations from the average speed are at least as likely to result in a traffic crash as equal positive deviations. The apparent risk posed by slow speed is indicated by Solomon's cumulative data (Figure 3). They show that the crash involvement rate for speeds less than the 5th percentile (i.e., the slowest five percent of traffic) was 2,915 crashes per 100 million miles traveled, or about eighteen times more risky than driving faster than the 95th percentile (the fastest five percent), for which the involvement rate was 165 crashes per 100 million miles. The involvement rate for all speeds below the 95th percentile was 254 crashes per 100 million miles, about fifty percent higher than the rate for speeds above the 95th percentile. These data suggest that the slowest speeds pose an especially great crash risk.

The second finding from Solomon's data, when plotted on a curve, is that a "rightward shift" from the mean occurs: The lowest crash involvement rate occurs some five to ten miles per hour above the mean travel speed. In fact, Figure 2 shows that the lowest involvement rate occurs at the 95th percentile speed, indicating that nearly all drivers keep their speed below that which would minimize their probability of having a

FIGURE 1

CRASH INVOLVEMENT RATE
VERSUS DEVIATION FROM AVERAGE SPEED
DAY AND NIGHT



SOURCE: Solomon (1964)

FIGURE 2

INVOLVEMENT RATE VERSUS DEVIATION FROM AVERAGE SPEED
DAY AND NIGHT DATA COMBINED

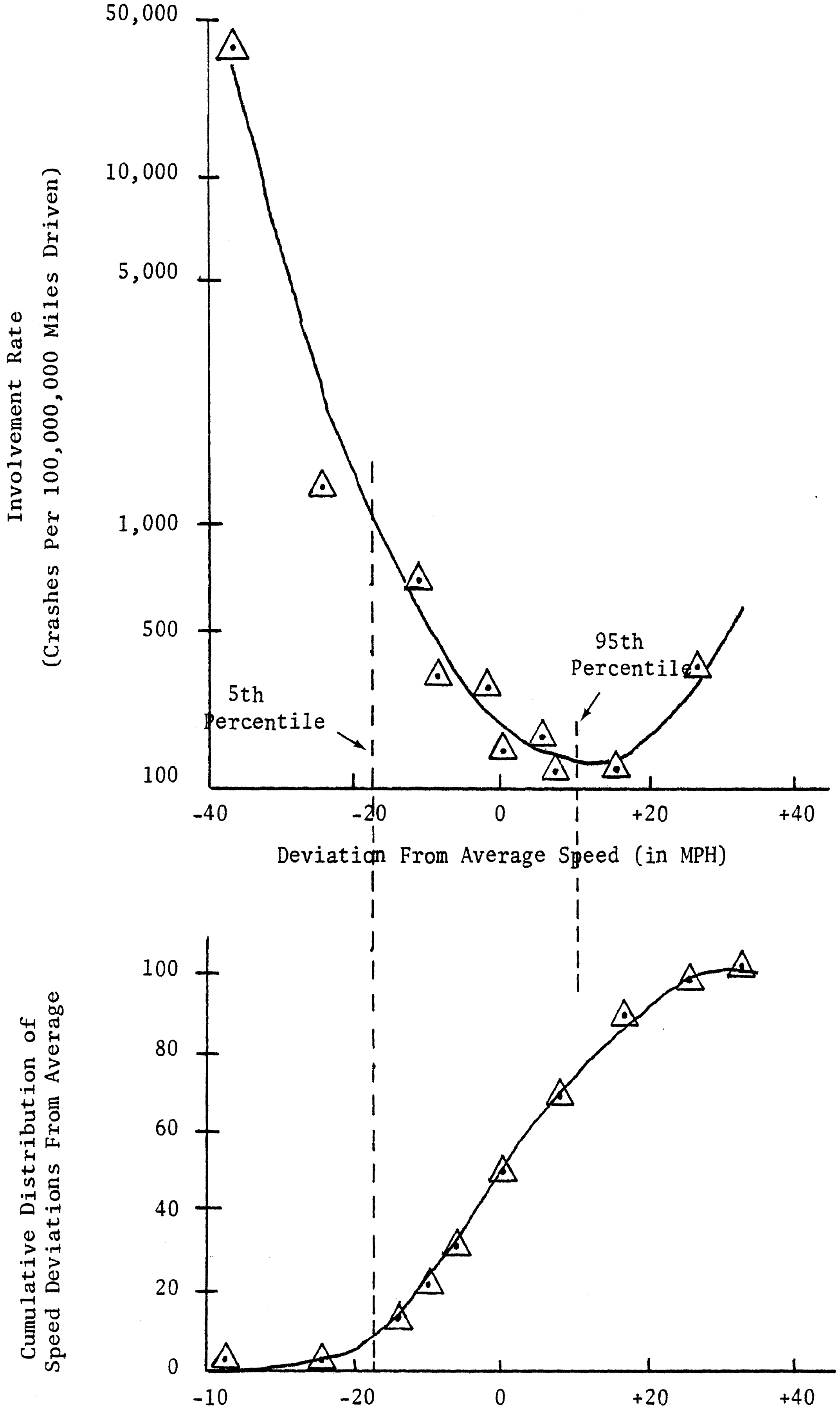
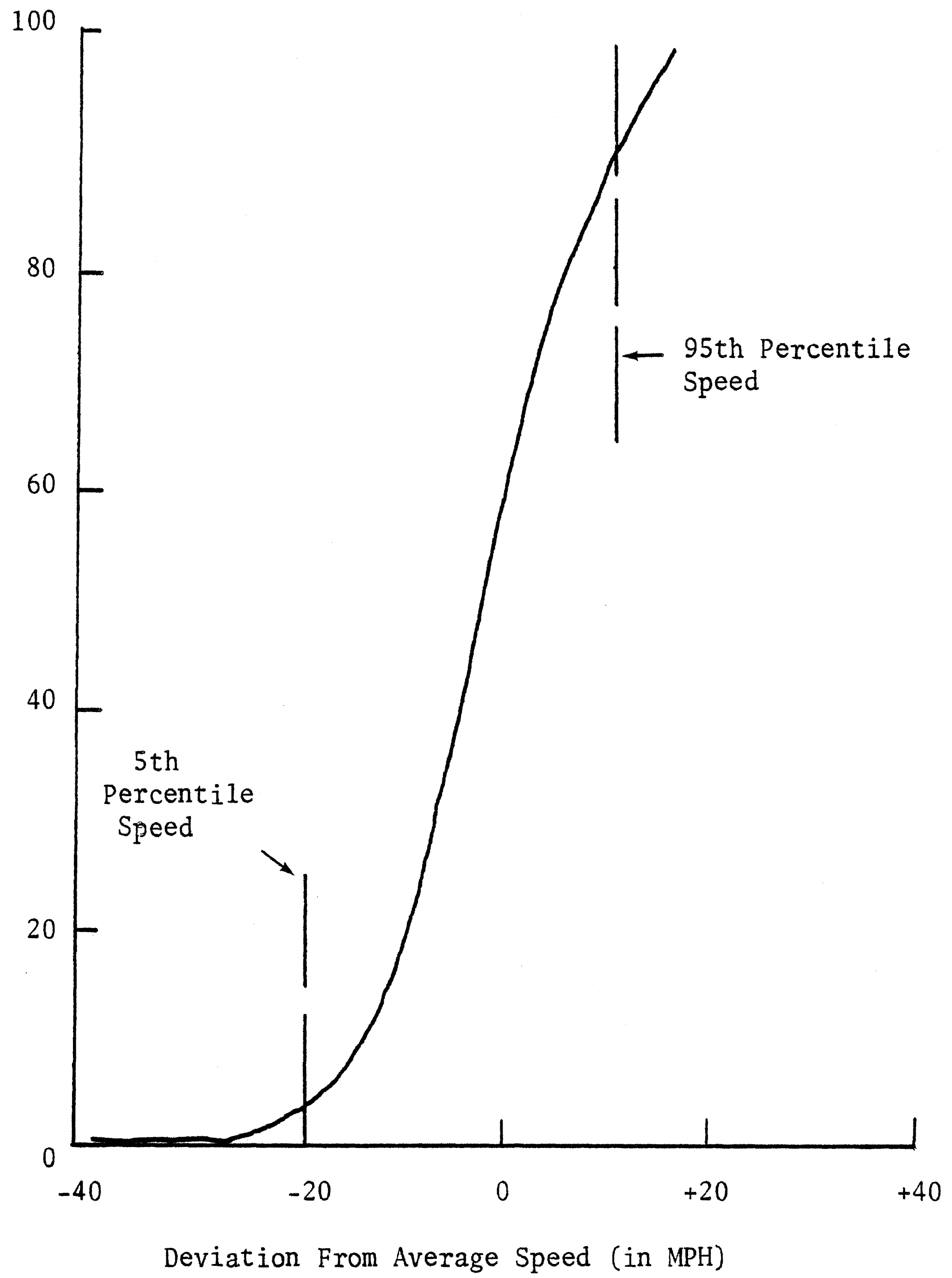


FIGURE 3

CUMULATIVE PERCENTAGE OF VEHICLE MILES
TRAVELED VERSUS DEVIATION FROM AVERAGE SPEED



SOURCE: Solomon (1964)

crash. Those data show that half of Solomon's drivers drove so slowly that their crash risk was at least fifty percent higher than the minimum, and five percent drove so slowly that their crash risk was well over five times the minimum. By comparison, only a negligible number of drivers drove so fast that they exposed themselves to correspondingly high levels of risk. Thus Solomon's data might indicate, at first impression, that most drivers drive too slow.

