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Speed metrics and crash risks: statistical assessment and implications for highway safety policy

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Speed metrics and crash risks –statistical assessment and implications for highway safety policy

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1.0 GENERAL INTRODUCTION

1.1 Introduction

The safety of the motoring public has long been an important consideration of professionals in a wide range of disciplines. For the purposes of this document safety is defined as the relative freedom from crash risk, so that an increase in safety is equivalent to a decrease in crashes or their risk.

Each of these disciplines has its own area (or areas) of expertise and concern. For example, the medical profession is concerned about the amount and types of injuries, the speedy transport of the injured to care centers, and providing appropriate medical care. Mechanical engineers are interested in improving the safety of the vehicles, to reduce the potential for crashes and to reduce the risk of injury for those vehicles that are involved in crashes. For that portion of the civil engineering profession involved in traffic safety, the interest, concern, and focus have been on finding ways to improve the safety of the roadway environment.

There has long been an interest within this portion of the profession in achieving a balance between transportation efficiency and safety. It is a broad but important generalization that efficiency (characterized as the speed of movement) comes at the expense of safety. The goal of providing the most efficient mobility without unduly sacrificing safety equates to setting speed limits as high as possible without significantly raising crash risk. There is an issue of public policy with regard to speed limits and their acceptance and/or observation; anecdotal evidence is that increased speed limits are no more observed than were lower limits. This was recently the subject of discussion in the Iowa legislature during debate on changing the speed limit on rural interstate highways to 70 mph (Des Moines Register, April 20, 2005.

The role of technological innovations in the evaluation of roadway safety has been a peripheral focus in a number of studies (see, for example, the use of speed radar in Wiley et al (1949)), although it does not appear to have been the specific object of a study. There is a variety of new technologies, as well as new applications of old technologies, that appear to have the potential to provide valuable information to improve the quality of roadway safety research. One technology, currently used by such agencies as the Iowa DOT to evaluate mean speed on the roadway system is the automated traffic recorder or ATR. It is the purpose of this document to develop a method for and to report on the use of automated traffic recorders to evaluate the risk of crash involvement on a variety of highways in Iowa.

In 1964 the Federal Highway Administration (FHWA) published a report by David Solomon in which he reported an exhaustive study of the relationship between crashes on 2-lane and 4-lane roadways and a number of factors (Solomon, 1964). The factor which generated the greatest interest and has had a major influence on highway operations and traffic safety was that of the speed of the vehicles involved in the crashes and how this speed compared to the speeds of non-crash vehicles in the same sections. Solomon's work appears to be seminal in that it is often cited as the source of the 85^{th} percentile speed rule for setting speeds (see for example Cirillo (1968) and Kloeden et al (2002)). Since this time there have been numerous changes in the roadway system, most of which have made driving a safer endeavor. The current research makes a broadly based evaluation of the relationships between speed, the variation in the speed distribution (measured by the standard deviation and by the difference between the mean speed and the 85^{th} percentile speed), the difference between the 85^{th} percentile speed and the speed limit, and the risk of crash involvement. The goal of the research is to evaluate various metrics of speed on highways, determining their relationship to safety and thus providing a uniform basis for setting reasonable and enforceable speed limits that will strike a balance between the somewhat competing issues of mobility and safety.

Solomon's study was based on data from the mid-1950s. Since that time there have been a number of changes that have at least the potential to impact on highway safety and thus on the relationship between speed and crash risk. Some of these are as follows:

- The mix of vehicles has changed substantially. At the time the study data were collected trucks were less prevalent and not heavily used for the long-distance movement of goods; automobiles constituted a much higher percentage of the total vehicles. According to Solomon's data, approximately 22 percent of the vehicles were commercial; this increased to 30 percent at night. Based on 2002 data from the Iowa DOT, trucks averaged approximately 37 percent of the vehicles on I-80. According to preliminary 202 data from the Bureau of Transportation Statistics, trucks hauled about 58 percent of the tonnage of freight in the U.S.

- The vehicles themselves have changed substantially. Safety belts were just becoming available on cars in at the time of the study; today we have three-point seat belts at most or all locations within our vehicles and we have multiple airbags in all automobiles and their cousins (SUV and mini-vans). The litany of vehicle changes goes on to include better tires, energy-absorbing bumpers, disk and anti-lock brakes, more powerful headlights, side impact protection, and energy-absorbing vehicle structure. All of these have an impact on the safety of highway travel.

- The roadway environment has changed substantially as well. Speed limits are set somewhat more rationally, based on research such as Solomon's and others. Signing, striping, lighting, and traffic signals have been changed to improve visibility. Clear zones, as well as better protection of fixed objects in the clear zone, now provide a more forgiving environment for errant vehicles. Much has been done to make the roadway environment more understandable to drivers. We are well along in the process of modifying freeways and other limited access roadways to have all entrances and exits on the outside, providing a uniform expectation to drivers.

- The driving population has changed. Based on Census Bureau data, the 50-54 age group experienced the highest rate of growth, increasing by 55 percent over the last decade. The Bureau attributed this to baby-boomers entering this age group. The next largest growth for an age group was the 45-49, also part of the baby boom group. With the aging of the "baby-boomer" generation, a greater proportion of drivers is reaching an age at which they are losing visual acuity and cognitive functions, putting them at greater risk.

- Travel patterns have changed. According to Census Bureau data (ACS 2000), the average drive time has increased by nearly 20 percent since 1980, from 21.7 minutes to 25.5 minutes (in 2000). There has been about a 30 percent increase in the number of drivers traveling over 45 minutes to work, from 11.6 percent in 1980 to 15 percent in 2000. People travel farther for employment, recreation, and education today than in the mid-1950's. In addition to creating a greater degree of exposure for the average driver, the tendency to travel farther also has fostered a tendency toward multi-tasking (eating, cell phone usage, and shaving for three examples) in the moving vehicle, reducing the driver's ability to respond properly to roadway events by diverting his/her attention. The longer travel distances seem to go hand-in-hand with increased speeds, a not unreasonable coincidence given the reduced tolerance for delay.

1.2 Dissertation Organization

This dissertation is separated into two parts. The first part presents the development of a methodology to utilize automated traffic recorder and GIS-based crash data to evaluate the relationship between roadway speed, the variance in that speed, and crashes in various types of roadways. The second part applies the methodology to data from the State of Iowa, to present a comprehensive evaluation of these above-mentioned relationships. The dissertation is organized as follows:

- Introduction
- Literature review
- Study methodology
- Results
- Conclusions and recommendations

1.3 Statement of purpose and objectives

Solomon's study used data from 1955-56, covering about 600 miles of 2-lane and 4-lane rural highways (Solomon, 1964). Crash speeds were estimated by investigating police or were reported by the drivers involved. Interviews were conducted with approximately 290,000 drivers passing through these 600 miles, to determine a variety of personal socio-economic factors; their travel speeds through the roadway section of interest were monitored before they were stopped for interviewing. Crash risks were evaluated, based on these data, and were presented in what has come to be known as "Solomon's Curves." At the time of the report, travel on these two types of highways constituted about one-third of total travel. Today travel on 2-lane and 4-lane rural highways is less than 15 percent (2003 data from FHWA). Yet the results of his study are frequently cited (see for example Cirillo (1968) or Kloeden et al (2002) in Chapter 2) and have been incorporated into policies for setting speed limits on all types of roadways.

There are several ways new technologies can be used to provide an updated and improved evaluation of the relationship between speed and crash risk. In Solomon (1964), speed data were obtained for selected drivers by concealed speed measuring devices (no additional information is provided on the specifics of these devices and more importantly, no information is provided on their accuracy). Speed profiles were determined for each study section using (apparently) the floating car technique in which a test car is driven through the test section several times. Currently, each state's network of automatic traffic recorders (ATR) can provide speed data for a wide variety of roadway sections. These records permit an accurate assessment of the speed distribution and the variation in speeds in sections of interest. Crash records are now stored in data bases that are accessible to researchers, permitting more in-depth analysis of the records and a better correlation between crashes and their locations. Many new automobiles with air bags include what is called an event data recorder (EDR) that is similar to aviation's "black box" data recorders. This device provides a record of various inputs from the vehicle (speed, braking, throttle setting, air bag deployment, and change in speed) for the five seconds preceding a crash severe enough to deploy the air bag (NHTSA EDR Working Group summary report, 2001). Geographic data bases are available that include aerial photography and these can be used to characterize access density and a variety of potentially contributory parameters in a corridor and their relationship to crash risk. In today's political and social environment, as well as a purely practical matter, it would be impossible to stop 290,000 drivers to solicit their personal information.

Another factor that was not considered in Solomon was weather. Most states have automated weather recording systems that may permit an estimation of and possibly allow the (experimental) control of the effects of adverse weather conditions on crashes.

Other factors that have the potential to affect the relationship between speed and crash risk include the following:

- Sight distance and design speed. According to AASHTO (2001), "The available sight distance on a roadway should be sufficient to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in it path." Vehicles exceeding the design speed (irrespective of the speed limit), are subject to a reduction in the amount of time available to perceive and react to objects in the roadway.
- Stopping ability. As discussed above, there have been a number of changes in vehicles since Solomon's data were collected. Improvements in durability and traction capability of tires have generally improved vehicles' ability to make full use of the improvements in braking that have come from the almost universal use of disk brakes and the considerable use of anti-lock brakes. Improved smoothness and rideability of pavements also contribute to improved stopping ability. This improved stopping ability will have an impact on the overall crash risk and thus will modify the relationship between speed and crash risk.
- Vehicle energy. The increased number of heavy commercial vehicles and large sport utility vehicles in the highway mix means that there is a potential for more kinetic energy in a crash, thus potentially affecting the severity of crashes.

It is hypothesized that the one or more parameters related to the speed and variation of the traffic stream, such as the mean speed or the difference between the 85th percentile speed and the speed limit from the time immediately preceding a crash, will demonstrate a greater variance of distribution than the same parameters of the similar period one week earlier (in the absence of a crash). This document describes this test of this hypothesis, which utilizes speed data from Iowa's network of automated traffic recorders and crash data from the Iowa DOT's crash record system.

2.0 LITERATURE REVIEW

The history of research into the relationship between speed and crashes is long and varied. Early speed limits were set somewhat at the whim of elected officials, who were concerned with the then new automobile and its impacts on a largely rural society. Later limits were set based on a consensus of reasonable speed for certain environments. Speed limits have been set as an element of national policy, for example as an energy conservation measure as during the Second World War or the "energy crisis" of the 1970's. Safety concerns prompt speed limits such as in school zones. A synthesis of research over the past 55 years into this relationship is presented in this section.

2.1 Illinois urban experience (1949)

An interesting study was conducted by Wiley et al (1949) on the effects of speed limit signage on vehicular speeds in Champaign and Urbana, Illinois. Their objective was to determine the actual travel speeds on various sections of roadway, while varying the posted speed limits. They note that speed is not well understood and that speed limits depend more on (page 1), "...custom, assumption, and tradition in establishing speed limits. The result is that most present-day speed limits have been handed down from 'Model-T days' and officials still seem loath to change them. Furthermore, it is evident that a strong, popular belief still exists that alleged high speeds, per se, are fruitful causes of traffic accidents and that lower speeds can be obtained by posting low speed limits." They go on to note (page 1), "Traffic engineers, however, have long observed that modern traffic tends to run at speeds which the motorists themselves consider to be reasonable and safe, irrespective of any posted limits."

They note the difficulty of enforcing an artificially low speed limit and that the practice was to set speed limits low and for the police to then tolerate a large deviation from that limit on the faster side. As they observe (pages 1 & 2), "In effect, this establishes an actual speed limit, which in itself may be reasonable, but which is unknown because of the false value on the speed limits signs and the unknown and often variable tolerance. Such practice is not only unfair and confusing to the motorist and the police but also extremely misleading to the public."

Their methodology was straight-forward. They selected four roadway sections on state highways passing through Champaign. Intersections were stop controlled. Speeds were measured using Enoscopes and stop watches; they were verified to be accurate within 5 percent by the use of an Illinois DOT radar speed meter. Initially the streets were posted at 25-mph. They reposted the limits to 30-mph or 35-mph, then measured speeds 1 and 4 days after the change. They then removed the signs, leaving no posted limits, and measured speeds at 1 and 5 days. Next the speed limits were set at 20-mph, with measurements at 1 and 5 days afterwards. Finally the limits were reset to 25-mph and the speeds were checked to confirm the first measurements. In all cases counts were taken over a period of about ½ hour and included no more than 100 cars. The duration of the study lasted about five months, beginning in January of 1948 and concluding on the first of June. They do not discuss weather conditions that might have differing impacts on the vehicle speeds.

They conclude that (page 4), "…speed ranges and variations are so nearly alike in all cases for the same street as to demonstrate clearly that the posted speed limits are entirely ignored and that traffic ran at 'natural' speeds irrespective of whether the signs read 20, 25, 30, or 35 mph or whether there were no signs at all." They recommend a speed limit for each roadway segment studied that would be consistent with the 90th percentile speed and that would coincide with the tolerance in local enforcement of the posted limits. They present graphs showing (page 5), "…the relation between the average speed and the 85- and 90-percentile speeds at the sign-speed stations for each speed limit. They indicate that these percentile speeds are not excessive…" The issue of importance to the current study is that even 50-plus years ago it was known that speed limits, if they are to be observed, must reflect the composite judgment of drivers as to the appropriate speed for the road in question.

2.2 Study of rural highways across the country

David Solomon's research (1964) was an extensive evaluation of the relationship between speed and crash risk (among other factors). In his introduction (page 1) he notes, "Many of these relationships (between speed, vehicle and driver characteristics, and accidents) have not been clearly understood in the past." This research formed the basis of many policies for setting speed limits, on all types of highways. This is clearly beyond his intent as he states in the preface, "The study was confined to 2- and 4-lane main rural highways of the nonfreeway (sic) type, and the findings are limited to these types of main rural highways." He observes that at the time (page 6) "...the study sections are representative of highways that accommodate more than one-third of all the vehicle-miles of highway travel in the United States." His study covered 600 miles of these highways, on 35 sections in 11 states, and included crash records of approximately 10,000 drivers, speed profile determination, spot speed studies, and interviews with 290,000 drivers.

His approach was first to determine the average speeds within each roadway section by the use of a study vehicle and team moving with the normal flow of traffic. Speed profiles of the sections were plotted and were evaluated by highway department staff to select a specific site within each section that the staff members felt was representative of the overall section. Next the teams measured the spot speeds of the 290,000 drivers, with (page 7) "Concealed, speed measuring devices were used to record the speed of individual drivers..." At a point farther down the road the drivers were stopped and were interviewed to gather data for characterizing them on the basis of sex, age, etc. Crash data were obtained from state records and covered 10,000 drivers that had crashed in the study sections over a 3 to 4-year period ending in 1958. The speeds of the vehicles involved in the crashes were taken from the crash records. Speed distributions, involvement rate plots, and speed – cumulative percentage plots were presented.

The speed related findings of particular interest to the present study showed that the accident involvement rate (number of vehicles involved in accidents per 100 million vehicle-miles of travel) reached a low point (at a rate of about 90 crashes per 100 MVMT) at a travel speed of about 65-mph in the daytime (see Figure 1) . The low point for night-time travel was at a rate of about 230 per 100 MVMT, at a speed of about 57-mph. Travel at low speeds (20 mph or less) presents a substantial additional risk of crash involvement.

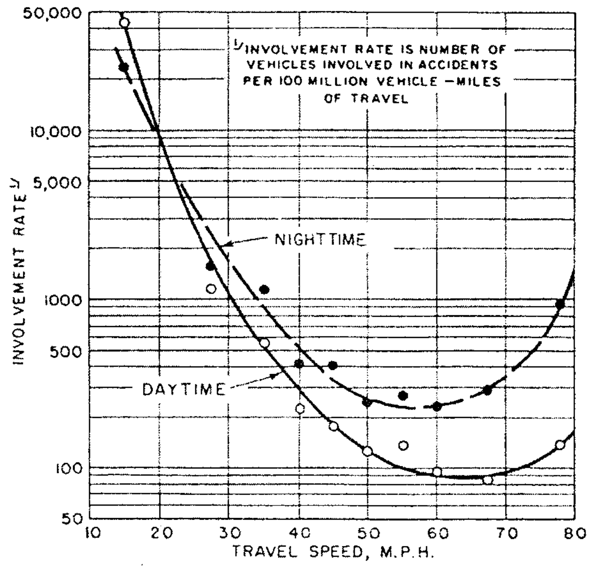

Figure 1 Travel Speed vs. Involvement Rate

Two of his conclusions are of continuing interest and relevance, that the lowest risk of being involved in an accident comes at a speed close to the average travel speed in a corridor and that the risk of being involved in an accident is reduced if the variation between drivers' speeds is reduced (see Figure 2, below). Figure 2 differs from Figure 1 in that it presents the involvement rate in terms of what Solomon referred to as "variation" from average speed, rather than the travel speed he used in Figure 1. The use of the variation from average speed has the effect of normalizing data from a variety of speed limits. It is not explained why the minimum crash involvement came at a speed variation that is about 5 mph above the average speed rather than at the average speed as might be expected. Although he is often credited with recommending the use of the 85th percentile speed as the speed limit, there is no mention of the 85th percentile speed in his report. It is important to remember his observation that "nearly half of all the accident involvements were either rear-end collisions or same direction sideswipes." His roadway sections did not have controlled access and although there were no major intersections there is no information as to other points of access such as driveways. He notes the possibility that as many as half of the low-speed crashes could have occurred at intersections but does not discuss the fact that for each low-speed rear end collision there must also be a vehicle that was going faster. Crashes due to drivers that were inattentive, speeding, or following too close may have been included in these low speed crashes.

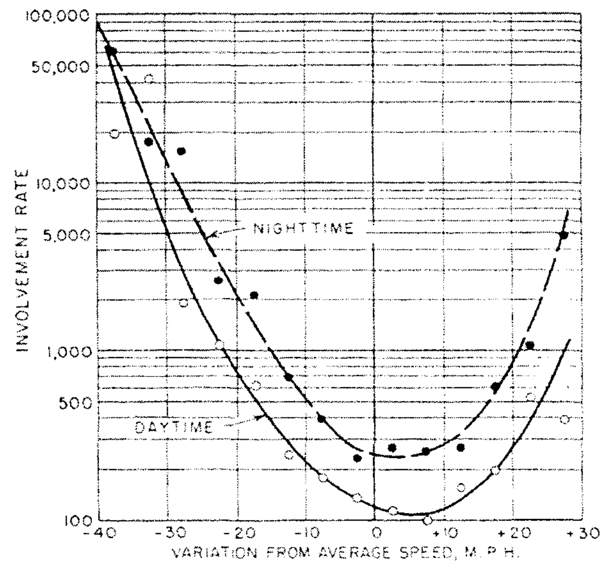

Figure 2 Variation from Average Speed vs. Involvement Rate

2.3 The interstate system

In 1968 Cirillo presented a brief report covering speed aspects of a larger study, the "Interstate System Accident Research Study II." Speed data were provided by 20 state highway agencies, reporting only day-time speeds (between 9:00 A.M. and 4:00 P.M.). The crash data used were limited to the same time period. Her analysis methods and results were similar to those of Solomon, although she noted that the average speed on the interstate system is about 7 mph higher than on main rural highways (if referring to Solomon's findings this would put the speed on the interstate highways at about 72 mph. She presented a curve showing accident risk (rate per 100 MVMT) *versus* speed variation (in mph, the difference from the mean speed). The lowest risk was at a speed 10 mph greater than the mean speed, at a rate of 25 vehicle involvements (as opposed to crashes) per 100 MVMT). She also plotted Solomon's data for conventional rural highways; the lowest risk on his curve was at about 5 mph above the mean speed at a rate just over 100 per MVMT. The importance of her research to the present study is that her findings paralleled Solomon's, albeit for the interstate highway system.

2.4 State highway in Indiana

In this small study on a single highway in Indiana, the researchers (West and Dunn), utilized data from magnetic loop detectors in state highway 37 near Bloomington, Indiana. Crash speeds were estimated by an accident investigation team from the Institute for Research in Public Safety at Indiana University; their findings were correlated with the speed data from the detectors. They studied 36 cases, with good or better correlation in speed for 1 or more of the vehicles in 32 of the 36 cases.

Their results, similar to those of Solomon, were that the risk of crash involvement was highest at very low speeds and that the lowest risk occurred at a speed around 10 mph above the mean speed. They then went on to remove crashes at intersections, reasoning that turning traffic would be forced to reduce speed and thus was not representative of free-flowing traffic, and found that (when turning related accidents were not included) the rates for speed deviations above and below the mean speed were essentially the same.

They conclude (page 55), "This also indicates what these limits should be for safe travel on the highways. Since the standard deviation of speed is approximately 6 to 8 mph for these roads in Indiana, if the standard 85th percentile speed were used and enforcement were provided at the 95th percentile for the upper limits, this would provide speed enforcement for the high-speed drivers in the high accident involvement region." The main importance of this study is of the need to control for atypical traffic situations such as turning movements in determining the operating speeds of roadway sections (unlike Solomon).

2.5 Socially optimal speed limit

In a report that does not directly relate to highway safety but is nonetheless of interest due to its discussion of the bases for drivers' personal speed decisions, Crouch (1976) developed a philosophical argument considering the socially optimal speed limit. The study, conducted shortly after the institution of the 55-mph national speed limit in the United States in 1974, suggested that if the police act as society's agents they will not attempt to enforce a speed limit that is set below the optimum limit; rather their enforcement will be limited to the level needed to bring speeds down to the optimum level. Crouch concludes by noting (page 198), "Somewhat ironically, however, if the police do behave as postulated here not much harm is generated by a speed limit which is too low." This conclusion should be compared with the comments of Wiley et al as cited above regarding the setting of artificially low speed limits and relaxed enforcement and that this practice is unfair to both the public and the police.

2.6 Legal approach to speed management

Another approach is taken by Ruschmann, et al. (1981) in their evaluation of how to manage the risk of unsafe speed, that is, the risk of increased crashes associated with higher speeds. This report reviews and evaluates other studies, summarizing a number of earlier reports (including Solomon's 1964 study). They cite a 1977 study by Treat and associates from Indiana, in which the researchers found (page 9). "...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..." Ruschmann, et al. further referred to other studies that confirmed that this was an appropriate estimate of the range. They point out that clinical studies provided some support for Solomon's finding that excessive negative speed deviation (driving too slowly) presented a high crash risk; they further note, "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." This is consistent with the findings of West and Dunn as were noted above but actually seems to conflict with Solomon's discussion of the higher crash risk associated with low speeds and his inclusion of this in his crash risk assessment.

Ruschmann,et al. conclude with several recommendations, one of which is germane to the present discussion. Speed limits should be reasonable, that is they should not prohibit non-risky speeds. Punishment for "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 (sic) procedures."(page 42) Minimum speeds as well as maximum speeds should be included. They also note that using our present system of criminal enforcement of speed laws will not provide an effective deterrent to speeding and that it would require an order of magnitude increase in police officers to control speeding using our current procedures. They discuss some interesting concepts regarding incentives and disincentives for speeding, pointing out, for example, that trucking companies that pay drivers by the mile are encouraging their drivers to speed in order to maximize their income. They further discuss the use of incentives to reward non-speeders, while noting that it might be difficult to identify them, as well as the possibility of disincentives levied on speeders by insurance companies.

2.7 Swedish experience

In a study reported in the proceedings of an OECD (Organisation for Economic Cooperation and Development) symposium, Nilsson (1981) reported on some overall crash statistics and their relationship to changes in speed limits on national highways in Sweden. Speed limits were reduced in response to an energy crisis; speeds measured on the highways were lower by 7 to 11 percent following the change in limits. Crashes were significantly reduced in most cases, with reductions ranging from 5 to 25 percent of personal injury accidents and up to 52 percent for fatal accidents. The traffic flows were reported to be unchanged over the two periods (before and after). Comparisons were made between those roadways whose speed limits were changed and other, similar roadways that remained unchanged; the author noted that there was a crash reduction over the study period on the unchanged roadways but that the reduction was much less than on those roads where the speed limits were reduced.

2.8 German experience

This brief report by Lenz in the OECD symposium (1981) evaluated the impacts on crashes on the autobahn of posting a speed limit of 130 kph (equivalent to about 80 mph), *versus* posting a speed advisory of the same speed. Two sets of sites were considered, in the first set the speed limit was in place for one year; it was changed to a recommended (advisory) speed for the second year. At the second set of sites the order of signing was reversed. The study found that the number of crashes was reduced for all cases where speed limits were set. The reduction in crashes resulting from implementing a speed limit of 130 kph was the same for one year as it would have been for two years of the long-term temporal reduction in autobahn crashes that began in 1968. They note that the speed limit provided "a reduction in accident figures of 11 percent and in serious injury and fatality figures of 23 percent" when compared to the speed recommendation. The greatest impact of a speed limit was found on the rate of night-time crashes, where the reduction in crash rate was twice as great as during the day.

2.9 Finnish experience

In a study similar in concept to Lenz's above, Salusjarvi (proceedings of the OECD symposium in 1981) found that recommending the appropriate speed on rural main roads reduced speed by 2 kph (not an operationally significant figure). The study involved changing the speed limits on these roads to one of three cases; above, at, and below the 85th percentile speed. In the first case the standard deviation of the speed distribution decreased while the mean speed and total number of crashes increased. In the second case the mean speed did not change while the standard deviation decreased, the total number of crashes remained the same, and the number of injury crashes decreased. In the third case the mean speed decreased, there was no change in the number of crashes, and the author did not report any change in standard deviation. Overall, the average effect of the imposition of speed limits on crash results had a more significant impact on crashes, resulting in a 10 percent decrease in total crashes, a 25 percent increase in property damage only crashes, and a 46 percent decrease in crashes involving fatalities or injuries. The author notes a significant limitation in that the roadway sections chosen had a high crash rate, which would be "...a major limitation on generalizing the effect." The author did not discuss the likelihood of the regression to the mean phenomenon as a possible explanation for the reduction of crashes following the change in speed limits, although that may have been his intention. The importance of this to the current research is to emphasize the possible contribution of the regression to the mean to crash reductions if sites are not randomly selected. The current research is based on using the ATR sites without selecting for high crash rates and, therefore, regression to the mean should not be an issue.

2.10 Irish experience

The Irish experience is reported by Hearne in the proceedings of the OECD symposium (1981). On one hand the Irish experience somewhat confirmed the concept that speed limits should be set at the 85th percentile speed, while on the other hand they found that the average speed of trucks is a more important concern in terms of crash risk. The speed limit for trucks was set at 15 mph less than that for cars. As Hearne notes a speed differential for trucks was implemented in spite of the conflict with Solomon's findings regarding speed deviation. Their finding that the average speed of trucks is a more important concern in crash risk suggests that the impact of truck traffic needs to be considered in speed studies.

2.11 External cost approach to speed limits

In this interesting abridged report of a study by Jondrow, et al. reported, in the Transportation Research Record 887 (1982), a rationale for calculating speed limits based on the external (i.e., societal) costs of individual driver's decisions regarding appropriate speed. The authors first present an equation for the optimal speed for an individual driver, bringing in values of the driver's time value, the cost of gasoline, the increase in usage of gasoline from an increase in speed, the (negative) value of an increased fatal crash risk, and the increase in probability of having a fatal crash. They then modify this equation to include the impact the speeding driver has on the crash risk of other drivers. Finally they apply this equation to the (at that time current) national 55-mph speed limit to determine if it is optimal. They conclude that the optimal speed (considering various values of human life) is above 55 mph and that the national speed limit was an expensive way to save lives.

2.12 Other factors, the Michigan experience

In this 1992 report Parker conducted a survey of speed zoning procedures throughout the United States, and compared how these procedures would impact the speed limits within Michigan. The study employed a before and after design with a comparison group. He found that (page 85) "The current Michigan practice of posting speed limits within 5 mi/h of the 85th percentile speed has a beneficial effect, although small, on reducing total accidents, but has a major beneficial effect on providing improved driver compliance." He also found that there was no benefit to setting limits lower than 5 mph below the 85th percentile speed. Other speed zoning methods would not improve traffic safety in Michigan. He recommended that speed studies be conducted over a 24-hour period, to reduce the impacts of short-term variations in the rate. He recommended against the use of radar methods, finding that they underestimated speed by 3 mph. This study provides support for the 85th percentile value as the most reasonable speed limit and the effect of doing so on crashes.

2.13 Urban low-speed, Australian experience

Kloeden et al. (1997) conducted a case-control study of injury crashes on urban roadway sections in Adelaide that had speed limits of 60 kph. They used a criterion for injuries in that one or more people in the crash had to have been transported to a hospital, as well as other control criteria. In this study they also conducted an extensive review of the literature of speed versus crashes, with some interesting observations. They take exception to the findings of Solomon (and others) concerning the risks related to very low speeds in a high (roadway) speed environment. They note that Solomon's data could well have been influenced by the drivers executing turns off of or onto the highway and thus would not reflect drivers' free-moving speed choice. The issue of speed variance is also criticized (Page 21),

> ...the speed variation idea gained weight, more through successive restatements than through good research, it would seem.
>
> Conceptually it is possible to separate speed variance from mean speed, but practical demonstrations of separate effects are difficult. This is because, in reality, both factors are

strongly tied to the characteristics of the road, which are fundamental determinants of the local accident rate. (In theory, the role of speed variation would best be addressed by examining accident rates for a set of roads that were matched for geometry and other characteristics, but which had a different degree of speed variation for the same mean speed).

In their study they evaluated the relative crash risk of traveling at a speed other than 60 kph in a 60 kph zone; they found that the risk at 70 kph (10 kph over) was more than 4 times the risk at 60 kph. The risk of traveling slower than 60 kph was lower until a speed of 40 kph was reached, when it was 1.4 times as risky. They do note that the confidence intervals show that this increase in risk at lower speed could be due to "random variation." .

An interesting additional discussion relates to the possible causes for the increased crash risk with increased speed. .The factors the authors discussed include the reduction in the reaction and braking distances due to excess speed, the relationship between the crash energy and speed, the relationship between vehicle speed and loss of control, and a combination of these factors. Efforts were made to control for other, driver-related risk factors, especially that of alcohol impairment. The value of this study to the present research is in identifying contributory factors to be evaluated and in casting some doubt on the issue of speed variance as the causative factor in roadway crashes.

2.14 Non-controlled access highways

This study by Parker (1997) covered the effects of raising and lowering speed limits on 98 sites in 22 states, during the period October 1985 to September 1992. He concluded that there was no practically significant change in the 85th percentile speed due to changes in the posted speed limit, even for speed limit reductions of up to 15 mph. For sites where the speed limits were lowered by 15 mph the change in average speed was less than 1 mph. Using several statistical methods to analyze the before and after conditions, he determined (Page 71) "...that there is not sufficient evidence in this dataset to reject the hypothesis that total crashes or fatal and injury crashes changed when posted speed limits were either raised or lowered." He concluded (Page 82), "Based on the best information available to date, there is no evidence to suggest that lowering or raising posted speed limits on nonlimited access roadways has an effect on crashes. Reducing the posted speed limit without utilizing other enforcement, educational, and engineering measures does not appear to be an effective safety treatment." These comments address the social issues of reducing speed limits in the expectation that this will in and of itself make the roadway safer. The basis of the current research is to determine the relationship between speed (and variance) and crash risk.

2.15 Australian experience part 2

In a follow-up to the Australian study discussed above, Kloeden et al. (2002) applied a logistic regression model to the data used in the earlier study with the goal of determining a curve showing the relationship between speed and crash risk. Their results were somewhat paralleled and confirmed the earlier results, in that each 5 kph increase in speed (above the 60 kph reference speed) resulted in a doubling of the crash risk. A secondary element of the study was (Page i) "...to examine the effect of hypothetical speed reductions on this set of crashes and urban crashes in general..." This portion of the study found that the result of eliminating all speeds above 60 kph should be a reduction of casualty (injury) crashes of 25 percent. They also determined, under some hypothetical scenarios that reducing the general urban area speed limit from 60-kph to 50-kph would result in a large reduction in casualty crashes. This assumed that compliance with the new speed limit would be in proportion to the compliance under the old speed limit. Based on other research (see for example Parker 1997) evaluated above this is a less than sanguine assumption in the absence of special speed enforcement measures.

2.16 Early effects of return to the 65 mile per hour speed limit

In a report based on slightly more than one year's data from 32 states that restored the 65 mph speed limit, Chang and Paniati (1990) found no statistically significant difference in fatalities on rural interstate highways that could be attributed to the higher limit. They point out several possible factors that may influence such findings including the small amount of speed data after the change in limit, changed observance of the new speed limits, and changed seat belt use.

2.17 Saving lives with higher speeds

In a study funded by the AAA Foundation for Traffic Safety, Lave and Elias (1992) evaluated the impact of the end of the 55 mile per hour "National Speed Limit" on highway safety. They concluded that other researchers, in reporting just the increases in crashes on the interstate system that followed the speed limit change, were ignoring reduced crashes on other roadways. As postulated by the current researchers, drivers that were seeking to avoid the lower speed limits on the interstates by traveling on less rigorously patrolled highways may have had more crashes on these secondary highways. When the 55-mph limit was rescinded the drivers would then return to the interstates. Therefore it would be appropriate to consider the changes in crashes on a statewide basis when evaluating the impact of the speed limit change. Lave and Elias found that there was an overall 3.4 percent reduction in the fatality rates following the repeal of the 55-mph speed limit, in those states that adopted the higher speed limit. They attributed this to the diversion of traffic from the less safe rural highways to the safer interstate system.

2.18 Speed limit impacts in Iowa.

In an unpublished creative component for Iowa State University, Muniandy cited earlier work by Garber and Gadiraju (1991) and Brown, et al. (1990) in discussing speed dispersion as an explanatory variable. Speed dispersion was defined as the 85th percentile speed minus the mean speed.

$$\text{Speed dispersion} = (85^{th} \text{ percentile speed}) - (\text{mean speed}) \tag{2.1}$$

Using a group of time-series plots of dispersion for various types of roadways, he concluded that the speed dispersion increased on rural interstate highways following the change to a 65-mph speed limit; the speed dispersion decreased for rural primary and secondary roads.

In modeling the speed-related parameters he found an increase of 28 injury crashes per year for each increase of one mph in the speed dispersion on urban interstate highways. For rural primary highways the result was even more dramatic, with an increase of 60 injury crashes per year for each one mph increase in speed dispersion (p.49).

2.19 Bayesian analysis of speed data in Iowa

In this study on rural interstates in Iowa, Raju et al (1998) applied Bayesian techniques to evaluating changes in fatal crashes following the increase to a 65-mph speed limit in 1987. Bayesian techniques make use of prior information to predict future behavior and are especially useful in dealing with phenomena that are relatively rare and that may be subject to the regression to the mean phenomenon. The researchers evaluated both quarterly and annual crash rates and found that there were changes in these rates attributable to the increased speed limit; the quarterly frequency increased by 4 fatal crashes while the annual frequency increased by 9 fatal crashes. The report does not discuss the apparent difference between these estimates. There also is no discussion of traffic volumes or of other factors that may contribute to changes in fatal crashes. The authors state (p. 53) "It is important to note, however, that overall traffic safety may be improved by the increase, if sufficient to attract a large enough number of users from less-safe facilities." It appears from the context that this "increase" is meant to be the increase in fatal crashes and that the intended meaning is that there would be a net reduction in fatal crashes statewide. The authors conclude (p. 54-55) "However, regardless of the specific number of fatalities resulting from increased speed limits, it is clear that increased speed limits have serious safety implications."

2.20 Minimum Speed Research

In a recently completed study of traffic on rural interstate highways in Florida, Muchuruza and Mussa (2005) found that 9 percent of the crash-involved vehicles were traveling less than the 40 mph minimum speed; this in contrast to the 0.14 percent of the total number of vehicles that were traveling at that slow speed. They also determined that the minimum crash risk came at the 85th percentile speed. They found that the mean speed was

73 mph, or 3 mph above the speed limit, and that some 56 percent of drivers were exceeding the speed limit. It should be noted that their analysis of the crash speeds is derived from crash records, which speeds are lower than those measured at automated traffic monitoring stations. As they observe (page 5), "Examination of the two distributions show that the estimated pre-crash speeds are skewed to the left of the actual vehicle speeds collected at the sites." The difference is significant, at least 5 mph from their plot of the two distributions, and it may be that this difference should be applied to the crash data. If this is the case it would be expected to reduce the percentage of crash involved vehicles at the low end of the speed distribution. It also calls into question the validity of crash speed estimates in crash records in general, at least those that are not derived from actual vehicle data. This possibility bears on the importance having good speed data on which to base decisions.

2.21 Urban Freeways in Los Angeles

Some interesting relationships were found between mean speed, lane-to-lane speed variation, and volume to types of collisions on on heavily traveled freeways in Southern California. Golob and Recker (2003) used 30-second slices of speed data from detectors in the vicinity of crashes to evaluate the impact of speed, weather, and lighting on crash types. Their evaluation covered three lanes of several freeways, having up to six lanes; these lanes were the innermost, the outermost, and one other lane in the group. Some of their findings are as follows:

- Crashes in the innermost lanes were related mostly to volume

- Crashes in the outermost lanes were related mostly to speed differences between adjacent lanes

- The severity of crashes was mostly related to volume, rather than speed.

- Only 13 percent of the crashes were related to wet weather conditions

- They were able to predict types of crashes in terms of traffic volume but they could not predict crash rates

Of particular interest to the current research is their use of the difference between the 90^{th} and 50^{th} percentile speeds as a measure of variation.

2.22 Speed Cameras in England

In a study of work zone traffic management, Freeman et al (2004) reported on an analysis of various control measures and their effectiveness at reducing the number of personal injury (and fatality) crashes in work zones. They reported that one of these control measures, the use of speed cameras, had a positive impact on work zone crashes but that these cameras were associated with a higher crash risk in areas outside the work zones. They suggest (p. 42), "However it should be noted that it appears in general sites with speed cameras were chosen as they were thought to have a high accident risk." This may be a form of selection bias, in that due of the expense of installing speed cameras their use is reserved for areas that are experiencing above average crash risk. They did not report on the effectiveness of the cameras in these non-work areas, that is, if the addition of the cameras to high risk areas had had a positive impact on crash risk.