However, when Solomon's serious crash data are examined separately, a different relationship between speed and crash involvement rate emerges. As Figure 4 shows, Solomon's U-shaped curves "shift to the left" with increasing crash severity until, for fatal crashes, the point of symmetry is close to, and possibly even to the left of, the mean speed of traffic. The risk of a fatal crash is as great when traveling above the 95th percentile speed as it is when traveling below the 5th percentile speed—in both cases the probability of being killed is about twice that of traveling at the mean speed. That the highest and lowest speeds are most risky is borne out by Solomon's finding that 32 percent of all fatal crashes and 38 percent of all injuries occurred at speeds outside the 5th and 95th percentiles.

Solomon's findings were generally confirmed by a later study conducted by the Research Triangle Institute (1970); however, the RTI study did not show the "rightward shift" of the speed-crash involvement curve that appeared in Solomon's study. In the RTI data, the minimum crash involvement rate occurred at the mean travel speed, not above it. Another difference between the Solomon and RTI studies is that the latter study did not develop speed distribution data, so that it is not possible to determine whether the RTI data confirm Solomon's findings regarding the relative risks of traveling above the 95th percentile and below the 5th percentile speeds.

Clinical Studies Relating Speed and Crash Risk

More recent studies of traffic crash causation have used the so-called "clinical approach" in which trained experts make a detailed investigation of individual crashes and make a determination of what causal factors

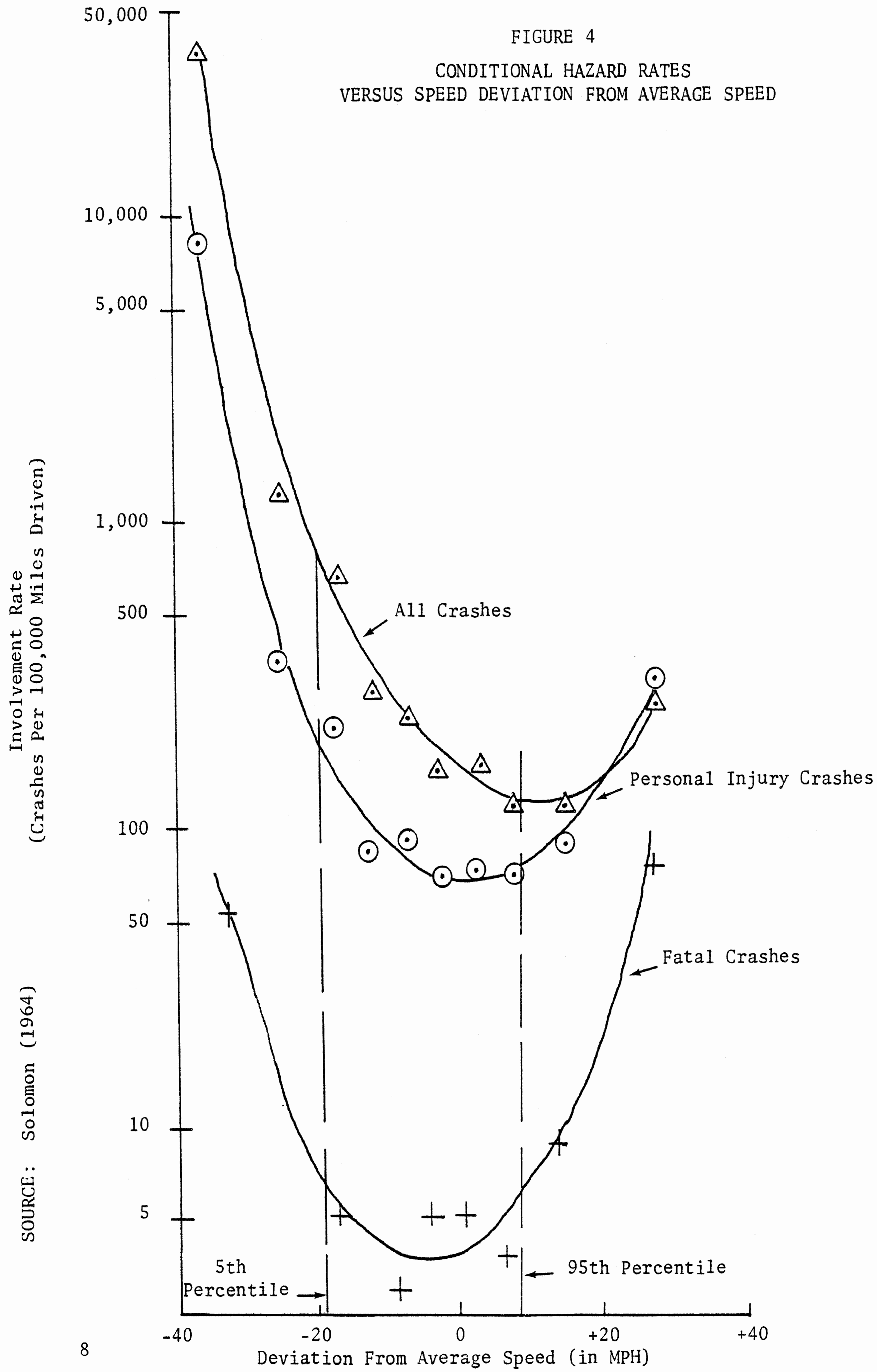


FIGURE 4
CONDITIONAL HAZARD RATES
VERSUS SPEED DEVIATION FROM AVERAGE SPEED
50,000
10,000
5,000
1,000
500
100
50
10
5
Involvement Rate
(Crashes Per 100,000 Miles Driven)
All Crashes
Personal Injury Crashes
Fatal Crashes
5th
Percentile
95th Percentile
-40
-20
0
+20
+40
Deviation From Average Speed (in MPH)
SOURCE: Solomon (1964)

were present. The clinical approach complements the statistical approach: it specifies distinct causes of crashes, the prevalence of which can be confirmed by statistical study.

The most comprehensive clinical study of traffic crash causation is the Indiana Tri-Level Study of the Causes of Traffic Accidents, conducted between 1972 and 1977 in Monroe County (Bloomington), Indiana, and reported by Treat and associates in 1977.

In the Tri-Level study, assessments of causation were based on data collected by researchers sent to the scene of crashes immediately after they occurred. These assessments were based on data collected at two different levels of detail: Level B data, obtained from on-site investigations; and Level C data, based on independent in-depth investigations of a subset of the Level B crashes by trained professionals. In the Tri-Level study, a "causal factor" was defined as a factor necessary or sufficient for a crash to occur. In other words, but for the occurrence of the factor, the crash would not have occurred. Three levels of confidence—definite, probable, and possible—were established and used in making judgments as to the causal role of a given factor.

Factors were initially divided into three broad classes: human, vehicle, and environmental factors. The in-depth (Level C) data revealed that human factors were at least a possible causal factor in 93 percent of the crashes; environmental factors in 34 percent, and vehicular factors in 13 percent. Human factors were then subclassified into specific categories; among these categories, excessive speed was a definite causal factor in seven to eight percent and at least a probable causal factor in 16 to 19 percent of the crashes (see Table 1). "Excessive speed" was defined in qualitative terms—greater than the speed that a person who drives to a high but reasonable standard of good defensive driving practice would choose under the conditions—rather than quantitative terms, that is, the posted or advisory speed limit.

TABLE 1

THE ROLE OF "EXCESSIVE SPEED"
AS A CAUSAL FACTOR IN CRASHES

DEGREE OF CERTAINTY	LEVEL OF STUDY	% ACCIDENTS WITH EXCESSIVE SPEED AS A CAUSE
CERTAIN	C	7.9
	B	7.1
CERTAIN OR PROBABLE	C	16.0
	B	13.8
CERTAIN OR PROBABLE OR POSSIBLE	C	19.0
	B	16.4

SOURCE: Treat et al. (1977)

Jones, Treat, and Joscelyn (1981) examined the role of speed in traffic crashes reported in various other crash files. For the excessive-speed category, overall estimates of speed involvement (definition of the term "involvement" varied somewhat from file to file) ranged from the seven percent figure reported in the Tri-Level Study to twenty-five percent of all crashes; the data believed to provide the best indication yielded estimates in the range of 16 to 23 percent. The Indiana figure represented a conservative "causal-certain" estimate by the technician teams; when probable and possible causal factors were added, the Indiana figure was fourteen to nineteen percent—an estimate consistent with that provided by other files.

When only fatal crashes were considered, rather than crashes of all severities, the involvement of excessive speed was found to be considerably higher. Data gathered by the National Safety Council (1980), supplied by police departments in eleven states and 41 cities, indicated that excessive speed was cited as a driver error in 30 percent of all fatal crashes. The National Safety Council (1978) reported that data from the National Highway Traffic Safety Administration's Fatal Accident Reporting System (FARS) for 1976 indicated excessive speed in 37 percent of all vehicles involved in fatal crashes. Because the FARS data included crashes in which multiple vehicles were involved, the involvement rate was slightly less than the reported figure of 37 percent. In the Texas Fatal Accident File for 1976, speeding over the limit was indicated in 24 percent of all fatal crashes, and speeding too fast for conditions in an additional eight percent, for a total of 32 percent. In the Collision Performance and Injury Report file (Highway Safety Research Institute 1978a), speeding errors were found in 35 percent of the fatal cases.

Although the 55-mph national maximum speed limit has been in effect since 1974, there are still little data regarding the involvement rate of 55-mph speed violations in crashes. Crash data from the state of Washington for 1978 indicate that one fifth of the speed-related crashes of all severities involved a 55-mph violation. The proportion of 55-mph cases was likely higher among fatal crashes involving excessive speed.

With respect to speed too slow, clinical studies support but do not quantify the findings, of Solomon and RTI, that excessively slow speeds are a serious problem and that among reportable traffic crashes, speeds too slow were at least as important as excessively high speeds. The highway safety literature canvassed by Jones, Treat, and Joscelyn (1981) revealed no clinical study that specifically examined the possibility or tested the contention that driving too slowly relative to other traffic is in fact the safety problem that the Solomon and RTI data would indicate. It is also possible that clinical studies cannot determine the involvement of slow speeds. Many instances of slow driving may be due to conditions over which the driver has little or no control, such as slowing to turn, or slowing on account of pedestrians or other vehicles, rather than a discretionary and inadvisable choice of a slow speed. Then, too, slow driving may lead to crashes by increasing the conflict rate, such as by forcing following traffic to pass the slow vehicle. It is likely that clinical studies can identify only the grosser cases of slow driving and thus underestimate the influence of this behavior.

The Indiana study provides some indication as to the involvement of too-slow speeds in traffic crashes. One category of driving errors, "inadequately defensive driving technique—should have adjusted speed," appears to be at least a probable cause in four percent, and at least a possible cause in seven percent of all crashes. Too-slow travel by the lead vehicle is a possible factor among rear-end collisions, which constitute a substantial portion of all crashes. Crashes resulting from "improper overtaking"—the National Safety Council (1980) reports that 3.6 percent of all crashes (2.7 percent of fatal crashes) fell into this category—also may have been prompted by too-slow travel. Finally, delays in recognizing vehicles stopped or slowed ahead were cited as at least a probable cause of nine percent of all crashes in the Tri-Level study; many of these also could have stemmed from driving too slowly. Based on the limited data, Jones, Treat, and Joscelyn (1981) estimated that discretionary decisions to travel too slowly play a causal role in as many as five to ten percent of all traffic crashes.

Treat and associates (1980), who canvassed selected accident files, developed estimates of the involvement of speeding in traffic crashes. Table 2 presents ranges of possible involvement rates, and single-figure estimates of involvement, for all speeding and for specific types of speeding.

CIRCUMSTANCES OF SPEEDING AND TRAFFIC CRASHES

Circumstances of speeding include the driver, the environment, and characteristics of the crash itself. Studies have been conducted to determine the association of these circumstances with speeding when speeding is identified as a cause of a traffic crash. Primary sources of the data include the Collision Performance and Injury Report (CPIR) files maintained at the University of Michigan Highway Safety Research Institute (1978a), and the 1976 Texas Five Percent Sample files (Highway Safety Research Institute 1978b). Results of these studies are summarized in Table 3.

Results are available for speed too fast only. In the Texas data, speeding is divided between speeding "over the limit" and speeding "too fast for conditions." The CPIR data classify all excessive speed violations together.

What Kinds Of Crashes Are Related To Speeding?

As indicated by the Solomon and RTI studies, as well as by the clinical study of Treat and associates, crashes involving excessive speed are more **serious** than crashes in general; that is, fatal and serious crashes are overrepresented among crashes involving excessive speed. In both the Texas and CPIR files, crashes involving speeding resulted in fatalities approximately twice as often as would have been expected based on the appearance of fatal crashes in the files as a whole. The Texas data

TABLE 2

ESTIMATES OF INVOLVEMENT
OF SPEED IN ALL TRAFFIC CRASHES

Type of Speed UDA	Range Indicated By Selected Files (% of all Crashes)	Single Figure Best Estimate (% of all Crashes)
Too fast, absolute	4-16	10
Too fast, relative	5-12	8
Too slow, absolute	Not known	-
Too slow, relative	Not known	-
Too fast, all	9-28	18
Too slow, all	5-20	10
Absolute, all	Not known	-
Relative, all	Not known	-
All Speed UDAs	14-48	28

SOURCE: Treat et al. (1980)

TABLE 3

SUMMARY OF LARGEST AND MOST OVERREPRESENTED CATEGORIES OF DESCRIPTIONS FOR CRASHES INVOLVING "SPEEDING TOO FAST"

DESCRIPTION (Source)	LARGEST CATEGORY(S)	MOST OVERREPRESENTED CATEGORY(S)
Severity-Damage (Texas 5%)	Minor-Moderate Damage (levels 1-3)	Very Severe Damage
Severity-Injury (Texas 5%)	No Injury (72%)	Fatal
Severity-Injury (CPIR)	Minor Injury (43%)	Severe Thru Fatal
Single v. Multiple Vehicle (CPIR & Texas 5%)	CPIR: evenly divided	Single Vehicle
	Texas: over limit= Single (61%)	Single Vehicle
	Texas: for cond. = Multiple (61%)	Single Vehicle
Configuration (CPIR)	Nonmoving vehicle Intersecting (44%) (right angle and oblique)	Nonmoving vehicle Sideswipe, rear-end
Driver Age (Texas 5%)	20-24 yrs. (25%)	10-14, 15-19, 20-24 yrs.
Driver Sex (Texas 5%)	Males (75%)	Males
Roadway Class (Texas 5%)	City Streets (44%) U.S./State trunkline	County Roads, State, Secondary & Interstate/ Turnpikes
Roadway Lane Configuration (CPIR)	2-lane (53%)	
Road Alignment (Texas 5%)	Straight & Level (89%)	Curves, Hill, or Both
Road Alignment-Horiz. (CPIR)	Straight (61%)	Curve

SOURCE: Jones, Treat, and Joscelyn (1981) indicate that speeding over the limit is associated with a higher level of crash severity than speeding too fast for conditions, although both types of excessive speed are associated with increased levels of damage and injury. These findings are consistent with those reported by Treat et al. (1977), namely, that a greater proportion of personal-injury crashes occurred among crashes where "excessive speed" was a factor.

In both the Texas and CPIR files, single-vehicle crashes are overrepresented among those caused by speeding; this is true in the Texas data for both over-the-limit and too-fast-for-conditions speeding.

Regarding collision trajectory, the data show no clear pattern. "Sideswipe" crashes are the most overrepresented, but these constitute only a small proportion of all crashes. Rear-end crashes are slightly overrepresented, and so are head-on crashes--a surprising finding. Intersection-type crashes, which make up the largest category of crashes, are underrepresented among the speed-related collisions.

Where Do Speed-Related Crashes Occur?

While speed-related crashes occur everywhere, the roadway class most overrepresented among speed-related crashes were county roads, interstate highways, turnpikes, and state secondary roads. On the basis of **roadway lane configuration,** divided highways were overrepresented: on the other hand, nondivided highways with four or more lanes were underrepresented—a finding that could be attributable to the confounding influence of traffic density, since most multilane undivided highways are found in urban areas where traffic is dense.

Classifying by **terrain,** crashes occurring on curves and hills are overrepresented among the crashes; however, most crashes (nearly 90 percent) occurred on straight roadways on level terrain, and thus the speeding problem manifests itself under all types of terrain and road alignment.

When do Speed-Related Crashes Occur?

Data files examined by Treat (1980) show that with respect to **time of day**, speed-related crashes are most overrepresented at night, especially between 1 and 4 a.m. With respect to **road and weather conditions,** speeding was overrepresented in the CPIR file under conditions of rain and snow and when the road surface was reported as "slippery." While there is no distinction drawn between speed over the limit and speed too fast for conditions in the CPIR file, it is likely that precipitation-related crashes appeared more frequently in the too-fast-for-conditions category.

Who Are The Speeders?

When the crashed drivers involved in speed-related collisions were examined with respect to sex, males were found to overrepresented among over-the-limit speeders by a factor of about 1.2 in the Texas data and to a lesser extent among the too-fast-for-conditions speeders. Males accounted for high proportions of crash-involved drivers as a whole because they are more frequently found on the roads, but they were overrepresented among speeding, crashed drivers. In the Texas data, 83 percent of the crashed drivers judged to be speeding over the limit were male.

With respect to **age**, younger drivers were overrepresented among the crashed population. In the Texas data, drivers under the age of fifteen were the most overrepresented in both the over-the-limit and too-fast-for-conditions categories. Drivers aged fifteen to nineteen years, and twenty to twenty-four years, respectively, were the next most overrepresented classes. Drivers under 25 years of age comprised 56 percent of all over-the-limit drivers, compared to 48 percent of the too-fast-for-conditions drivers and 37 percent of all crashed drivers. The data gathered by Treat and associates (1977) confirm the involvement of young drivers in speed-related crashes: the Tri-Level Study data show that drivers under the age of twenty were judged to have exceeded the limit more than twice as often as crashed drivers aged twenty and above.

Why Do Drivers Speed?

It is known that some unsafe driving behaviors are **conscious and intentional,** while others--such as inattention or distraction--are not primarily the products of the driver's conscious decision. CPIR files examined by Treat and associates (1980), to determine the reasons for speeding, included forty-four cases in which speed caused a crash to occur. It was found that in the great majority (34 of 41, or 83 percent) of the cases examined, excessive speed was the result of a conscious and intentionally undertaken behavior. The remaining cases revealed impairment, principally by alcohol, as the reason for the speeding. Both over-the-limit and too-fast-for-conditions speeding was found to be overwhelmingly conscious and intentional--79 percent and 92 percent, respectively. Lack of an adequate number of speed-too-slow cases in the CPIR files prevented a comparable assessment; however, all three speed too-slow cases that were found and examined involved conscious and intentional decisions to drive too slowly. That most speeders intentionally drive too fast is substantiated by surveys in which drivers cite reasons for committing violations. Behind most of these reasons is an expressed need to get to some destination more quickly, for example, because the driver is on a long trip, late, or "in a hurry." Other reasons include "trying out" a new car, following the "pace" set by other traffic, and simply "showing off." Researchers are currently examining in more depth the reasons why drivers speed, and why other drivers obey posted limits.