2.23 Conclusions

Over the course of the last 55 years there has been considerable effort expended in evaluating the relationship between speed and crash risk in a variety of roadway environments. Solomon concluded that it was the variation from the mean speed that presented greater crash risk, yet he did not control for factors such as turning vehicle crashes that would at least modify the shape of the curves he offered to demonstrate the risk. His estimates of the speed of crash involved vehicles was to some degree based on driver self-reporting (police reports provided other crash speeds); as noted by Muchuruza and Mussa even official crash reports appeared to be skewed to the left (toward lower speeds) when compared to the measured speed distributions in the areas of the crashes.

A number of researchers examined the change in crashes following the repeal of the national maximum speed limit of 55 mph, with varied conclusions. Chang and Paniati found no statistically significant change attributable to the speed limit change. Lave and Elias, while noting an increase in crashes on interstate highways found that for states that raised the speed limits on interstate highways there was a decrease in crashes overall (considering all highways in the states). Raju et al concluded that an increase in fatal crashes in Iowa was due to the change to a speed limit of 65-mph on rural interstate highways. Muniandi found a significant increase in crash risk with increases in speed dispersion on rural interstate highways in Iowa, following the institution of a 65-mph speed limit on those highways. An examination of fatal crash rate data (taken from the Iowa Safety Management System report for 2002) for the period (Figure 3) shows that this finding may be due to variations in the data. It appears that there was a general long-term downward trend in the fatal crash rates for the rural interstates as well as for the state as a whole. For the three years preceding the change in speed limit the fatal rate on the interstates was low and this may have impacted their findings. It does appear that the rate of decline in the statewide fatal crashes rates was less following the change in speed limits and that the crash rates on the rural interstates flattened out. These data do seem to indicate that speed is related to crash risk, although as discussed by Kloeden et al (1997) it would be difficult to separate speed *per se* from variations in the speed distribution.

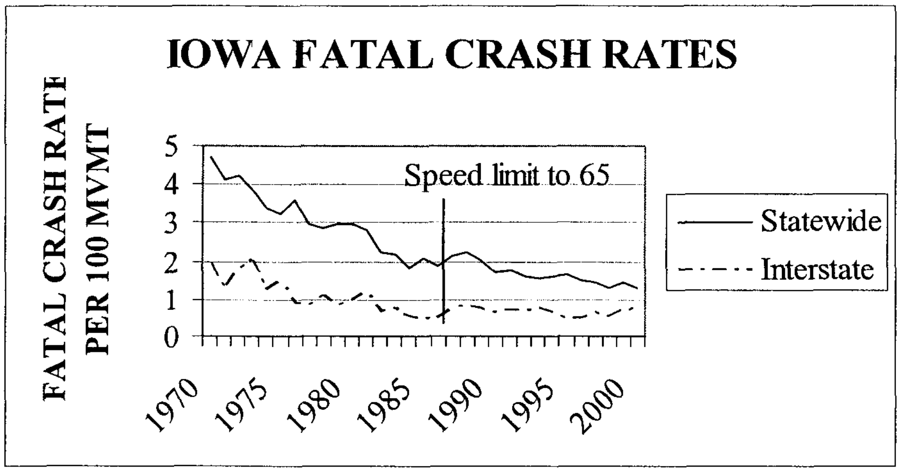

Figure 3 Iowa Fatal Crash Rates Over Time

There is a broad although not necessarily universal agreement among the researchers cited that there is a relationship between some element of speed and crash risk. Some of the researchers have tied crash risk to a broadly defined variation from mean speed (Solomon, Cirillo, e.g.) while others (Kloeden et al) have tied crash risk to absolute speed. There have been efforts to tie the change in the interstate speed limit from 55 mph to 65 mph to crash risk (Muniandi, Raju et al, Lave & Elias, e.g.) with somewhat varying results. In none of these cases was there an analysis of vehicle speeds and how they varied with changes in the speed limits. It may well be that the increased crash risk could be related to an increase in the variation of the speeds, as some drivers increase their speed more than other drivers after the speed limit is raised. The methods used have ranged from extensive interviews with drivers to statistical analyses based on aggregated data over wide geographic areas. Less common was any discussion of possible factors that would influence risk, only Kloeden et al (2002) discussed possible factors that could influence crash risk and they appear to have been the only ones that controlled for such factors as alcohol impairment. Some cases cited were narrowly based (West and Dunn 1971, for example) or used broad extrapolations of speed measures (Solomon 1964, for example). The need exists to examine a broad range of locations and roadway types, using speed data specific to each type and limited to representative sections. There is also a need to examine a wide variety of speed metrics (statistical and other measures of the variations in the speed distributions), in order to determine what if any of these metrics is related in a statistically significant manner to crash risk.

3 STUDY METHODOLOGY

The purpose of this study was to develop and evaluate a methodology for quantifying the relationship between vehicular speed and crash risk, utilizing available data sources. The process has involved a number of tasks, described in more detail in the balance of this chapter. The first task was to identify and locate the sites of the automatic traffic recorders (ATR) that capture speed data. The next task was to identify roadway sections, develop criteria for selecting study segments, and select appropriate study sections. Following a meeting with staff from the Iowa DOT's Office of Transportation Data, the next task involved the collection of six years of data (1998-2003) on six compact disks. Other data collection involved the acquisition of FHWA data regarding Vehicle Miles of Travel for 1950 and 2000; census data from the Census Bureau and the American Community Surveys of 1980, 1990, and 2000; and crash rate summaries from the Iowa DOT. The next major task was the processing and analysis of the speed data, utilizing Visual Basic code to assemble data and calculate descriptive statistics such as the mean speed, 85th percentile speed, and standard deviation and variance of the speed distributions. The processing and analysis of crash data, obtained from the Iowa DOT crash data bases, and selected using ArcGIS. The first step in the process was to develop an ArcGIS model with the Iowa DOT statewide road data base, a database containing the identification and geographic coordinates of the ATR's, and that portion of the DOT crash records containing time and date information covering the same time frame as the speed data. Roadway sections of interest were identified using the criteria described above to select homogeneous sections. Finally, statistical analyses were conducted on the case hour vs. control hour data. The case hour is the hour immediately prior to the hour in which the crash occurred and the control hour is the same hour but one week earlier. Using SAS, statistical evaluations were made of the relationships between the speed profiles in the roadway sections and the risk of crash involvement.

3.1 ATR Site Identification and Road Segmentation

The process of selecting candidate roadway segments was relatively straightforward. The latitude and longitude data for each ATR, provided by the Iowa DOT, were transformed to state plane coordinates within the Arc Map software. These transformed data were utilized to locate the ATR stations on the state road data base. One criticism of Solomon's work, raised by several of the later researchers, is exemplified by the comment of Kloeden et al (p. 10), "It is difficult to comprehend how speeds measured at one location can be considered to be adequately representative of speeds on road sections up to 91 miles in length." In order to minimize potential speed differences that might arise from using roadway segments that were too long, a restrictive procedure was used to select the candidate segments. Using the Iowa state road and aerial photographic bases, adjacent sections were evaluated visually to determine their homogeneity with the ATR sections in terms of the following criteria:

- Uniformity of access
- Type of development
- The presence of major alignment changes
- The presence of rail or highway crossings.

Uniformity of the speed limits was also a factor in selecting adjacent sections. On interstate highways and other freeways, homogeneous sections were established between the immediately adjacent interchanges on either side of the ATR. In other cases, the homogeneous sections were taken as bounded by a change in speed limit, by a change in the through traffic volume on the main line roadway as reported in the statewide road data base, by the location of a crossroad with traffic volume (as determined by the DOT listing of segment AADT) greater than ten percent of the traffic volume on the study section, or by a crossroad with more than a single crash recorded during the study period. Figure 4 presents the ATR locations in the context of Iowa's major state highways; appendix D contains a summary table of all the speed-related ATR's, with capsule descriptions.

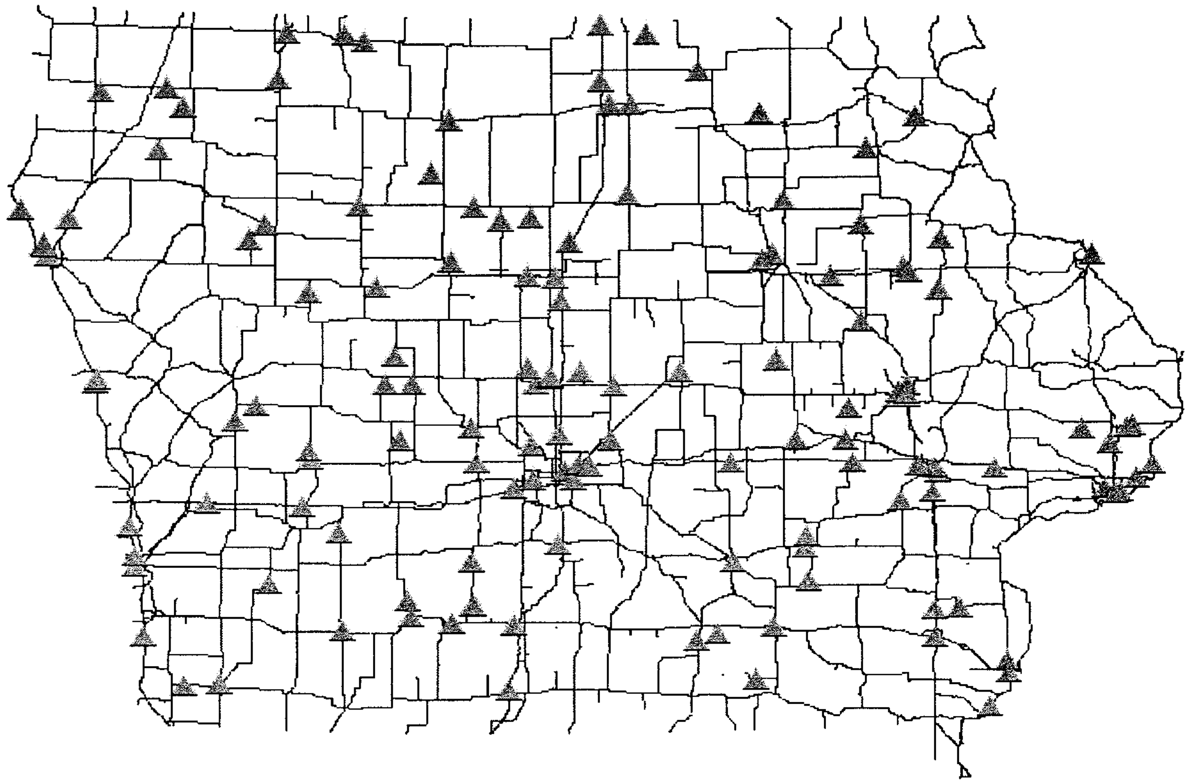

Figure 4 Iowa ATR sites on State Road Network

3.2 Crash Data Collection

Crashes within each selected segment were selected utilizing the Iowa DOT's crash data base and the State Road data base with the ESRI ArcMap software. Selected crashes for each location were exported as data base files for the analysis of the speed data. These files (generally one per year per ATR) were combined into a single data base with the roadway information from the DOT's State Road Database, the several crash data files, and a summary sheet combining all of the crash data.

3.3 Speed Data Collection

Raw speed data were provided by the Iowa Department of Transportation Office of Transportation Data, covering the years 1998 through 2003 with minor gaps. These data were provided on compact disks, with one disk per year. Each disk contains one folder per month with each folder containing from 4,000 to 7,000 files. In a typical month more than 2,000 of these files contain speed data (the balance are index files or vehicle classification data). The overall number of files is about 420,000; Figure 5 is a representation of the file structure and size.

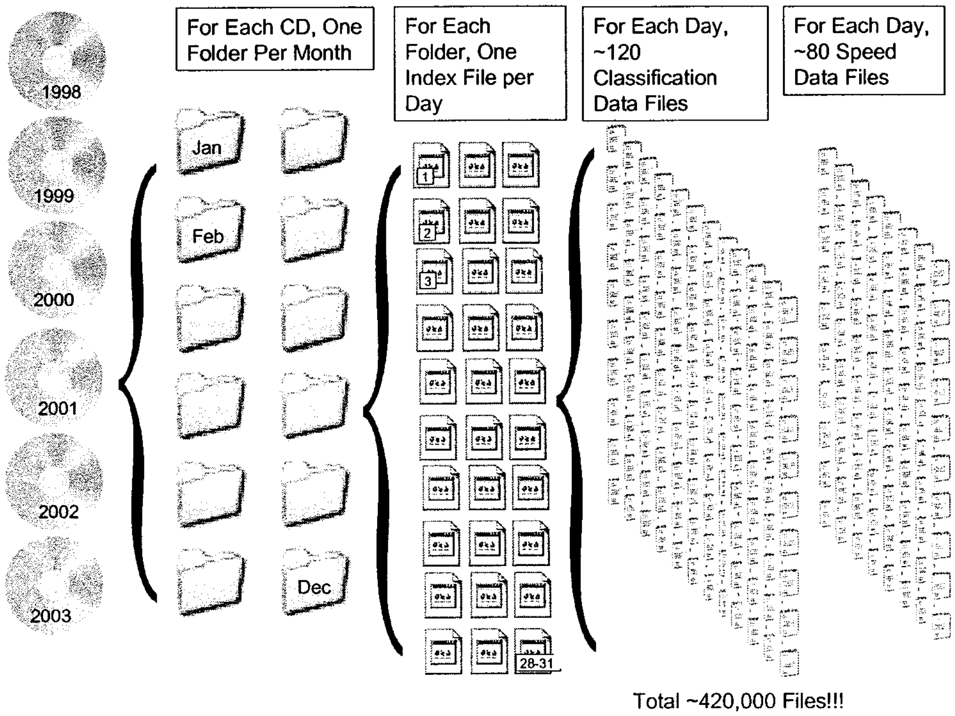

Figure 5 The file management problem

The initial processing of the desired speed data from these files began with opening the space-delimited index file for the appropriate date and then visually identifying the appropriate data file. In the sample shown (Figure 6) ATR 100 is identified as being on files 3 and 4 for March 1, 2000. The first (D0301003.PRN) is the vehicle classification file and the second (D0301004.PRN) is the speed data file.

```
D0301001.PRN 000000002400 000000002400 01 030100 0000 030100 2400
D0301002.PRN 000000002400 000000002400 01 030100 0000 030100 2400
D0301003.PRN 000000001000 000000001000 01 030100 0000 030100 2400
D0301004.PRN 000000001000 000000001000 01 030100 0000 030100 2400
D0301005.PRN 000000001020 000000001020 01 030100 0000 030100 2400
D0301006.PRN 000000001020 000000001020 01 030100 0000 030100 2400
D0301007.PRN 000000001030 000000001030 01 030100 0000 030100 2400
D0301008.PRN 000000001040 000000001040 01 030100 0000 030100 2400
D0301009.PRN 000000001040 000000001040 01 030100 0000 030100 2400
D0301010.PRN 000000001050 000000001050 01 030100 0000 030100 2400
D0301011.PRN 000000001050 000000001050 01 030100 0000 030100 2400
D0301012.PRN 000000001060 000000001060 01 030100 0000 030100 2400
D0301013.PRN 000000001060 000000001060 01 030100 0000 030100 2400
D0301014.PRN 000000001090 000000001090 01 030100 0000 030100 2400
D0301015.PRN 000000001090 000000001090 01 030100 0000 030100 2400
D0301016.PRN 000000001110 000000001110 01 030100 0000 030100 2400
D0301017.PRN 000000001110 000000001110 01 030100 0000 030100 2400
D0301018.PRN 000000001130 000000001130 01 030100 0000 030100 2400
D0301019.PRN 000000001130 000000001130 01 030100 0000 030100 2400
D0301020.PRN 000000001150 000000001150 01 030100 0000 030100 2400
D0301021.PRN 000000001150 000000001150 01 030100 0000 030100 2400
D0301022.PRN 000000001160 000000001160 01 030100 0000 030100 2400
D0301023.PRN 000000001160 000000001160 01 030100 0000 030100 2400
D0301024.PRN 000000001173 000000001173 01 030100 0000 030100 0300
D0301025.PRN 000000001173 000000001173 01 030100 0000 030100 0300
D0301026.PRN 000000001177 000000001177 01 030100 0000 030100 2400
D0301027.PRN 000000001177 000000001177 01 030100 0000 030100 2400
D0301028.PRN 000000001180 000000001180 01 030100 0000 030100 2400
D0301029.PRN 000000002010 000000002010 01 030100 0000 030100 2400
D0301030.PRN 000000002010 000000002010 01 030100 0000 030100 2400
D0301031.PRN 000000002020 000000002020 01 030100 0000 030100 2400
D0301032.PRN 000000002020 000000002020 01 030100 0000 030100 2400
D0301033.PRN 000000002030 000000002030 01 030100 0000 030100 2400
D0301034.PRN 000000002030 000000002030 01 030100 0000 030100 2400
D0301035.PRN 000000002060 000000002060 01 030100 0000 030100 2400
D0301036.PRN 000000002060 000000002060 01 030100 0000 030100 2400
D0301037.PRN 000000002070 000000002070 01 030100 0000 030100 2400
D0301038.PRN 000000002070 000000002070 01 030100 0000 030100 2400
D0301039.PRN 000000002090 000000002090 01 030100 0000 030100 2400
D0301040.PRN 000000002090 000000002090 01 030100 0000 030100 2400
D0301041.PRN 000000002100 000000002100 01 030100 0000 030100 2400
D0301042.PRN 000000002100 000000002100 01 030100 0000 030100 2400
```

Figure 6 Sample Index File

Each speed data file contains two, three or four rows of data per hour, consisting of one row for each lane of through traffic (roads with more than four lanes use one ATR for each direction of travel). Figure 7 presents a sample speed data file, again for March 1, 2000. The first three rows contain identification data including the location, time, and date. The fourth line contains the column headings for the speed bins with each bin being five miles per hour wide. The speed for each bin as listed is the maximum speed assigned to the bin; for the purposes of this paper the mid-point of the speed range within each bin is used. The first bin represents speeds 40 mph and lower; the "mid-point" of this bin was taken as 37.5 mph. Similarly, the last bin represents speeds from 85 to 147 mph; the "mid-point" of this bin was taken as 87.5 mph. These are a simplification but due to the generally small proportion of vehicles in these bins should not significantly impact the mean speed. The desired data file was then opened as a space-delimited text file and then the descriptive statistics for the desired hour were computed. These statistics are the mean speed, the 85th percentile speed, the dispersion (difference between the 85th percentile speed and the mean speed), the standard deviation of the speed distribution, the departure, the variance, and the volume. For each crash these values were computed for the "case" (or study) hour, the hour ending immediately before the hour in which the crash occurred, and the control hour, the same hour of the day one week earlier. The case hour was used because it was thought that speed during the hour in which the crash happened would reflect the presence of the crash and not the immediate pre-crash conditions. The control hour one week earlier was chosen to reflect conditions that were representative of a normal, non-crash flow regime.

```
000000001000 000000001000 01 0000 030100 2400 030100 0060 04 4 100    102  300
0000 0000 0000 0000 0000 0000 0000 0000 0000 0022XXXX 'FHWA-ADR
'HONEY CREEK          '78                    'I 29 4.8 KM N OF S JCT I 680
03 11        0040 0045 0050 0055 0060 0065 0070 0075 0080 0085 0147
01 04        0001 0002 0003 0004
00 00
01 01 0 0100 0000 0000 0000 0002 0007 0019 0048 0033 0003 0003 0000
01 02 0 0100 0000 0000 0000 0000 0000 0002 0002 0003 0000 0000 0000
01 03 2 0100 0000 0000 0000 0000 0000 0000 0001 0001 0001 0000 0001
01 04 2 0100 0000 0000 0000 0001 0002 0010 0029 0013 0005 0000 0000
01 01 0 0200 0000 0000 0000 0000 0001 0020 0021 0008 0003 0001 0000
01 02 0 0200 0000 0000 0000 0000 0000 0000 0001 0001 0001 0001 0000
01 03 2 0200 0000 0000 0000 0000 0000 0000 0001 0000 0001 0000 0001
01 04 2 0200 0000 0000 0000 0000 0001 0007 0023 0011 0000 0000 0001
01 01 0 0300 0000 0000 0000 0001 0004 0015 0025 0020 0003 0002 0000
01 02 0 0300 0000 0000 0000 0000 0000 0000 0003 0002 0001 0000 0000
01 03 2 0300 0000 0000 0000 0000 0000 0000 0001 0001 0000 0000 0000
01 04 2 0300 0000 0000 0000 0000 0003 0005 0027 0017 0006 0001 0001
01 01 0 0400 0000 0000 0000 0001 0003 0019 0023 0012 0003 0001 0000
01 02 0 0400 0000 0000 0000 0000 0000 0000 0002 0001 0000 0000 0000
01 03 2 0400 0000 0000 0000 0000 0000 0000 0000 0001 0001 0000 0000
01 04 2 0400 0000 0000 0000 0000 0005 0006 0034 0017 0004 0001 0001
01 01 0 0500 0000 0000 0000 0000 0003 0009 0025 0017 0004 0001 0000
01 02 0 0500 0000 0000 0000 0000 0000 0000 0000 0000 0001 0000 0000
01 03 2 0500 0000 0000 0000 0000 0000 0000 0003 0006 0001 0000 0000
01 04 2 0500 0000 0000 0001 0000 0005 0018 0042 0040 0005 0002 0000
01 01 0 0600 0000 0000 0000 0000 0005 0019 0049 0032 0007 0001 0000
01 02 0 0600 0000 0000 0000 0000 0000 0002 0003 0006 0000 0000 0000
01 03 2 0600 0000 0000 0000 0000 0000 0000 0013 0018 0002 0006 0000
01 04 2 0600 0000 0000 0000 0000 0009 0028 0078 0093 0021 0003 0001
01 01 0 0700 0000 0000 0000 0001 0004 0038 0094 0053 0014 0000 0000
01 02 0 0700 0000 0000 0000 0000 0000 0001 0005 0012 0002 0000 0000
01 03 2 0700 0000 0000 0000 0000 0000 0003 0043 0089 0063 0022 0002
01 04 2 0700 0000 0000 0000 0000 0012 0061 0237 0185 0056 0008 0002
01 01 0 0800 0000 0000 0000 0001 0004 0044 0135 0108 0032 0008 0000
01 02 0 0800 0000 0000 0000 0000 0000 0004 0016 0025 0008 0001 0000
01 03 2 0800 0000 0000 0000 0000 0000 0008 0034 0122 0060 0023 0006
01 04 2 0800 0001 0000 0000 0000 0009 0071 0216 0246 0064 0018 0004
01 01 0 0900 0000 0000 0000 0000 0013 0062 0158 0121 0021 0004 0001
01 02 0 0900 0000 0000 0000 0000 0001 0009 0030 0040 0003 0000 0001
```

Figure 7 Sample Speed Data File

The mean speed for any given period is calculated as follows:

- Multiply the "mid-point" speed of each bin by the number of vehicles in that bin.
- Sum the products of all the bin multiplications; then divide this sum by the total volume of traffic during the stated period to calculate the mean speed.

The standard deviation of the speed distribution is calculated as follows:

- Calculate the difference between the mean speed and the "mid-point" speed of each of the speed bins; square each of these differences.
- Multiply each of these squares by the count in the respective speed bin; sum these products.

- Divide the sum of the products by the total vehicle count during the period to get the variance of the speed distribution; take the square root of the variance to yield the standard deviation.

Because of the magnitude of the data processing required, a Visual Basic program was developed to calculate the mean speeds, volumes, and variances for the case hour and control hours. The program is set up to access the data base for each ATR that was created as described above. It utilizes the date and time information to find the appropriate data in the ATR data files, calculates the basic statistics for the study and control hours of each crash, and adds the results to the data base for the ATR. It also performs several error checks on the data, checking for anomalies such as missing data or problems with data collection. The data for each crash or control hour were combined into data bases by type of facility for further processing including analysis using the Statistical Analysis Software (SAS) package. Other Visual Basic programs were developed to compute the hour-by-hour and the day-by-day distributions of speeds at each ATR. Code for these programs is included in Appendix A. Typical problems identified include the following:

- All traffic in a single speed bin, indicating a malfunctioning loop
- A lane volume that exceeds the single lane capacity, indicating another type of loop malfunction

The 85th percentile speed was calculated using a simple routine as follows:

- Calculate the cumulative traffic volume for each bin, including all the traffic in preceding bins
- Multiply the total volume for the hour by .85
- Using simple logical functions, determine the two bins whose cumulative volumes bracket the volume calculated in the second step
- By simple proportions calculate the 85th percentile speed

The 85th percentile speed for each case or control hour was entered into the data base for each ATR; the speed dispersion was then calculated by subtracting the mean speed from the 85th percentile speed. The departure is calculated by subtracting the speed limit from the case hour 85th percentile speed. The calculations were performed within the SAS data bases for use in the SAS modeling and within the categorical data bases (freeway, expressway, etc.) for the general statistics.

3.4 Descriptive Statistics

An example of the descriptive statistics for a typical crash is presented in Table 1. These statistics were used to develop "box and whisker" plots as an aid to visualizing the differences between the case and control hours. Figure 8 presents a sample plot for the data in Table 1. As may be seen, for this example the mean speed (the line across the middle of the box) in the immediate pre-crash hour is lower than for the week before. Also the minimum speed (the lower "whisker") is somewhat lower and there is a greater spread between the 25 percent and 75 percent values (the lower and upper limits of the boxes, respectively).

Table 1 Descriptive Statistics Example for Box and Whisker Plot

	1 HOUR BEFORE	1 WEEK BEFORE
Mean	66.31	68.06
Std Dev	5.18	3.75
Median	67.76	68.97
Q1	65.88	67.39
Q3	69.20	69.87
Min	48.50	53.33
Max	71.04	72.69
25th Pct	65.88	67.39
50th Pct	1.88	1.57
75th Pct	1.44	0.90

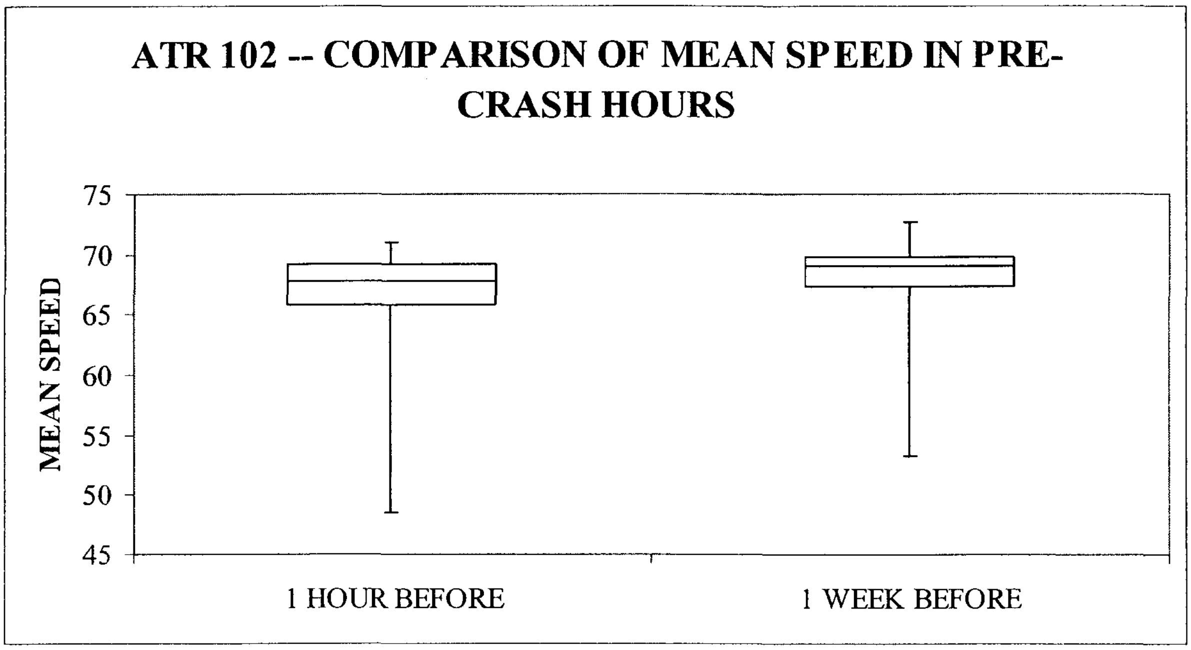

Figure 8 Sample Box and Whisker Plot for ATR Speed Data

3.5 F-Test of Two Distributions

The next step in the process was to compare the variances of the speed distributions for the case and control hours, using the F-test to determine if the differences were significant at the 95 percent confidence level (one-tailed test at 0.025). Because most tables for the F-test have no detail beyond a degree of freedom of (typically) 120, an F-test calculator was used to obtain the "p" value for each pair of distributions. F-test comparisons were made on all crashes for which there were paired case-control hour speed data.

3.6 Correction for False Discovery

One of the problems identified in some statistical references is that of the false positive in the analysis of large data sets, sometimes referred to as the "data mining problem". It relates to the fact that in a single test of significance there may be, for example, a 0.95 probability of correctly rejecting the null hypothesis. If a number of tests are conducted with the same probability criterion for each there is a significant chance that there will be a false positive. That is, some of the tests might lead to incorrectly rejecting the null hypothesis. Using as an example a series of 20 tests, each with a 0.95 probability of supporting the null hypothesis, the possibility that none will be significant is 0.95^{20}, or a value of 0.35849. The possibility of having at least one false positive is the difference, 1-0.35849 = 0.64151.

In the current research the F-test has been applied to some 1,244 pairs of distributions. The one-tailed level-of-significance was taken as 0.025, equivalent to a 95 percent confidence interval. Applying the F-test to the data resulted in approximately 18 percent (218 cases) of the cases having a case hour distribution that was statistically different from the control hour distribution, i.e., rejecting the null hypothesis. The Benjamini-Hochberg False Discovery Rate (FDR) correction method was then applied to these data, resulting in a corrected rate of rejection of the null hypothesis of 13 percent (159 cases).

The application of the correction is relatively straightforward. When the analyses (including F-test) of all valid crash and speed data was complete, all of the "p" values were ranked in ascending order, and then the correction for each value was computed by dividing that value's rank by the total number of values. The correction was then multiplied by the original "p" value. The result is that the largest value of "p" is not changed and that the smallest values of "p" are changed the most. In the cusp region around a value of 0.025 the correction increased the P values by about 3 times. Therefore the equivalent "raw" significance level to remain valid was about 0.008 rather than 0.025.

3.7 Crash Models

The statistical tools of SAS were used to model the relationship between the dependent variable crash risk and several explanatory variables including the following:

- Mean speed
- Standard deviation of the speed distribution
- Variance (of the speed distribution)
- Speed dispersion (the difference between the case hour 85th percentile and mean speeds)

- Speed departure (the difference between the case hour 85th percentile speed and the speed limit)
- Ratio of the traffic volume to the reported average daily traffic (ADT)

The type of model selected for these analyses was the logistic regression model. Logistic regression modeling was chosen because the response variable – whether a crash occurs or not – is categorical. Categorical variables are those that represent conditions or states and often take only the values of 0 and 1. The dependent variable evaluated is the crash occurrence; since it can only take two values, 0 and 1 (there was no crash or there was a crash) it is necessary to use logistic regression. The use of linear regression assumes continuous response variables, and that the explanatory variables are additive would not be appropriate because it also requires that the error in response variables are normally distributed and homoscedastic. The variables listed above are the continuous explanatory variables; the following variables are the categorical explanatory variables that were included in the data input to the modeling software:

- Time of day. "T" which takes any one of four states depending on the time of day. "T" is equal to 1 if the case hour is between 7:00 and 9:00 AM, to 2 if the case hour is between 4:00 and 6:00 PM, 3 if the case hour is between 11:00 PM and 5:00 AM, and 0 otherwise.
- Week day or week end

The input files for the SAS modeling were prepared using the following steps:

- The individual ATR data bases were combined into a single data base for each type of facility
- Categorical variables were set for crash status, time of day (morning rush hour, evening rush hour, or late night), type of roadway (freeway, expressway, or undivided), and weekend
- Formatting changes were made to make the files consistent with the requirements for SAS input files

- The dispersion, departure, and hourly volume divided by the reported average daily traffic were entered

In logistic regression the model takes the following form:

$$\text{Ln}\ (P/(1-P)) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \qquad (3.1)$$

In this case the dependent variable "P" is the probability of a crash and the explanatory variables are the dispersion, the departure, and the volume to ADT ratio, respectively. It should be emphasized that the logistic regression modeling was conducted on two cases, with approximately equal numbers of each, the immediate pre-crash hour and the control hour one week earlier. The probability "P" that results from this modeling reflects the methodology used to conduct the modeling and not the actual probability of a crash's occurrence.

A sensitivity analysis was made of the logistic regression model results. This involved varying the value of one variable while holding the other variables at their respective average values (average for the type of facility).

An analysis was made of the relationship between the explanatory variables, to determine the extent of correlation. The multi-variate correlation method of the software package JMP was used for this evaluation. Table 2 presents the results of this analysis for the interstate highway segments.

Table 2 Multivariate Correlation Matrix for Interstate Highway Analysis Metrics

	casemean	controlmean	case85	control85	vol	casedep	controldep	disp
casemean	1.00	0.82	0.55	0.43	-0.25	0.55	0.43	-0.51
controlmean	0.82	1.00	0.34	0.57	0.00	0.34	0.57	-0.54
case85	0.55	0.34	1.00	0.79	-0.13	1.00	0.79	0.43
control85	0.43	0.57	0.79	1.00	0.10	0.79	1.00	0.35
vol	-0.25	0.00	-0.13	0.10	1.00	-0.13	0.10	0.13
casedep	0.55	0.34	1.00	0.79	-0.13	1.00	0.79	0.43
controldep	0.43	0.57	0.79	1.00	0.10	0.79	1.00	0.35
disp	-0.51	-0.54	0.43	0.35	0.13	0.43	0.35	1.00

The case and control departure are fully correlated to the case and control hour 85th percentile speeds, as would be expected since they are derived therefrom. The dispersion is somewhat correlated to the case and control hour departures, although it is more highly correlated to the crash density.

Table 3 presents the correlation matrix for the metrics of the expressway speed data. Unlike the interstate case, the dispersion is highly, albeit negatively, correlated to most of the explanatory variables. There is a positive correlation between the dispersion and the case hour volume. Most importantly, there is not a great degree of correlation between the dispersion and the case or control hour departures. To reiterate, the following defines the explanatory variables in the correlation matrices:

- Case and control means – the mean speed during the case or control hours, respectively
- Case and control 85 – the 85th percentile speed during the case or control hours, respectively
- Vol – the volume during the case hour
- Case and control dep – the difference between the 85th percentile speed and the speed limit during the case or control hours (departure)
- Disp – the case hour dispersion (difference between the 85th percentile and mean speeds)

Table 3 Multivariate Correlation Matrix for Expressway Analysis Metrics

	case mean	control mean	case85	control85	vol	casedep	controldep	disp
case mean	1.00							
control mean	0.95	1.00						
case85	0.99	0.91	1.00					
control85	0.95	1.00	0.92	1.00				
vol	-0.70	-0.78	-0.68	-0.78	1.00			
casedep	0.42	0.12	0.49	0.13	-0.12	1.00		
controldep	0.45	0.16	0.52	0.17	-0.21	1.00	1.00	
disp	-0.96	-0.98	-0.93	-0.97	0.71	-0.20	-0.24	1.00

Table 4 presents the correlation matrix for the non-interstate freeways. For these facilities there is a high degree of correlation between the dispersion and the departures; there are also significant negative correlations between the dispersion and the other explanatory variables.

Table 4 Multivariate Correlation Matrix for Freeway Analysis Metrics

	Case mean	Control mean	Case 85	Control 85	vol	Case dep	Control dep	disp
Case mean	1.00							
control mean	0.90	1.00						
case 85	0.97	0.80	1.00					
control 85	0.91	0.96	0.86	1.00				
vol	-0.82	-0.88	-0.68	-0.75	1.00			
case dep	-0.40	-0.68	-0.18	-0.51	0.75	1.00		
control dep	-0.66	-0.65	-0.52	-0.49	0.87	0.75	1.00	
disp	-0.73	-0.87	-0.54	-0.73	0.92	0.86	0.83	1.00

Table 5 presents the correlation matrix for the two-lane highway analysis variables.

Table 5 Multivariate Correlation Matrix for Two-Lane Highway Analysis Metrics

	Case mean	Control mean	Case 85	Control 85	vol	Case dep	Control dep	disp
case mean	1.00							
control mean	0.89	1.00						
case 85	0.89	0.77	1.00					
control 85	0.83	0.90	0.86	1.00				
vol	-0.27	-0.14	-0.40	-0.34	1.00			
case dep	0.89	0.77	1.00	0.86	-0.40	1.00		
control dep	0.83	0.90	0.86	1.00	-0.34	0.86	1.00	
disp	-0.05	-0.10	0.40	0.22	-0.34	0.40	0.22	1.00

In the case of the two-lane highways there is little correlation between the dispersion and the other explanatory variables. It is interesting to compare this matrix to the others; there is little consistency between the correlations on one type of facility to those on another.

4 RESULTS

As discussed in the methodology, analyses were made of the crash and speed data to include model evaluations of case vs. control hour speed metrics as well as sensitivity analyses of the resulting models, correlations between explanatory variables, and speed variations by time-of-day and day-of-year vs. crash count. The results of these analyses are presented in the following sections.

4.1 Speed as a function of time-of-day by roadway type

There is a difference of about 2.6 mph in the hourly mean speed for all interstate ATR's over the course of an average day, ranging from a minimum of 68.1 mph at 5:00 AM to a high of 70.7 mph from 4:00 to 7:00 PM. As expected, there are also variations between the lanes; the inner lanes (those next to the median) on the typical, 4-lane interstate highway average from 3.0 to 3.7 mph faster than the outer lanes. This difference between lane groups also varies throughout the day, ranging from a low of 2.1 mph between midnight and 6:00 AM to a high of 5.0 mph from 4:00 to 5:00 PM. See Figure 9 for a summary of speed by lane.

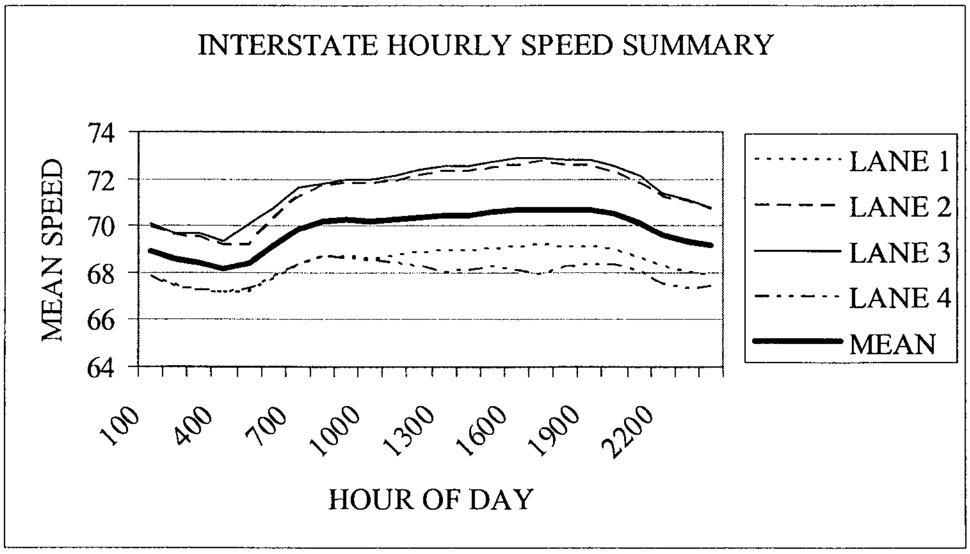

Figure 9 Interstate Highway Speed Summary by Time of Day

Figure 10 presents the crash frequency distribution for the interstate highways by time of day. Speed is found to explain 24 percent ($R^2 = 0.24$) of the variation in crash count when regressed by time of day.

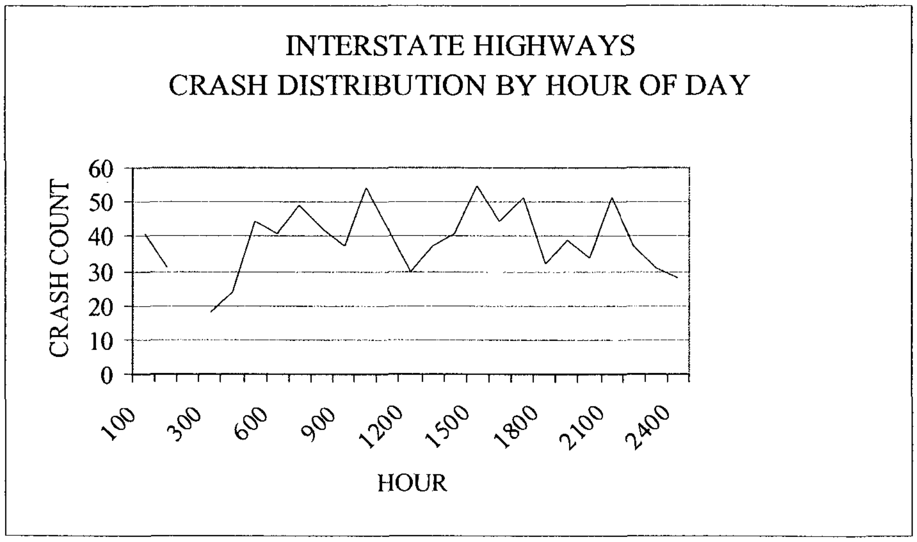

Figure 10 Interstate Highway Crashes by Time of Day

On freeways (speed limits less than 65 mph) there is a variation of about 3.1 mph in the average speed by hour of the day; the overall average speed is 68.6 mph. Between the hours of 3:00 to 7:00 PM the average speed was nearly 69.5 mph; the hours from 2:00 to 4:00 AM had an average speed of approximately 66.5 mph. As with the interstate highways, there is a noticeable difference in the speed distributions by lane with the maximum difference of 3.3 mph occurring in the afternoon from 2:00 to 4:00. Figure 11 presents a summary of the distribution of the mean speed by lane and time of day. Figure 12 presents the distribution of freeway crashes by time of day. Speed is found to explain 24 percent ($R^2 = 0.24$) of the variation in crash count when regressed by time of day. The time of the lowest frequency of crashes corresponds to the lowest mean speed, although this is typically also the time of lowest volume traffic which may influence the results.

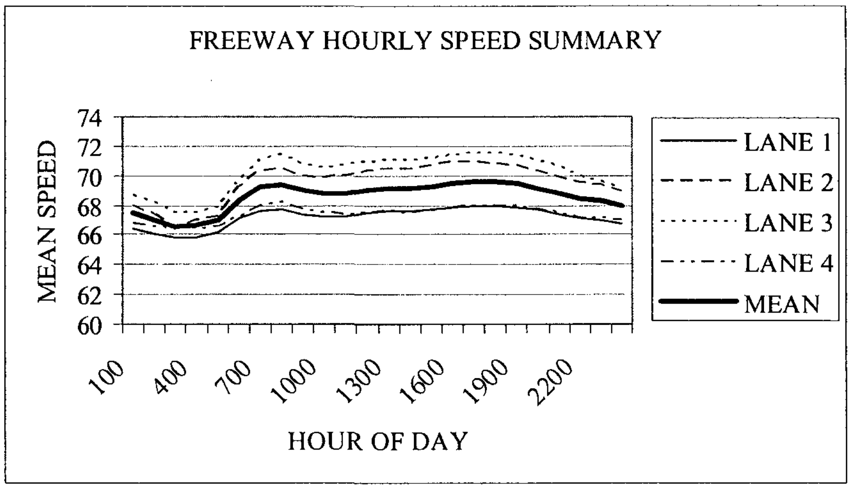

Figure 11 Freeway Speed Summary by Time of Day

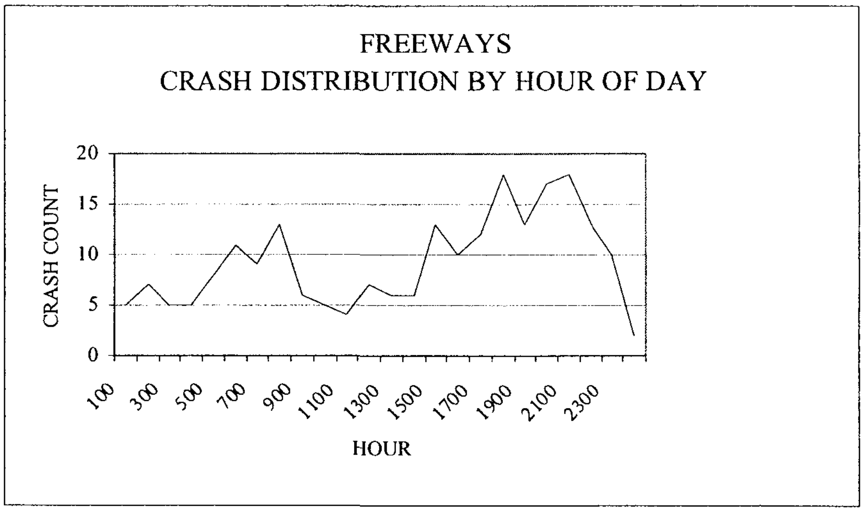

Figure 12 Freeway Crashes by Time of Day

The results of the expressway analyses are somewhat limited by the small number of expressway ATR sites with speed data, which total only five. For some reason all of the sites had the highest speeds in lane number 3, with the mean speed in lane 3 at nearly 68 mph. Lane 2, the other inside lane, had a mean speed of just over 63 mph, lower by 1.5 mph than the mean speed in its companion outside lane (number 1). These variations may be due to commuting or travel patterns, or random errors in the data. Figure 13 presents a summary of the speed distribution on the expressways by lane and time of day.

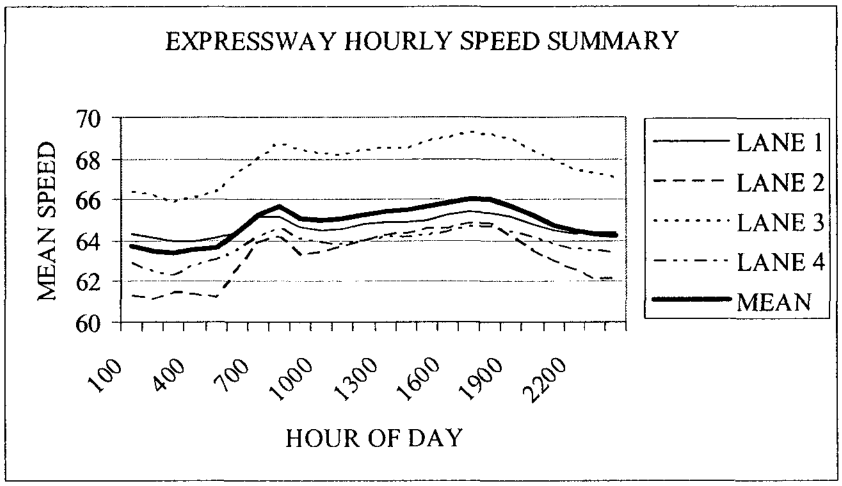

Figure 13 Expressway Speed Summary by Time of Day

Figure 14 presents the crash count by hour of the day. Speed is found to explain 32 percent ($R^2 = 0.32$) of the variation in crash count when regressed by time of day

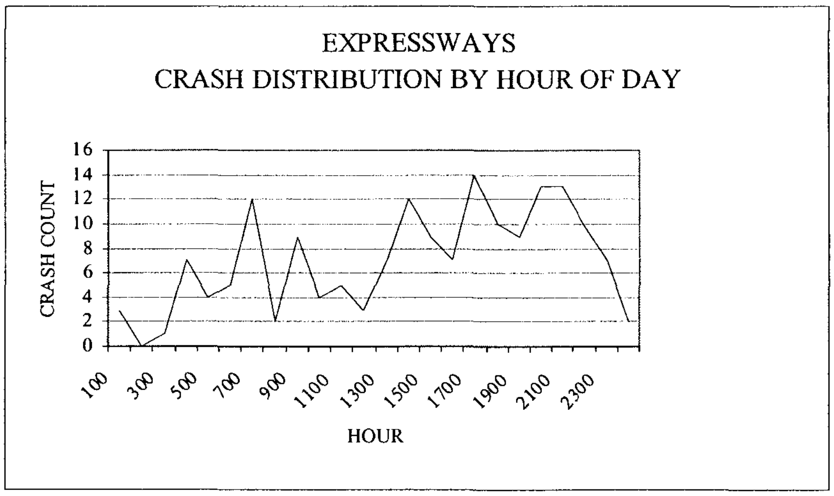

Figure 14 Expressway Crashes by Time of Day

The hourly mean speed for the two-lane highways reaches a peak of 59.9 mph at 4:00 AM and a minimum of 58.6 mph at 10:00 PM. There is not an obvious relationship between the mean speed and the crash frequency distributions, as seen on Figures 15 and 16, except that the period of highest speed corresponds to the time of day of the lowest crash frequency.

This may be due to a low volume of traffic than to the speed. Speed is found to explain only two percent ($R^2 = 0.02$) of the variation in crash count when regressed by time of day.

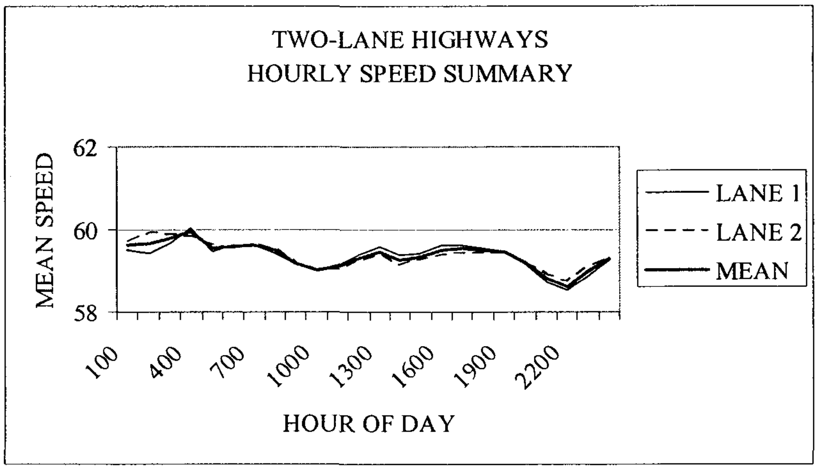

Figure 15 Two-Lane Highway Speed Summary by Time of Day

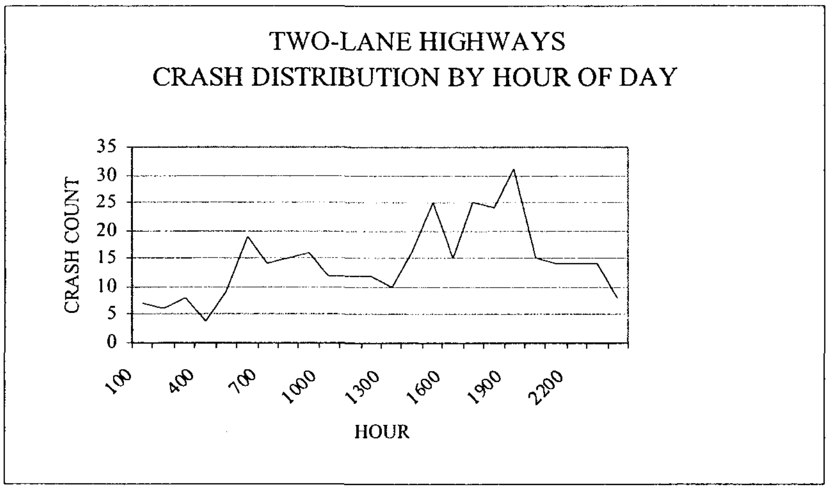

Figure 16 Two-Lane Highway Crashes by Time of Day

4.2 Speed as a function of day of year by roadway type

As was discussed above, on the interstate highways the mean speed varies between lanes when evaluated over the course of a day. As Figure 17 shows this pattern is also present throughout the year. The mean speed for the outer lanes is 68.7 mph while the mean speed for the inner lanes is 3.7 mph faster. There is also a seasonality to the daily mean speed, that is, the mean daily speeds tend to be slightly higher during the summer months. Possible explanations for this include the influence of weather (on winter travel) or vacation travel (related to higher volumes or to different travel purpose). There are two minima to the inner lane mean speeds that correspond roughly to the Labor Day and Thanksgiving Day holidays. At these times the lane differential nearly disappears.

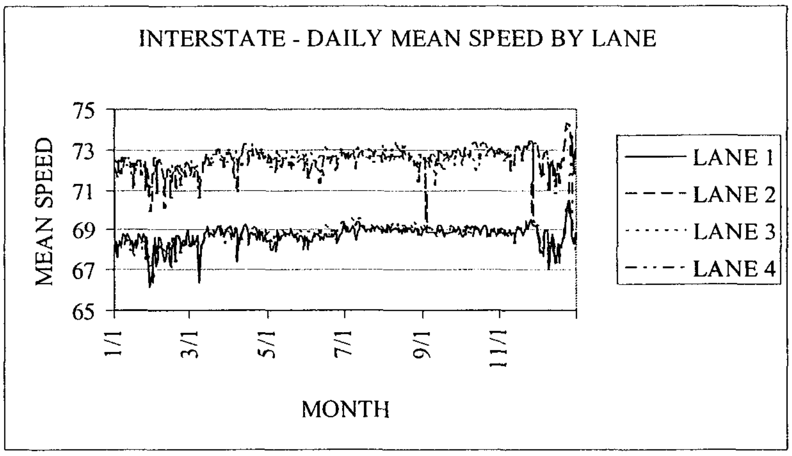

Figure 17 Interstate Highway Speed Summary by Day

Non-interstate freeways show a similar pattern to the interstates, with the inner lanes averaging about 3 mph faster than the 68 mph mean speed in the outer lanes. There appears to be more variation in the individual lane means, and a somewhat smaller difference between the inner and outer lane pairs. The daily variation of mean speed by lane is presented in Figure 18.

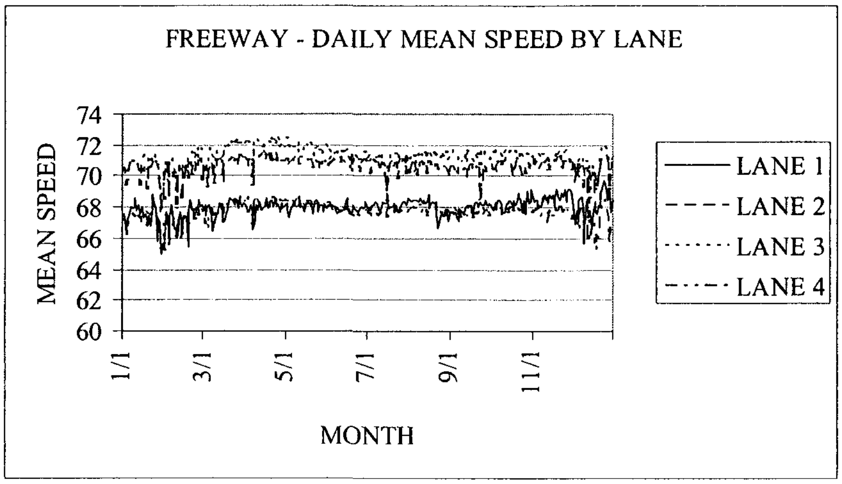

Figure 18 Freeway Speed Summary by Day

The expressways show a very different pattern, with Lane 3 having a mean speed of 68.4 mph, 3.7 mph higher than the other inner lane (Lane 2). Lanes 1 and 4 are very similar, with an identical mean speed of 61.9 mph. It should be noted that two of these five expressways have 55 mph speed limits (the other three are 65 mph). ATR 217, one of the two with a 55-mph speed limit and one with a very large difference between Lane 3 and the other lanes, has the highest crash rate and crash density observed on the expressways studied. Iowa DOT staff members have indicated that ATR 217 is not currently being used, because of problems with the ATR and its loops. However, none of the data for ATR 217 show any obvious problems that would dictate removing them from the study, although removing the ATR 217 data from the data base reduces the differential between lanes two and three. Figure 19 below presents the expressway mean speed by lane (data from ATR 217 included).

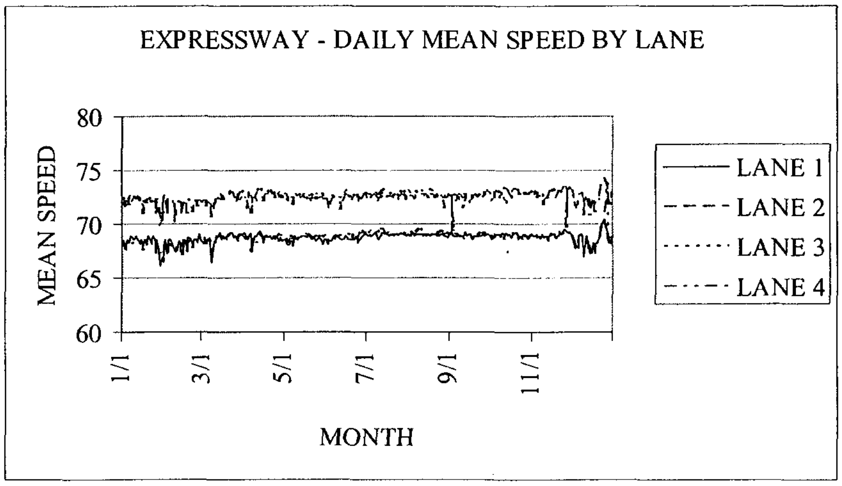

Figure 19 Expressway Speed Summary by Day

4.3 Correlation between dispersion and departure

Prior to developing the models, an evaluation was conducted to determine possible correlations between the candidate explanatory variables. It was expected that either dispersion or departure (or both) would be related to crash risk. If speed alone is the primary factor influencing crash risk then the expectation would be that the departure would be correlated to the crash risk. Conversely, if the variation in speeds between vehicles is the primary factor then the dispersion would be correlated to crash risk. Because the dispersion and departure are both speed related measures it was deemed important to evaluate the extent to which they are correlated. The use of correlated explanatory variables would violate the assumption of independence inherent in the regressions used. Using the hourly values of mean and 85th percentile speeds, which cover the entire six-year study period, average values of dispersion and departure were calculated for each ATR. The data were grouped by type and plotted, yielding Figures 20 through 23.

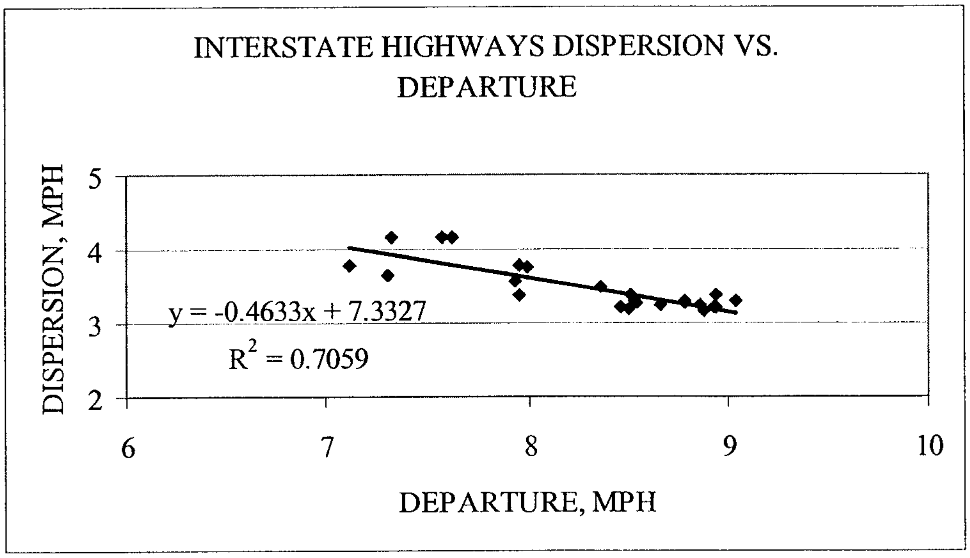

Figure 20 Dispersion vs. Departure Interstate Highways

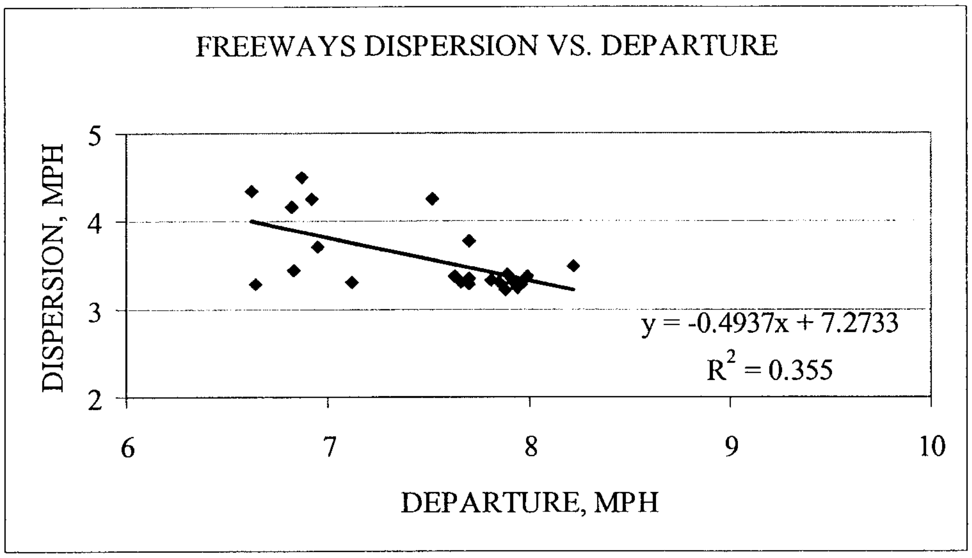

Figure 21 Dispersion vs. Departure Freeways

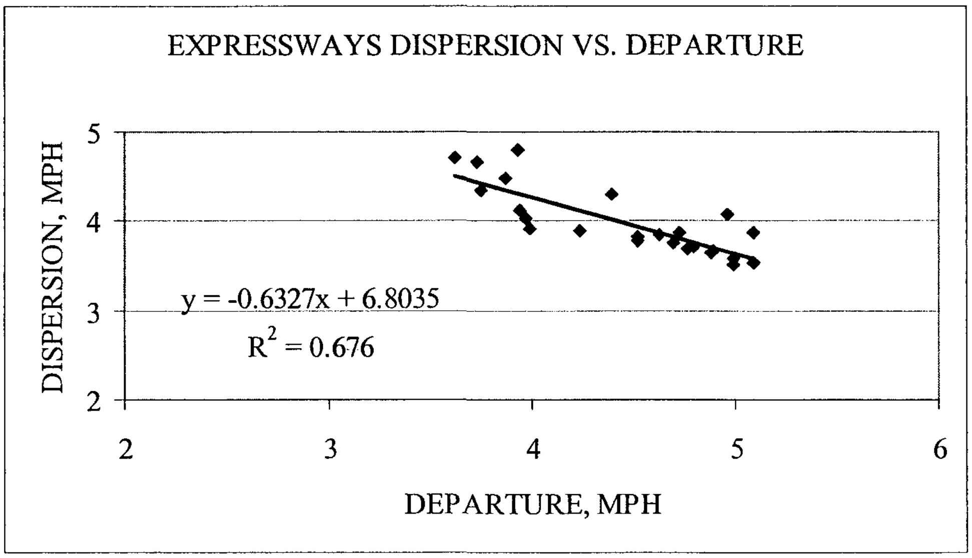

Figure 22 Dispersion vs. Departure Expressways

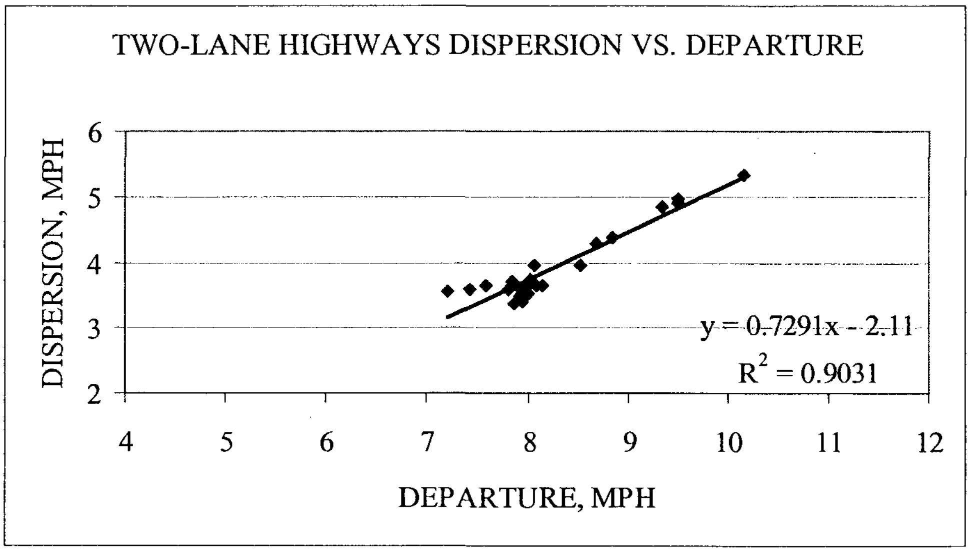

Figure 23 Dispersion vs. Departure Two-Lane Highways

There is a significant level of correlation between the dispersion and the departure, with the degree of correlation being dependent on the type of facility. It is an interesting, if not unexpected, observation that the slope of the regression line for the two-lane highways is positive, versus the negative slope on all of the facilities with four lanes. This is likely an artifact of the nature of driving on two-lane roads, with their sometimes limited passing opportunities.

4.4 Evaluation of standard deviation of speed distributions

An analysis was conducted of the standard deviations of the case hour and control hour speed distributions for each category of ATR site. The case hour is the hour ending immediately prior to the time of the crash and the control hour is exactly one week earlier than the case hour.

4.4.1 Interstate Highways

The case hour speed distributions on the interstate highways (defined as rural, with 65mph speed limits) had a mean standard deviation of 6.12 mph *versus* 5.96 mph for the control hour speed distributions. The standard deviations of these standard deviations were 1.31 and 1.12, respectively. Figure 24 presents a box and whisker plot summarizing this comparison.

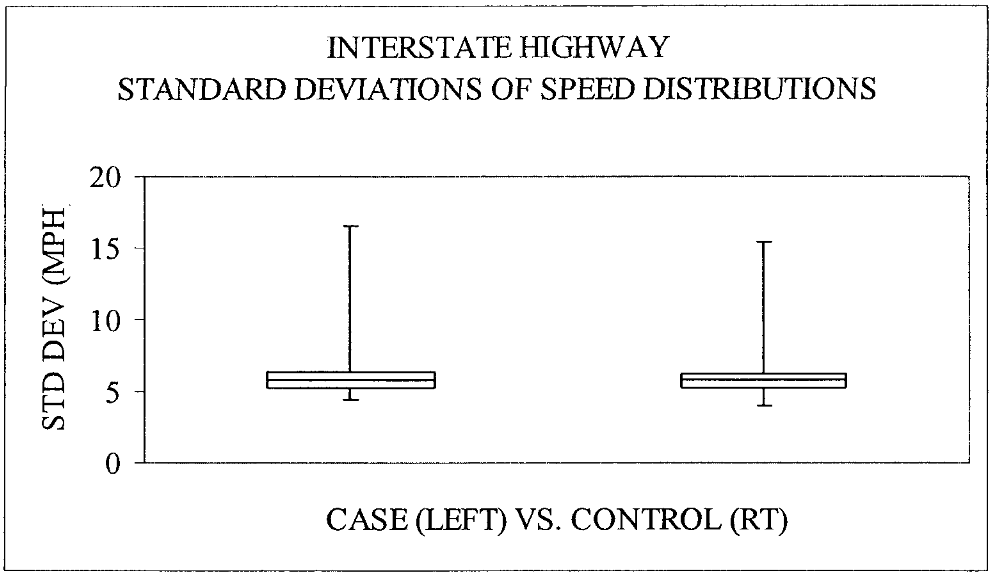

Figure 24 Box and Whisker Plot of Interstate Highway Standard Deviations

4.4.2 Freeways

The case hour speed distributions on the freeways (non-interstates as well as interstates with speed limits less than 65 mph) had a mean standard deviation of 6.36 mph *versus* 6.28 mph for the control hour speed distributions. The standard deviations of these standard deviations were 1.70 and 1.54, respectively. Figure 25 presents a box and whisker plot summarizing the analyses of these standard deviations.

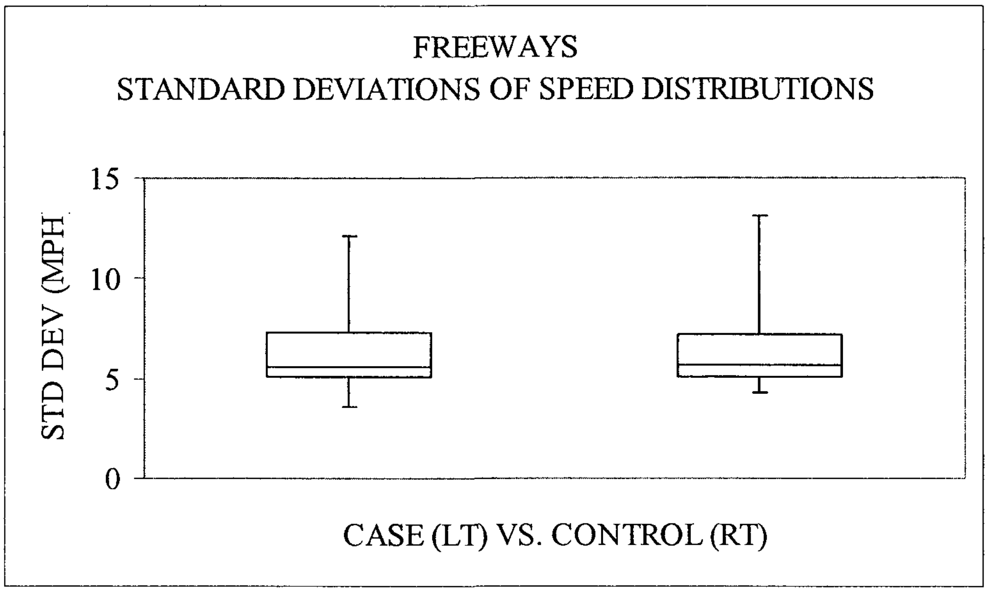

Figure 25 Box and Whisker Plot of Freeway Standard Deviations

4.4.3 Expressways

The case hour speed distributions on the expressways had a mean standard deviation of 6.93 mph *versus* 6.89 mph for the control hour speed distributions. The standard deviations of these standard deviations were 2.05 and 1.87, respectively. Figure 26 presents a box and whisker plot summarizing the analyses of these standard deviations.

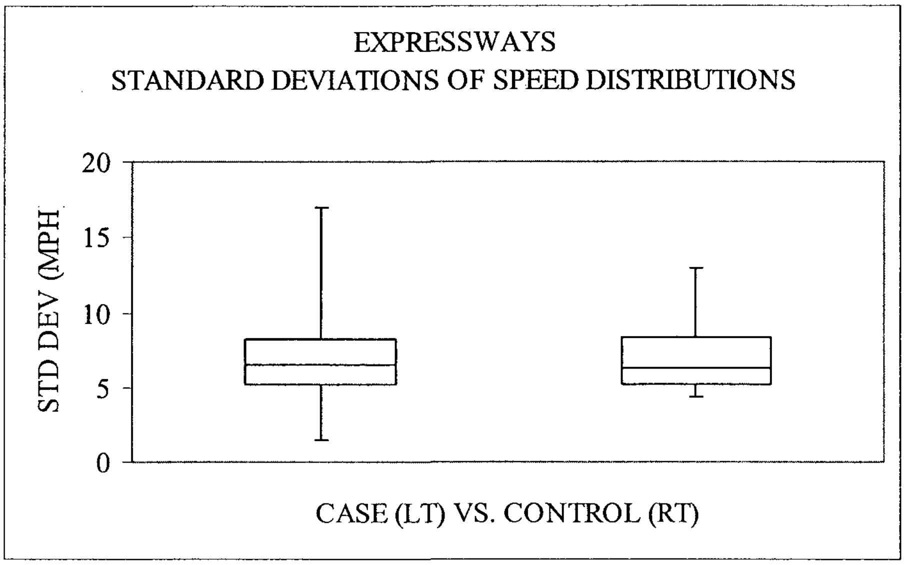

Figure 26 Box and Whisker Plot of Expressway Standard Deviations

4.4.4 Two-lane highways

The case hour speed distributions for the two-lane highways had a mean standard deviation of 6.14 mph *versus* 6.21 mph for the control hour speed distributions. The standard deviations of these standard deviations were 1.26 and 1.43, respectively. Figure 27 presents a box and whisker plot summarizing the analyses of these standard deviations.

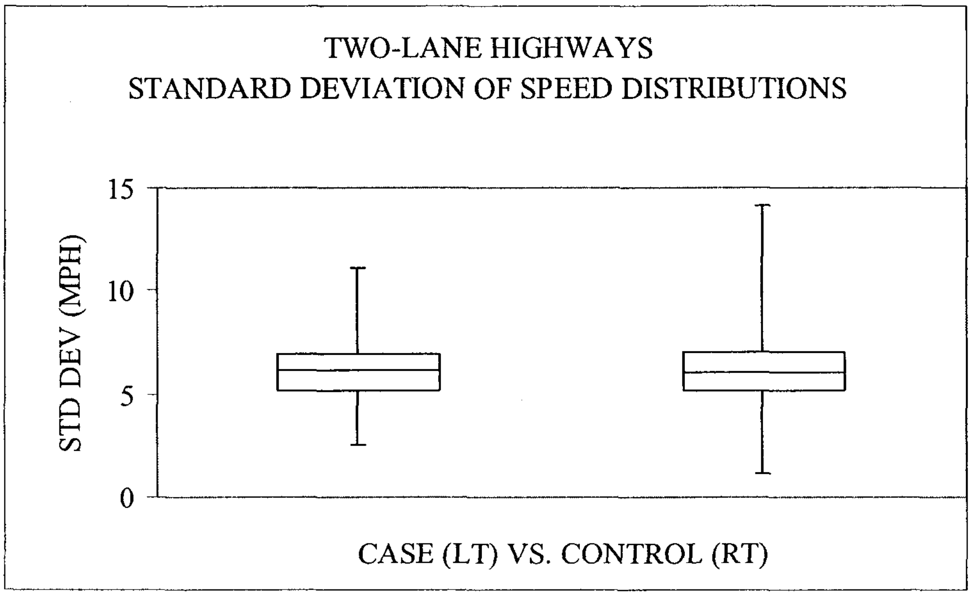

Figure 27 Box and Whisker Plot of Two-Lane Highways' Standard Deviations

4.5 Crash risk vs. speed and volume measures

A number of possible correlations were evaluated for the different roadway types. Various explanatory variables, listed in the modeling subsection below, were compared to the crash rate (crashes per million vehicle miles) and crash density (crashes per mile per year). Models were examined for all of the comparison plots and the key findings are summarized in the following paragraphs.

4.5.1 Interstate highways

For the interstate highways the most significant model with regard to crash risk was the crash density *versus* overall average departure (the departure considering all of the data, not just the crash data). Figure 28 plots this relationship. Models for Figures 28 through 44 were developed using the statistical software package JMP.

The model and R^2 values for the data plotted in Figure 28 show a relatively strong relationship. The form of the model is similar to that found by Solomon, that is, concave upward. The polynomial (2^{nd} order) model calculated for these data had an R^2 of 0.56. The model is strongly influenced by the data from ATR 117 (I-80 east of the east system interchange near Des Moines). With the values for ATR 117 included the mean of the crash density is 1.68, while with it removed the mean is 1.25. The standard deviation of the crash density is 1.68 with ATR 117 included and just 0.56 with it removed. The effect of the removal of ATR 117 from the analysis changes the R^2 of the model from 0.56 to 0.33. The crash density vs. the case hour departure showed no significant model with ATR 117. When the ATR 117 data are removed the model becomes somewhat significant with an $R^2 = 0.39$.