Because inapproprate speed increases the risk of a traffic crash and associated losses, society has taken formal action to reduce the crash risk to a level that it considers acceptable. As in the case of other traffic crash risks, society's primary strategy has been to use the legal system to deal with unacceptably risky speeds. The legal system relies on the principle of **deterrence** to manage the speed crash risk: a driver who is caught engaging in risky behavior is punished (usually by a fine or license suspension). The punishment is intended to prevent the driver from committing future violations, and to discourage other drivers who are not punished. Punishment or the threat of punishment is a negative consequence of speeding that a driver weighs against its positive consequences, such as saving travel time. It is intended that punishment, actual or threatened, will provide enough of a "surrogate risk," in addition to the actual risks of a crash and increased cost of operating a vehicle, to cause a driver to decide against speeding. The legal strategy, one of **increasing the disutility** of speeding, is society's most common strategy for managing the risk of inappropriate speeds. Other risk-management strategies, such as incentives to nonspeeders, are also available to society.

The legal approach to the speed crash risk begins with a definition of what behavior is prohibited. The definition process with respect to speed parallels that of other unsafe driving behaviors, such as driving while impaired by alcohol and following too closely, where the crash risk varies in proportion to some numerical value. For example, studies of the alcohol crash risk have shown that crash risk becomes unacceptably high at blood alcohol concentrations above .10% w/v, and legislation has been enacted that prohibits vehicle operation at BACs above this level. By the same token, speed limits have evolved from a determination of what speeds present an unacceptably high risk.

SOCIETY'S RESPONSE TO THE SPEED-CRASH RISK

A legal definition of speed, or of any other unsafe driving behavior, must allow an external observer of traffic to determine whether an unsafe driving action has occurred, and should lend itself to detection using low-cost, readily available, and nonobtrusive technology. The definition should be tied to the amount of risk (probability of causing a traffic crash; and the severity of the crash should one occur) resulting from unsafe driving, and should take into account the driver's conscious decision-making process regarding whether to drive safely or unsafely.

Researchers at the University of Michigan Highway Safety research Institute (HSRI) have refined earlier work (Lohman et al. 1976; Hiett et al. 1975) defining the concept of unsafe driving acts, or UDAs. A UDA is an act or omission by a driver that increases the risk of a traffic crash above a level that is socially acceptable, observable, and flows from a driver's conscious decision to drive in an unsafe manner (Treat et al. 1980).

With respect to speed, there are two definitions of speed UDAs. The first of these is the **relative-speed UDA,** the act of driving a vehicle at a speed that is so different from the speeds of other traffic that the risk of a crash becomes higher than socially acceptable. Preliminary data indicate that speeds less than the fifth percentile, or greater than the 95th percentile speed of traffic, are unacceptable. The second UDA is the **absolute-speed UDA**, the act of driving a vehicle faster than an appropriately established maximum speed limit or, in a normal driving environment (such as dry pavement, good visibility, no construction zones and normal traffic density), driving slower than an appropriately established minimum limit. The two UDAs as defined by HSRI are mutually exclusive; rules for deciding whether a speed UDA has occurred and, if so, what UDA it was, are set out in Table 4.

The UDA definitions are applicable to, and also parallel to, the legal definitions of speed that have developed. They relate vehicle speed to crash risk, and permit observation of traffic to determine whether unacceptable risk has been created. Speed laws, discussed in this section, should be considered against the goal of risk management: legal sanctions are used to discourage driver decisions to drive in an unacceptably risky manner.

Law Generation: Prohibition of Unsafe Speeds

History of Speed Limits. Restrictions on speed were known even before the invention of the automobile. The first known "speed limit" in the United States was enacted in Newport, Rhode Island in 1678; it prohibited riding horses at a gallop in the city streets (Ladd 1959). The first American speed limit applicable to automobiles was passed in Connecticut in 1901. It set a maximum urban speed limit of 8 mph, and a 12 mph maximum elsewhere in the state (Labatut and Land 1950). Speeding was by far the driving offense of greatest public concern early in the twentieth century. Early attempts to control speed often were one facet of a then-strong movement to control the automobile. For that

TABLE 4

CLASSIFICATIONS OF POSSIBLE SPEED UDAs
(Assumes mutually exclusive definitions)

Absolute Speed of Subject Vehicle	Classification		
	Mean Traffic Speed Higher Than Maximum Limit	Mean Traffic Speed Lower Than Minimum Limit	Mean Traffic Speed Within Both Limits
Higher Than Maximum Limit	Absolute (too fast)	Absolute (too fast)	Absolute (too fast)
Lower Than Minimum Limit	Absolute (too slow) Under Good Conditions; Relative (too slow) Under Poor Conditions	Relative (too fast or too slow)	Absolute (too slow) Under Good Conditions; Relative (too slow) Under Good Conditions
Within Both Limits	None	Relative (too fast)	Relative (too fast or too slow)

reason, traffic countermeasures from that era were often colorful and emotional. Many early speed limits were unreasonablv low and often punishable by severe sanctions. As the number of registered vehicles grew, public pressure increased for more reasonable speed restrictions and a focus on reckless driving rather than on speed per se (Joscelyn and Elston 1970).

By 1930 two separate and opposing theories of speed control had evolved. One theory stressed that road and weather conditions, and other circumstances, varied so widely that no single limit was feasible; under that theory, the proposed remedy was a general law prohibiting speeds that were not "reasonable and prudent." The opposing theory found the "reasonable and prudent" standard too vague and relying too much on the driver's judgment. It led to the recommendation of a fixed limit instead (Taylor 1930). The "reasonable and prudent" standard survives in the form of "basic speed laws" that are found in most states; these supplement the absolute speed limits that are part of every state's vehicle code. The difference in speed-control philosophy was reflected in then-existing speed laws, some of which set maximum limits, some of which simply prohibited speeds that were not then "reasonable and prudent." The 1930 Uniform Vehicle Code recommended a statewide maximum limit of 45 mph, with limits of 25 mph in residential districts and 20 mph in business districts.

During the 1930s greater attention was paid to the relationship between speed and traffic crashes. Organized traffic-safety compaigns were instituted by safety groups, and state and local governments instituted crash-reduction programs that emphasized strict speed enforcement. During this time efforts were made to study the effects of speed control and to take a more realistic approach to the problem of inappropriate speed.

During the Second World War, the shortage of rubber and gasoline led state governments and eventually Congress to impose a maximum 35 mph speed limit as an emergency conservation measure; another purpose of wartime speed restrictions was to save manpower by preventing traffic crashes (Ladd 1959). After the wartime speed limit was repealed in 1945, states reverted to their essentially non-uniform speed laws. Some states retained unreasonably low maximum limits, which produced pressure for more realistic legislation. Other states retained the "reasonable and prudent" standard and had no maximum limits, and this prompted public pressure as well. The 1956 Uniform Vehicle Code recommended a more realistic set of speed limits: 60 mph (55 mph at night), except for 30 mph in cities. The code also permitted appropriate authorities, such as highway commissions, to alter statewide limits in certain areas if justified by an engineering and traffic survey. As construction of the Interstate system and turnpikes proceeded during the 1950s and 1960s, there was additional pressure for modernizing speed laws. State traffic officials surveyed by Webster and Guren (1966) recommended supplementing basic speed laws with maximum limits as high as 70 mph on limited access highways.

By 1973, maximum limits of 70 mph or more were in force on turnpikes and freeways in a number of states, especially in the Midwest and West, and several Western states had no fixed maximum limits. However, the Arab oil embargo led Congress to impose a national 55 mph limit as an emergency conservation measure. Although fuel soon thereafter became plentiful (though at a considerably higher price), lingering concern over dwindling fuel supplies, and the discovery that highway deaths had decreased significantly under the lower speed limits, led to retention of the 55 mph limit. In 1978 Congress strengthened the enforcement of the national speed limit by increasing penalties levied against states with unsatisfactory compliance records. Congress has also appropriated millions of dollars to assist law enforcement agencies in achieving driver compliance.

Methods of Setting Speed Limits. The first maximum **speed limits** were sometimes the result of an intuitive judgment of what speeds were "safe," and sometimes were intended to harass automobile owners rather than promote safe travel. Objective methods of establishing speed zones have been cited since 1932, although many of these were relatively simple techniques (Joscelyn and Elston 1970). Carter (1949) recommended that speed limits be set with reference to the "pace speed" of traffic, a 10 mph band in which the majority of vehicle speeds occur. Under normal conditions the speed limit would be set at the highest speed within that band, which corresponds to the 85th percentile speed. The 85th percentile became the primary criterion for setting speed limits, although these limits were supplemented in most jurisdictions by "arbitrary" statewide or local maximum limits (see Oppenlander 1963). In their review of the literature on speed limits, Joscelyn and Elston (1970) reviewed a number of studies showing that the 85th percentile speed was generally recognized as the preferred speed limit. This speed was considered reasonable by drivers (since it was higher than the speed most of them would themselves select) and it was consistent with drivers' own judgments of what speed is safe and prudent. Thus it avoided a common problem of earlier speed limits that were unreasonably low: these were frequently violated and tended to produce a wide—and thus unsafe—range of travel speeds. The Research Triangle Institute study of the relationship between speed and traffic crashes confirmed the reasonableness of the 85th percentile criterion, as did Solomon (1964). The RTI study recommended that maximum limits be set at the 85th percentile speed, with enforcement action to occur above the 95th percentile (or five to seven mph above the posted limit); and that minimum speeds, if desired, be set at the 15th percentile speed, with enforcement action to occur below the 5th percentile speed. The 85th percentile speed criterion remains in wide use, subject—since 1973—to the overriding national maximum speed of 55 miles per hour.