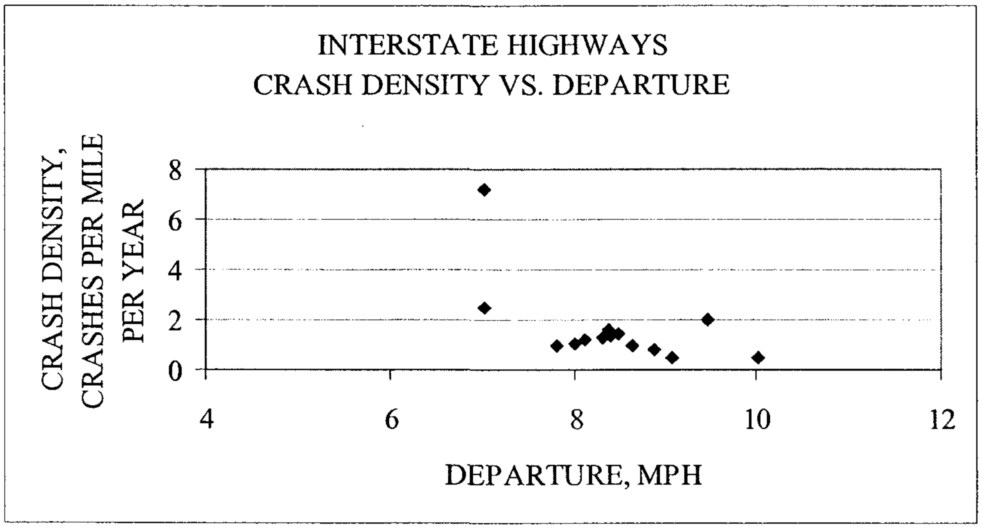

Figure 28 Interstate Highway Crash Density vs. Overall Average Departure

Figure 29 presents the scatter plot for the crash rate *versus* the case hour departure. The model had an R^2 of 0.22.

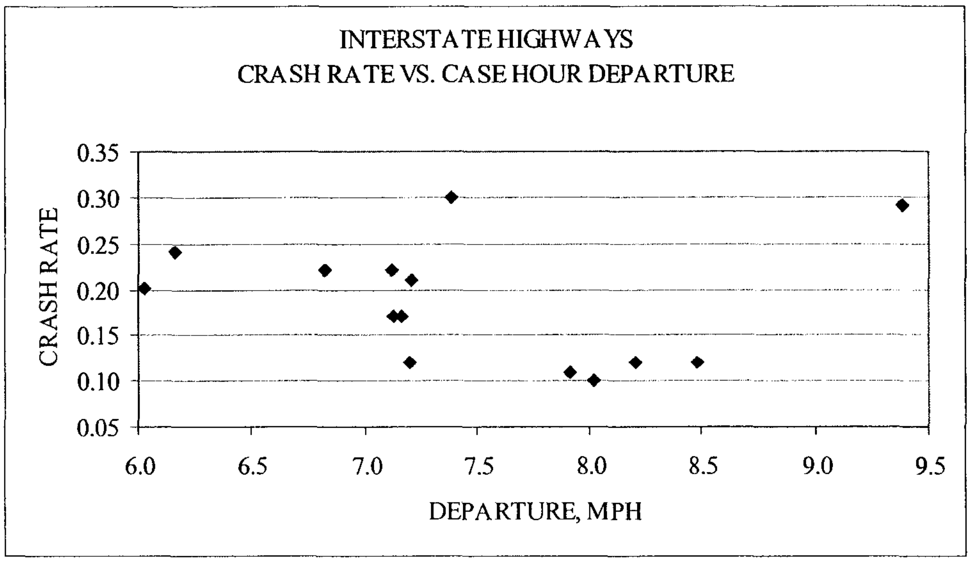

Figure 29 Interstate Highway Crash Rate vs. Case Hour Departure

The model of crash density versus the case hour dispersion shows a significant relationship. The R^2 coefficient was 0.4852. Figure 30 presents the scatter plot of this comparison. Equation 4.1 presents the regression equation for the model, which reduces to equation 4.2.

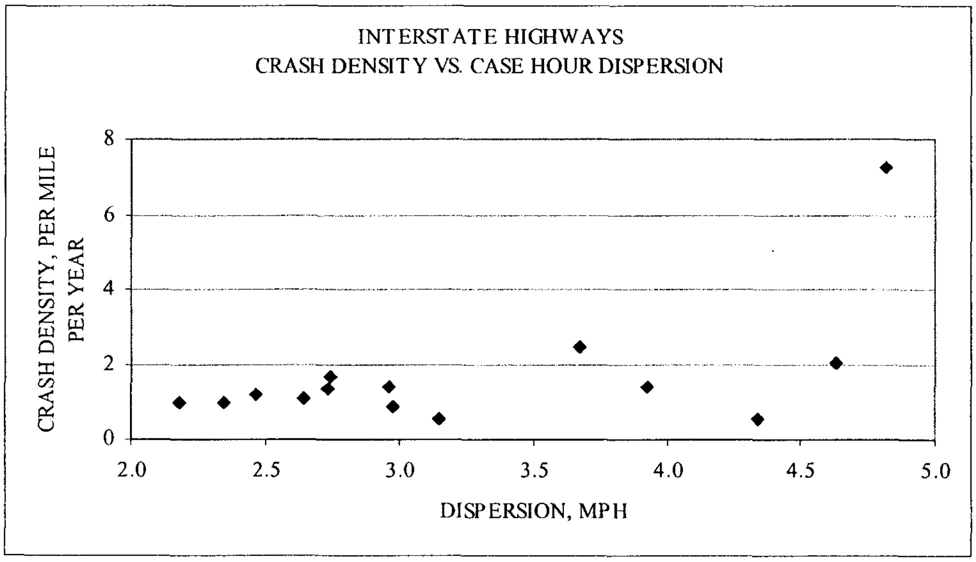

Figure 30 Interstate Highway Crash Density vs. Case Hour Dispersion

$$498y = 1.1603409\ (x - 3.25589)^2 + 0.511577\ x - 0.802576 \qquad (4.1)$$

$$y = 1.1603\ x^2 - 7.0443\ x + 11. \tag{4.2}$$

Figure 31 presents the scatter plot of the comparison of the crash rate to the case hour dispersion. The model had an R^2 of 0.388. Equation 4.3 is the model equation as returned by JMP, it reduces to equation 4.4.

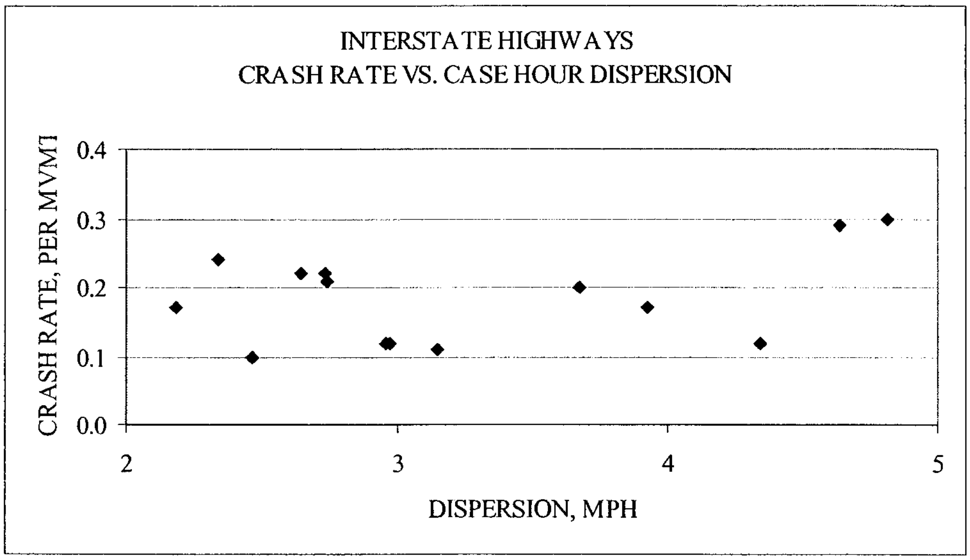

Figure 31 Interstate Highway Crash Rate vs. Case Hour Dispersion

$$y = 0.0564\ (x - 3.25571)^2 - 0.0006148\ x + 0.14732 \tag{4.3}$$

$$y = 0.0569\ x^2 - 0.3714\ x + 0.7513 \tag{4.4}$$

The analysis found little correlation between the crash density and the case hour speed departure. Figure 32 presents the scatter plot of these data.

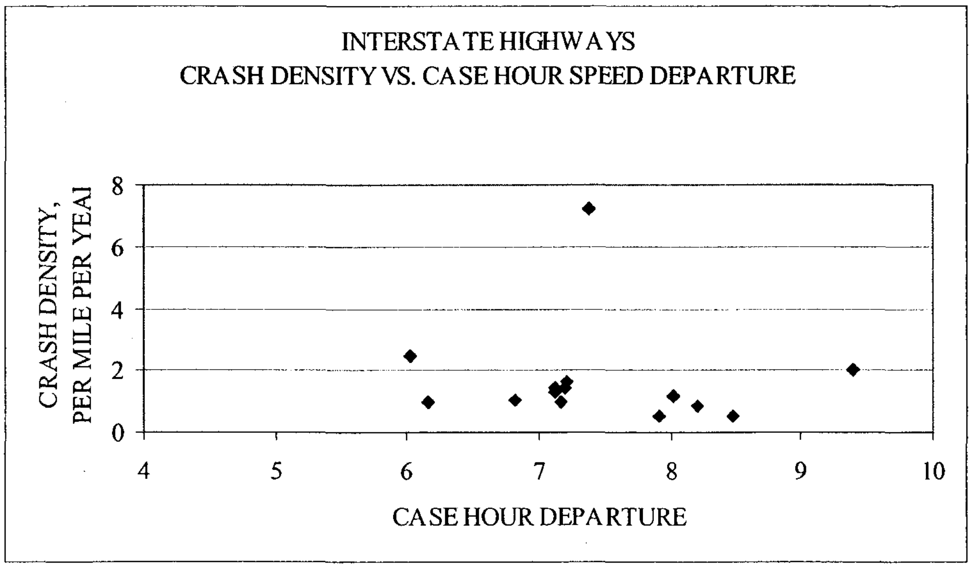

Figure 32 Interstate Highway Crash Density vs. Case Hour Departure

It should be noted that all of these study segments are in areas with a 65-mph speed limit; two interstate highways in areas with lower speed limits are evaluated in the freeways' category because it is expected that these facilities have been designed using a lower design speed.

4.5.2 Freeways

Statistical analyses of the freeway data found significant relationships between the crash density and both the dispersion and the departure (both case hour). The crash density vs. departure, shown in Figure 33, showed an R^2 coefficient of 0.84. Equation 4.5 presents the model equation from the JMP regression which reduces to the form shown in Equation 4.6:

$$y = 0.1654665\,(x-6.24333)^2 + 0.973713\,x - 3.207252 \qquad (4.5)$$

$$y = 0.1654\,x^2 - 1.0926\,x + 3.2451 \qquad (4.6)$$

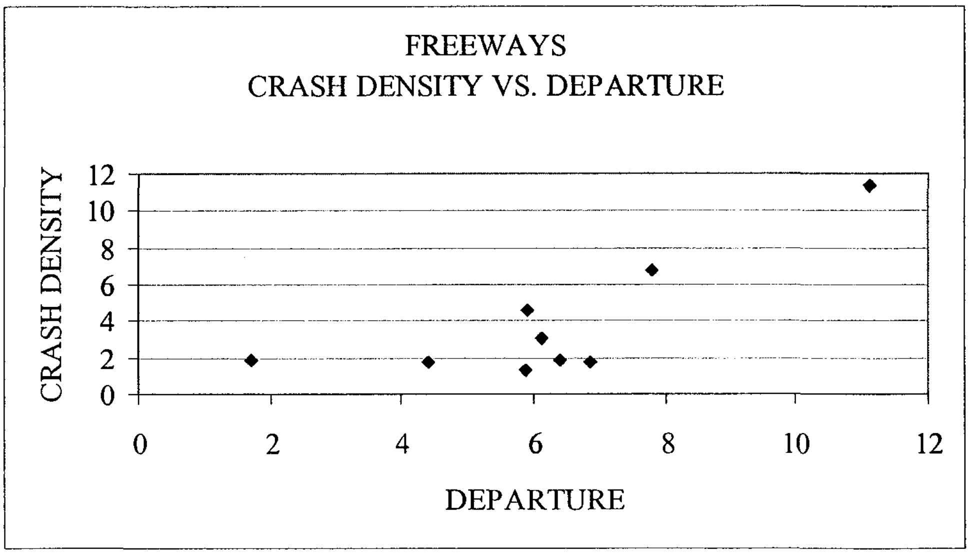

Figure 33 Freeway Crash Density vs. Case Hour Departure

The results of the regression on the crash rate *versus* the case hour speed departure showed no correlation. The JMP analysis returned a 2nd order polynomial regression model with an R^2 value = 0.049. Figure 34 presents the scatter plot of these data.

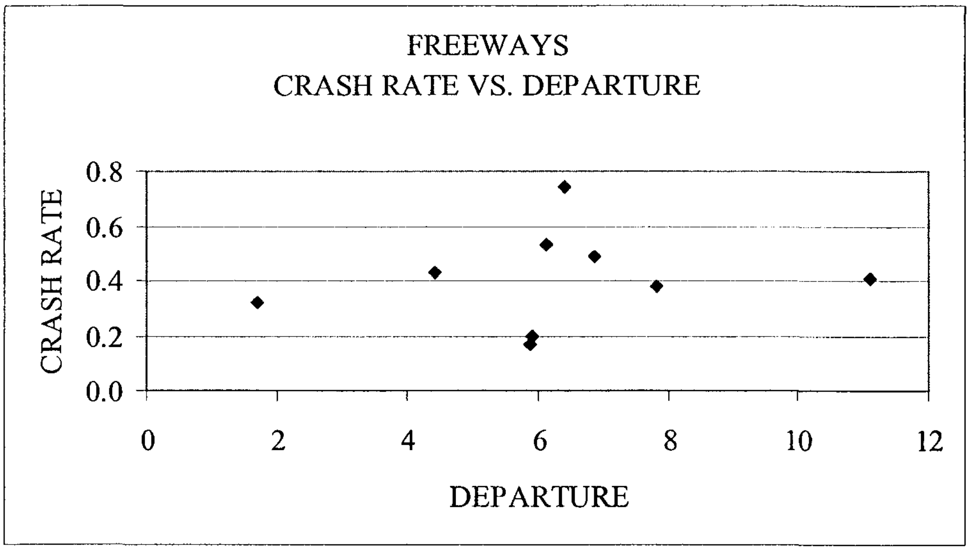

Figure 34 Freeway Crash Rate vs. Case Hour Departure

The crash density *versus* case hour dispersion analysis showed a strong correlation, with the 2nd order polynomial model having an R^2 equal to 0.925. Figure 35 presents the scatter plot of the analysis data. Equation 4.7 presents the model equation from the JMP regression which reduces to the form shown in equation 4.8.

$$y = 0.4552337(x - 3.53)^2 + 2.0784969\,x - 4.086517 \qquad (4.7)$$

$$y = 0.4516\,x^2 - 1.1077\,x + 1.5387 \qquad (4.8)$$

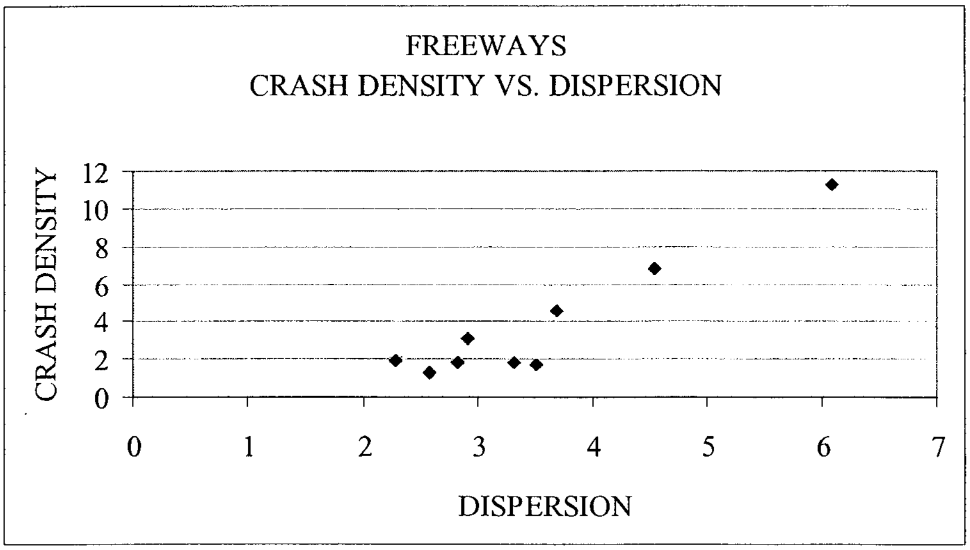

Figure 35 Freeway Crash Density vs. Case Hour Dispersion

The linear regression of the crash rate *versus* the case hour dispersion showed no correlation, with an $R^2 = 0.0004$ on a linear model. Figure 36 presents the scatter plot of the crash rate vs. dispersion data.

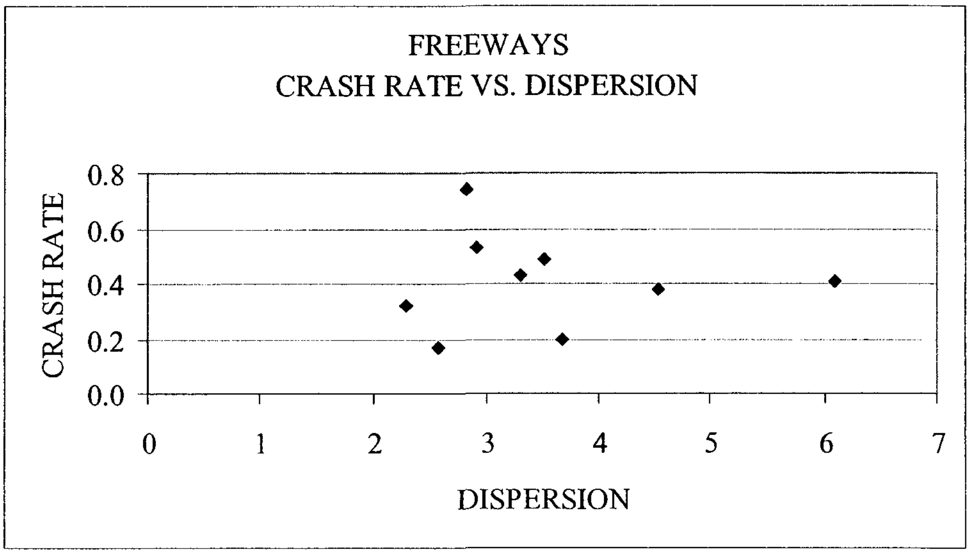

Figure 36 Freeway Crash Rate vs. Case Hour Dispersion

4.5.3 Expressways

The results of the analysis of the crash density *versus* the case hour departure yielded a model with little correlation. The scatter plot of these data is presented as Figure 37. The R^2 value was equal to 0.0426. No model equations are presented.

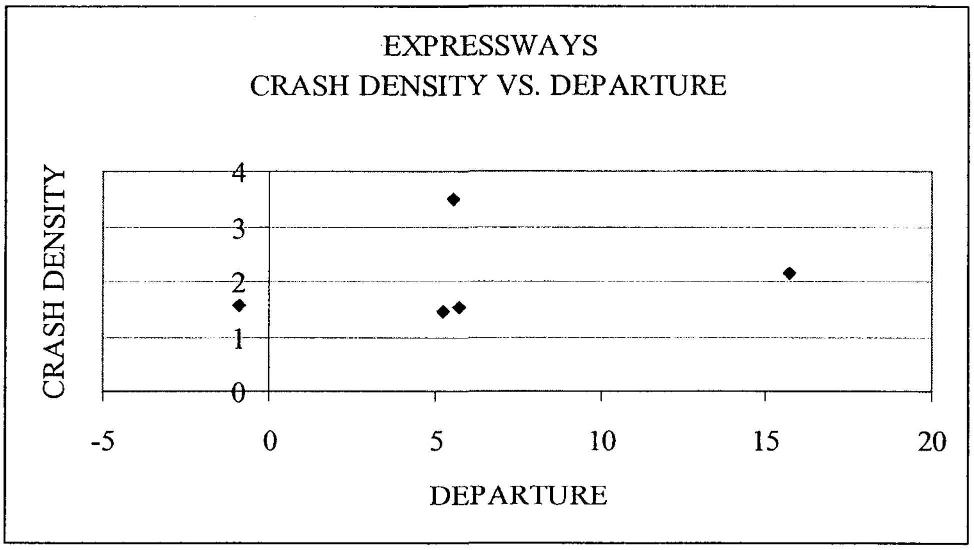

Figure 37 Expressway Crash Density vs.Case Hour Departure

The evaluation of the crash rate *versus* the <u>case hour</u> departure returned a linear model with an R^2 of 0.417. The scatter plot of these data is presented in Figure 38. Equation 4.7 presents the model equation.

$$y = 0.01204\ x + 0.456509 \qquad (4.9)$$

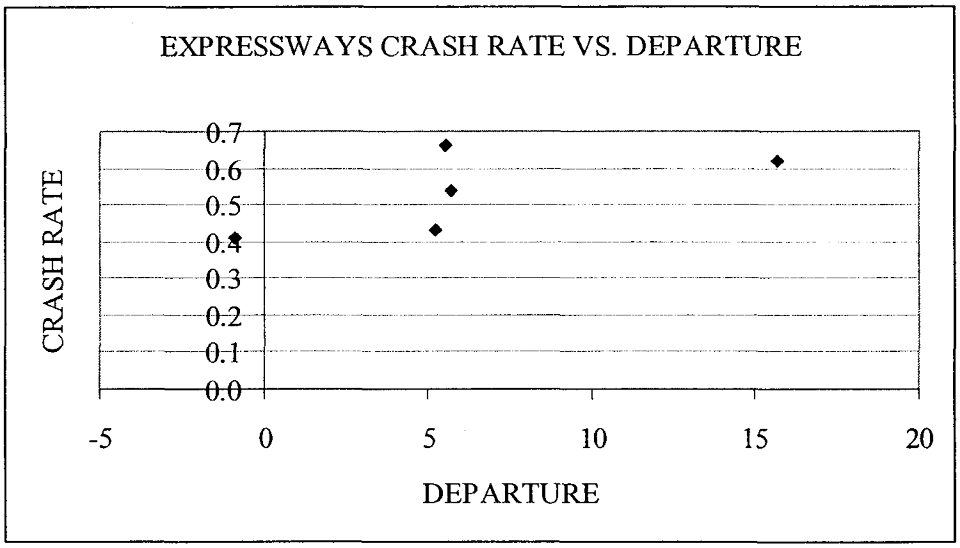

Figure 38 Expressway Crash Rate vs. Case Hour Departure

The crash density *versus* <u>case hour</u> dispersion showed an R^2 of 0.857 on the polynomial model. Figure 39 presents the scatter plot of the data evaluated. Equation 4.10 presents the model equation which reduces to the form shown as equation 4.11.

$$y = 0.128411\ (x - 4.61)^2 + 0.302259\ x + 0.3314007 \qquad (4.10)$$

$$y = 0.1288\ x^2 - 0.8851\ x + 3.0679 \qquad (4.11)$$

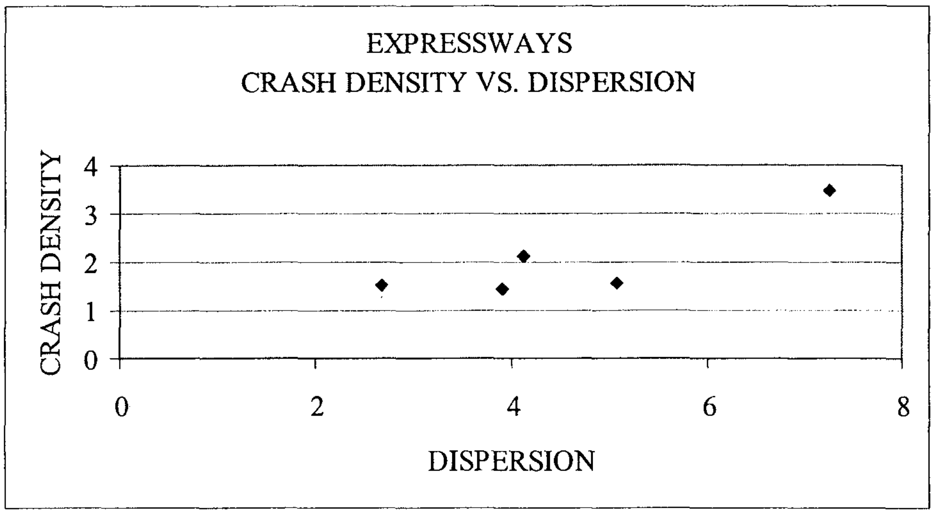

Figure 39 Expressway Crash Density vs. Case Hour Dispersion

The evaluation of the crash rate *versus* case hour dispersion showed an R^2 value of 0.426 on a 2nd order polynomial model. Figure 40 presents the scatter plot of these data. Equation 4.12 presents the model equation which reduces to the form shown in equation 4.13.

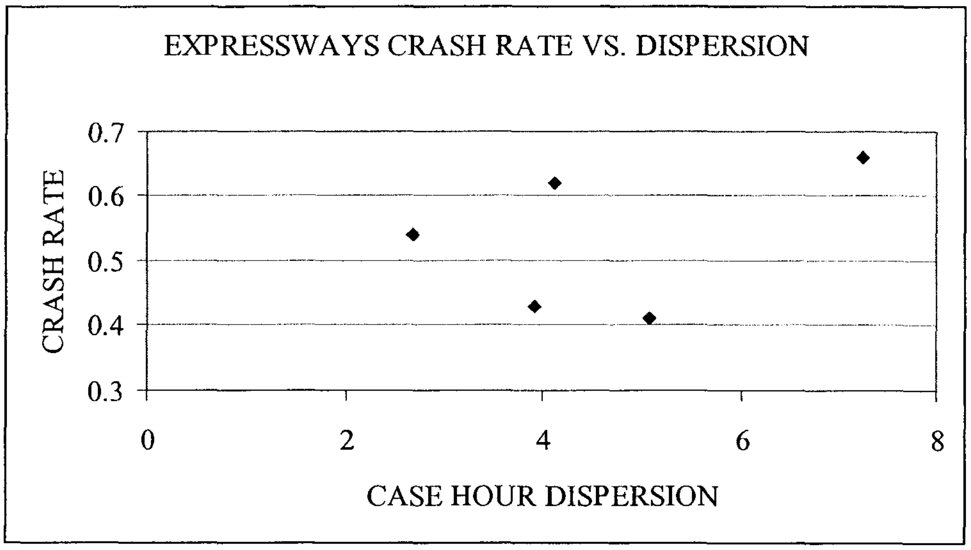

Figure 40 Expressway Crash Rate vs. Case Hour Dispersion

$$y = 0.0228644\,(x - 4.61)^2 + 0.0038321\,x + 0.4607059 \qquad (4.12)$$

$$y = 0.023\,x^2 - 0.208\,x + 0.949 \qquad (4.13)$$

It should be recognized that due to the small number of expressways sites, the statistical foundation is not particularly strong for arguing any conclusions from these results.

4.5.4 Two-Lane Highways

The analysis of the crash density *versus* case hour departure for the two-lane highways found a weak correlation, with an R^2 of about 0.223 for a polynomial model. Equation 4.14 presents the model from the JMP regression, which reduces to the form shown in equation 4.15. Figure 41 presents the scatter plot of the data.

$$y = -0.0110029 (x - 7.75909)^2 - 0.1371806 x + 1.8836334 \quad (4.14)$$

$$y = -0.0063 x^2 - 0.045 x + 1.5256 \quad (4.15)$$

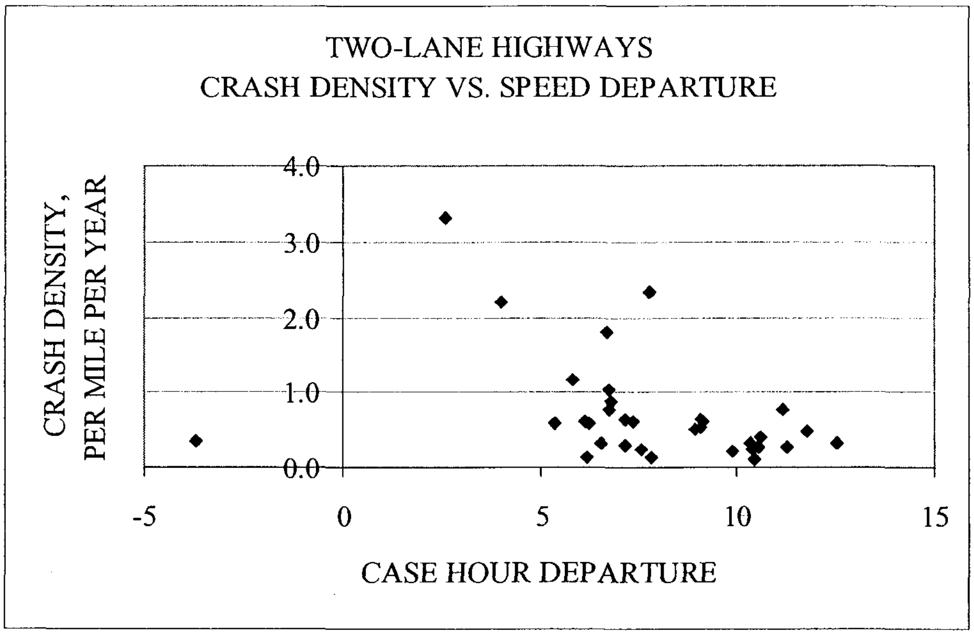

Figure 41 Two-Lane Highways Crash Density vs. Case Hour Speed Departure

The analysis of the crash rate *versus* case hour speed departure found a weak correlation, with an R^2 of 0.1633 for a polynomial model. Equation 4.16 presents the model from the JMP regressions, which reduces to the form shown in equation 4.17 respectively. Figure 42 presents the scatter plot of the data.

$$y = 0.0094525\,(x - 7.75909)^2 - 0.0195665\,x + 0.9896329 \qquad (4.16)$$

$$y = 0.0094525\,x^2 - 15.53775\,x + 61.19311 \qquad (4.17)$$

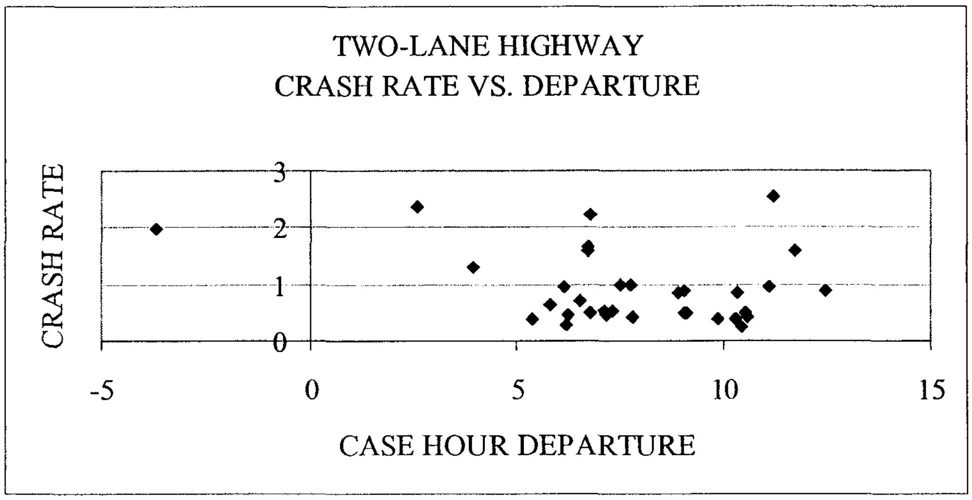

Figure 42 Two-Lane Highway Crash Rate vs. Case Hour Speed Departure

The analysis of the crash density *versus* case hour dispersion found essentially no correlation; the R^2 values ranged from 0.03 to 0.05 for linear to second order polynomial models. No model equations were developed. Figure 43 shows the scatter plot for these data.

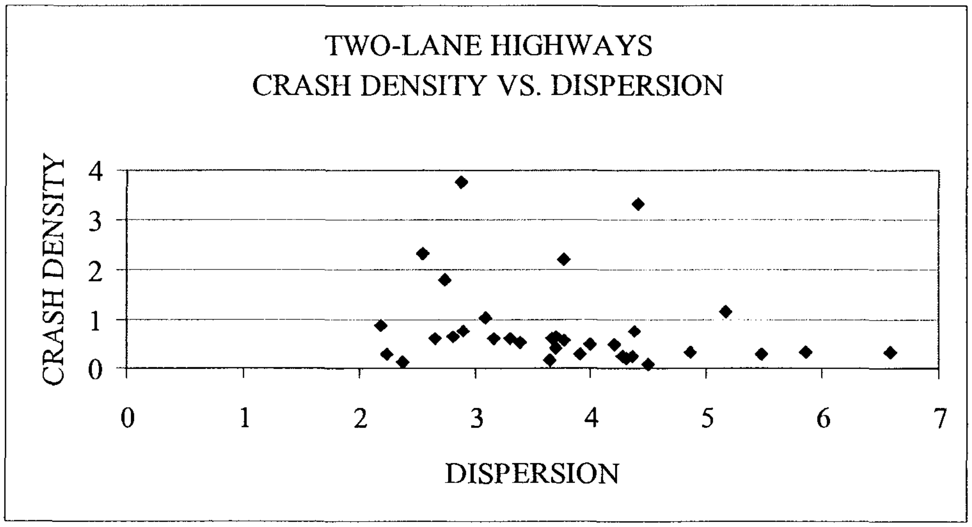

Figure 43 Two-Lane Highways Crash Density vs. Case Hour Dispersion

The analysis of the crash rate *versus* the case hour dispersion found no correlation, with the JMP linear model having an R^2 of 0.002. No equations are presented. Figure 44 presents the scatter plot of these data.

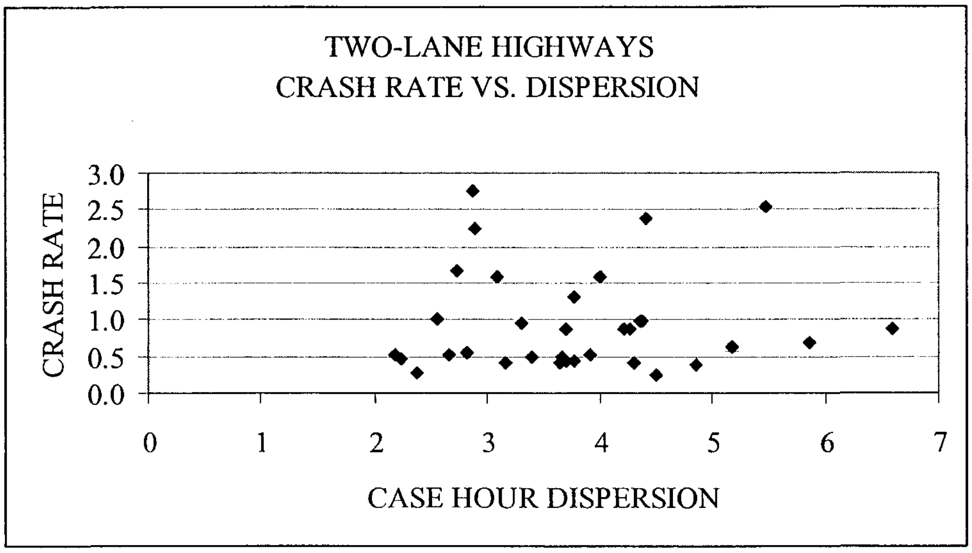

Figure 44 Two-Lane Highway Crash Rate vs. Case Hour Dispersion

Table 6 presents a summary of the various average metrics utilized in these analyses, without weather related crashes.

Table 6 Summary of Speed Distribution Metrics

MEASURE	INTERSTATE	FREEWAY	EXPRESSWAY	TWO-LANE
CASE HOUR MEAN SPEED	69.2	64.9	62.7	58.7
CONTROL HOUR MEAN SPEED	70.0	66.3	63.5	58.8
CASE HOUR 85TH %ILE SPEED	72.4	68.5	67.3	62.2
CONTROL HOUR 85TH %ILE SPEED	73.5	69.9	67.5	62.7
DISPERSION (MPH)	3.3	3.5	4.6	3.8
DEPARTURE (MPH)	7.4	6.2	6.3	7.8
CRASH RATE (PER MVMT)	0.19	0.41	0.53	0.96
CRASH DENSITY (PER MI PER YR)	1.68	3.80	2.03	0.79
VOLUME	970	1231	535	117
VOL/ADT	0.044	0.043	0.052	0.052

Appendix B includes tables summarizing the speed metrics as well as plots of crash rate or crash density *versus* the various parameters evaluated, for each type of facility.

4.6 Crash Models

Logistic regression modeling was conducted on all crashes and and then on only crashes that were not weather related. The following repeats from Chapter 2 the explanatory variables considered:

- Mean speed
- The variance of the case hour speed distribution
- Volume
- Dispersion (difference between the mean and 85th percentile speeds) – representative of the variation in the vehicle stream
- Departure (difference between the 85th percentile speed and the speed limit) – representative of the speed of the vehicle stream normalized for the speed limit
- Ratio of the hourly volume to the reported ADT for the study segment – a normalized measure of the vehicle volume
- Time of day
- Weekday or weekend

4.6.1 All crashes

The first model considered all of the crashes, including those that were related to weather or had weather as a contributing circumstance. The model for the freeways (combining interstate highways and other freeways) showed a strong correlation between the speed departure, speed dispersion and the ratio of the case hour volume to the segment ADT on one hand, and crash risk on the other hand. The mean speed did not enter the model as it is strongly correlated to the dispersion. Recall that the logistic regression model takes the following form:

$$\text{Ln}\,(P/(1-P)) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \qquad (4.17)$$

In this case the dependent variable "P" is the probability of a crash and the explanatory variables are the dispersion, the departure, and the volume to ADT ratio, respectively. For the freeway case this equation becomes:

$$\text{Ln}\,(P/(1-P)) = -0.0431 + 0.1523\,(\text{dispersion}) - 0.1141\,(\text{departure}) + 5.2652\,(\text{case hour volume/segment ADT}) \quad (4.18)$$

The standard errors of the regression coefficients are (respectively) 0.16, 0.03, 0.01, and 1.85. The equation yields the following equation to solve for P:

$$P = (e^{\beta 0 + \beta 1x1 + \beta 2x2 + \beta 3x3})/(1 + e^{\beta 0 + \beta 1x1 + \beta 2x2 + \beta 3x3}) \quad (4.19)$$

Table 7 presents a sample sensitivity analysis on P for values of departure on either side of the average. It is developed holding the dispersion and vol/ADT ratio constant at their respective average values while varying the departure. It should be emphasized that the probability "P" does not directly correlate to crash frequency or crash rate. The sensitivity analyses provide insight as to the impact of changes in the explanatory variables on this probability and thus an inference as to the impact of these changes on crash risk or crash frequency.

Table 7 Sensitivity Assessments for Freeway Model

	intercept	dispersion	departure	vol/ADT
coefficients	-0.0431	0.1523	-0.1141	5.2652
Value of Explanatory Variable		4	3	0.1
		4	4	0.1
		4	5	0.1
		4	6	0.1
Average Freeway Values		3.75	5.12	0.038
P/(1-P) =	2.1177	P =	0.67925	
P/(1-P) =	1.8893	P =	0.6539	
P/(1-P) =	1.6856	P =	0.62764	
P/(1-P) =	1.5038	P =	0.60061	
P/(1-P) =	1.1548	P =	0.53592	(Avg)

For the two-lane highways dispersion and departure entered the model. The model form is similar to that for the freeways; with the coefficients on the explanatory variables the equation becomes:

$$\text{Ln}\,(P/(1-P)) = 0.3930 - 0.0457\,(\text{dispersion}) - 0.0573\,(\text{departure}) \quad (4.20)$$

The standard errors of the coefficients are (respectively) 0.13, 0.02, and 0.02. The equation solving for P becomes:

$$P = (e^{\beta 0 + \beta 1x1 + \beta 2x2})/(1 + e^{\beta 0 + \beta 1x1 + \beta 2x2}) \quad (4.21)$$

Table 8 presents a sensitivity analysis on "P" for values of departure on either side of the average while holding dispersion constant at its average.

Table 8 Two-Lane Highway Estimates from Modeling Results

	intercept	dispersion	departure	
coefficients	0.3930	-0.0457	-0.0573	
Value of Explanatory Variable		4	3	
		4	4	
		4	5	
		4	6	
Average Two-Lane Values		3.91	6.98	
P/(1-P) =	1.03904	P =	0.50957	
P/(1-P) =	0.98118	P =	0.49525	
P/(1-P) =	0.92654	P =	0.48093	
P/(1-P) =	0.87494	P =	0.46665	
P/(1-P) =	0.83061	P =	0.45373	(Average)

The logistic regression modeling of the expressway data found no significant results for any of the parameters considered; only the categorical variable W (weekday or weekend) entered the model and it was not statistically significant.

As noted above, sensitivity analyses were conducted of each of the models, to determine the impact of changing one of the explanatory variables on crash probability "P" while holding the other variables constant. Table 9 summarizes these analyses.

Table 9 Sensitivity Analysis of Model Results (For All Crashes)

	CRASH PROBABILITY CHANGE	
CHANGE IN VARIABLE	FREEWAYS	TWO-LANES
Each 1 mph change in dispersion yields a	+7.5%	-2.5%
Each 1 mph change in departure yields a	-5.1%	-2.9%
Each 1% increase in Vol/ADT ratio yields a	+2.3%	N/A

Average values of the explanatory variables were used in the models, as found during the data analysis process. Single variables were then changed in unit increments to determine the change in the dependent variable crash probability ("P"). In both models the results were nearly linear on the variables dispersion and departure within a range of 4 or 5 mph on either side of the average value. The volume/ADT ratio for the freeways' model was approximately linear from the mean value of about 0.04 to 0.11. In Table 9 the positive sign on the probability change indicates that the change in probability moves in the same direction as the change in the variable; the negative sign indicates that the change in probability has the opposite direction to the change in the variable. For example, a 1-mph increase in freeway dispersion yields a 7.5 percent increase in crash probability; a similar increase in departure yields a 5.1 percent reduction in crash probability. Figures 45 through 49 present plots of the models (those with the highest correlations).

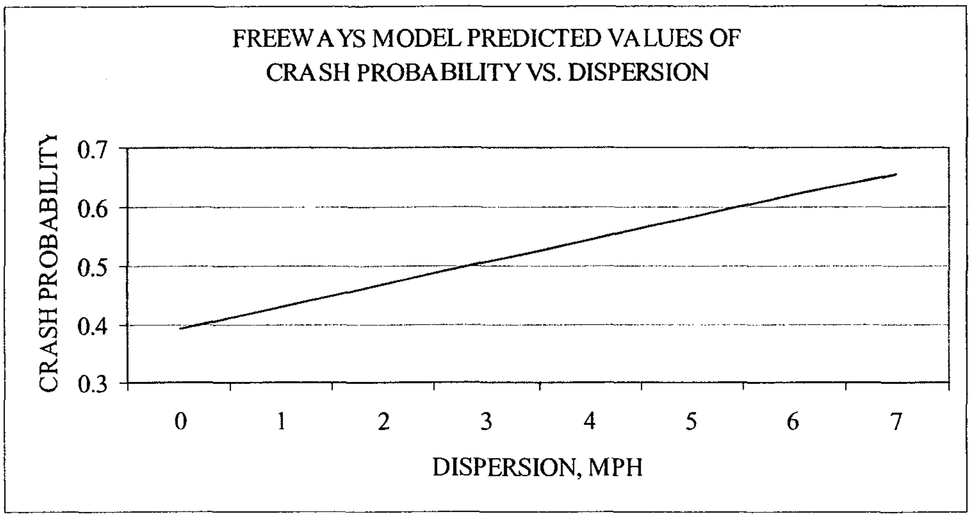

Figure 45 Freeway Crash Probability vs. Dispersion

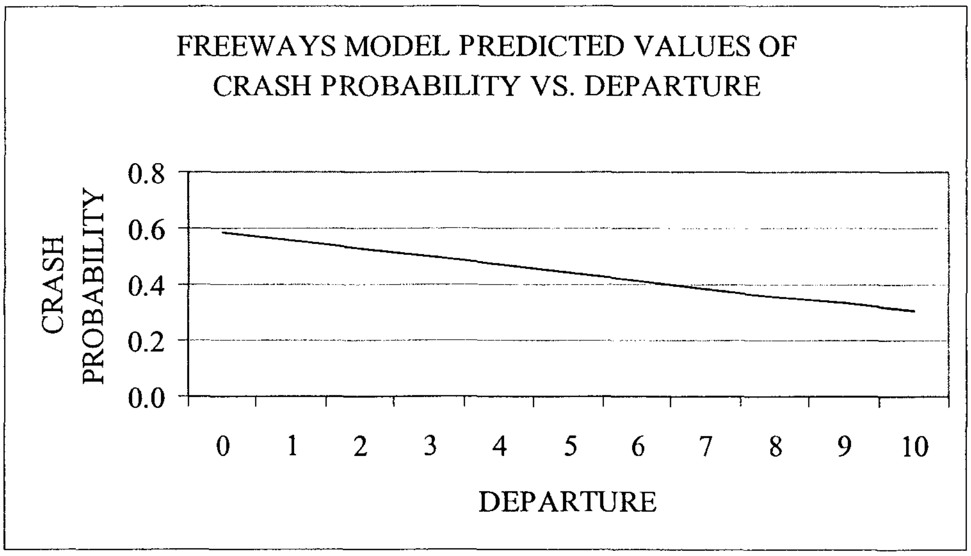

Figure 46 Freeway Crash Probability vs. Departure

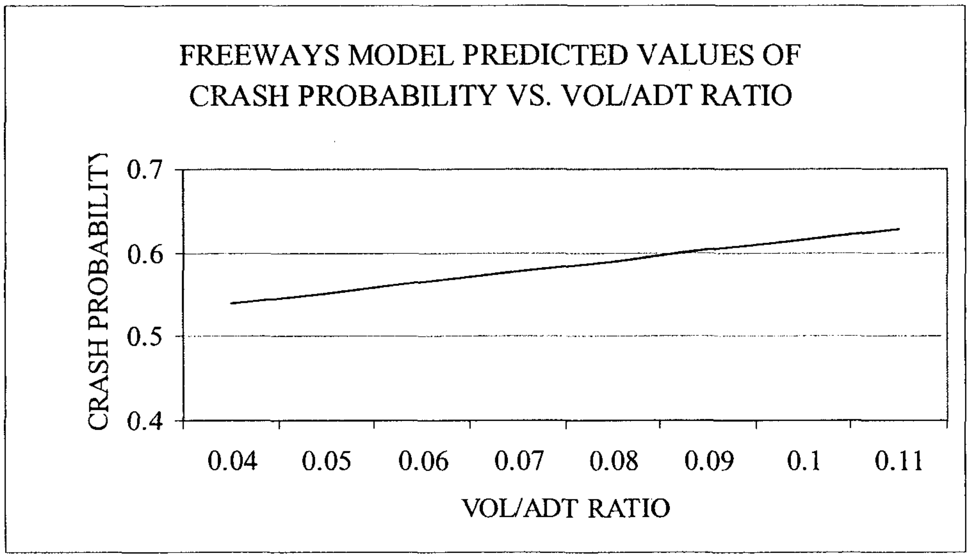

Figure 47 Freeway Crash Probability vs. Volume/ADT

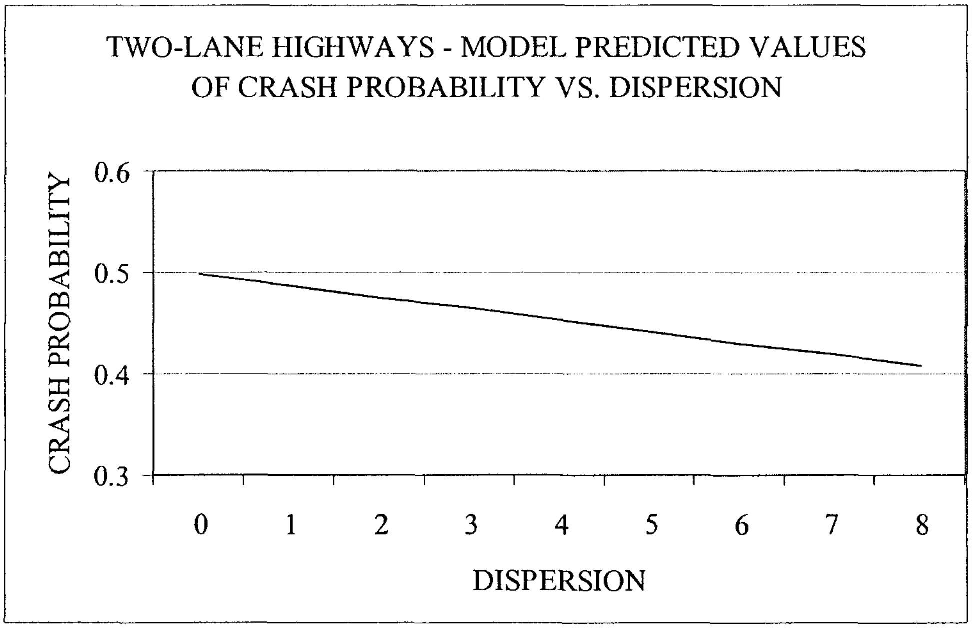

Figure 48 Two-Lane Highway Crash Probability vs. Dispersion

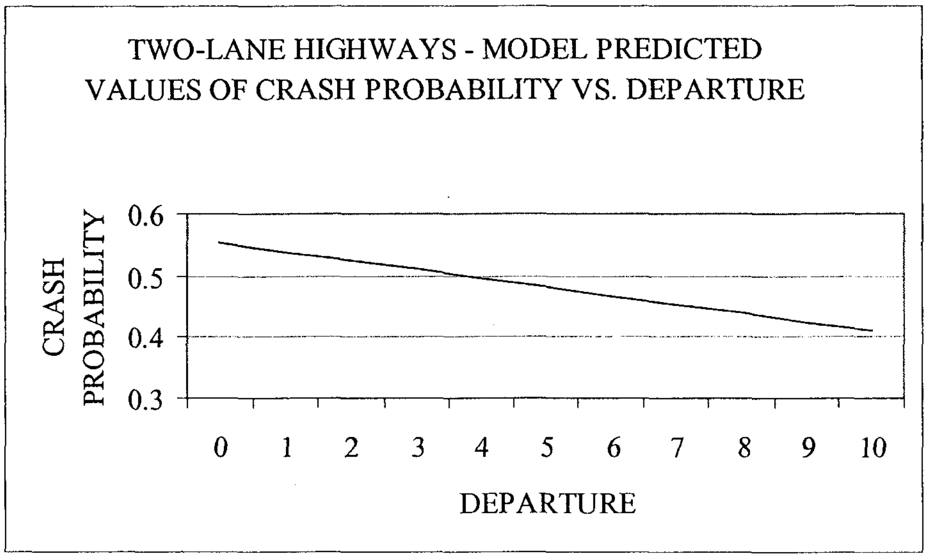

Figure 49 Two-Lane Highway Crash Probability vs. Dispersion

4.6.2 Non-weather crashes

When weather related crashes are removed there is a noticeable change in the results of the modeling. The modeling for the freeways (combining interstate highways and other freeways) shows a strong correlation between the speed departure, variance of the case-hour speed dispersion and the weekday status on one hand, and crash risk on the other hand. For the freeway case the logistic model equation becomes:

$$\text{Ln}\,(P/(1-P)) = 1.3272 + 0.00598\,(\text{variance}) - 1.8834\,(\text{status}) \quad (4.23)$$

The standard errors of the coefficients are (respectively) 0.22, 0.003, and 0.19. Equation 4.23 yields the following equation to solve for P:

$$P = (e^{\beta 0 + \beta 1 x 1 + \beta 2 x 2})/(1+ e^{\beta 0 + \beta 1 x 1 + \beta 2 x 2}) \quad (4.24)$$

Table 10 presents a sensitivity analysis of the freeways' model.

Table 10 Sensitivity Analysis of Freeway Model

	WEEKDAY		WEEKEND	
VARIANCE	ODDS	P	ODDS	P
28	4.458	0.817	0.678	0.404
29	4.484	0.818	0.682	0.405
30	4.511	0.819	0.686	0.407
31	4.538	0.819	0.690	0.408
32	4.566	0.820	0.694	0.410
33	4.593	0.821	0.698	0.411
34	4.621	0.822	0.703	0.413
35	4.648	0.823	0.707	0.414
36	4.676	0.824	0.711	0.416
37	4.704	0.825	0.715	0.417
38	4.732	0.826	0.720	0.418
39	4.761	0.826	0.724	0.420
40	4.789	0.827	0.728	0.421

Within this range of the variance the value of "P" increases by about 0.35 percent for each 1 mph^2 increase in the variance of the case hour speed distribution. The change is the same for both the weekday and weekend cases. It is interesting to note that the weekend crash probability "P" is only about one-half of that for weekdays; however, if the exposure difference (5 days vs. 2 days) is taken into consideration there is a greater crash risk on the weekends than during the week. The weekend risk is about 24 percent greater than that during the week.

For the expressways the removal of the weather related crashes did not change the results of the modeling; in either case only the intercept entered the model.

When weather related crashes are removed from the input to the two-lane highways' model the dispersion entered the model. The model form is similar to that for the freeways; with the coefficients on the explanatory variables the equation becomes:

$$\text{Ln}\,(P/(1-P)) = 0.2262 - 0.0483\,(\text{dispersion}) \qquad (4.25)$$

The standard errors of the coefficients are (respectively) 0.12 and 0.02. The equation solving for probability "P" becomes:

$$P = (e^{\beta 0 + \beta 1 x 1})/(1+ e^{\beta 0 + \beta 1 x 1}) \qquad (4.26)$$

Table 11 presents a sensitivity analysis of probability "P" for some sample values of the dispersion for the two-lane highways. The average value of the dispersion for all two-lane highways was 3.74 mph, which yielded a "P" value of 0.511. The sensitivity analysis indicates that a 1.0 mph increase in the case hour speed dispersion is associated with a 2.4 percent decrease in crash risk.

Table 11 Sensitivity Analysis of Two-Lane Highways (w/o weather)

DISPERSION	ODDS	P
1	1.195	0.544
2	1.138	0.532
3	1.085	0.520
4	1.034	0.508
5	0.985	0.496
6	0.938	0.484
7	0.894	0.472
8	0.852	0.460

4.7 Weather Effects

Weather has a major impact on travel safety. Of the total 1,937 crashes within the ATR segments during the six years of data analyzed, 556 or 29 percent were weather related. On a percentage basis, weather-related crashes ranged from 0 percent (6 sites) to 63 percent (ATR 104 on I-35 in Hamilton County) of the total. If weather-related crashes are removed from the data base, the crash rates are affected as follows:

- Interstate highways – 0.32 crashes per Million Vehicle Miles of Travel (MVM) for all crashes and 0.19 without weather-related crashes.
- Freeways – 0.55 crashes per MVM for all crashes and 0.41 without weather-related crashes
- Expressways – 0.65 crashes per MVM for all crashes and 0.53 without weather-related crashes

- Two-lane highways – 1.26 crashes per MVM for all crashes and 0.96 without weather related crashes

With regard to the modeling of crash probability, the removal of weather related crashes had an important impact on the results. For the freeways' model the impact was the removal of the dispersion and departure and the addition of the variance of the case hour speed distribution and the weekday/weekend status. For the two-lane highways the impact was to remove the speed departure from the model leaving only the dispersion.

The data in the current research show that the crash parameters during this 6-year range of data ranged as follows:

- Two-lane highways – crash rate of 1.26 per million vehicle miles of travel (MVMT); the crash density was 0.98 crashes per mile per year for all crashes. The crash rate for non-weather related crashes was 0.96; the density was 0.79.
- Expressways – crash rate of 0.65 per MVMT and crash density of 2.49 per mile per year for all crashes. For non-weather related crashes the rate was 0.53 and the density was 2.03.
- Freeways – crash rate of 0.55 per MVMT and crash density of 5.15 per mile per year for all crashes. For non-weather related crashes the rate was 0.41 and the density was 3.80.
- Interstate highways – crash rate of 0.32 per MVMT and crash density of 2.14 per mile per year for all crashes. For non-weather related crashes the rate was 0.19 and the density was 1.68.

5 CONCLUSIONS AND RECOMMENDATIONS

There are a number of issues that must be considered in evaluating the results of this study. These are discussed in the following sections.

5.1 Discussion of results

The modeling results and the statistics on the dispersion and departure suggest that speed is not the main issue, as these values on the freeways are very close to those for the interstate highways. However, the analyses do not show a single factor that can be consistently evaluated to suggest the crash risk on any type of roadway. This should not be unexpected, considering how differently the various categories of highways operate. For example, passing is clearly more problematic on two-lane highways than on multi-lane facilities. If variation from the mean speed is the causative factor, it would be reasonable to assume that dispersion, the difference between the 85th percentile and mean speeds, would be a good indicator of crash risk. While this is supported by the analyses for the divided facilities (interstates, freeways, and expressways), it is not supported for the two-lane roads based on the regression utilizing the overall data.

The logistic regression model for the two-lane highways shows that a 1-mph increase in dispersion results in a 2.5 percent reduction in crash risk. On freeways and interstates, that same 1 mph increase in dispersion is expected (based on the logistic regression model) to result in a 7.5 percent increase in crash risk. It should be emphasized that these conclusions come from the modeling, which is based on comparing the case hour to a control hour. One should exercise caution in extrapolating these results directly to crash rate or density. If only those crashes that are not related to weather are considered, the model results suggest that the variance of the speed distribution on the freeways has a positive correlation with the crash probability, such that a 1-mph^2 increase in the variance is associated with a 0.35 percent increase in probability.

The relation of departure to crash risk was found by the regression model to be more consistent between the freeways and two-lane roads, although the results are not consistent with the expectation that speed alone is the greatest risk factor on the highway. In both cases (freeways and two-lanes) an increase in the departure is associated with a decrease in crash risk; for a 1 mph increase in the departure the freeway crash risk is expected to decrease 5.1 percent while for the two-lanes the reduction is 2.9 percent. It should be noted that this does not mean that speeding is safer. It is likely that speeding is acting as a surrogate for some other factor. The ability to drive at higher speeds is constrained as traffic volumes increase, which may indicate that volume is that factor. It may also be that speeds that are inappropriate for the conditions (such as traffic or weather) are still important.

On the freeways the model showed that an increase of 1 percent in the ratio of the case hour volume to the ADT is associated with a 2.3 percent increase in crash risk. This again would tend to suggest that the enforcement emphasis should be on the highest volume roadways, the urban freeways. Two of these, I-29/80 in Council Bluffs and I-74 in Bettendorf, have the highest crash rates and crash densities of the freeways segments in the study.

Do the results of the research reject the initial hypothesis, that there is a speed related parameter that will demonstrate a greater variation of distribution in the pre-crash hour than in the control hour one week earlier? Some of the speed metrics evaluated did demonstrate greater variation in the crash hour versus the control hour. The more important question is whether aggregated speed data can be used to determine if speed or variance contributes more to crash risk. Based on the current research it appears that the data from automatic traffic recorders do not provide sufficient detail to make that determination.

Based on the results of the analyses conducted in this study, there is a definite relationship between the dispersion of the speed distribution (the difference between the 85th percentile speed and the mean speed) and the probability of a crash when all crashes are considered. On freeways, each 1 mph increase in the speed dispersion is associated with a 7.5 percent increase in the crash probability; on two-lane highways the effect is a 2.5 percent decrease in the crash probability. There is also a relationship between the normalized speed of the traffic stream (as measured by the departure, the difference between the 85th percentile speed of the case hour and the speed limit) and the crash risk. On freeways each 1 mph increase in the departure is associated with a 5.1 percent reduction in the crash probability. On two-lane highways the effect is smaller, a 2.9 percent reduction in the crash probability.

One additional measure entered the model for the freeways; the ratio of the case hour volume to the reported ADT. In the freeways' model a 1 percent increase in the volume/ADT ratio was associated with a 2.3 percent increase in the crash probability. There were more definitive results in some of the statistical analyses of the measures of departure and crash rate or density, for the interstate highways. The regression model produced a minimum crash density of 0.68 crashes per mile per year at a departure of 9.1 mph. This implies that a speed of 74 mph should be the safest speed. Solomon (see Figure 1) found the safest speed (on the rural highways he evaluated) to be about 65 mph. This speed was equal to or greater than the speed limits in approximately 75 percent of the roads he studied. It remains to be seen if the change to a 70 mph speed limit, established in Iowa in July of 2005, results in fewer crashes. Raju et all (1998) reported an increase in crashes on the rural interstates in Iowa when the speed limit was raised from 55-mph to 65-mph. It could be argued that as speed limits have increased, so have the speeds that people drive with the result that 85th percentile speeds are generally 5 to 10 mph over the speed limit.

If non-weather related crashes are considered alone, the results are quite different. For the freeways the logistic regression model showed that the variance of the case hour speed distribution was directly related to crash risk. It found that for each 1 mph^2 increase in variance the crash risk is expected to increase by about 0.35 percent. The model also showed that for the freeways the weekend is about 29 percent more risky than a two-day period during the week. For the two-lane highways dispersion remained as a model variable but departure did not. According to the model each 1 mph increase in the dispersion is associated with a 2.3 percent reduction in crash risk.

5.2 Policy Implications

There are a number of policy implications that result from the analyses and conclusions of this study. They are discussed in the following subsections.

5.2.1 Speed Externality

As discussed in the introduction, an externality is defined as a cost (or benefit) that is imposed by one person's actions on others. The dispersion of the speed distribution is somewhat linked to an increased crash risk; thus the driver whose driving behavior increases the dispersion may be increasing the crash risk and thus imposing an external cost on the other drivers. Under this scenario, enforcement should be focused on minimizing the dispersion by enacting and enforcing proper speed limits, increasing minimum speed limits and enhanced enforcement of the speed limits.

5.2.2 Speed Enforcement

The results of the current research do not directly address the issue of speed enforcement, at least with regard to a direct relationship between speed and crash risk. Neither the mean speed nor the speed departure was found to be significantly correlated to crash risk on the interstate highways or freeways. The current research determined that the mean speed on Iowa's interstate system is over 70-mph, more than 5-mph over the speed limit (at the time of the data collection). Fewer than 16 percent of the drivers travel within the speed limit and the 85th percentile speed is nearly 75-mph.

Although it would be tempting to link the findings of this research with recommendations for setting speed limits or their enforcement, caution should be exercised in advocating such a linkage. All of these analyses have been based on aggregated data, those speed data from either the case hour or the control hour. These speed data are grouped into 5-mph bins and thus do not permit the determination of the actual speed of crash-involved vehicles. It is not necessarily intuitive to assert that increasing the speed of the vehicle stream will reduce the crash risk. It may be more reasonable to conclude that the results indicate that there is something happening some time before the crash that makes the dispersion increase and the 85th percentile speed decrease. It may be advisable to consider the development of a predictive model to identify these deviations in real-time, thus perhaps permitting the intervention of law enforcement prior to a crash in order to prevent the crash from occurring. With regard to two-lane highways, it may also be the case that the dispersion of the traffic stream must decrease with increasing volume. An analysis of this relationship found a weak correlation between the case hour volume and the dispersion; however, it should be noted that the highest value of the case hour volume was 364, not a significant percentage of a two-lane highway's capacity. It does appear that consideration should be given to setting and enforcing more realistic speed limits for weather conditions that create greater crash risk.

5.2.3 Automated Enforcement

The results of the current research cannot be construed as supporting a specific conclusion with regard to automated enforcement. There are issues that would have to be addressed if automated speed enforcement is to be used. Privacy, accuracy, and spoofing are some of these issues. These were discussed in the introduction. Advanced technology radar systems could also be used, such as frequency-agile systems where the frequency is changed on a millisecond basis, to frustrate both radar detectors and spoofers. There is a new passive radar detection system that makes use of signals from cell-phone towers which works by detecting the Doppler shift in the background radiation. Called CELLDAR (for cell phone radar), it has been tested on a proof-of-concept basis and presumably could be used to detect speeding vehicles without emitting radiation.

5.2.4 Automated Speed Control

Because the current research indicates that dispersion may be related to crash risk, there may be a benefit from the control of vehicle speeds to minimize variation of vehicle speed. One method that could be used is the automated control of speeds of vehicles. There are policy issues that arise from the possible use of automated speed control, as follows:

- Whether the posted speed limit is always appropriate, such as for weather problems, construction zones, or high volume traffic (if not modified to reflect these differing conditions)
- Variation in speed determination of vehicles, which could be addressed by simple GPS systems to report the exact vehicle speed to the vehicle operator
- How to pay for a system
- Who should pay for the system
- How to deal with older vehicles

- How to deal with attempts to defeat the speed control system,such as by spoofing devices that would provide an excessive speed limit to the speed control system

5.3 Limitations of Current Research

It is well known that crashes are rare events. The total count of crashes in the study segments is 1,937, over 6 years, or about 323 per year. Over the study period the average number of reported crashes (according to Iowa DOT data) was about 62,000. The study area crashes thus represent approximately ½ percent of the total. Expanding the number of sites for which speed data are available would help in improving the statistical base for such a study. As discussed above, emerging technology such as CELLDAR has the potential to provide speed data unobtrusively and relatively cheaply, so it should be possible to generate speed data at crash "hot spots" or at a wider variety of locations.

The current research relies on aggregated speed data, from the state's network of ATR's. While some conclusions have been reached about the statistics of crash risk from certain speed measures, the overarching question remains somewhat unanswered, "does speeding in and of itself creates a crash risk, or is it the variation of that speeding vehicle from the speeds of the other vehicles in the traffic stream that creates the risk?" It appears that answering this question will require the use of disaggregated data, that is, the speeds of crash-involved vehicles as well as the speed profile of the traffic stream. To obtain these data may require access to the event data recorders (EDR) that are present in most vehicles equipped with air bags. Current versions of these devices record the speed, brake switch status, throttle position, seat belt use, and air bag deployment for (typically) five seconds prior to the deployment. Each vehicle manufacturer has a proprietary code for their device; at the present time only Ford and GM have made this code available to the public. One technology firm has developed software to permit the recovery of these pre-crash data from EDR-equipped Ford and GM vehicles. At the present time only law enforcement agencies have access to these data and in Iowa they are generally only accessed in the case of fatal crashes. Access to these data could facilitate future extensions of the current research for all crashes in those areas where useful speed profile information can be obtained. There are also social barriers to the acquisition of EDR data, including privacy and 5th Amendment considerations. Access to these data, stripped of personal identifiers, would be very useful to future studies on the relations between speed and crash risk.

5.4 Suggestions for Further Research

At the present time in Iowa the DOT's Office of Transportation Data recovers individual vehicle data from certain weigh-in-motion (WIM) ATR sites. These data are processed to reformat them into the 5-mph bin, aggregated data such as were used in this research. Retention of these data in their original format (or processed to reduce their size while retaining their information content) would be helpful for future research.

CELLDAR-like technologies would seem to promise the ability to accurately determine the speed of individual vehicles and the vehicle stream, without affecting drivers' behavior. However, while proved in concept, the technology should be tested with regard to its capability to reliably and rapidly detect the speed of individual vehicles in a traffic stream under all sorts of environmental conditions and locations.

Over the time frame of the data used in the current research there have been changes in vehicle technology and driver distractions. Still unknown are potential changes in speed behavior of drivers using cell phones and there are devices available now that permit the identification of vehicles in which a cell phone is being used. Using the passive speed measuring technology discussed above, it should be possible to measure and compare the speed profiles of cell-phone users vs. non-users.

One avenue of research that would be expected to receive great interest from governmental safety agencies is into the identification in real time of potential traffic problems via monitoring and sensing algorithms. If a law enforcement agency could be alerted to the onset of conditions that have an increased crash risk, such as an increase in the dispersion, they might be able to take action to modulate the traffic to reduce the risk. This could also be used with a system of automated speed control as discussed above, to reduce the speed of vehicles approaching an anomalous condition and thus mitigate the impacts of that condition.

Weather-related crashes play a significant role in crash performance. Weather-related speed limits intended to reduce crash risk could be studied, especially with regard to driver awareness of the need for such limits (Comte et al 1997).

Finally, the State of Iowa recently (July 2005) raised the speed limit on rural interstate highways to 70 mph. A future study should evaluate the impact of this change on speed metrics such as the dispersion and departure, as well as to see what changes have occurred in crashes and in the volumes on other highways.