Earlier maximum speed limits were **prima facie**; in other words, a driver who traveled faster than the posted limit could be convicted of speeding unless he or she could demonstrate that, given road, traffic, and weather conditions, his or her speed was not dangerous. Most states have since converted from prima facie to **absolute** speed limits: exceeding an absolute speed limit is an offense regardless of whether the speed was "safe" under the circumstances. In most states the absolute maximum limits are supplemented by provisions of the "basic speed law" that cover speeds below the maximum limits that are nonetheless unsafe because of ice, fog, heavy traffic, and the like. Basic speed laws frequently contain provisions requiring a driver to be able to stop within the "assured clear distance ahead." This enables the police to cite a driver whose vehicle strikes the rear of another vehicle.

The 55 mph **national maximum speed limit** was enacted by Congress in 1973 as an emergency conservation measure following the Arab oil embargo and the resulting fuel shortage. (Actually, Congress required that the states enact 55 mph limits or face economic sanctions.) While the 55-mph limit was enacted as a fuel-conservation law, similar to the wartime speed limits in 1942-45, studies of its safety impact showed that traffic fatalities declined as speed limits and travel speeds decreased. In the years preceding passage of the national maximum speed limit, the annual traffic fatality count averaged 55,000; in 1974, the death toll was 46,402 and the fatality count for subsequent years remained below 50,000 through 1977. The death rate per 100 million vehicle miles traveled was 4.6 in 1972 and 4.28 in 1973; it declined to 3.44 in 1974 and has remained below that figure since then (National Safety Council 1980). That reduction in fatalities and fatality rates followed a reduction in the speed limit is consistent with the experience of other countries: the establishment of speed limits in parts of Sweden during 1960-61 (Swedish Council on Road Safety undated; Road Safety Commission 1961), and in Finland during 1966 (Hakkinen and Leppanen 1968) was followed by a reduction in traffic deaths. Two international conferences, reported by Smeed (1961) and Prisk (1967), respectively, studied the speed-crash relationship. It was found that maximum speed limits reduced the amount of travel at excessively high speeds, and narrowed the range of travel speeds. It was also found that high speeds, per se, were associated with high crash rates. Campbell (1965) compared the fatality rates on California freeways with that of the Indianapolis 500-mile race and found the latter to have a per-mile fatality rate more than 1,000 times that of freeway travel. Among the factors cited for the high death rate associated with auto racing was the increased risk of striking another vehicle or a fixed object at high speeds, as well as a wider distribution of speeds. Not only do maximum speed limits tend to reduce the number of crashes caused by wide speed distributions and loss of vehicle control, but they reduce the force of traffic crashes in crashes that occur. It was reported as early as 1913 (in an article that appeared in Scientific American) that the destructive effects of a traffic crash increase in proportion to the square of the vehicle's speed. A crash at 70 mph is nearly twice as damaging as one at 50 mph, because twice as much energy is dissipated.

McClintock (1925) was one of the earliest advocates of **minimum speed limits;** he urged a minimum limit of one-half the legal maximum to promote the flow of traaffic and avoid congestion. When limited-access highways became frequent, traffic officials advocated minimum speed limits of 40 to 45 miles per hour that would narrow the range of travel speeds and promote safety (see Webster and Gruen 1966). Today, expressways in most jurisdictions have minimum speeds. In addition, states' basic speed laws contain a broad prohibition of unreasonably slow speeds on any highway.

In sum, most jurisdictions have several laws defining unsafe speeds and providing for the punishment of speed offenders. The first such law is the "basic speed law" that generally prohibits speeds that are too fast or too slow under the conditions. The second speed law imposes maximum statewide limits (subject to the 55-mph national maximum speed limit) as well as maximum limits for designated classes of roads (such as limited-access and rural highways, residential streets, and school zones). Provision is made for the adjustment of maximum limits when necessary. Most maximum speed limits are absolute, which means proof of a speed in excess of the applicable limit is sufficient to convict; a few states retain prima facie limits that allow a driver to escape conviction by proving that his or her speed was reasonable under the circumstances. Finally, many states imposed minimum limits for limited-access highways under normal driving conditions. Violating any of the speed laws is a criminal or criminal-like offense in most states: The suspected speeder is stopped by a police officer and either taken into custody or issued a citation in lieu of arrest. In most states, if the driver contests guilt, a trial governed by most of the rules of criminal procedure and evidence is held in a court of law. Penalties imposed upon those found guilty commonly include fines and the assessment of violation points on the offender's driving record. While jail is a possible sanction in about half the states, jail sentences are rarely imposed on convicted speeders. In all jurisdictions there exists some procedure by which courts report convictions to the driver-licensing agency.

POLICE ENFORCEMENT OF SPEEDING LAWS

In our society the legal approach based on the concept of deterrence is relied on as the primary strategy for managing the risk created by speeding. While there are many risk management systems of greater or lesser formality in our society (they include insurance companies, health care delivery systems, and family groups, for example), one system is primarily responsible for managing the speed-crash risk in particular as well as the traffic-crash risk in general. That system, the Traffic Law System, was described by Joscelyn and Jones (1972) and offered as a conceptual framework for studying the traffic crash problem (See Joscelyn and Jones 1978). In functional terms, the four functions of the TLS are law generation, enforcement, adjudication, and sanctioning. The preceding section dealt with laws designed to deter drivers from driving at inappropriate speeds. This section describes the methods of enforcing those speed laws, and the procedures used to determine guilt or innocence of accused speed offenders and sanction those found guilty.

Enforcement, in turn, is one of four top-level functions that police agencies perform in the course of providing police traffic services. Other functions include accident management and investigation; traffic direction and control; and general motorist services (Fennessy et al. 1968). The purpose of enforcement is to discourage drivers who are caught and punished for traffic violations from committing further violations (special deterrence); and to discourage members of the driving public, punished or not, from committing unsafe driving acts for fear of being caught and punished (general deterrence). Special deterrence involves surveillance of traffic, detecting offenders, apprehending them, and conducting various presanctioning and sanctioning activities. General deterrence is promoted by increasing the intensity of enforcement, both actual and perceived.

General Deterrence Countermeasures

Although police enforcement activity is aimed at special deterrence of offenders, it also supports and creates general deterrence. Regarding general deterrence, the most obvious way of increasing the atmosphere of police presence is to increase the actual intensity of enforcement by placing more police units on the road. This has its limitations, because funds and personnel available to most departments is limited.

The police enforcement process starts with the placement of enforcement units at locations where they can influence traffic flow. Ideally, the objective is to select the procedures and resources and use them at times and places to minimize overall crash risk in a jurisdiction. Most police agencies approach this problem subjectively, using experience supported by violation and crash data to determine where and when to place enforcement units. Their final decisions on deployment are strongly influenced by practical operational constraints, such as the resources available and the need to enforce other traffic as well as criminal laws.

When more formal deployment methods are used, they are usually a part of some selective enforcement scheme. It is based on the principle that patrol units should be allocated as a function of the number of crashes (or sometimes violations) of various types that occur at different times in a jurisdiction. Traffic volume may also be a factor. Often the function in question is judgmentally determined, and when it is not, it is usually linear. Some agencies (for example, the Tucson, Arizona Police Department) use computers to keep track of crashes and violations at different locations, but less formal tools--such as pin maps or even officers' judgment and experience—are more common. Some agencies with selective enforcement programs use indices based on workload or a jurisdiction's total "hazard" to determine when and where resources are to be deployed. A few agencies use algorithm or "cookbook" procedures to determine deployment, and a few have used computerized information systems.

In general, the traffic safety effect of the different deployment methods is not known. An evaluation of federally sponsored selective-enforcement programs (PRC Public Management Services, Inc. 1974) found that a "patrol-and-cite" strategy using selective enforcement methods reduced traffic crashes; the evaluation did not, however, study other deployment schemes and thus it is not known what fraction of the observed crash reduction was caused by selective enforcement alone.

Another means of promoting general deterrence is to increase the perceived level of enforcement without substantially increasing the actual enforcement level. The chief strategy of increasing perceived enforcement is public information and education, or PI&E. Mass media campaigns carried out by police agencies and safety groups "spread the word" about enforcement activity and encourage compliance with the law. Some police agencies believe that the recent widespread use of citizens' band (CB) radio has helped promote general deterrence; however, other departments object to CB because it alerts unsafe drivers to enforcement activity and reduces the overall credibility of the enforcement threat.

Another means of increasing perceived enforcement is to manipulate the use of enforcement symbols, patterns and configurations of patrol, and vehicle types. Patrol vehicles generate different deterrent threats, depending on their attention-getting properties and the degree to which they are associated with enforcement action. Automobiles, motorcycles, and aircraft are used as patrol vehicles, and police officers sometimes patrol on foot.

All law enforcement agencies make use of marked **patrol cars** as patrol vehicles (Darwick 1977). These vehicles are usually four-door police-package patrol sedans that may or may not be equipped with radar.

Motorcycles are usually used with either hand-held or vehicle-mounted radar units operated by the cycle rider. Motorcycle operators also work with marked patrol cars or other cycles (Darwick 1977). Although motorcycles are not used as extensively as patrol cars, Booth (1978) has found that they are more easily recognizable as enforcement vehicles.

Aircraft are sometimes used by traffic enforcement agencies. The types of aircraft most commonly used for traffic patrol are fixed-wing and short takeoff and landing airplanes, and helicopters (Darwick 1977). The greatest advantage of aircraft is the ability to cover vastly more territory than a conventional ground unit (Rasmussen 1977). Moreover, signs are often present on selected highways to advise drivers that the road is patrolled by aircraft. Measured miles are marked on the pavement so aircraft can pace speeding drivers and report them to ground units.

Foot patrol is not commonly used by enforcement agencies. It appears to be most useful in urban locations, where highway conditions are not conducive to parking a patrol vehicle safely (Darwick 1977).

Most departments favor conspicuously marked and placed patrol cars, reasoning that this increases their general-deterrence potential. Other departments, such as the Maryland State Police, favor covert strategies, such as the use of rented vehicles and unconventional vehicles in enforcement to give the impression that any vehicle on the highway could be a police vehicle. A study of current procedures used in speed enforcement, reported by Ruschmann et al. (1980), found no consistent rationale or policy with respect to the selection, marking, and placement of vehicles and equipment.