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APPENDIX A -- VISUAL BASIC CODE FOR DATA PROCESSING

Code for ATR Query Module

```
Private qYear, qMonth, qDay, qFileName As String
Private qATR, IntCrashTime  As Integer

Private Sub Command1_Click()

  Dim qDate, NewDate, sNewDate, ExcelFileName As String
  Dim LaneN As Integer
  Dim MSpeed As Single, SDev As Single, Varia As Single, Vol As Single
'Cannot write it like this:
' Dim MSpeed, SDev, Varia, Vol As Single
' Otherwise type missing
  Dim StartPos, tempMonth, tempDay As Integer
  Dim WeekBefore As Integer
  Dim CrashNum, k, qtime As Integer
  Dim CrashYear, CrashMonth, CrashDay, CrashTime As Integer
  Dim ErrorMsg As String

  CommonDialog1.ShowOpen
  ExcelFileName = CommonDialog1.FileName

    Dim myExl As Excel.Application
    Dim wb As Workbook
    Dim ws As Worksheet
'   Dim var As Variant
    Set myExl = New Excel.Application
    Set wb = myExl.Workbooks.Open(ExcelFileName)
     Set ws = wb.Worksheets("Base")
'->  Set ws = wb.Worksheets("sheet1")
' var = ws.Range("A1").Value
' or
'  var = ws.Cells(1, 1).Value
' ws.Cells(1, 1).Font.Bold = True
      myExl.Visible = True
      ws.Cells(1, 9) = "Calculation:"
      ws.Cells(1, 10) = "MeanSpeed"
      ws.Cells(1, 11) = "StdDev"
      ws.Cells(1, 12) = "Variance"
      ws.Cells(1, 13) = "Volumn"
      ws.Cells(1, 15) = "bMeanSpeed"
      ws.Cells(1, 16) = "bStdDev"
      ws.Cells(1, 17) = "bVariance"
      ws.Cells(1, 18) = "bVolumn"
```

```
  qATR = ws.Cells(2, 1)
  CrashNum = 0
  Do

    CrashNum = CrashNum + 1
'->    qATR = ws.Cells(CrashNum + 1, 1)
    CrashMonth = ws.Cells(CrashNum + 1, 4)
    CrashDay = ws.Cells(CrashNum + 1, 5)
    CrashYear = ws.Cells(CrashNum + 1, 6)
    CrashTime = ws.Cells(CrashNum + 1, 8)

    WeekBefore = 0
    qDate = CStr(CrashMonth) + "/" + CStr(CrashDay) + "/" + CStr(CrashYear)

    NewDate = qDate 'if in the hour of 2400, NewDate will be changed.
    qtime = Fix(CrashTime / 100)
'   t = Mid(qTime, 3, 2)
'   IntTime = CInt(Left(qtime, 2)) * 100
    If qtime < 1 Then 'Use the hour of 2400, one day before the crash happened
      NewDate = DateAdd("d", -1, qDate)
      IntCrashTime = 2400
    Else
      IntCrashTime = qtime * 100
    End If
      sNewDate = NewDate

quit4: qYear = Right(NewDate, 2)
    StartPos = InStr(1, NewDate, Chr(47), vbTextCompare)
    tempMonth = CInt(Mid(NewDate, 1, StartPos - 1))
    If tempMonth < 10 Then
      qMonth = "0" + CStr(tempMonth)
    Else
      qMonth = CStr(tempMonth)
    End If
    NewDate = Right(NewDate, Len(NewDate) - StartPos)
    StartPos = InStr(1, NewDate, Chr(47), vbTextCompare)
    tempDay = CInt(Mid(NewDate, 1, StartPos - 1))
    If tempDay < 10 Then
      qDay = "0" + CStr(tempDay)
    Else
      qDay = CStr(tempDay)
    End If
' time 2359 means that you need to use 2300 data. 2300 is the end of that time slot.

   qFileName = "c:\ATR\" + qYear + "\" + qYear + qMonth + "ATR\" _
```

```
        + "D" + qMonth + qDay + qYear + ".IND"  'ATR index file

  Call ATRProcess(ErrorMsg, MSpeed, SDev, Varia, Vol, LaneN)

  If ErrorMsg <> "" Then
    ws.Cells(CrashNum + 1, 9) = " -->"
    ws.Cells(CrashNum + 1, 19) = ErrorMsg
  Else
   If WeekBefore <> 111 Then
    If LaneN = 4 Then
     ws.Cells(CrashNum + 1, 9) = " -->"
    Else
     ws.Cells(CrashNum + 1, 9) = CStr(LaneN) + "Lane"
    End If

     ws.Cells(CrashNum + 1, 10) = MSpeed
     ws.Cells(CrashNum + 1, 11) = SDev
     ws.Cells(CrashNum + 1, 12) = Varia
     ws.Cells(CrashNum + 1, 13) = Vol
     NewDate = DateAdd("d", -7, sNewDate) 'Calculating the data one week before
      If Year(NewDate) < 1998 Then
       ws.Cells(CrashNum + 1, 9) = " -->"
       ws.Cells(CrashNum + 1, 19) = "No 1997 Data Available"
       GoTo quit3
      End If
     WeekBefore = 111
     GoTo quit4
   Else
     ws.Cells(CrashNum + 1, 15) = MSpeed
     ws.Cells(CrashNum + 1, 16) = SDev
     ws.Cells(CrashNum + 1, 17) = Varia
     ws.Cells(CrashNum + 1, 18) = Vol
     WeekBefore = 0
   End If
  End If

quit3: Loop Until IsEmpty(ws.Cells(CrashNum + 2, 3))
  wb.Save
  wb.Close
  myExl.Quit
  Set ws = Nothing
  Set wb = Nothing
  Set myExl = Nothing

 End Sub
```

```
Private Sub Command3_Click()
   Unload Form1
End Sub

Private Sub ATRProcess(ErrMsg As String, MeanSpeed As Single, StdDev As Single, _
             Variance As Single, TotalSC As Single, LaneNum As Integer)

 Dim NN, N, sATR As Integer
 Dim ExcelOpen As Integer
 Dim StringRow, tempFileName, sFileName, sFolder As String
 Dim p As Long
 Dim i, j, CRow As Integer
 Dim HourFound, SpeedCheck, WrongSpeed, CurrentRow, CurrentColumn As Integer
 Dim SpeedCount(20), MidBin(20), CountMultiplyBin(20), TotalCMB As Single
 Dim Diff(20), DifSqCount(20), SumDSC As Single

 Dim FSObj As Object
 Set FSObj = CreateObject("Scripting.FilesystemObject")

   ErrMsg = ""
   On Error GoTo OpenError
   ExcelOpen = 0

   NN = 0
   Open qFileName For Input As #1
   On Error Resume Next 'Without this, the code will crash when encountering abnormal
                 'characters in the index file
   Do Until EOF(1)
     Line Input #1, StringRow
       sATR = Mid(StringRow, 23, 4)
       If qATR = sATR Then
         If NN = 0 Then
           NN = 999
         Else
           NN = 99
           tempFileName = Mid(StringRow, 2, 12)
           Exit Do
         End If
       End If
   Loop
  Close #1

  On Error GoTo 0
   If NN = 0 Then
```

```
    ErrMsg = "Invalid ATR Number"
    Exit Sub
  End If
  If NN = 999 Then
    ErrMsg = "No Speed File Available"
    Exit Sub
  End If

 Dim exWBook As Object
 Dim exSheet As Object
Set ex = CreateObject("Excel.Application")
Set exWBook = ex.Workbooks().Add
Set exSheet = exWBook.Worksheets("sheet1")
exWBook.Visible = True
   N = 0
  On Error GoTo OpenError
  sFileName = "c:\ATR\" + qYear + "\" + qYear + qMonth + "ATR\" + tempFileName
  ExcelOpen = 9
  Open sFileName For Input As #2
     p = 35
     For i = 1 To 10
       p = p + 5
       ex.Cells(5, i + 4) = p
       MidBin(i + 4) = p - 2.5
     Next
       ex.Cells(5, 15) = 147
       MidBin(15) = 87.5
  On Error Resume Next
     Do Until EOF(2)
       Line Input #2, StringRow
       N = N + 1
       If N <= 6 Then GoTo quit1

       ex.Cells(N, 1) = CInt(Mid(StringRow, 1, 2))
       ex.Cells(N, 2) = CInt(Mid(StringRow, 4, 2))
       ex.Cells(N, 3) = CInt(Mid(StringRow, 7, 1))
       ex.Cells(N, 4) = CInt(Mid(StringRow, 9, 4))

       For i = 1 To 11
        p = 9 + i * 5
        ex.Cells(N, i + 4) = CInt(Mid(StringRow, p, 4))
       Next
quit1:  Loop
     Close #2 'close that *.PRN file
```

```
  On Error GoTo 0
  ex.Cells(N + 2, 1) = "Speed Count(an hour before the crash)"
  ex.Cells(N + 3, 3) = "Mid Pt"
  ex.Cells(N + 4, 3) = "No. * Bin Speed"
  ex.Cells(N + 5, 3) = "Difference"
  ex.Cells(N + 6, 3) = "DifSq * Count"
  ex.Cells(N + 8, 5) = "Mean Spd"
  ex.Cells(N + 8, 6) = "Std Dev"
  ex.Cells(N + 8, 7) = "Variance"
  ex.Cells(N + 8, 8) = "Volume"

   CRow = 7
   HourFound = 0
   LaneNum = 0
   WrongSpeed = 0
   For j = 1 To 20
    SpeedCount(j) = 0
   Next
  Do
   If ex.Cells(CRow, 4) = IntCrashTime Then
      LaneNum = LaneNum + 1
' Check the correctness of the original speed data, if SUM(each column)<>the value of first
cell?
      SpeedCheck = 0
      CurrentColumn = 5
      Do
        SpeedCheck = SpeedCheck + ex.Cells(CRow, CurrentColumn)
        CurrentColumn = CurrentColumn + 1
      Loop Until IsEmpty(ex.Cells(CRow, CurrentColumn))
      If ((ex.Cells(CRow, 5) = SpeedCheck) And (SpeedCheck <> 0)) Then
          WrongSpeed = WrongSpeed + 1
      End If

      HourFound = 99
 '    CRow = CRow + Slot - 1 'the 15-minute slot includes the crash time
     For j = 5 To 15
 '      SpeedCount(j) = ex.cells(CRow, j)
 '      For i = CRow - 1 To CRow - 3 Step -1
 '      For i = CRow To CRow + 3
          SpeedCount(j) = SpeedCount(j) + ex.Cells(CRow, j)
 '      Next
     Next
 '   Exit Do
   End If
   CRow = CRow + 1
```

```
  Loop Until IsEmpty(ex.Cells(CRow, 4))

    If HourFound = 0 Then
      ErrMsg = "No Speed Data Found in that Hour"
      ex.Cells(N + 9, 5) = "No Speed Data Found in that Hour"
'Have to save the original speed data like this, otherwise two Excel objects will conflict.
      GoTo quit5
    End If

' If original data doesn't have correct data format ...
     If (CurrentColumn < 16) Or (WrongSpeed >= 2) Then
      ErrMsg = "Wrong Speed Data"
      ex.Cells(N + 9, 5) = "Wrong Speed Data"
      GoTo quit5
     End If

'Calculate the speed distribution
  TotalSC = 0
  TotalCMB = 0
  For j = 5 To 15
   ex.Cells(N + 2, j) = SpeedCount(j)
   TotalSC = TotalSC + SpeedCount(j)
   ex.Cells(N + 3, j) = MidBin(j)
   CountMultiplyBin(j) = SpeedCount(j) * MidBin(j)
   ex.Cells(N + 4, j) = CountMultiplyBin(j)
   TotalCMB = TotalCMB + CountMultiplyBin(j)
  Next
   ex.Cells(N + 2, 16) = TotalSC

 'Check the original speed distribution, in case divided by zero.
     If TotalSC = 0 Then
      ErrMsg = "Total Speed Count = 0"
      ex.Cells(N + 9, 5) = "Total Speed Count = 0"
      GoTo quit5
     End If
'Continue calculating the speed distribution
   ex.Cells(N + 4, 16) = TotalCMB
   MeanSpeed = Round(TotalCMB / TotalSC, 2)
   ex.Cells(N + 9, 5) = MeanSpeed

  SumDSC = 0
  For j = 5 To 15
   Diff(j) = MidBin(j) - MeanSpeed
   ex.Cells(N + 5, j) = Diff(j)
```

```
   DifSqCount(j) = (Diff(j)) ^ 2 * SpeedCount(j)
   SumDSC = SumDSC + DifSqCount(j)
   ex.Cells(N + 6, j) = DifSqCount(j)
  Next
   ex.Cells(N + 6, 16) = SumDSC
   StdDev = Round((SumDSC / TotalSC) ^ 0.5, 2)
   Variance = Round(SumDSC / TotalSC, 2)
   ex.Cells(N + 9, 6) = StdDev
   ex.Cells(N + 9, 7) = Variance
   ex.Cells(N + 9, 8) = TotalSC
   GoTo quit5

OpenError:
 ' MsgBox "Error " & Format$(Err.Number) & " opening file." & vbCrLf & _
     Err.Description
  If ExcelOpen = 9 Then
      ErrMsg = "Error " & Format$(Err.Number) & _
      "-There should be Speed Data file. But, " & Err.Description
      GoTo quit6
  Else
      ErrMsg = "Error " & Format$(Err.Number) & _
      "-opening ATR Index file." & Err.Description
  End If
  Set FSObj = Nothing
  Exit Sub 'do not allow an error handler to continue to the routine's End statement
        'Use an Exit statement to leave the routine.

'quit5: sFileName = "c:\ATRProcessed\" + CStr(qATR) + "-" + qMonth + qDay +
CStr(IntCrashTime) + "-" + qYear + ".xls"
quit5: sFolder = "c:\ATRProcessed\" + CStr(qATR) + "\"  '+ qYear + "\"
   'Only one subfolder can be created at one time
     If FSObj.FolderExists(sFolder) = False Then
         FSObj.CreateFolder sFolder
     End If
'     MkDir (sFolder) ' Another way to create a new Excel folder
    sFileName = sFolder + CStr(qATR) + "_" + qMonth + qDay + "-" + CStr(IntCrashTime)
+ "_" + qYear + ".xls"
    exWBook.SaveAs sFileName
quit6: ex.Quit 'quit Excel
    Set exWBook = Nothing
    Set exSheet = Nothing
    Set ex = Nothing

    Set FSObj = Nothing
End Sub
```

ATR by 24 Hours

```
Private Declare Function APIBeep Lib "kernel32" Alias _
   "Beep" (ByVal dwFreq As Long, ByVal dwDuration As Long) As Long
Private qYear, qMonth, qDay, qFileName As String
Private IntCrashTime  As Integer
Private tempATR, qATR As String
Private SpeedCount(5, 20) As Long
Private RawSpeed(5, 20) As Integer

Private Sub Command1_Click()
 Dim TotalCount(5) As Long
 Dim TotalATR, ATRNum As Integer

 Dim StringRow, tempFileName, sFileName, stFileName, sFolder As String
 Dim MidBin(20), CountMultiplyBin(20) As Single
 Dim TotalCMB(5) As Single
 Dim MeanSpeed(5), Var(5) As Single

 Dim Pre85(5), EightyFifth(5) As Single
 Dim AccumCount(5) As Long

 Dim byHour As Integer
 Dim LaneNum As Integer
 Dim temp As Integer

' Dim Sheet_count As Variant
' Dim MyPos

 Dim LaneN, NN, N As Integer
 Dim MSpeed As Single, SDev As Single, Varia As Single, Vol As Single
 Dim SqDiff(5, 20), SumDSC(5) As Single
 Dim ATRDay As Integer
 Dim HourCount(5) As Integer
 Dim ErrType As Integer

 Dim qDate, NewDate, sNewDate, ExcelFileName As String
'Cannot write it like this:
' Dim MSpeed, SDev, Varia, Vol As Single
' Otherwise type missing
 Dim StartPos, tempMonth, tempDay As Integer
 Dim WeekBefore As Integer
 Dim CrashNum, k, qtime As Integer
 Dim CrashYear, CrashMonth, CrashDay, CrashTime As Integer
 Dim ErrorMsg As String
 Dim ii As Integer
 Dim FTestResult As String

' select an Excel file to process ATR one by one
 CommonDialog1.ShowOpen
 ExcelFileName = CommonDialog1.FileName

   Dim myExl As Excel.Application
   Dim wb As Workbook
   Dim ws As Worksheet
''  Dim var As Variant
   Set myExl = New Excel.Application
   Set wb = myExl.Workbooks.Open(ExcelFileName)

''->    Set ws = wb.Worksheets("Base")
```

```
  Set ws = wb.Worksheets("sheet1")
 '' var = ws.Range("A1").Value
 '' or
 ''  var = ws.Cells(1, 1).Value
 '' ws.Cells(1, 1).Font.Bold = True
     myExl.Visible = True

TotalATR = 0
Do
   TotalATR = TotalATR + 1
Loop Until IsEmpty(ws.Cells(TotalATR + 1, 1))
TotalATR = TotalATR + 3

ATRNum = 1
Do '--->Loop Until IsEmpty(ws.Cells(ATRNum, 1))
   qATR = ws.Cells(ATRNum, 1)

      ws.Cells(TotalATR, 1) = "ATR_" + qATR
      ws.Cells(TotalATR, 3) = "by 24 Hours"

      ws.Cells(TotalATR + 2, 1) = "Time of Day"

      ws.Cells(TotalATR + 1, 3) = "Mean Spd"
      ws.Cells(TotalATR + 1, 4) = "Mean Spd"
      ws.Cells(TotalATR + 1, 5) = "Mean Spd"
      ws.Cells(TotalATR + 1, 6) = "Mean Spd"
      ws.Cells(TotalATR + 2, 3) = "Lane 1"
      ws.Cells(TotalATR + 2, 4) = "Lane 2"
      ws.Cells(TotalATR + 2, 5) = "Lane 3"
      ws.Cells(TotalATR + 2, 6) = "Lane 4"

      ws.Cells(TotalATR + 1, 8) = "85% Spd"
      ws.Cells(TotalATR + 1, 9) = "85% Spd"
      ws.Cells(TotalATR + 1, 10) = "85% Spd"
      ws.Cells(TotalATR + 1, 11) = "85% Spd"
      ws.Cells(TotalATR + 2, 8) = "Lane 1"
      ws.Cells(TotalATR + 2, 9) = "Lane 2"
      ws.Cells(TotalATR + 2, 10) = "Lane 3"
      ws.Cells(TotalATR + 2, 11) = "Lane 4"

      ws.Cells(TotalATR + 1, 13) = "Var"
      ws.Cells(TotalATR + 1, 14) = "Var"
      ws.Cells(TotalATR + 1, 15) = "Var"
      ws.Cells(TotalATR + 1, 16) = "Var"
      ws.Cells(TotalATR + 2, 13) = "Lane 1"
      ws.Cells(TotalATR + 2, 14) = "Lane 2"
      ws.Cells(TotalATR + 2, 15) = "Lane 3"
      ws.Cells(TotalATR + 2, 16) = "Lane 4"

      ws.Cells(TotalATR + 1, 18) = "Valid Hrs"
      ws.Cells(TotalATR + 1, 19) = "Valid Hrs"
      ws.Cells(TotalATR + 1, 20) = "Valid Hrs"
      ws.Cells(TotalATR + 1, 21) = "Valid Hrs"
      ws.Cells(TotalATR + 2, 18) = "Lane 1"
      ws.Cells(TotalATR + 2, 19) = "Lane 2"
      ws.Cells(TotalATR + 2, 20) = "Lane 3"
      ws.Cells(TotalATR + 2, 21) = "Lane 4"

For byHour = 100 To 2400 Step 100 'Create a Excel file for each hour
 ''' Do '--->Loop Until IsEmpty(ws.Cells(ATRNum, 1))
```

```
      ws.Cells(TotalATR + 2 + byHour / 100, 1) = byHour

  ' Create a new Excel file for this ATR --->
    Dim FSObj As Object
    Set FSObj = CreateObject("Scripting.FilesystemObject")

      sFolder = "c:\ATRProcessed\" + qATR + "_N\"
      If FSObj.FolderExists(sFolder) = False Then
          FSObj.CreateFolder sFolder
      End If
      sFolder = sFolder + qATR + "_Hourly\"
      If FSObj.FolderExists(sFolder) = False Then
          FSObj.CreateFolder sFolder
      End If

       sFileName = sFolder + qATR + "_" + CStr(byHour) + ".xls"
If FSObj.fileExists(sFileName) = False Then
    Dim exWBook As Object
    Dim exSheet As Object
    Set ex = CreateObject("Excel.Application")
    Set exWBook = ex.Workbooks().Add
    Set exSheet = exWBook.Worksheets("sheet1")

    ex.Visible = True
'  ex.ActiveSheet.Name = "POLK I35"
'  ex.Sheets.Add
'  ex.ActiveSheet.Name = "WRIGHT"
  'Sheet_count = ex.ActiveWorkbook.Sheets.Count
  'MyPos = ActiveSheet.Index
  'Sheets(MyPos + 2).Activate

  ex.Cells(2, 1) = "Date"
  ex.Cells(2, 2) = "Error Types"
  For i = 5 To 15
    ex.Cells(1, i) = "Lane1"
  Next i
  For i = 17 To 27
    ex.Cells(1, i) = "Lane2"
  Next i
  For i = 29 To 39
    ex.Cells(1, i) = "Lane3"
  Next i
    For i = 41 To 51
    ex.Cells(1, i) = "Lane4"
  Next i

        p = 40
      For i = 5 To 14
        ex.Cells(2, i) = p
        p = p + 5
      Next
        ex.Cells(2, 15) = 147
        p = 40
      For i = 17 To 26
        ex.Cells(2, i) = p
        p = p + 5
      Next
        ex.Cells(2, 27) = 147
        p = 40
      For i = 29 To 38
```

```
        ex.Cells(2, i) = p
        p = p + 5
      Next
        ex.Cells(2, 39) = 147
       p = 40
      For i = 41 To 50
        ex.Cells(2, i) = p
        p = p + 5
      Next
        ex.Cells(2, 51) = 147

  If Len(qATR) = 1 Then tempATR = "   " + qATR
  If Len(qATR) = 2 Then tempATR = "  " + qATR
  If Len(qATR) = 3 Then tempATR = " " + qATR
  If Len(qATR) >= 4 Then tempATR = Right(qATR, 4)

   ATRDay = 0   'initialization --->
   For i = 1 To 4
    HourCount(i) = 0
    For j = 1 To 15
     SpeedCount(i, j) = 0
     SpeedCount(i, j) = 0
     SpeedCount(i, j) = 0
     SpeedCount(i, j) = 0
    Next j
   Next i

For CrashYear = 1998 To 2003  'begin searching in the original files --->
 For CrashMonth = 1 To 12
  For CrashDay = 1 To 31

    qYear = CStr(Right(CrashYear, 2))
    If CrashMonth < 10 Then
      qMonth = "0" + CStr(CrashMonth)
    Else
      qMonth = CStr(CrashMonth)
    End If
    If CrashDay < 10 Then
     qDay = "0" + CStr(CrashDay)
    Else
     qDay = CStr(CrashDay)
    End If

    qFileName = "c:\ATR\" + qYear + "\" + qYear + qMonth + "ATR\" _
          + "D" + qMonth + qDay + qYear + ".IND"  'ATR index file
   If FSObj.fileExists(qFileName) = False Then GoTo quit11 '--> Check if the file exist

   Open qFileName For Input As #1
   NN = 0
   Do Until EOF(1)
     Line Input #1, StringRow
     sATR = Mid(StringRow, 23, 4)
     If tempATR = sATR Then
      If NN = 0 Then
        NN = 999
      Else   'To find the second row which has the same name of speed data file

' the ATR speed data file name was found --->
        NN = 0
        tempFileName = Mid(StringRow, 2, 12)
```

```
        Close #1
        stFileName = "c:\ATR\" + qYear + "\" + qYear + qMonth + "ATR\" + tempFileName  'the *.prn files
    If FSObj.fileExists(stFileName) = False Then GoTo quit11 '--> Check if the file exist
   ' ExcelOpen = 9

    ATRDay = ATRDay + 1
    ex.Cells(ATRDay + 3, 1) = qMonth + "/" + qDay + "/" + qYear

   For i = 1 To 4
    For j = 1 To 16
      RawSpeed(i, j) = 0
    Next j
   Next i

   LaneNum = 0
   Open stFileName For Input As #2
      N = 0
      Do Until EOF(2)
        Line Input #2; StringRow
        N = N + 1
     If N = 4 Then 'verify the availablity of original speed-bin data 40 45 50 55 60 65 ..., this is AN IMPORTANT STEP.
      If (CInt(Mid(StringRow, 14, 4)) = 40) And (CInt(Mid(StringRow, 19, 4)) = 45) Then GoTo quit1
        Close #2
        ex.Cells(ATRDay + 3, 2) = "Wrong speed-bin data file"
        GoTo quit11
     End If
     If N <= 6 Then GoTo quit1
        temp = CInt(Mid(StringRow, 9, 4))
        If (LaneNum > 0) And (temp <> byHour) Then GoTo quit15

If (temp < 100) Or (temp > 2400) Then GoTo quit15
'In ATR8040_3/29/2000 .prn file, recorded hours are wrong. There are over a dozen 2400Hr.
'Also, it has 5500Hr, 0002Hr and 1626Hr.
'Don't have to use Fix(byHour/100) to see if it has a decimal part, because we only search for 100, 200, 300, ... til 2400.
          If temp = byHour Then
            LaneNum = LaneNum + 1
If CInt(Mid(StringRow, 4, 2)) <> LaneNum Then GoTo quit15 'deal with a dozen 24Hr
            RawSpeed(LaneNum, 2) = CInt(Mid(StringRow, 4, 2))
            For i = 1 To 11
              p = 9 + i * 5
              RawSpeed(LaneNum, i + 4) = CInt(Mid(StringRow, p, 4))
              On Error Resume Next 'ATR2030_03/13/1998 .prn lost a speed bin
            Next
          End If
quit1:  Loop
quit15:  Close #2 'close that *.PRN file

  For i = 1 To LaneNum
       SpeedCheck = 0
       For j = 5 To 15
         SpeedCheck = SpeedCheck + RawSpeed(i, j)
       Next
       If SpeedCheck > 2100 Then
         ex.Cells(ATRDay + 3, 3) = "Too High Counts"
         GoTo quit10
       End If

      For j = 5 To 15
        If ((RawSpeed(i, j) > SpeedCheck * 0.95) And (SpeedCheck > 30)) Then
          ex.Cells(ATRDay + 3, 2) = "Possible Spd Err/Bad Weather"
```

```
        GoTo quit10
      End If
    Next

    For j = 5 To 15
          ex.Cells(ATRDay + 3, j + 12 * (i - 1)) = RawSpeed(i, j)
          SpeedCount(i, j) = SpeedCount(i, j) + RawSpeed(i, j)
          If j = 15 Then HourCount(i) = HourCount(i) + 1
    Next 'For j = 5 To 15
quit10: Next ' For i = 1 To LaneNum

  GoTo quit11
    End If 'If NN = 0 Then
    Else 'If tempATR = sATR Then
     If NN = 999 Then NN = 0 'To prevent the third ATR file is wrong,
                   'for example, ATR=1100, Day=990326
    End If
  Loop 'Do Until EOF(1)
  Close #1
quit11:  Next CrashDay 'For CrashDay = 1 To 31
 Next CrashMonth ' For CrashMonth = 1 To 12
Next CrashYear 'For CrashYear = 1998 To 2003

  For j = 5 To 15
   MidBin(j) = 37.5 + 5 * (j - 5)
  Next
  For i = 1 To 4
   MeanSpeed(i) = 0
   SumDSC(i) = 0
   Var(i) = 0
   EightyFifth(i) = 0
   AccumCount(i) = 0
  For j = 5 To 15
   SqDiff(i, j) = 0
  Next
  Next

  ex.Cells(ATRDay + 5, 3) = "Total Hours"
  For i = 1 To 4
    ex.Cells(ATRDay + 5, 5 + 12 * (i - 1)) = HourCount(i)
  Next

  ex.Cells(ATRDay + 6, 3) = "Speed Bin Count"
  ex.Cells(ATRDay + 7, 3) = "Total Counts"
  ex.Cells(ATRDay + 8, 3) = "Mid Pt of Each Bin"
  ex.Cells(ATRDay + 9, 3) = "Counts * Mid Pt"
  ex.Cells(ATRDay + 10, 3) = "Total(Mid Pt*Count)"
  ex.Cells(ATRDay + 11, 3) = "Mean Speed"
  ex.Cells(ATRDay + 12, 3) = "Sq Diff"
  ex.Cells(ATRDay + 13, 3) = "SqDiff * Count"
  ex.Cells(ATRDay + 14, 3) = "Total(SqDiff*Count)"
  ex.Cells(ATRDay + 15, 3) = "Variance"
  ex.Cells(ATRDay + 16, 3) = "Pre 85 (TotalCount*0.85)"
  ex.Cells(ATRDay + 17, 3) = "Accumulated Count"
  ex.Cells(ATRDay + 18, 3) = "85%th Speed"

     For i = 1 To 4
      TotalCount(i) = 0
      For j = 5 To 15
       TotalCount(i) = TotalCount(i) + SpeedCount(i, j)
```

```
            ex.Cells(ATRDay + 6, j + 12 * (i - 1)) = SpeedCount(i, j)
            ex.Cells(ATRDay + 8, j + 12 * (i - 1)) = MidBin(j)
          Next j
          ex.Cells(ATRDay + 7, 5 + 12 * (i - 1)) = TotalCount(i)
        Next i

For i = 1 To 4  'main calculation
  If TotalCount(i) = 0 Then GoTo quit9

  TotalCMB(i) = 0
  For j = 5 To 15
    CountMultiplyBin(j) = SpeedCount(i, j) * MidBin(j)
    TotalCMB(i) = TotalCMB(i) + CountMultiplyBin(j)
    ex.Cells(ATRDay + 9, j + 12 * (i - 1)) = CountMultiplyBin(j)
  Next
  ex.Cells(ATRDay + 10, 5 + 12 * (i - 1)) = TotalCMB(i)

  MeanSpeed(i) = Round(TotalCMB(i) / TotalCount(i), 2)
  ex.Cells(ATRDay + 11, 5 + 12 * (i - 1)) = MeanSpeed(i)

  For j = 5 To 15
    SqDiff(i, j) = (MidBin(j) - MeanSpeed(i)) ^ 2
    ex.Cells(ATRDay + 12, j + 12 * (i - 1)) = SqDiff(i, j)
    ex.Cells(ATRDay + 13, j + 12 * (i - 1)) = SqDiff(i, j) * SpeedCount(i, j)
    SumDSC(i) = SumDSC(i) + SqDiff(i, j) * SpeedCount(i, j)
  Next
  ex.Cells(ATRDay + 14, 5 + 12 * (i - 1)) = SumDSC(i)
  Var(i) = Round(SumDSC(i) / TotalCount(i), 2)
  ex.Cells(ATRDay + 15, 5 + 12 * (i - 1)) = Var(i)

  Pre85(i) = Round(TotalCount(i) * 0.85, 2)
  ex.Cells(ATRDay + 16, 5 + 12 * (i - 1)) = Pre85(i)
  For j = 5 To 15
    AccumCount(i) = AccumCount(i) + SpeedCount(i, j)
    ex.Cells(ATRDay + 17, j + 12 * (i - 1)) = AccumCount(i)
    If Pre85(i) <= AccumCount(i) Then
      EightyFifth(i) = MidBin(j) - ((AccumCount(i) - Pre85(i)) * (MidBin(j) - MidBin(j - 1)) / SpeedCount(i, j))
      ex.Cells(ATRDay + 18, 5 + 12 * (i - 1)) = Round(EightyFifth(i), 2)
      GoTo quit9
    End If
  Next
quit9: Next i 'For i = 1 To 4  main calculation

    exWBook.SaveAs sFileName
    ex.Quit 'quit Excel
    Set exWBook = Nothing
    Set exSheet = Nothing
    Set ex = Nothing

    For j = 3 To 6
      ws.Cells(TotalATR + 2 + byHour / 100, j) = MeanSpeed(j - 2)
    Next
    For j = 8 To 11
      ws.Cells(TotalATR + 2 + byHour / 100, j) = Round(EightyFifth(j - 7), 2)
    Next
    For j = 13 To 16
      ws.Cells(TotalATR + 2 + byHour / 100, j) = Var(j - 12)
    Next
    For j = 18 To 21
      ws.Cells(TotalATR + 2 + byHour / 100, j) = HourCount(j - 17)
```

```
    Next

Else 'If FSObj.fileExists(sFileName) = False Then
  ErrMsg = "The file has existed in the folder. No more process is needed."
End If
    Set FSObj = Nothing

Next ' For byHour = 100 To 2400 Step 100

TotalATR = TotalATR + 29
ATRNum = ATRNum + 1
Loop Until IsEmpty(ws.Cells(ATRNum, 1))

  wb.Save
  wb.Close
  myExl.Quit
  Set ws = Nothing
  Set wb = Nothing
  Set myExl = Nothing

  APIBeep 1000, 300
    Call Delay
  APIBeep 1250, 300
    Call Delay
  APIBeep 1500, 300
    Call Delay
  APIBeep 1750, 300
    Call Delay
  APIBeep 2000, 300

 End Sub

Private Sub Command3_Click()
  Unload Form1
End Sub

Private Sub Delay()

    For tTimer = 1 To 1500 'Delay loop between beeps
    Next tTimer

End Sub
```

ATR by 365Day

```
Private Declare Function APIBeep Lib "kernel32" Alias _
  "Beep" (ByVal dwFreq As Long, ByVal dwDuration As Long) As Long
Private qYear, qMonth, qDay, qFileName As String

Private IntCrashTime  As Integer
Private tempATR, qATR As String
Private SpeedCount(5, 20) As Long
Private DaySpdCount(5, 20) As Long
Private RawSpeed(5, 20) As Long

Private Sub Command1_Click()
 Dim TotalCount(5) As Long
 Dim TotalATR, ATRNum As Integer
```

```
 Dim StringRow, tempFileName, sFileName, stFileName, sFolder As String
 Dim MidBin(20), CountMultiplyBin(20) As Single
 Dim TotalCMB(5) As Single
 Dim MeanSpeed(5), Var(5) As Single

 Dim Pre85(5), EightyFifth(5) As Single
 Dim AccumCount(5) As Long

 Dim byHour As Integer
 Dim LaneNum As Integer
 Dim dDate As Integer
 Dim DaySum As Long
 Dim YearCount As Integer

' Dim Sheet_count As Variant
' Dim MyPos

 Dim LaneN, NN, N As Integer
 Dim MSpeed As Single, SDev As Single, Varia As Single, Vol As Single
 Dim SqDiff(5, 20), SumDSC(5) As Single
 Dim ExRow As Integer
 Dim HourCount(5) As Integer
 Dim ErrType As Integer

 Dim qDate, NewDate, sNewDate, ExcelFileName As String
'Cannot write it like this:
' Dim MSpeed, SDev, Varia, Vol As Single
' Otherwise type missing
 Dim StartPos, tempMonth, tempDay As Integer
 Dim WeekBefore As Integer
 Dim CrashNum, k, qtime As Integer
 Dim CrashYear, CrashMonth, CrashDay, CrashTime As Integer
 Dim ErrorMsg As String
 Dim ii As Integer
 Dim FTestResult As String

' select an Excel file to process ATR one by one
 CommonDialog1.ShowOpen
 ExcelFileName = CommonDialog1.FileName

  Dim myExl As Excel.Application
  Dim wb As Workbook
  Dim ws As Worksheet
"  Dim var As Variant
  Set myExl = New Excel.Application
  Set wb = myExl.Workbooks.Open(ExcelFileName)

"->   Set ws = wb.Worksheets("Base")
 Set ws = wb.Worksheets("sheet1")
" var = ws.Range("A1").Value
" or
"  var = ws.Cells(1, 1).Value
" ws.Cells(1, 1).Font.Bold = True
    myExl.Visible = True

TotalATR = 0
Do
  TotalATR = TotalATR + 1
Loop Until IsEmpty(ws.Cells(TotalATR + 1, 1))
TotalATR = TotalATR + 2
```

```
ATRNum = 1
Do '--->Loop Until IsEmpty(ws.Cells(ATRNum, 1))
   qATR = ws.Cells(ATRNum, 1)

     ws.Cells(TotalATR, 1) = "ATR_" + qATR
     ws.Cells(TotalATR, 3) = "by 365 Days"

     ws.Cells(TotalATR + 2, 1) = "Month_Day"

     ws.Cells(TotalATR + 1, 3) = "Mean Spd"
     ws.Cells(TotalATR + 1, 4) = "Mean Spd"
     ws.Cells(TotalATR + 1, 5) = "Mean Spd"
     ws.Cells(TotalATR + 1, 6) = "Mean Spd"
     ws.Cells(TotalATR + 2, 3) = "Lane 1"
     ws.Cells(TotalATR + 2, 4) = "Lane 2"
     ws.Cells(TotalATR + 2, 5) = "Lane 3"
     ws.Cells(TotalATR + 2, 6) = "Lane 4"

     ws.Cells(TotalATR + 1, 8) = "85% Spd"
     ws.Cells(TotalATR + 1, 9) = "85% Spd"
     ws.Cells(TotalATR + 1, 10) = "85% Spd"
     ws.Cells(TotalATR + 1, 11) = "85% Spd"
     ws.Cells(TotalATR + 2, 8) = "Lane 1"
     ws.Cells(TotalATR + 2, 9) = "Lane 2"
     ws.Cells(TotalATR + 2, 10) = "Lane 3"
     ws.Cells(TotalATR + 2, 11) = "Lane 4"

     ws.Cells(TotalATR + 1, 13) = "Var"
     ws.Cells(TotalATR + 1, 14) = "Var"
     ws.Cells(TotalATR + 1, 15) = "Var"
     ws.Cells(TotalATR + 1, 16) = "Var"
     ws.Cells(TotalATR + 2, 13) = "Lane 1"
     ws.Cells(TotalATR + 2, 14) = "Lane 2"
     ws.Cells(TotalATR + 2, 15) = "Lane 3"
     ws.Cells(TotalATR + 2, 16) = "Lane 4"

     ws.Cells(TotalATR + 1, 18) = "Avg Vol"
     ws.Cells(TotalATR + 1, 19) = "Avg Vol"
     ws.Cells(TotalATR + 1, 20) = "Avg Vol"
     ws.Cells(TotalATR + 1, 21) = "Avg Vol"
     ws.Cells(TotalATR + 2, 18) = "Lane 1"
     ws.Cells(TotalATR + 2, 19) = "Lane 2"
     ws.Cells(TotalATR + 2, 20) = "Lane 3"
     ws.Cells(TotalATR + 2, 21) = "Lane 4"

     TotalATR = TotalATR + 3

  If Len(qATR) = 1 Then tempATR = "   " + qATR
  If Len(qATR) = 2 Then tempATR = "  " + qATR
  If Len(qATR) = 3 Then tempATR = " " + qATR
  If Len(qATR) >= 4 Then tempATR = Right(qATR, 4)

For CrashMonth = 1 To 12 'begin searching in the original files --->
   If CrashMonth < 10 Then
     qMonth = "0" + CStr(CrashMonth)
   Else
     qMonth = CStr(CrashMonth)
   End If
```

```
' Create a new Excel file for this ATR --->
 Dim FSObj As Object
 Set FSObj = CreateObject("Scripting.FilesystemObject")

   sFolder = "c:\ATRProcessed\" + qATR + "_N\"
   If FSObj.FolderExists(sFolder) = False Then
      FSObj.CreateFolder sFolder
   End If
   sFolder = sFolder + qATR + "_Daily\"
   If FSObj.FolderExists(sFolder) = False Then
      FSObj.CreateFolder sFolder
   End If

    sFileName = sFolder + qATR + "_M" + qMonth + "_Daily.xls"
If FSObj.fileExists(sFileName) = False Then
 Dim exWBook As Object
 Dim exSheet As Object
 Set ex = CreateObject("Excel.Application")
 Set exWBook = ex.Workbooks().Add
 Set exSheet = exWBook.Worksheets("sheet1")

 ex.Visible = True
' ex.ActiveSheet.Name = "POLK I35"
' ex.Sheets.Add
' ex.ActiveSheet.Name = "WRIGHT"
 'Sheet_count = ex.ActiveWorkbook.Sheets.Count
 'MyPos = ActiveSheet.Index
 'Sheets(MyPos + 2).Activate
 ex.Cells(1, 1) = "ATR_" + qATR
 ex.Cells(2, 1) = "Month_Day"
 ex.Cells(2, 2) = "Err Type"
 For i = 5 To 16
  ex.Cells(1, i) = "Lane1"
 Next i
 For i = 18 To 29
  ex.Cells(1, i) = "Lane2"
 Next i
 For i = 31 To 42
  ex.Cells(1, i) = "Lane3"
 Next i
 For i = 44 To 55
  ex.Cells(1, i) = "Lane4"
 Next i

    p = 40
   For i = 5 To 14
     ex.Cells(2, i) = p
     p = p + 5
   Next
     ex.Cells(2, 15) = 147
     ex.Cells(2, 16) = "Valid Hrs"
    p = 40
   For i = 18 To 27
     ex.Cells(2, i) = p
     p = p + 5
   Next
     ex.Cells(2, 28) = 147
     ex.Cells(2, 29) = "Valid Hrs"
    p = 40
   For i = 31 To 40
```

```
        ex.Cells(2, i) = p
        p = p + 5
      Next
        ex.Cells(2, 41) = 147
        ex.Cells(2, 42) = "Valid Hrs"
       p = 40
      For i = 44 To 53
        ex.Cells(2, i) = p
        p = p + 5
      Next
        ex.Cells(2, 54) = 147
        ex.Cells(2, 55) = "Valid Hrs"

    ExRow = 2   'initialization --->

  For CrashDay = 1 To 31
   qDate = 99
   YearCount = 0
      For i = 1 To 4
       For j = 1 To 15
         SpeedCount(i, j) = 0
         SpeedCount(i, j) = 0
         SpeedCount(i, j) = 0
         SpeedCount(i, j) = 0
       Next j
      Next i

   For CrashYear = 1998 To 2003

     qYear = CStr(Right(CrashYear, 2))
     If CrashDay < 10 Then
      qDay = "0" + CStr(CrashDay)
     Else
      qDay = CStr(CrashDay)
     End If

     qFileName = "c:\ATR\" + qYear + "\" + qYear + qMonth + "ATR\" _
            + "D" + qMonth + qDay + qYear + ".IND"  'ATR index file
   If FSObj.fileExists(qFileName) = False Then GoTo quit11 '--> Check if the file exist

   Open qFileName For Input As #1
   NN = 0
   Do Until EOF(1)
      Line Input #1, StringRow
      sATR = Mid(StringRow, 23, 4)
      If tempATR = sATR Then
       If NN = 0 Then
         NN = 999
       Else   'To find the second row which has the same name of speed data file

' the ATR speed data file name was found --->
         NN = 0
         tempFileName = Mid(StringRow, 2, 12)
         Close #1
         stFileName = "c:\ATR\" + qYear + "\" + qYear + qMonth + "ATR\" + tempFileName  'the *.prn files
   If FSObj.fileExists(stFileName) = False Then GoTo quit11 '--> Check if the file exist
  ' ExcelOpen = 9

    ExRow = ExRow + 1
    If qDate = 99 Then
```

```
    ex.Cells(ExRow, 1) = qMonth + "_" + qDay
    qDate = 0
    ExRow = ExRow + 1
  End If
    For i = 1 To 4
   For j = 1 To 16
     RawSpeed(i, j) = 0
   Next j
 Next i
    For i = 1 To 4
      HourCount(i) = 0
      For j = 1 To 15
        DaySpdCount(i, j) = 0
        DaySpdCount(i, j) = 0
        DaySpdCount(i, j) = 0
        DaySpdCount(i, j) = 0
      Next j
    Next i

      ex.Cells(ExRow, 1) = CStr(CrashYear)

 LaneNum = 0   'read data from original speed file
 Open stFileName For Input As #2
    N = 0
    Do Until EOF(2)
      Line Input #2, StringRow
      N = N + 1
   If N = 4 Then 'verify the availablity of original speed-bin data, this is AN IMPORTANT STEP.
    If (CInt(Mid(StringRow, 14, 4)) = 40) And (CInt(Mid(StringRow, 19, 4)) = 45) Then GoTo quit1
        Close #2
        ex.Cells(ExRow, 2) = "Wrong speed-bin data file"
        GoTo quit11
   End If
      If N <= 6 Then GoTo quit1

          LaneNum = CInt(Mid(StringRow, 4, 2))
          For i = 1 To 11
            p = 9 + i * 5
            RawSpeed(LaneNum, i + 4) = CInt(Mid(StringRow, p, 4))
          Next

         SpeedCheck = 0
         For j = 5 To 15
            SpeedCheck = SpeedCheck + RawSpeed(LaneNum, j)
         Next
         If SpeedCheck > 2100 Then
           ex.Cells(ExRow, 2) = "Too High Counts"
           GoTo quit1
         End If
         For j = 5 To 15
          If ((RawSpeed(LaneNum, j) > SpeedCheck * 0.95) And (SpeedCheck > 30)) Then
           ex.Cells(ExRow, 2) = "Possible Spd Err/Bad Weather"
            GoTo quit1
          End If
         Next
         For j = 5 To 15
           DaySpdCount(LaneNum, j) = DaySpdCount(LaneNum, j) + RawSpeed(LaneNum, j)
           If j = 15 Then HourCount(LaneNum) = HourCount(LaneNum) + 1
         Next 'For j = 5 To 15
quit1:  Loop 'Do Until EOF(2)
```

```
quit15: Close #2 'close that *.PRN file
    For i = 1 To 4
     If (HourCount(i) <> 0) And (HourCount(i) <> 24) Then
      ex.Cells(ExRow, 2) = "Less than 24Hr Data"
      GoTo quit11
     End If
    Next
      YearCount = YearCount + 1
     For i = 1 To 4
      DaySum = 0
      For j = 5 To 15
       ex.Cells(ExRow, j + 13 * (i - 1)) = DaySpdCount(i, j)
       DaySum = DaySum + DaySpdCount(i, j)
       SpeedCount(i, j) = SpeedCount(i, j) + DaySpdCount(i, j)
      Next
      ex.Cells(ExRow, 4 + 13 * (i - 1)) = DaySum
      ex.Cells(ExRow, 16 + 13 * (i - 1)) = HourCount(i) ' Not always the 24hr
     Next
     GoTo quit11

    End If 'If NN = 0 Then
   Else 'If tempATR = sATR Then
    If NN = 999 Then NN = 0 'To prevent the third ATR file is wrong,
                   'for example, ATR=1100, Day=990326
   End If
  Loop 'Do Until EOF(1)
  Close #1
quit11: Next CrashYear

  For j = 5 To 15
   MidBin(j) = 37.5 + 5 * (j - 5)
  Next
  For i = 1 To 4
   MeanSpeed(i) = 0
   SumDSC(i) = 0
   Var(i) = 0
   EightyFifth(i) = 0
   AccumCount(i) = 0
  For j = 5 To 15
   SqDiff(i, j) = 0
  Next
  Next

     For i = 1 To 4
      TotalCount(i) = 0
      For j = 5 To 15
       TotalCount(i) = TotalCount(i) + SpeedCount(i, j)
      Next j
     Next i

If (TotalCount(1) = 0 And TotalCount(2) = 0 And TotalCount(3) = 0 And TotalCount(4) = 0) Then GoTo quit12

     For i = 1 To 4
      For j = 5 To 15
       ex.Cells(ExRow + 1, j + 13 * (i - 1)) = SpeedCount(i, j)
       ex.Cells(ExRow + 3, j + 13 * (i - 1)) = MidBin(j)
      Next j
      ex.Cells(ExRow + 2, 5 + 13 * (i - 1)) = TotalCount(i)
     Next i
```

```
' ex.Cells(ExRow + 5, 3) = "Total Hours"
' For i = 1 To 4
'    ex.Cells(ExRow + 5, 5 + 12 * (i - 1)) = HourCount(i)
' Next
  ex.Cells(ExRow + 1, 3) = "Speed Bin Count"
  ex.Cells(ExRow + 2, 3) = "Total Counts"
  ex.Cells(ExRow + 3, 3) = "Mid Pt of Each Bin"
  ex.Cells(ExRow + 4, 3) = "Counts * Mid Pt"
  ex.Cells(ExRow + 5, 3) = "Total(Mid Pt*Count)"
  ex.Cells(ExRow + 6, 3) = "Mean Speed"
  ex.Cells(ExRow + 7, 3) = "Sq Diff"
  ex.Cells(ExRow + 8, 3) = "SqDiff * Count"
  ex.Cells(ExRow + 9, 3) = "Total(SqDiff*Count)"
  ex.Cells(ExRow + 10, 3) = "Variance"
  ex.Cells(ExRow + 11, 3) = "Pre 85 (TotalCount*0.85)"
  ex.Cells(ExRow + 12, 3) = "Accumulated Count"
  ex.Cells(ExRow + 13, 3) = "85%th Speed"

 For i = 1 To 4  'main calculation
   If TotalCount(i) = 0 Then GoTo quit9

   TotalCMB(i) = 0
   For j = 5 To 15
     CountMultiplyBin(j) = SpeedCount(i, j) * MidBin(j)
     TotalCMB(i) = TotalCMB(i) + CountMultiplyBin(j)
     ex.Cells(ExRow + 4, j + 13 * (i - 1)) = CountMultiplyBin(j)
   Next
   ex.Cells(ExRow + 5, 5 + 13 * (i - 1)) = TotalCMB(i)

   MeanSpeed(i) = Round(TotalCMB(i) / TotalCount(i), 2)
   ex.Cells(ExRow + 6, 5 + 13 * (i - 1)) = MeanSpeed(i)

   For j = 5 To 15
     SqDiff(i, j) = (MidBin(j) - MeanSpeed(i)) ^ 2
     ex.Cells(ExRow + 7, j + 13 * (i - 1)) = SqDiff(i, j)
     ex.Cells(ExRow + 8, j + 13 * (i - 1)) = SqDiff(i, j) * SpeedCount(i, j)
     SumDSC(i) = SumDSC(i) + SqDiff(i, j) * SpeedCount(i, j)
   Next
   ex.Cells(ExRow + 9, 5 + 13 * (i - 1)) = SumDSC(i)
   Var(i) = Round(SumDSC(i) / TotalCount(i), 2)
   ex.Cells(ExRow + 10, 5 + 13 * (i - 1)) = Var(i)

   Pre85(i) = Round(TotalCount(i) * 0.85, 2)
   ex.Cells(ExRow + 11, 5 + 13 * (i - 1)) = Pre85(i)
   For j = 5 To 15
     AccumCount(i) = AccumCount(i) + SpeedCount(i, j)
     ex.Cells(ExRow + 12, j + 13 * (i - 1)) = AccumCount(i)
     If Pre85(i) <= AccumCount(i) Then
       EightyFifth(i) = MidBin(j) - ((AccumCount(i) - Pre85(i)) * (MidBin(j) - MidBin(j - 1)) / SpeedCount(i, j))
       ex.Cells(ExRow + 13, 5 + 13 * (i - 1)) = Round(EightyFifth(i), 2)
       GoTo quit9
     End If
   Next
quit9: Next i 'For i = 1 To 4  main calculation
   ExRow = ExRow + 15

    ws.Cells(TotalATR, 1) = qMonth + "_" + qDay

    For j = 3 To 6
      ws.Cells(TotalATR, j) = MeanSpeed(j - 2)
```

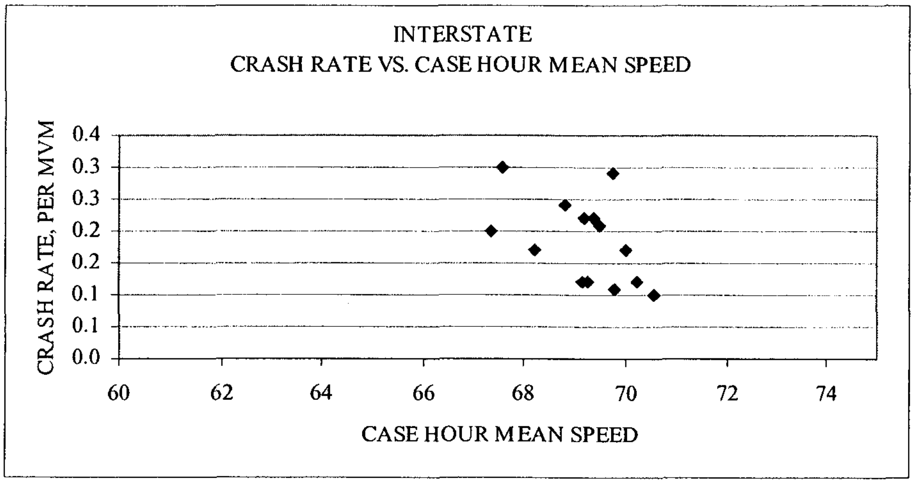
```
      Next
      For j = 8 To 11
        ws.Cells(TotalATR, j) = Round(EightyFifth(j - 7), 2)
      Next
      For j = 13 To 16
        ws.Cells(TotalATR, j) = Var(j - 12)
      Next
      For j = 18 To 21
       If YearCount <> 0 Then
        ws.Cells(TotalATR, j) = Round(TotalCount(j - 17) / YearCount, 0)
       End If
      Next
     TotalATR = TotalATR + 1
quit12:   Next CrashDay
      exWBook.SaveAs sFileName
      exWBook.Close
      ex.Quit 'quit Excel
      Set exWBook = Nothing
      Set exSheet = Nothing
      Set ex = Nothing
 Else 'If FSObj.fileExists(sFileName) = False Then
   ErrMsg = "The file has existed in the folder. No more process is needed."
 End If
      Set FSObj = Nothing

  Next CrashMonth

TotalATR = TotalATR + 2
ATRNum = ATRNum + 1
Loop Until IsEmpty(ws.Cells(ATRNum, 1))

   wb.Save
   wb.Close
   myExl.Quit
   Set ws = Nothing
   Set wb = Nothing
   Set myExl = Nothing

   APIBeep 1000, 300
     Call Delay
   APIBeep 1250, 300
     Call Delay
   APIBeep 1500, 300
     Call Delay
   APIBeep 1750, 300
     Call Delay
   APIBeep 2000, 300

 End Sub

Private Sub Command3_Click()
   Unload Form1
End Sub

Private Sub Delay()

      For tTimer = 1 To 1500 'Delay loop between beeps
      Next tTimer

End Sub
```

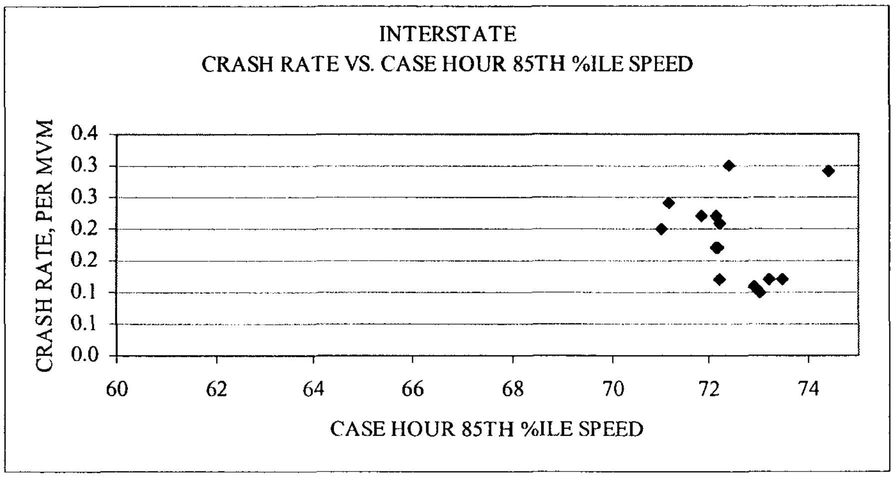
APPENDIX B – SUMMARY TABLES OF SPEED METRICS BY TYPE OF FACILITY

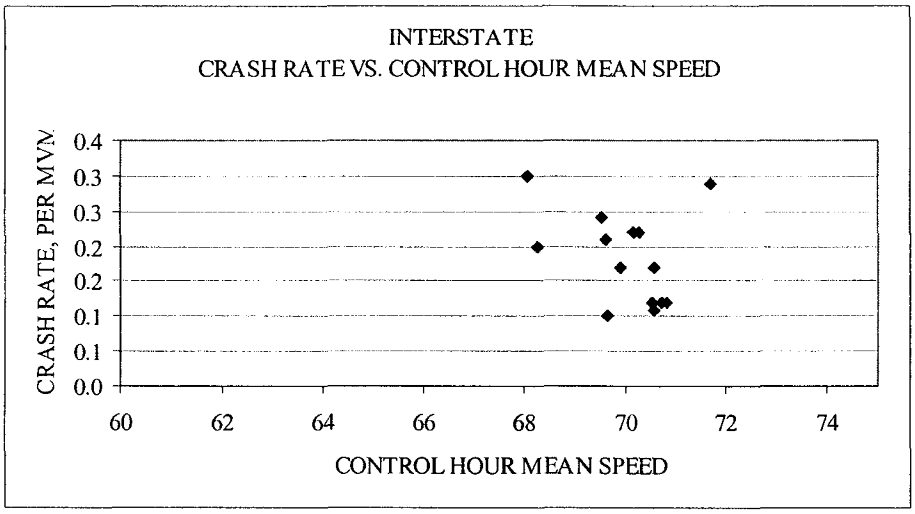
PLOTS OF PARAMETER COMPARISONS

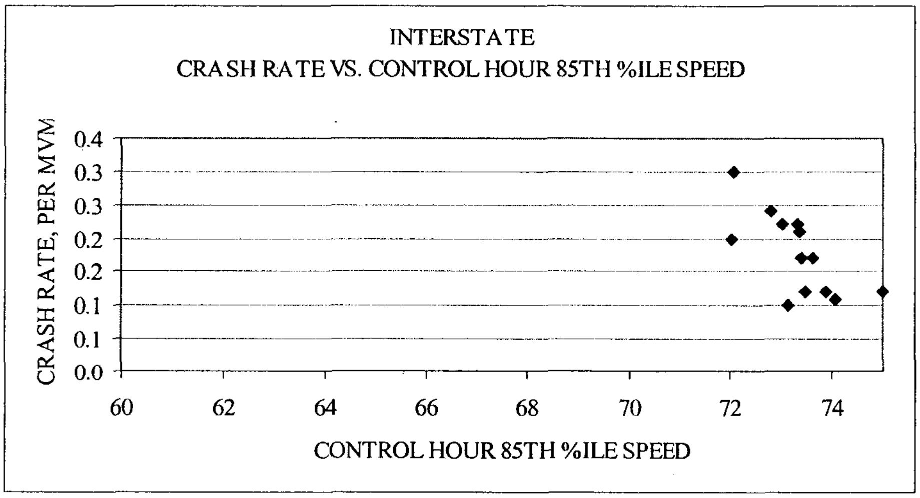
INTERSTATE HIGHWAY

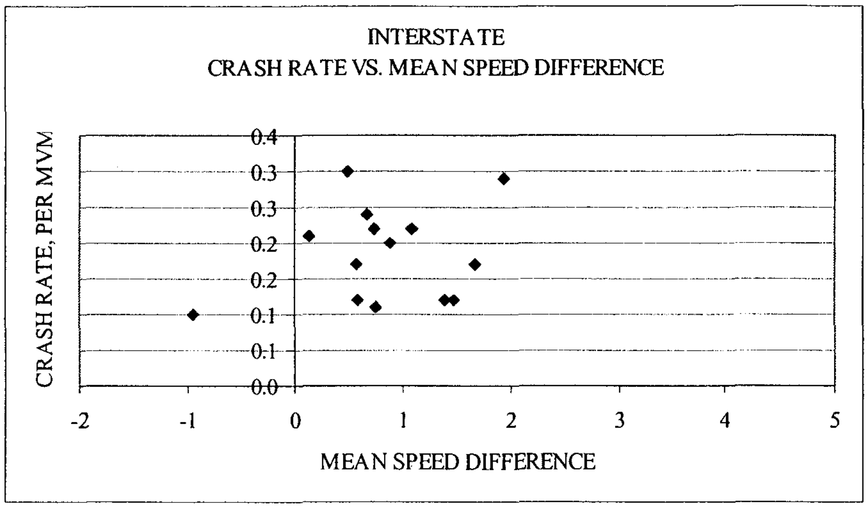
	AVG SPEED		85TH %ILE SPEED		CRASH						DEPARTURE		
ATR NO.	CASE	CONT	CASE	CONT	RATE	DENS	LMT	VOL	ADT	VOL/ADT	CASE	CONT	DISP
100	69.47	69.60	72.21	73.38	0.21	1.63	65	846	21200	0.0399	7.21	8.38	2.74
102	69.13	70.52	73.48	75.01	0.12	0.52	65	428	11900	0.0360	8.47	10.01	4.34
104	70.23	70.82	73.20	73.89	0.12	0.84	65	840	18600	0.0452	8.20	8.89	2.97
105	68.82	69.50	71.16	72.81	0.24	0.98	65	512	11300	0.0453	6.16	7.81	2.34
106	69.76	70.53	72.91	74.07	0.11	0.51	65	662	13200	0.0502	7.91	9.07	3.15
109	69.38	70.13	72.12	73.33	0.22	1.31	65	623	16600	0.0375	7.12	8.33	2.74
110	68.20	69.86	72.13	73.41	0.17	1.40	65	801	22400	0.0358	7.13	8.41	3.93
111	69.24	70.71	72.20	73.49	0.12	1.41	65	1733	31100	0.0557	7.20	8.49	2.96
113	69.18	70.26	71.82	73.02	0.22	1.05	65	595	12900	0.0461	6.82	8.02	2.65
115	69.75	71.68	74.39	75.33	0.29	2.02	65	864	19200	0.0450	9.39	10.33	4.63
116	67.35	68.23	71.03	72.04	0.20	2.46	65	1578	34100	0.0463	6.03	7.04	3.67
117	67.56	68.05	72.38	72.05	0.30	7.24	65	1585	65800	0.0241	7.38	7.05	4.82
POLK 1-35	70.55	69.60	73.02	73.13	0.10	1.19	65	1593	34200	0.0466	8.02	8.13	2.46
WRIGHT	69.98	70.55	72.17	73.64	0.17	0.95	65	915	15000	0.0610	7.17	8.64	2.18
AVG.	69.19	70.00	72.44	73.47	0.19	1.68		970		0.04	7.44	8.47	3.26

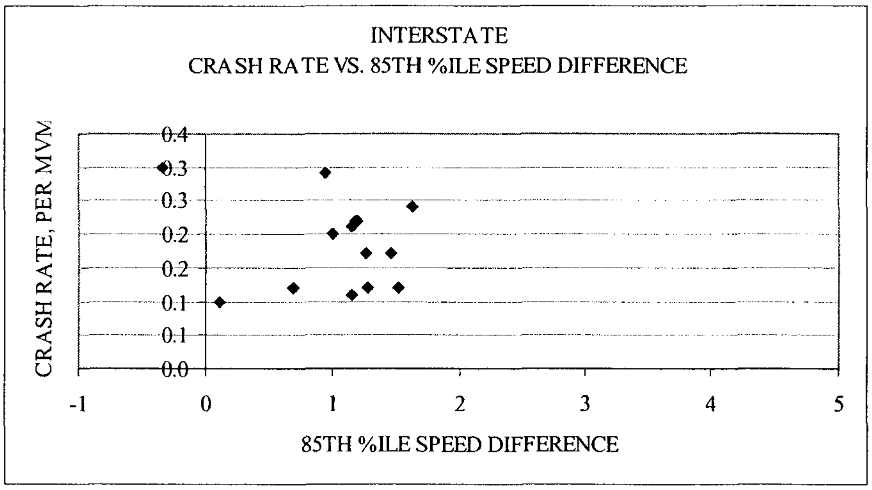


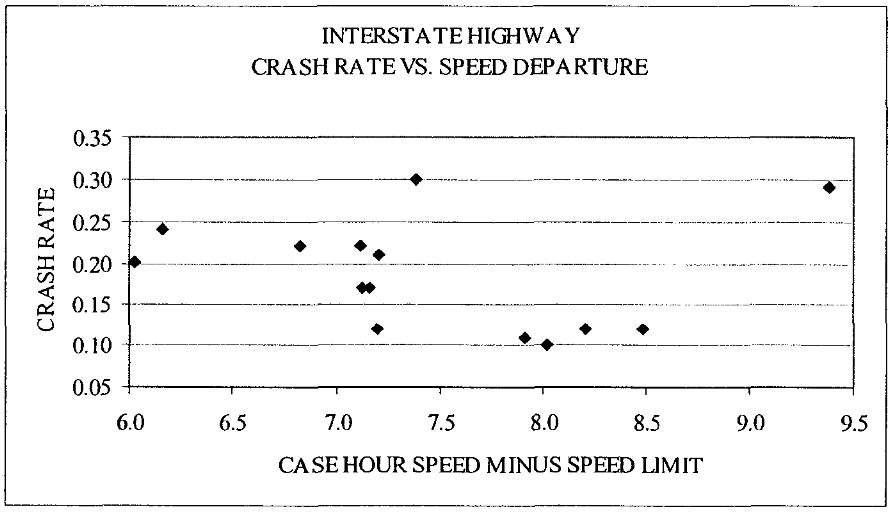

INTERSTATE
CRASH RATE VS. CASE HOUR 85TH %ILE SPEED
CRASH RATE, PER MVM
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
60
62
64
66
68
70
72
74
CASE HOUR 85TH %ILE SPEED

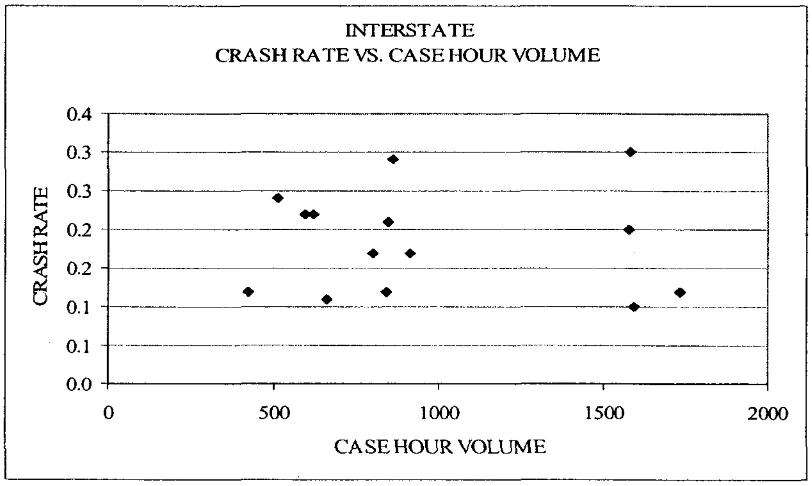

INTERSTATE
CRASH RATE VS. CONTROL HOUR MEAN SPEED
CRASH RATE, PER MVM
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
60
62
64
66
68
70
72
74
CONTROL HOUR MEAN SPEED

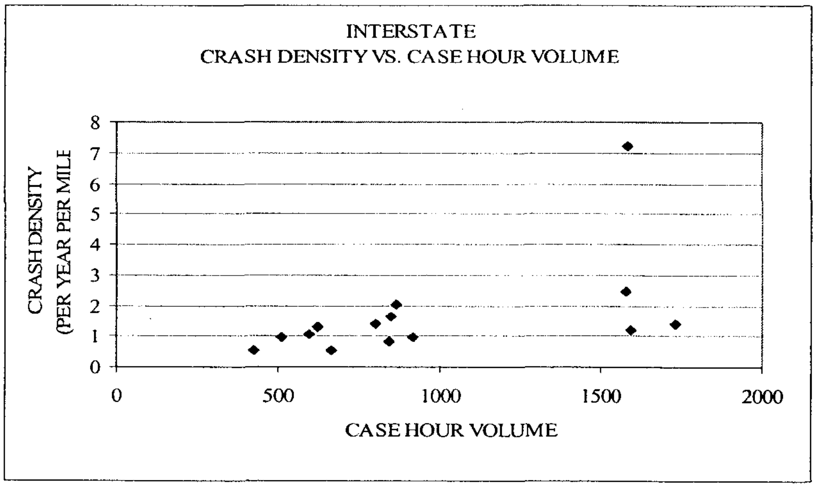

INTERSTATE
CRASH RATE VS. CONTROL HOUR 85TH %ILE SPEED
CRASH RATE, PER MVM
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
60
62
64
66
68
70
72
74
CONTROL HOUR 85TH %ILE SPEED

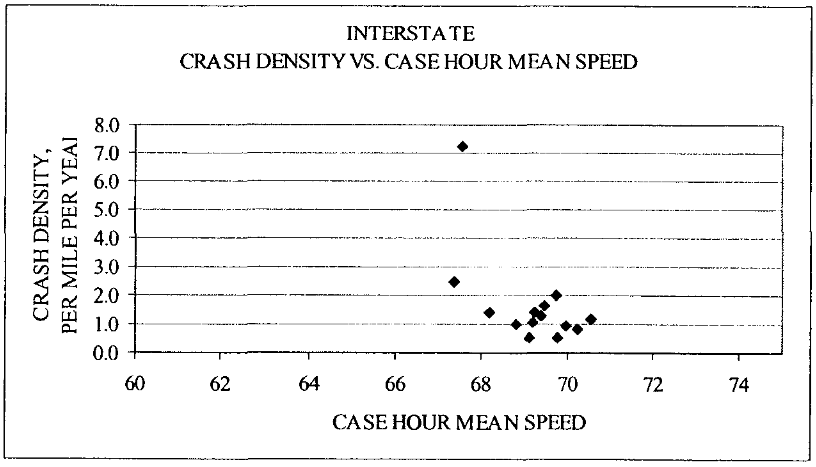

INTERSTATE
CRASH RATE VS. MEAN SPEED DIFFERENCE
CRASH RATE, PER MVM
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
-2
-1
0
1
2
3
4
5
MEAN SPEED DIFFERENCE

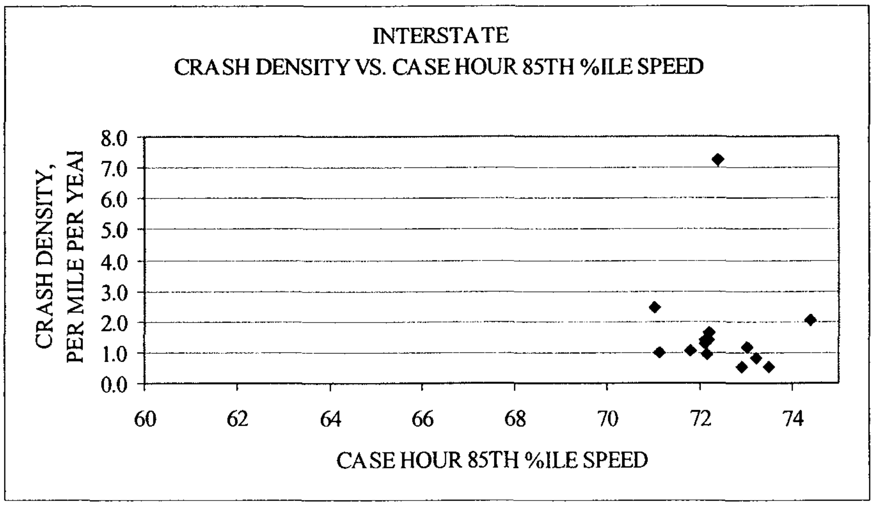

INTERSTATE
CRASH RATE VS. 85TH %ILE SPEED DIFFERENCE
CRASH RATE, PER MVM
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
-1
0
1
2
3
4
5
85TH %ILE SPEED DIFFERENCE

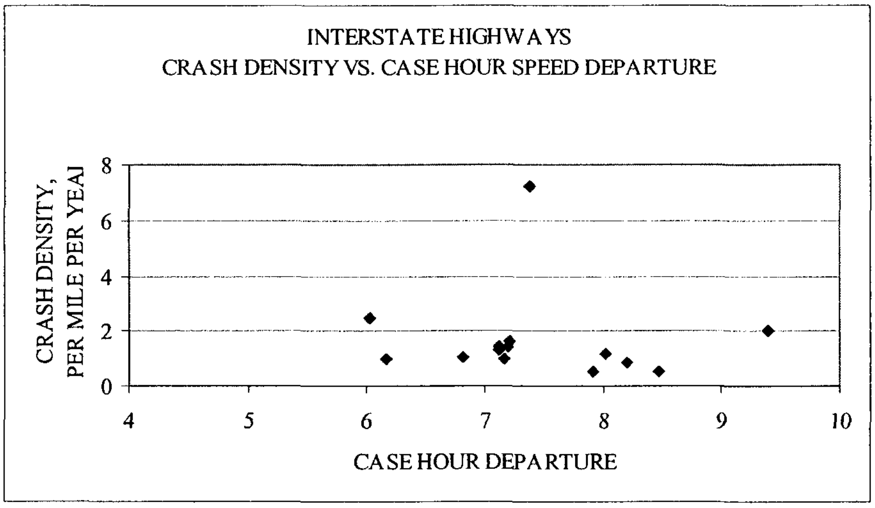

INTERSTATE HIGHWAY
CRASH RATE VS. SPEED DEPARTURE
CRASH RATE
0.35
0.30
0.25
0.20
0.15
0.10
0.05
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
CASE HOUR SPEED MINUS SPEED LIMIT

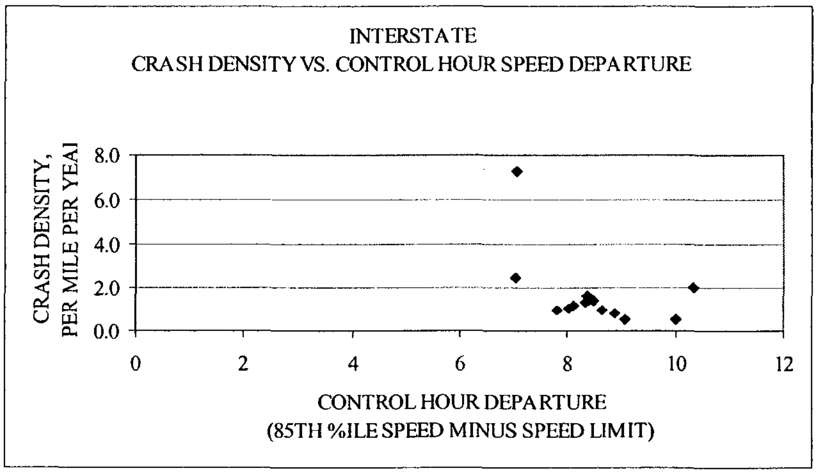

INTERSTATE
CRASH RATE VS. CASE HOUR VOLUME
CRASH RATE
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
0
500
1000
1500
2000
CASE HOUR VOLUME

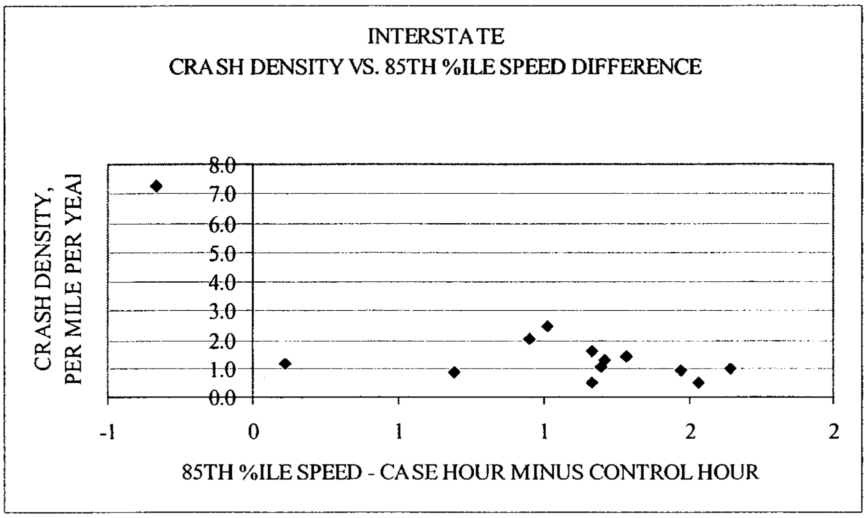

INTERSTATE
CRASH DENSITY VS. CASE HOUR VOLUME
CRASH DENSITY
(PER YEAR PER MILE
8
7
6
5
4
3
2
1
0
0
500
1000
1500
2000
CASE HOUR VOLUME

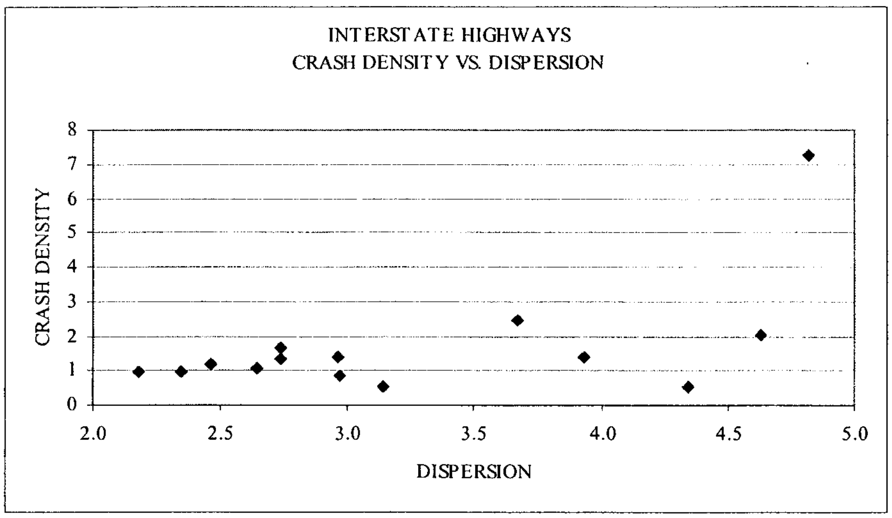

INTERSTATE
CRASH DENSITY VS. CASE HOUR MEAN SPEED
CRASH DENSITY,
PER MILE PER YEAI
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
60
62
64
66
68
70
72
74
CASE HOUR MEAN SPEED


INTERSTATE
CRASH DENSITY VS. CASE HOUR 85TH %ILE SPEED
CRASH DENSITY, PER MILE PER YEAI
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
60
62
64
66
68
70
72
74
CASE HOUR 85TH %ILE SPEED


INTERSTATE HIGHWAYS
CRASH DENSITY VS. CASE HOUR SPEED DEPARTURE
CRASH DENSITY, PER MILE PER YEAI
8
6
4
2
0
4
5
6
7
8
9
10
CASE HOUR DEPARTURE

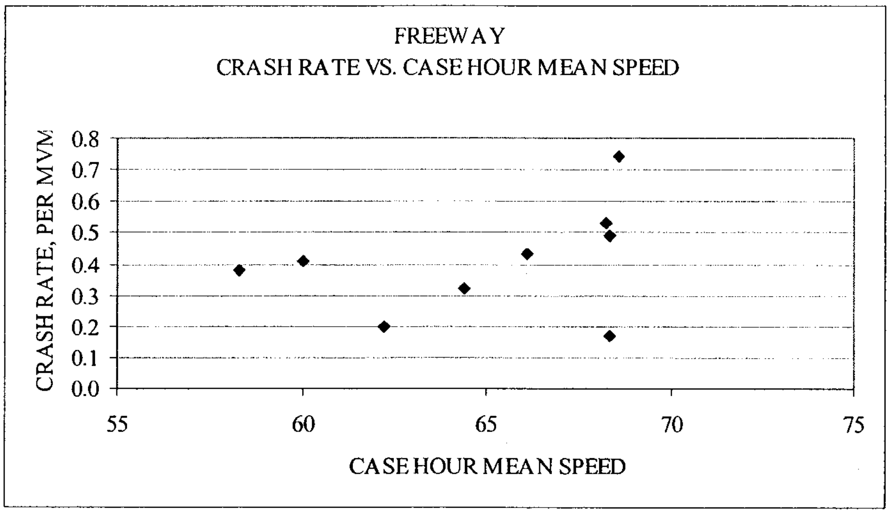

INTERSTATE
CRASH DENSITY VS. CONTROL HOUR SPEED DEPARTURE
CRASH DENSITY, PER MILE PER YEAI
8.0
6.0
4.0
2.0
0.0
0
2
4
6
8
10
12
CONTROL HOUR DEPARTURE
(85TH %ILE SPEED MINUS SPEED LIMIT)

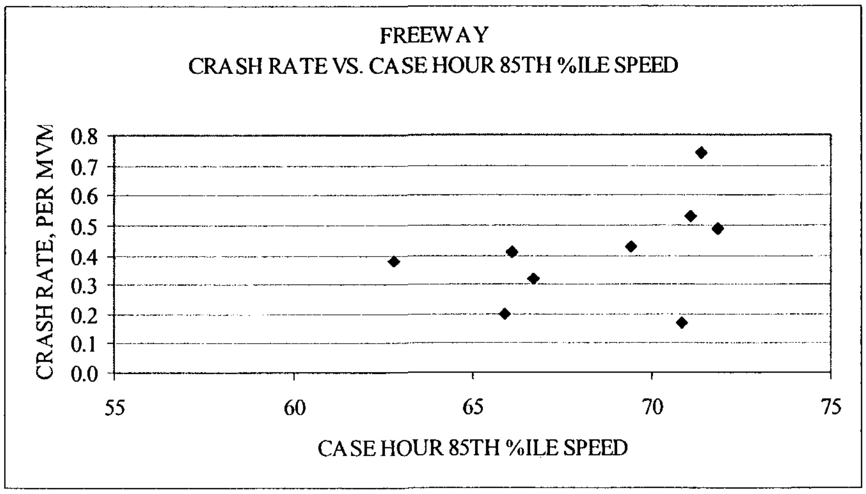

INTERSTATE
CRASH DENSITY VS. 85TH %ILE SPEED DIFFERENCE
CRASH DENSITY, PER MILE PER YEAI
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1
0
1
1
2
2
85TH %ILE SPEED - CASE HOUR MINUS CONTROL HOUR