One promising strategy for increasing perceptions of enforcement intensity is to use scheduling techniques for patrol vehicles that achieve the maximum carryover effect of police presence. This strategy, which was used in Texas and reported by Brackett and Edwards (1977), is not, however, in common use today.

Special-Deterrence Countermeasures

Special-deterrence countermeasures, like general-deterrence countermeasures, begin with the deployment of patrol vehicles and the selection of a patrol strategy. Because special deterrence focuses on individual violators of speed laws, it is necessary for the police to identify violators and to collect evidence that will support a finding of their guilt.

A variety of speed-measuring devices are in use for that purpose.

Speed-Measurement Devices. As recently as twenty years ago, **pacing** was the principal means of determining vehicle speeds. The procedure is still used today, though not as extensively (Darwick 1977; Witheford 1970). The more common form of pacing is **speedometer pacing** in which the officer selects a suspect vehicle and adjusts the patrol car speed to that of the suspect; when both vehicles are traveling at the same speed, the officer will look at the speedometer and determine the speed of both vehicles. There is a variation of the pacing technique in which the officer holds the patrol car at a steady pace (for example, at the speed limit or five miles per hour above it) and determines whether the suspect vehicle is "pulling away," in which case enforcement action will occur (Darwick 1977).

In a few locations, especially California, **odometer pacing** is used. In that procedure, the officer selects a steady pace while using the odometer to determine whether the distance between the suspect vehicle and the patrol vehicle is increasing, in which case the suspect's speed is greater than the patrol car speed. The change of distance is determined by selecting a landmark (for example, the shadow under a bridge overpass) and noting the change in the odometer reading as the suspect and patrol vehicles pass the landmark; then selecting a second landmark and again noting the change in odometer readings (Darwick 1977).

The **stopwatch** was perhaps the earliest speed measuring device, predating even the speedometer and odometer. Today its main use is in conjunction with speed measurements from aircraft. For aircraft speed surveillance, markers are placed or painted on highways to measure fixed distances. Aircraft or helicopters cruise above the measured course and personnel aboard them clock passing traffic, determining their speeds from a conversion table. When the airborne personnel detect a violator, a description of the offending vehicle is relayed to a ground unit, which verifies the description and stops the vehicle. Watches are also used, but rather infrequently, in urban areas such as school zones where the speed limit is low.

Radar, which stands for Radio Detection and Ranging, began to be used in speed enforcement about 1947. Radar uses the Doppler principle: Waves reflected off a moving object change frequency in proportion to the object's speed. Radar units emit radio waves in the direction of traffic: The change in frequency in these waves, which is proportional to the speed of the vehicle that reflects them, is converted into speed and displayed to the officer operating the unit (Witheford 1970). Radar units can be attached to patrol vehicles and operated in the **moving mode,** or can be operated in the **stationary mode** while attached to the vehicle, mounted on a tripod or bridge railing, or held in the officer's hand. Hand-held units are especially popular with motorcycle officers.

Stationary-mode measurements are taken from approaching or receding traffic. To ensure accurate readings, the unit must not be moved while being operated. Moving mode measurements can be taken from traffic approaching the patrol vehicle (the more common method) or from traffic traveling in the same direction. In the moving mode, the change in frequency indicates the difference in speeds between the patrol and suspect vehicles: The radar unit subtracts the speed of the patrol car when it approaches the suspect; and adds the patrol car speed when it is moving in the same direction as the suspect. Thus moving radar requires accurate measurement of both the difference in speeds and the patrol car speed.

Whenever a radar unit measures speed on an angle instead of straight ahead or behind, a phenomenon known as **cosine error** results. This occurs because the radar unit measures the component of the target's speed along the line of sight between the radar and its target. The size of that component is proportional to the cosine of the angle between the radar and the target: As the angle increases, the cosine becomes less than one, and the measured component becomes less than the actual target speed. In the stationary mode, cosine error presents no serious problem, because it always favors the driver and is not a valid defense. However, since moving-mode radar also measures the patrol vehicle's speed, cosine error could result in the undercalculation of how fast the patrol vehicle is traveling, which could in turn overcalculate the driver's speed. To minimize the effects of cosine error some police departments have instructed officers to ensure that the radar antenna is aligned with the patrol vehicle's direction of travel to within eight degrees (Michigan State Police 1979); at such an angle the cosine error is minimal.

Research has also identified a number of other potential errors that occur in the operation of radar, such as "shadow" readings caused by large vehicles such as trucks; "bumping" errors, or erroneous readings caused by sudden changes in the patrol car speed; "panning" errors caused by the radar unit antenna moving through its own display; "scanning" errors produced by improper use or placement of the antenna; and "ghost" readings caused by CB radios, power lines, and other nearby energy sources (U.S. Department of Transportation 1980). These errors are not caused by the scientific invalidity of radar's operating principles but rather by improper operation of the unit or by forces external to the unit. To minimize the occurrence of these errors, operators must be trained to recognize sources of errors and must follow proper operating procedures, including selecting an area free of distorting influences (Denver Police Department 1979; Michigan State Police 1979). It is especially important that the operator make a visual identification of the offending vehicle if the radar unit indicates that a violation has occurred. Observation screens out most erroneous readings and fulfills the legal requirement that an officer view the offense and identify the offender. Because of the importance of viewing the offense, the "automatic lock" feature of modern radar units has fallen into disfavor with courts and police officials.

VASCAR, which stands for Visual Average Speed Computer and Recorder, is a time-distance computer that calculates speed. It is favored by some departments for use when conditions are not favorable for using radar. To operate VASCAR the operator must feed both time and distance data for a given vehicle. Distance data can be fed directly if the length of a course is known (for example, 500 yards between two overpasses), or can be measured by the VASCAR unit and then stored. Time data are entered by activating a switch when a suspect vehicle enters the course and deactivating it when the suspect completes it. Since distance divided by time equals speed, the quotient determined by VASCAR is the vehicle's speed (O'Neal 1967). VASCAR is no longer used widely because police departments have experienced extensive downtime problems, because of judicial reluctance to accept the device as evidence, and because radar is considered just as reliable. However, since VASCAR emits no radiation it cannot be found by radar detectors (Darwick 1978).

All of the speed detection devices in common use have to be attended by a human operator. **Automated detection devices** have been designed to eliminate this need. One such device, called ORBIS III, determines speed using pavement sensors that determine speed by dividing the distance between the sensors by the time required to pass over both. If the speed determined by the device exceeds a preset speed, a camera attached to the ORBIS unit automatically photographs the offending vehicle together with the violation date, time, and location. Legal action is based on registration information obtained from the vehicle's license plate number (Myers and Ottman undated). ORBIS III was tested in Arlington, Texas, in 1970-72. Most owners of speeding vehicles detected during the test were issued warning letters, although some owners were issued citations and chose to pay the fine (Vought Missiles and Space Company undated). It appears that the effects of ORBIS on speed were more the result of general deterrence among Arlington's drivers than special deterrence of those who were cited or warned.

Video recording equipment has also been used to support traffic enforcement, especially to document impaired driving. Such equipment has been used infrequently to detect speeders. The equipment consists of portable videotape units mounted in patrol cars to film drivers' behavior; they have zoom lenses and instant replay capability.

Apprehension. Defining the speed limit as the 85th-percentile speed of traffic assures that there will be more violators than police officers; in addition, police officers have duties other than apprehending speeders. Police agencies also desire to maintain good public relations, must compensate for measurement errors, and generally concentrate only on the highest-risk speeders. All of these factors make it necessary to decide when to pursue and when not to pursue a speeder.

Nearly all police agencies have speed "tolerances": they range from unwritten and unofficial policies to official written guidelines, such as those used by the California Highway Patrol (at five miles per hour over the limit the officer should stop; at ten miles per hour over the officer shall stop and should cite) (Ruschmann et al. 1980). Thirty-one selected police agencies contacted regarding their speed enforcement procedures reported tolerances ranging from five to 15 miles per hour (Ruschmann et al. 1980). That range is consistent with the Research Triangle Institute (1970) recommendation that enforcement take place at speeds five to seven mph above the posted speed. In addition to speed tolerance policies, officers are often given discretion whether to stop, warn, or cite, depending on the conditions surrounding a violation (such as weather and/or road conditions, or the driver's "attitude").

In most cases the officer(s) who detected the speeder will also apprehend. This reflects the decision of most police departments to use the **solo configurtation** in which one unit both detects and apprehends. Sometimes a department will rely on the **team configuration** in which personnel in one unit measure speeds and identify violators, and one or more "catch" vehicles are deployed downstream to apprehend them. Aircraft measurement procedures use a form of the team configuration; personnel aboard the aircraft measure speeds and report violators to ground units that stop them.

Pursuit procedures for cooperative drivers are fairly standard among police agencies. The patrol vehicle is positioned behind or at the side of the violator's vehicle, and flashing lights or hand signals are used to signal the violator to stop. A siren is used only when the driver fails to respond to other signals. Procedures for pursuing drivers who attempt to escape vary considerably. Most agencies appear to rely on the officer's judgment for deciding when to initiate, conduct, or terminate hot pursuit. Some agencies place restrictions on the officer's decision (for example, pursuit is allowed only when the violator's speed is at least 20 mph over the limit); a few caution against "hot pursuit" or discourage it altogether.

The pursued vehicle is pulled over to the side of the road or to the curb on city streets. The berm or median strip may be used on divided highways. Side streets are often used for pulling over vehicles detected speeding on busy city streets. The police car is positioned behind the violator one-fourth to one-third of a car width from the violator out toward the road. This protects the officer from oncoming traffic as he stands at the violator's vehicle. Most agencies queried have the policy that the violator's vehicle be approached from the driver's side, but some, such as the California Highway Patrol, reportedly encourage officers to approach from the passenger side. The officer's personal safety is the major factor in deciding how the approach should be made.

The officer may check the vehicle's registration number and the driver's license after the stop. Some agencies do this routinely, and others do it only if they are suspicious of the vehicle or the driver. Typically, the officer asks the driver for the driver's license and explains the posted speed limit and the speed at which the driver was traveling. The officer may allow the driver to view the radar reading if radar was used for measuring speed.

Presanctioning and Sanctioning. Once the officer has stopped the violator, he or she must decide whether to arrest, cite in lieu of arrest, or release the driver. Formal arrests in which the driver is taken into custody are very rare. The most frequent outcome is the issuance of a citation requiring the driver to appear before a court or other adjudicatory agency and answer the speeding charge. In some instances, especially where speeding is still classified as a criminal offense, the driver is required to post bond or collateral to ensure appearance in court. The charged speed appearing on the citation is not necessarily the speed measured by the officer. Some agencies commonly "round down" the measured speed, often to the next lower multiple of five, to account for possible measurement errors and other factors, such as reducing the number of violation points the driver will receive if convicted.

In some instances the police officer will administer the sanction directly in the form of a warning rather than a citation. Police agency policies on warnings vary widely. Some departments rarely issue warnings, while others warn half or more of all drivers they stop for speeding. In general, warnings are used infrequently, usually when the measured speed was not excessively over the limit or when the speed measurement procedure could be challenged as inaccurate. Verbal warnings are preferred to written warnings in speed enforcement; the written warning is apparently used more widely to deal with equipment violations. The few agencies that do issue written warnings seem to have a relatively high ratio of warnings to citations (Ruschmann et al. 1980).

ADJUDICATION AND SANCTIONING

In most states speeding is still classified as a misdemeanor and the apprehension and prosecution of speeders are governed by the rules of criminal procedure, as well as by the constitutional guarantees of proof beyond a reasonable doubt and possibly jury trial and the right to a court-appointed attorney. In most states jail is still a possible penalty for speeding, although jail sentences are extremely rare. In all states, a fine or penalty is a possible sanction, as is license suspension for repeated violations. In a number of jurisdictions where speeding is technically a crime, procedures have been developed to speed up the processing of cases. Procedures allowing violators who plead guilty to less risky speed offenses and pay fines in person or by mail are common, and some jurisdictions have assigned parajudicial personnel (commonly called "referees" or "commissioners") to hear and dispose of guilty and no-contest pleas (Ruschmann et al. 1980).

A growing number of states have dropped confinement to jail as a possible penalty for speeding and thus have been able to dispense with rights to jury trial and appointed attorneys. Some states have allowed parajudicial personnel to hear cases, and others have relaxed the requirements for proving guilt. Two states, New York and Rhode Island,

and the District of Columbia have transferred the adjudicatory function from the courts to an administrative agency (Muller, Day, and Oldham 1980).

In all jurisdictions, conviction rates for speeding are high, probably on the order of 90 percent or more of all citations that are answered by drivers. Fines, averaging about $50 (including court costs), are the most common sanction by far. Few citations are contested and therefore trials are uncommon; when they do occur, they last five to ten minutes. A few courts appear to entertain doubts about the validity of radar, in light of a well-publicized 1979 Miami trial court ruling that radar speed measurements cannot prove guilt beyond a reasonable doubt. However, the Miami ruling appears to be a minority view and most judges accept radar measurements taken from a properly working and correctly used device. Police report that speedometer pacing is generally accepted as evidence, though it is viewed as somewhat less accurate than radar. A few courts accept visual observation coupled with an expert judgment regarding speed, provided the officer can demonstrate his or her expertise in judging speeds.

SPEED ENFORCEMENT NEEDS

Common experience indicates that drivers who speed face only a small probability of being detected and punished. Joscelyn and Jones (1981) estimated that the average speeder faces one chance in 10,000 of being cited. This estimate is consistent with the finding of Sheehe (1963) that the probability of citation is one in 7,600 and with the estimate of Craig (1980), Commissioner of the California Highway Patrol, of one in 22,000. It is logical to conclude from these data that existing police resources are not sufficient to deal with the large number of speed violations that are committed.

Joscelyn and Jones (1981) estimated how many police personnel would be needed to control the risk posed by one aspect of speeding, namely speeding too fast. They considered two definitions of speeding: first, the definition of speeding as an unsafe driving act, in which the top five percent of speeds present an unacceptably high risk of a traffic crash; and second, the common practice of posting speed limits (other than the 55-mph speed limit) at the 85th percentile speed of traffic. The former, more conservative definition was used as the basis of their estimates.

By definition, the highest five percent of all vehicle speeds are unacceptably risky (Treat et al. 1980). Translated into vehicle miles traveled, approximately 80 billion of the estimated 1.4 trillion miles traveled each year by American drivers are driven at unacceptably high speeds. Assuming that speeding is evenly distributed across time and among the approximately 3 million miles of surfaced roadways in the United States, and that each "speeding trip" lasts ten miles, about 900,000 instances of excessive speed occur every hour, or on the average, every mile of highway has three drivers per hour who travel at excessively high speeds.

Presently in the United States about 100,000 full time police officers perform traffic duties—including speed enforcement. Assuming that each officer can issue six citations per hour (a conservative upper bound for officer activity) and does not have to appear in court during his or her regular shift, each officer can cover two miles of highway per hour, which means that all traffic officers working around the clock can cover only about 200,000 of the nation's three million miles of highways. Of course, no police officer works around the clock, and a more reasonable estimate is that existing police personnel can provide the equivalent of around-the-clock coverage of 50,000 miles of highways. Thus, to provide coverage for all surfaced roads in the United States, six million police officers are needed.

Fortunately, the concept of deterrence does not assume or require that every violator be caught and punished. Rather explicitly the concept of deterrence is based on the principle that the punishment of some offenders is sufficient to deter others from committing the offense. What is not known, however, is how many offenders must be caught to present a credible deterrent threat. Research studies suggest that the "halo" effect around a police unit on the highway persists for several miles in either direction; other research has found that significant increases in citation activity reduce the incidence of speeding as a reaction to perceived enforcement action. It would not be unreasonable to assume that citing one-sixth of all speeders would deter the remaining drivers from speeding; that being the case, the requirement for police officer strength falls from six million to one million. This estimate—quick and conservative as it is—indicates that police personnel needs are ten times present resources. In terms of cost, present traffic enforcement entails an estimated total cost of $2 billion; a tenfold increase in police strength would generate costs in the order of $20 billion (Joscelyn and Jones 1981).

The implication of these data--that only a miniscule fraction of speeders are caught, and that on the order of a tenfold increase in police strength would be required to create a credible deterrent threat--is that present methods and present resources probably cannot bring about a significant increase in speed enforcement. Given current revenue problems at all levels of government, it is unlikely that a substantial increase in police traffic resources will soon occur. The limited existing resources and the low probability that they will be significantly increased indicate that the underlying premises of traffic law enforcement should be reexamined.

Reexamination of expectations is especially important with respect to the 55-mph national maximum speed limit. The 55-mph violation is a highly visible one. The national speed limit is generally supported by safety and energy-conservation constituencies. Congress has enacted legislation that imposes fiscal penalties on states that do not show substantial compliance with the 55-mph limit. This is so even though conclusive and detailed data regarding the safety and conservation benefits of the 55-mph limit have yet to be developed, and even though it is possible that the expenditure of police resources, as well as the added risks resulting from using traditional enforcement procedures to secure compliance with the limit, may outweigh the safety and conservation gains brought about by strict enforcement. Aside from the 55-mph violation, **other speeding violations--especially those involving speeds much higher than those of other traffic—pose a significant safety problem.** Violations of lower speed limits (e.g., 25 mph, 30 mph, 35 mph) also create risk. They occur very frequently—so frequently, in fact, that existing police resources cannot deal with more than a small fraction of violators. Again, the cost of increasing traditional police-oriented enforcement procedures could be greater than the benefits of such enforcement. Preliminary analyses suggest that it will be impossible to achieve significant reductions in speedng without gross increases in the actual level of enforcement. Such increases--even if they are warranted by the corresponding benefits—are unlikely.

EXAMINING ALTERNATIVE METHODS OF MANAGING THE SPEED CRASH RISK

Examination of current police practices and the response of the driver to the deterrent approach does not suggest that the fundamental concept is flawed. In fact, it appears that relatively minimal police resources have been remarkably effective in obtaining general compliance with speed laws. These data strongly support the continuation of present police practices and the concept of deterrence. The major reason why speed enforcement is so costly and labor intensive is that speeding is considered a crime in most states and an offense with many trappings of a crime in others. Under our legal system, a series of time-consuming procedures are required to ensure that the suspected speeder is given fair treatment. These procedures include the requirement that a highly trained police officer personally witness the offense and identify the offender; that the driver be given the opportunity to contest the charge in a court of law; and that guilt be established beyond a reasonable doubt and in accordance with formal rules of criminal procedure and evidence. Although the Constitution and state law impose these requirements on criminal speeding prosecutions, it is not necessary for states to treat speeding as criminal in the first place.

Most speeding violations are relatively straightforward acts. Even though speeding creates risk and should be deterred, using the same approach to discourage speeding that is used to deter deliberately planned crimes seems unnecessary. Similarly, since the most common sanction is a relatively small fine with little social stigma attached, providing all the safeguards of the criminal law system seems equally unnecessary. This does not suggest that deliberate or reckless speeding should escape the attention of the formal system of criminal justice--only those speeding offenses that create relatively low risk compared to criminal conduct and that are not accompanied by criminal intent should be handled through noncriminal procedures.

One suggested risk-management approach, described by Ruschmann et al. (1979), calls for classifying speeding as a "civil offense" similar to parking offenses in most localities. Under such an approach, enforcement would be focused on the vehicle rather than its driver. The registered owner--individual or corporate--of an offending vehicle would be subject to a civil sanction, namely a monetary penalty. Proof of an offense would consist of (a) evidence that a posted limit, maximum or minimum, was violated and (b) identity of the registered owner. Enforcement of sanctions (i.e., compelling payment) could be accomplished by using the central record systems linked to vehicle registration and titling. Penalties outstanding against vehicle owners would have to be paid before the vehicle could be reregistered or the title transferred. Unpaid penalties could create a lien against the vehicle, and civil process similar to repossession for nonpayment of an auto loan could be used to seize and sell vehicles on which penalties are not paid.

Although automated detection and measuring technology is available, it has not been developed and implemented in the United States because speed offenses continue to be handled through a highly formal, legal approach that requires costly and time-consuming enforcement procedures. A small number of states, though, have taken the first step toward automated enforcement by treating most speeding violations as "civil" rather than "criminal" in nature and by transferring the responsibility for hearing and deciding speeding cases from the courts to specialized administrative agencies. Nearly half of the remaining states have to a greater or lesser extent removed criminal attributes from speeding offenses (Mullen, Day, and Oldham 1980). No state, however, has implemented a program of automated enforcement on other than a pilot basis, and no such efforts are planned for the immediate future.

Detecting and punishing those associated with speeding, whether the speed violation is called a "crime," a "civil offense," or something else, is the classic negative approach to modifying behavior. Reliance on punishments to discourage speeding is based on the assumption that unsafe driving flows from a human decision based on a balancing of the utilities and disutilities of driving unsafely. The utilities or "benefits" of speeding include, for example, saving time, relieving frustration, and experiencing the thrill of taking risks. The chief disutility of speeding is being involved in a crash and suffering an injury or financial loss. Because the possibility of a crash is not sufficient to influence many drivers to avoid speeding, society has taken action to increase the disutility of speeding by adding the "surrogate" risk of being cited and punished. Sanctions administered through the Traffic Law System constitute the chief strategy by which society attempts to influence driver decisions whether to speed. When the Traffic Law System attempts to manage the speed-crash risk, the risk management process is called "general deterrerence."

However, negative approaches do not have to rely on the Traffic Law System. Other risk-management systems, such as insurers, have appeal because they do not have to abide by the legal constraints that the Constitution requires. For example, an insurer can impose a rate increase on a speeder, based on reasonable evidence, without following the same strict procedural formalities required to convict a speeder in court.

Punishments applied by any risk-management system may be actual or perceived; deterrence theory (and common sense) dictate that the influence on behavior is greatest when both actual and perceived punishments occur.

Almost all efforts to manage the risk of unsafe driving have concentrated on punishing persons who drive unsafely. This strategy, **increasing the disutility of unsafe driving,** adds legal or other punishment to the other disutilities (principally the risk of having a crash) of unsafe driving with the intent that it alter a decision from one to drive unsafely to a decision to drive safely. Increasing the disutility of unsafe driving is only one available means of prompting decisions to drive safely. Three others are: decreasing the utility of unsafe driving; increasing the utility of safe driving; and decreasing the disutility of safe driving.

Decreasing the utility of unsafe driving is a strategy that in effect eliminates the financial and social rewards that one receives by driving unsafely. For example, a trucking company that pays its drivers by the mile rewards speeders with higher pay, more free time, or both, as compared with nonspeeders. Changing the company pay policy could eliminate these rewards and decrease the utility of speeding.

Increasing the utility of safe driving is, in effect, the offer of a reward to safe drivers that is large enough to shift a decision to drive unsafely to one to drive safely. Assuming that nonspeeders can somehow be identified, they could be given monetary rewards or public recognition. Rewards could be both perceived (the possibility of receiving a prize) or actual (a safe driving certificate), Education and information efforts are required to support both actual and perceived rewards of safe driving, especially the latter.

Decreasing the disutility of safe driving is a strategy that removes "punishments" associated with compliance with the speed limit. Persuading employers not to discipline tardy workers might eliminate the penalty a worker would pay if he or she obeyed posted speed limits after leaving late for work. Strategies to decrease incentives for disobeying the speed limit include informing drivers that the travel time saved by speeding is minimal.

Jones and Joscelyn (1981) examined a variety of risk-management strategies to be directed against driver decisions to speed. They recommended a series of countermeasures, including the enhancement of traditional enforcement procedures, as well as nontraditional countermeasures that do not necessarily rely on punishment. Aside from automated detection and enforcement, Jones and Joscelyn recommended a variety of on-board detection and warning systems: an operating speed recorder that would alert owners of vehicles to speed violations committed by drivers; an on-board system that would warn passengers on buses and vans that the vehicle was being operated at an excessive speed; programs that would encourage other drivers to report speeders to corporate fleet owners and police departments or driver-licensing authorities; and information programs that would detail the actual increases in costs associated with high-speed driving and the modest increase in travel time that results from obeying the speed limit. These countermeasures increase the probability of speeders being detected; encourage persons outside formal risk-management systems (for example, parents) to influence driver decisions regarding speed; provide drivers with information helpful in deciding what speed to select; and rely on systems other than the Traffic Law System to reward compliance and punish noncompliance with speed laws. All of the recommended concepts appear feasible but require additional study prior to their being implemented. Elements of the recommended countermeasures pose problems of acceptability, and some of them (such as automated enforcement) are vulnerable to sabotage. All of the concepts are potentially costly, although they may be more efficient than a corresponding expenditure for more police resources. Finally, unintentional speeding (for example, following the "pace" of leading traffic) may not be as amenable to the countermeasures proposed by Jones and Joscelyn, who focused on conscious and intentional speeding. Nonetheless, in light of how limited existing police resources and procedures are in regard to reducing the speed-crash risk, implementing--or at least evaluating--the recommended countermeasures is indicated.

RECOMMENDATIONS FOR ACTION

The previous section has presented an overview of the speed-crash risk and management actions undertaken to deal with the risk. Traffic law enforcement has been shown effective in reducing the speed-crash risk, but enforcement resources are limited. Near-term management actions will depend upon using traffic law enforcement most effectively. Longer term management action will necessarily include alternative approaches. Speed is a highway safety problem. Action needs to be taken at the state and local level to support both near-term and longer term approaches. Local programs that deal with the speed-crash risk should include the following elements.

- **Enact and post reasonable maximum and minimum speed limits.** Public antipathy to speed law enforcement stems in part from improperly established limits that make nonrisky behavior illegal. Improper limits also tend to misallocate police resources if they are enforced. Proper limits help the public select safe travel speeds, create respect for the law, and develop public support for enforcement action against those who violate the law.

- **Decriminalize minor speeding offenses.** Treating minor speeding acts as civil offenses will not reduce the deterrent effect of the law. It will reduce the cost of case handling both for the state and for the driver. Simple speeding has been treated as a civil offense for years in several states and has proved to be a workable approach. It also facilitates the administrative processing of cases (as opposed to processing within the judicial system) should that be desired.

- **Enlist the aid of the media in disseminating information about the limited utility associated with speeding.** Public information and education efforts have focused on speeding for years. Most of the emphasis has been on the risks associated with unsafe driving. This approach is useful and should not be discontinued but it should be augmented by information on how little can be gained by speeding. Drivers need to have information on both the risks and the benefits to make intelligent decisions.

- **Implement selective enforcement programs.** The value of a carefully targeted police traffic enforcement program is well established. Despite this knowledge, many departments do not have a formal program. Often this is so because the community places higher priorities on other aspects of police service, such as crime prevention. Citizens must demand protection from the traffic crash risk as well. The police response should include a carefully planned program that identifies the speed-crash risk and allocates resources to deal with the risk. Care should be taken to ensure that an actual selective enforcement program is implemented. Merely increasing citation activity is not selective enforcement and may not achieve risk management objectives.

- **Encourage appropriate adjudication and sanctioning**

practices. The proper disposition of speed cases is critical to the success of a risk management program. Low risk offenders can be handled summarily, with due regard to the need for fundamental fairness, and receive sanctions such as fines and accrue points towards license suspension. High risk offenders—such as those who engage in reckless driving, road racing, fleeing a police officer, or other deliberate unsafe speeding acts—require more than cursory attention. Prompt adjudication of high risk offenders and deliberate imposition of more severe sanctions (including license suspension and incarceration where warranted) are critical to the success of a local speed control program. It must be known in the community that serious offenses will be dealt with promptly and severely for a general deterrence program to be effective.

- **Install speed monitoring devices on vehicles.** The police cannot monitor all driver behavior. Society must develop additional control systems. Application of available speed monitoring technology should be encouraged and fostered by action of public agencies. Installation of speed monitoring devices on vehicles that transport school children, the handicapped, or other similar populations that are owed a high standard of care would be a good starting point. Creation of incentives such as tax credits should also be considered to encourage private fleet operators to install monitors.

- **Increase the use of automated detection devices.** Automated detection devices are a promising technology but their general use is limited by the state of the current law. Potential applications do exist. For example, automated devices could monitor speed behaviors on restricted areas (such as parking lots). Offending vehicles could be denied access as a sanction. School parking lots or other areas under control of public agencies may provide early opportunities for the application of this technology. Other restricted areas (including, for example, parks, private parking lots, and military bases) that are not public highways could also serve to develop applications of automated detection technology.

Each of these approaches will promote reduction of the speed-crash risk in the near-term future while laying a foundation for the implementation of longer term approaches that do not rely as heavily on traditional labor intensive enforcement approaches.

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