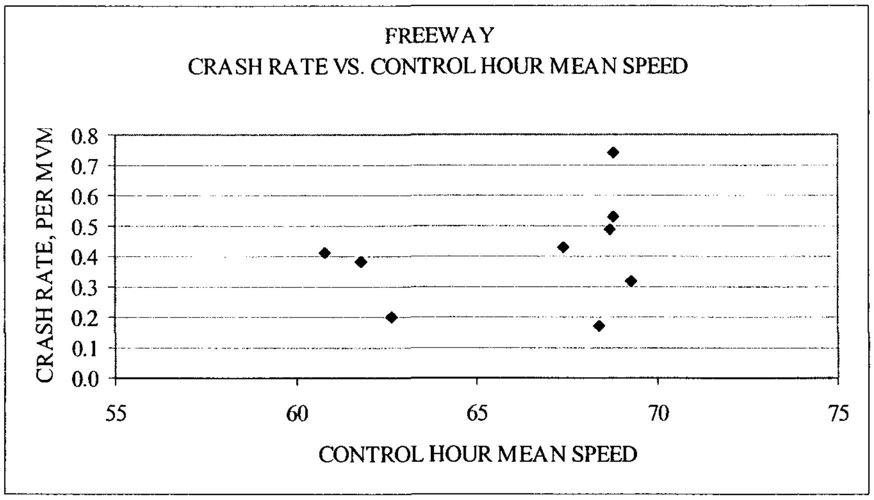

INTERSTATE HIGHWAYS
CRASH DENSITY VS. DISPERSION
CRASH DENSITY
8
7
6
5
4
3
2
1
0
2.0
2.5
3.0
3.5
4.0
4.5
5.0
DISPERSION

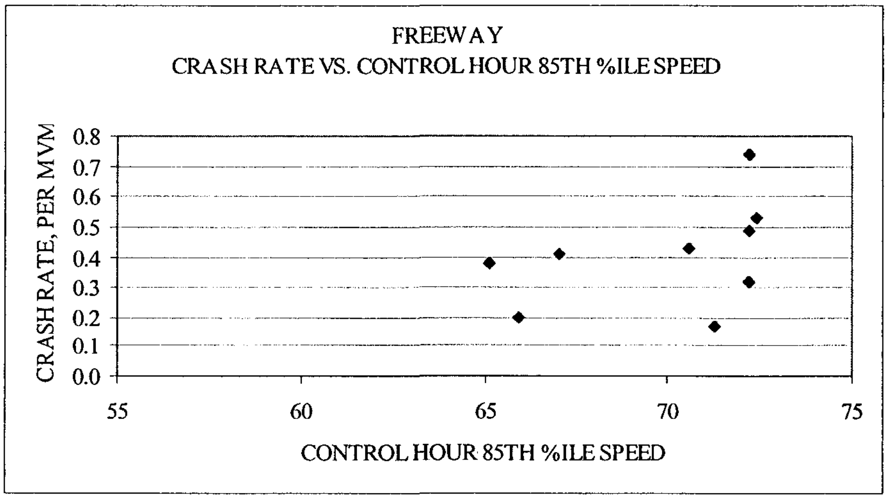
FREEWAYS (W/O INTERSTATES)

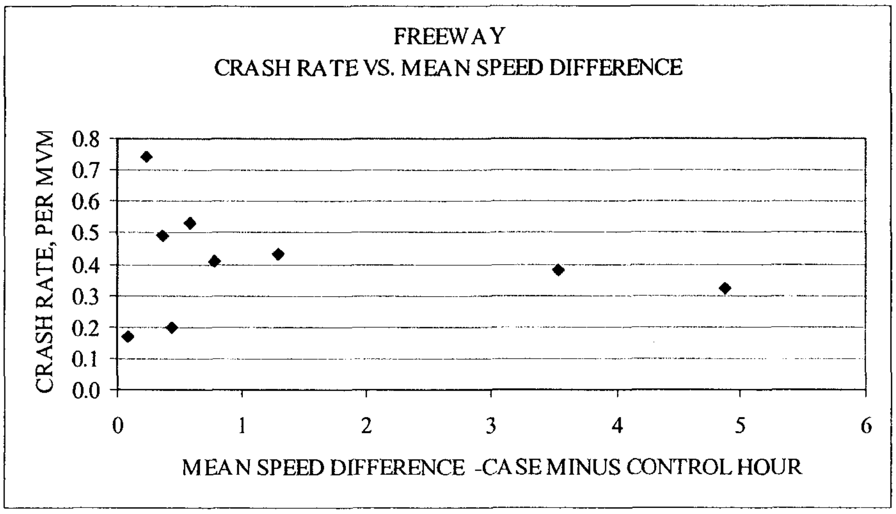
	AVG SPEED		85TH %ILE SPEED		CRASH						DEPARTURE		
ATR	CASE	CONT	CASE	CONT	RATE	DENS	LIMIT	VOL	ADT	VOL/ADT	CASE	CONT	DISP
206	66.11	67.40	69.42	70.60	0.43	1.79	65	535	11300	0.047	4.42	5.60	3.31
242	68.21	68.80	71.13	72.40	0.53	3.07	65	675	15900	0.042	6.13	7.40	2.92
245	68.33	68.70	71.85	72.20	0.49	1.70	65	470	9500	0.049	6.85	7.20	3.52
247	68.56	68.80	71.39	72.20	0.74	1.85	65	286	6800	0.042	6.39	7.20	2.83
249	64.41	69.30	66.70	72.20	0.32	1.90	65	732	16100	0.045	1.70	7.20	2.29
250	68.31	68.40	70.89	71.30	0.17	1.29	65	858	20600	0.042	5.89	6.30	2.58
701	62.21	62.65	65.90	65.90	0.20	4.56	60	1391	63400	0.022	5.90	5.90	3.69
704	60.02	60.80	66.11	67.00	0.41	11.30	55	3852	76000	0.051	11.11	12.00	6.09
705	58.26	61.80	62.80	65.10	0.38	6.78	55	2278	48400	0.047	7.80	10.10	4.54
AVG.	64.94	66.29	68.47	69.88	0.41	3.80		1231		0.043	6.24	7.66	3.53

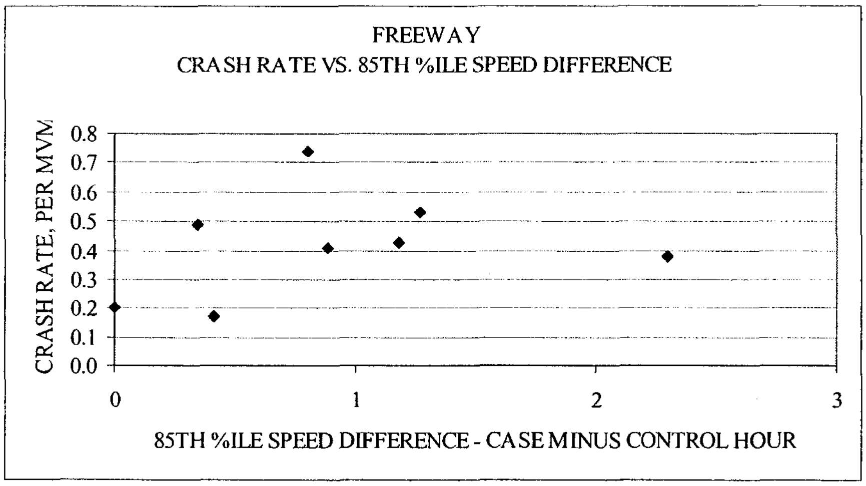


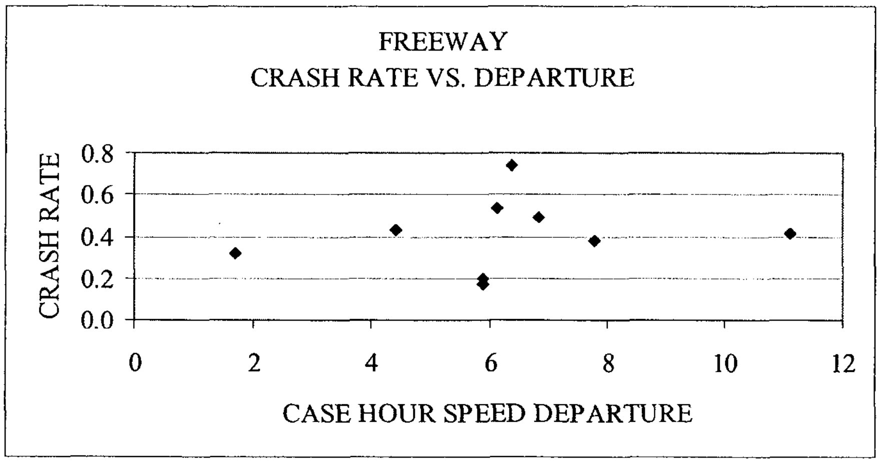

FREEWAY
CRASH RATE VS. CASE HOUR 85TH %ILE SPEED
CRASH RATE, PER MVM
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
55
60
65
70
75
CASE HOUR 85TH %ILE SPEED

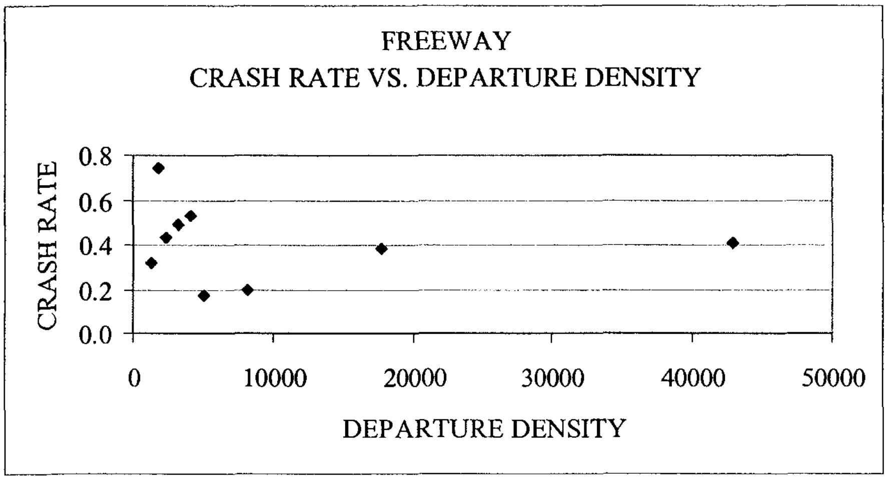

FREEWAY
CRASH RATE VS. CONTROL HOUR MEAN SPEED
CRASH RATE, PER MVM
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
55
60
65
70
75
CONTROL HOUR MEAN SPEED

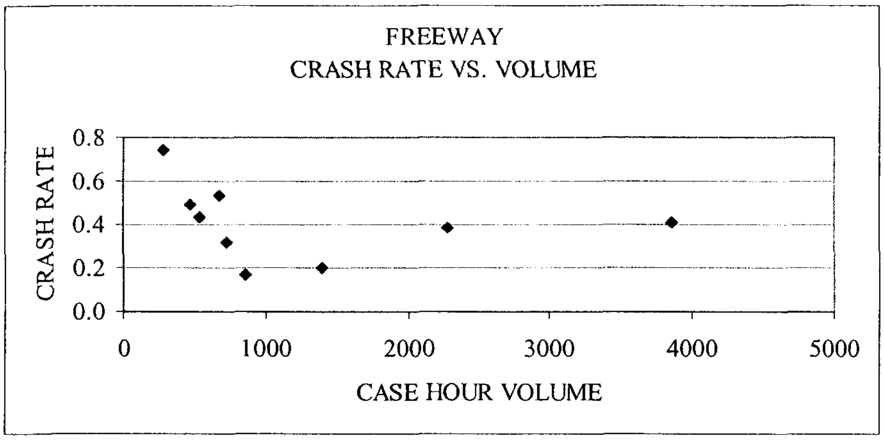

FREEWAY
CRASH RATE VS. CONTROL HOUR 85TH %ILE SPEED
CRASH RATE, PER MVM
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
55
60
65
70
75
CONTROL HOUR 85TH %ILE SPEED

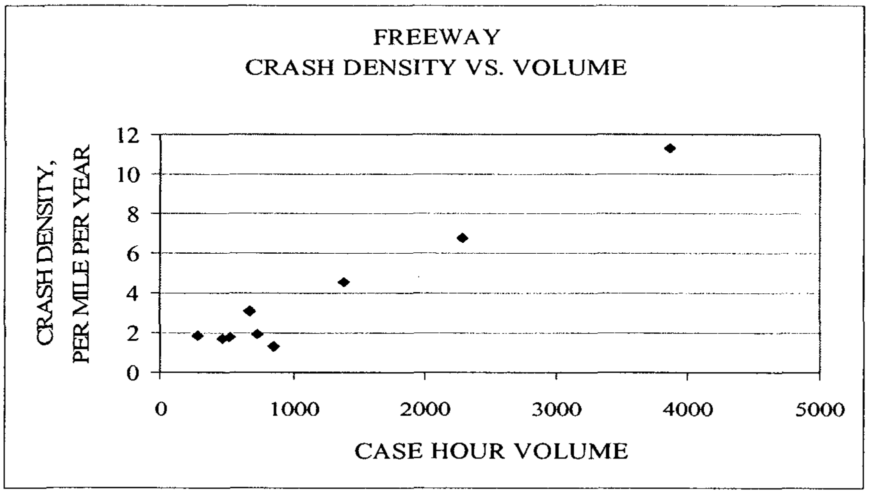

FREEWAY
CRASH RATE VS. MEAN SPEED DIFFERENCE
CRASH RATE, PER MVM
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
MEAN SPEED DIFFERENCE -CASE MINUS CONTROL HOUR

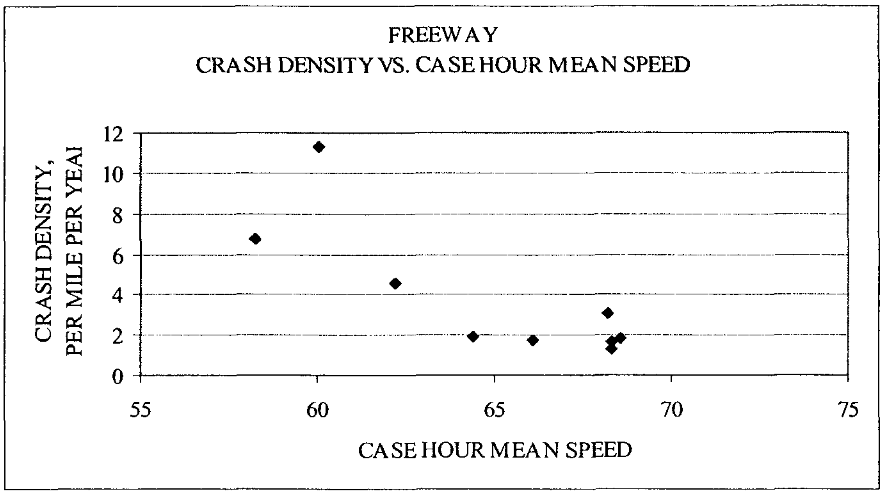

FREEWAY
CRASH RATE VS. 85TH %ILE SPEED DIFFERENCE
CRASH RATE, PER MVM
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
85TH %ILE SPEED DIFFERENCE - CASE MINUS CONTROL HOUR

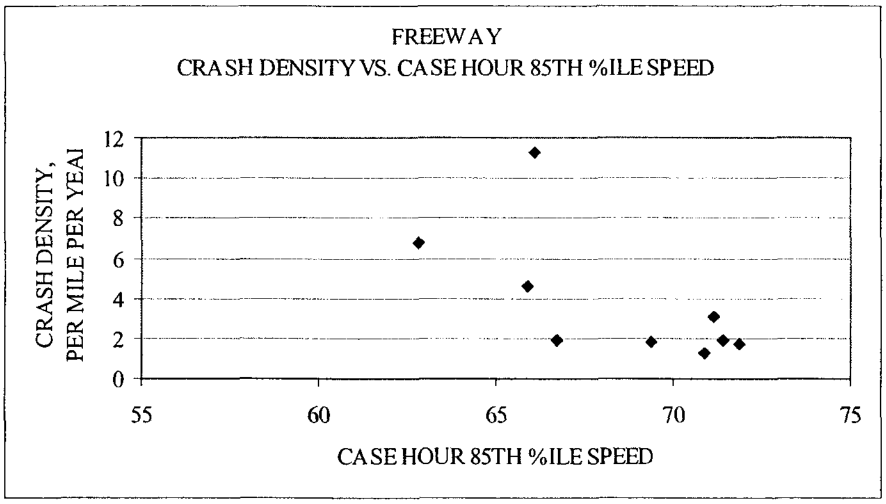

FREEWAY
CRASH RATE VS. DEPARTURE
CRASH RATE
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
CASE HOUR SPEED DEPARTURE

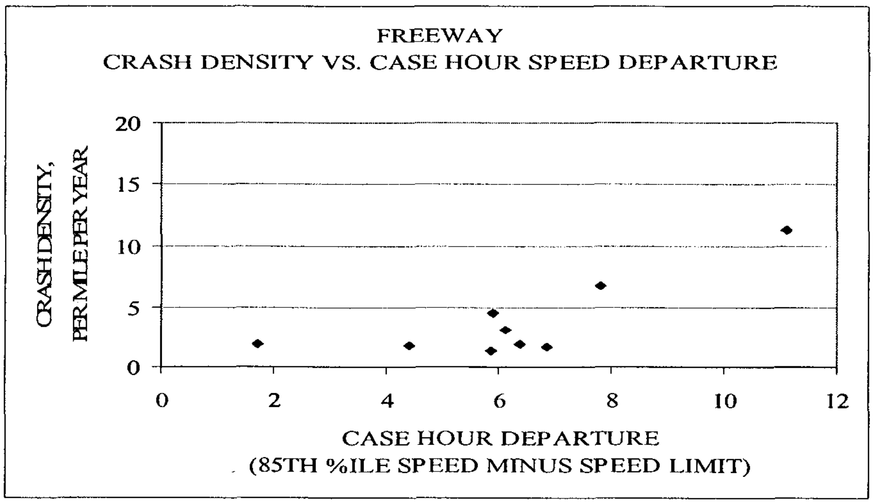

FREEWAY
CRASH RATE VS. DEPARTURE DENSITY
CRASH RATE
0.8
0.6
0.4
0.2
0.0
0
10000
20000
30000
40000
50000
DEPARTURE DENSITY

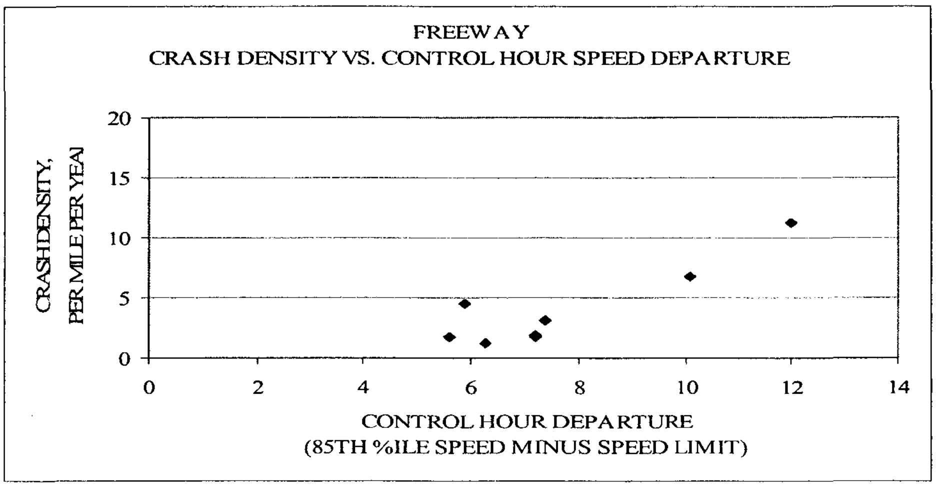

FREEWAY
CRASH RATE VS. VOLUME
CRASH RATE
0.8
0.6
0.4
0.2
0.0
0
1000
2000
3000
4000
5000
CASE HOUR VOLUME

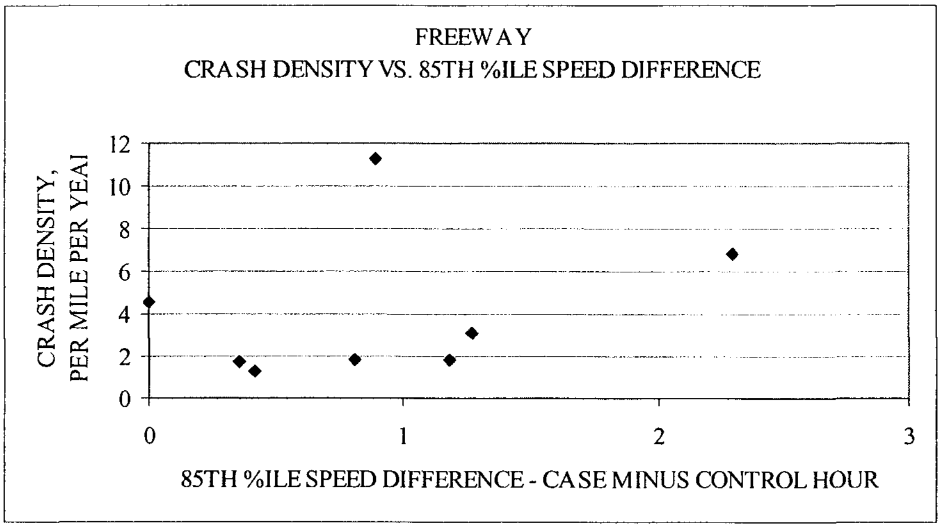

FREEWAY
CRASH DENSITY VS. VOLUME
CRASH DENSITY,
PER MILE PER YEAR
12
10
8
6
4
2
0
0
1000
2000
3000
4000
5000
CASE HOUR VOLUME


FREEWAY
CRASH DENSITY VS. CASE HOUR MEAN SPEED
CRASH DENSITY,
PER MILE PER YEAI
12
10
8
6
4
2
0
55
60
65
70
75
CASE HOUR MEAN SPEED


FREEWAY
CRASH DENSITY VS. CASE HOUR 85TH %ILE SPEED
CRASH DENSITY,
PER MILE PER YEAI
12
10
8
6
4
2
0
55
60
65
70
75
CASE HOUR 85TH %ILE SPEED

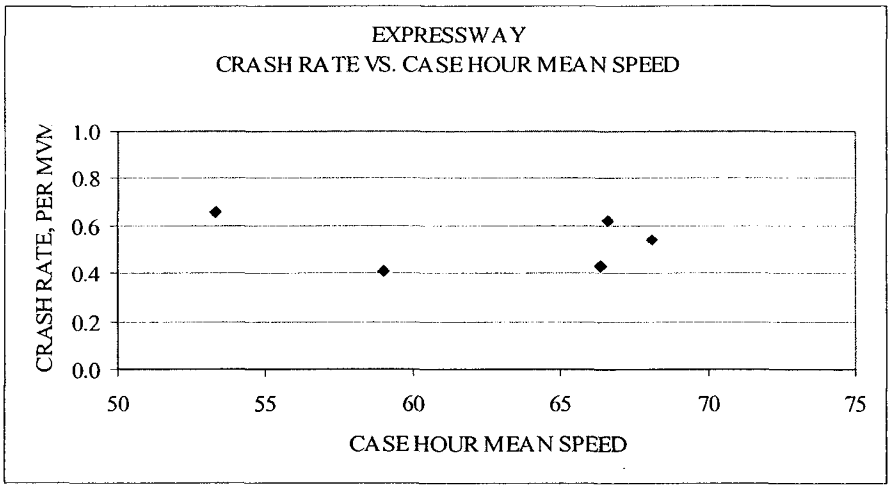

FREEWAY
CRASH DENSITY VS. CASE HOUR SPEED DEPARTURE
CRASH DENSITY,
PER MILE PER YEAR
20
15
10
5
0
0
2
4
6
8
10
12
CASE HOUR DEPARTURE
(85TH %ILE SPEED MINUS SPEED LIMIT)

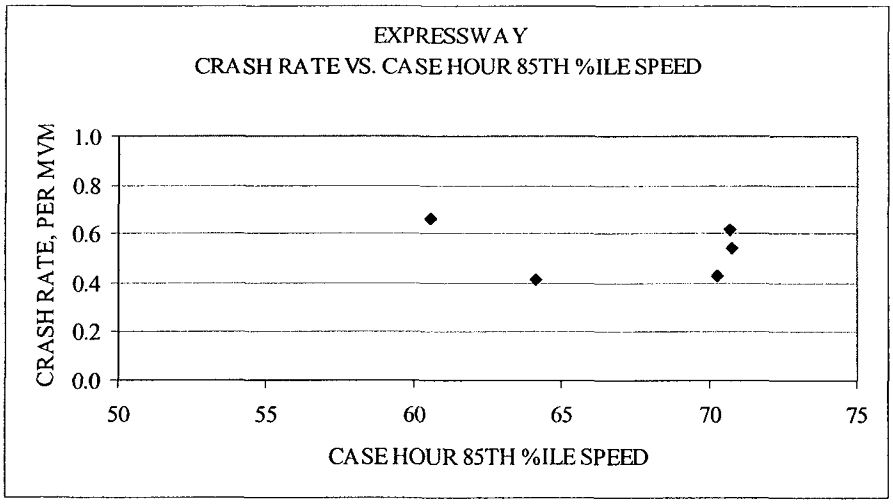

FREEWAY
CRASH DENSITY VS. CONTROL HOUR SPEED DEPARTURE
CRASH DENSITY, PER MILE PER YEAR
20
15
10
5
0
0
2
4
6
8
10
12
14
CONTROL HOUR DEPARTURE (85TH %ILE SPEED MINUS SPEED LIMIT)

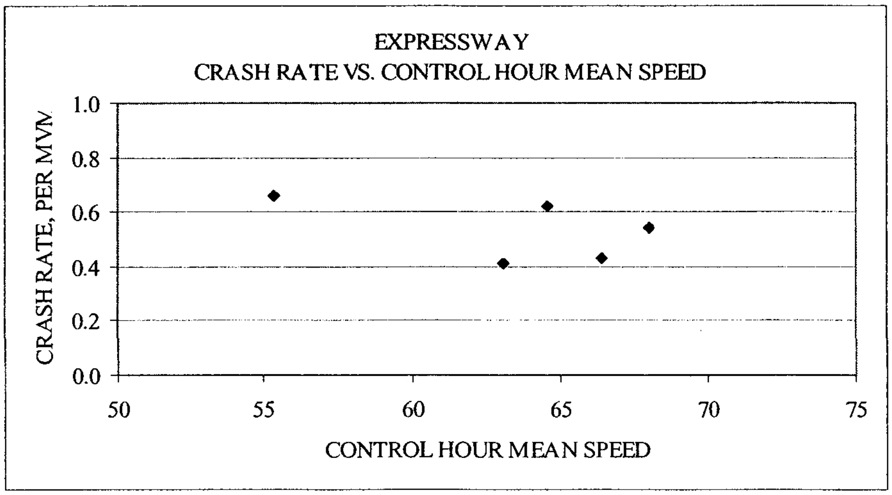

FREEWAY
CRASH DENSITY VS. 85TH %ILE SPEED DIFFERENCE
CRASH DENSITY, PER MILE PER YEAR
12
10
8
6
4
2
0
0
1
2
3
85TH %ILE SPEED DIFFERENCE - CASE MINUS CONTROL HOUR

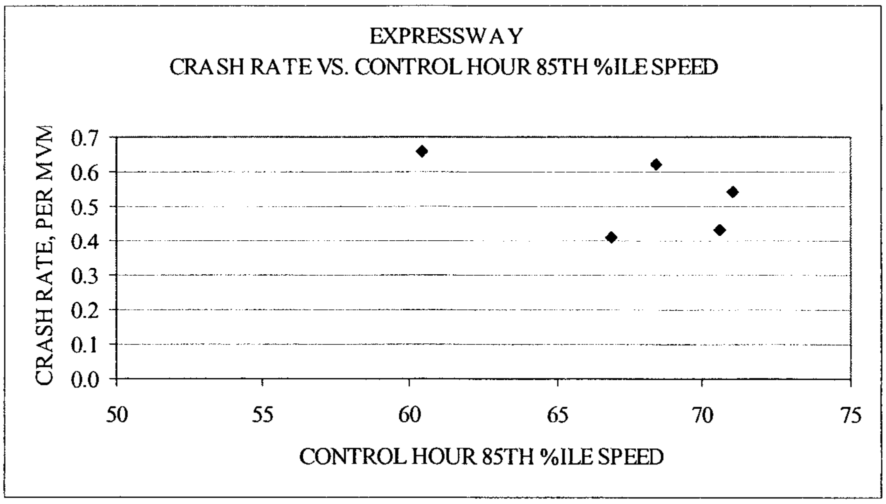
EXPRESSWAYS

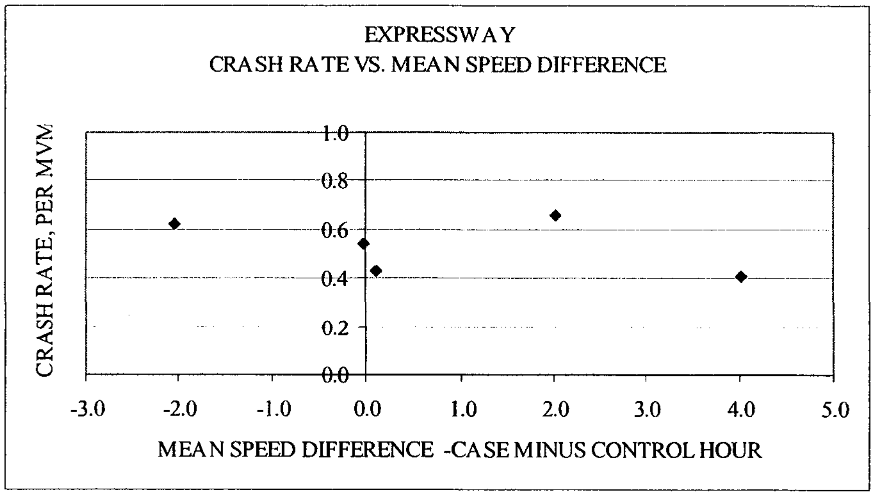
	AVG SPEED		85TH %ILE SPEED		CRASH						DEPARTURE		
ATR	CASE	CONT	CASE	CONT	RATE	DENS	LIMIT	VOL	ADT	VOL/ADT	CASE	CONT	DISP
204	59.01	63.03	64.09	66.84	0.41	1.55	65	439	10400	0.042	-0.91	1.84	5.08
205	68.07	68.05	70.74	71.05	0.54	1.53	65	523	7800	0.067	5.74	6.05	2.67
217	53.30	55.33	60.56	60.41	0.66	3.48	55	776	14500	0.054	5.56	5.41	7.26
243	66.34	66.45	70.25	70.58	0.43	1.44	65	506	9100	0.056	5.25	5.58	3.91
246	66.59	64.54	70.71	68.41	0.62	2.13	55	432	9800	0.044	15.71	13.41	4.13
AVG.	62.66	63.48	67.27	67.46	0.53	2.03		535		0.052	6.27	6.46	4.61

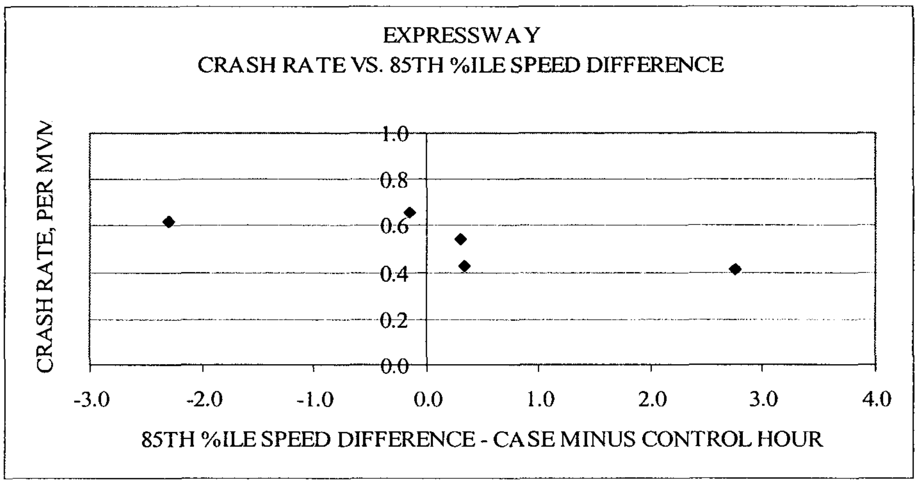


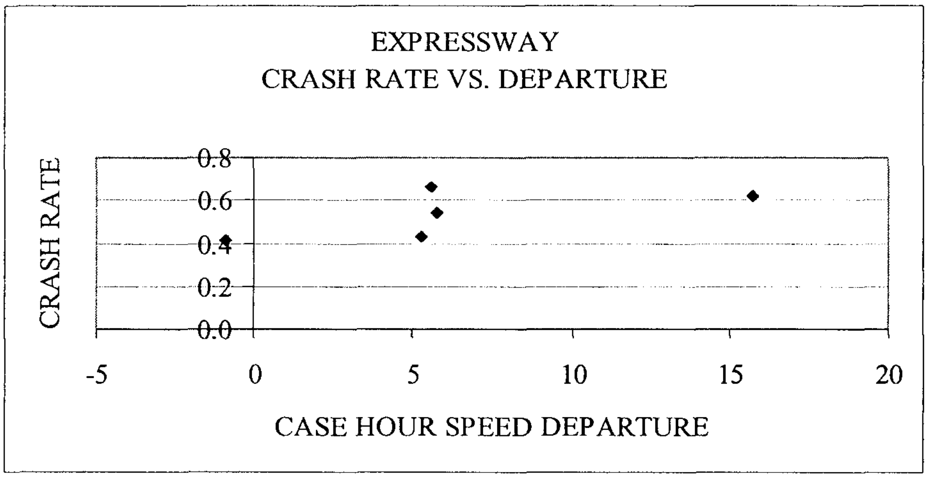


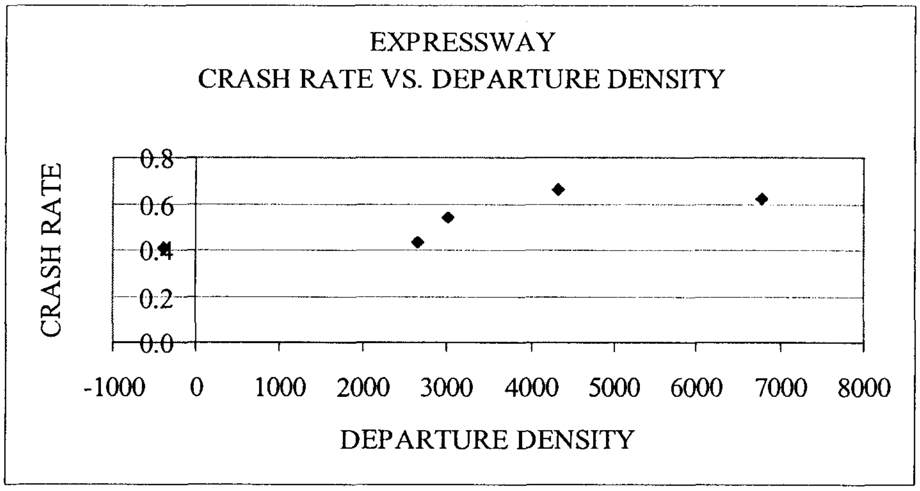

EXPRESSWAY
CRASH RATE VS. CONTROL HOUR MEAN SPEED
CRASH RATE, PER MVM
1.0
0.8
0.6
0.4
0.2
0.0
50
55
60
65
70
75
CONTROL HOUR MEAN SPEED

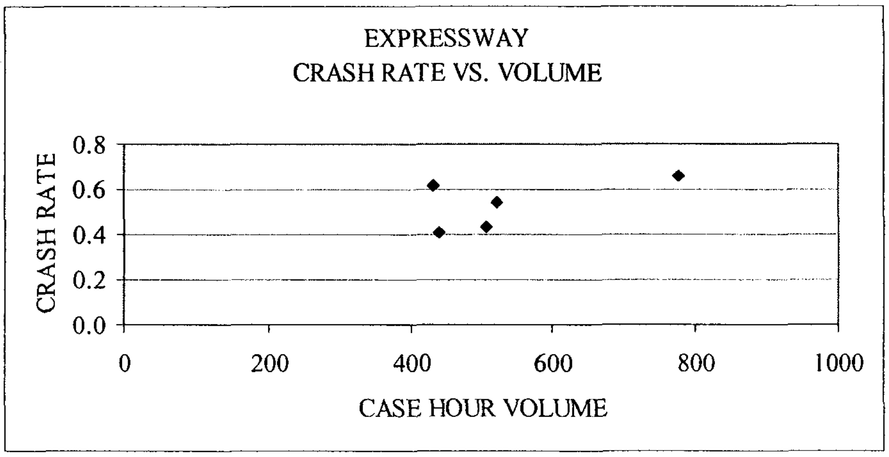

EXPRESSWAY
CRASH RATE VS. CONTROL HOUR 85TH %ILE SPEED
CRASH RATE, PER MVM
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
50
55
60
65
70
75
CONTROL HOUR 85TH %ILE SPEED

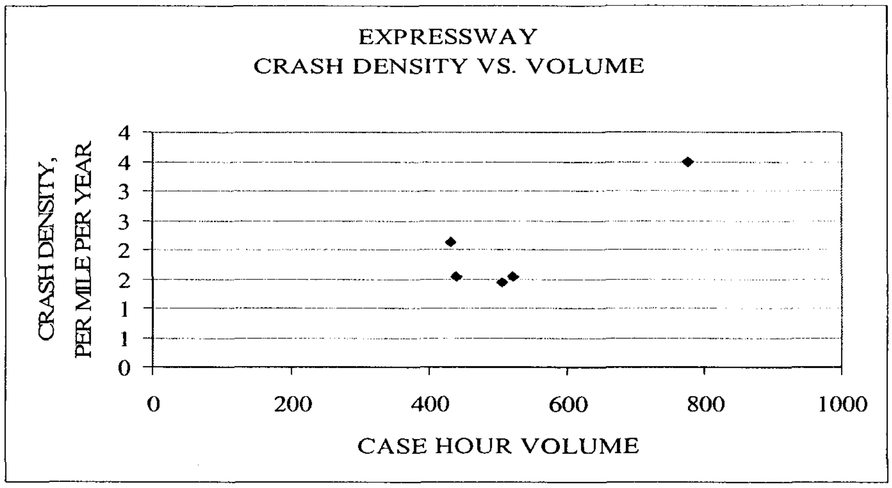

EXPRESSWAY
CRASH RATE VS. MEAN SPEED DIFFERENCE
CRASH RATE, PER MVM
1.0
0.8
0.6
0.4
0.2
0.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
MEAN SPEED DIFFERENCE -CASE MINUS CONTROL HOUR

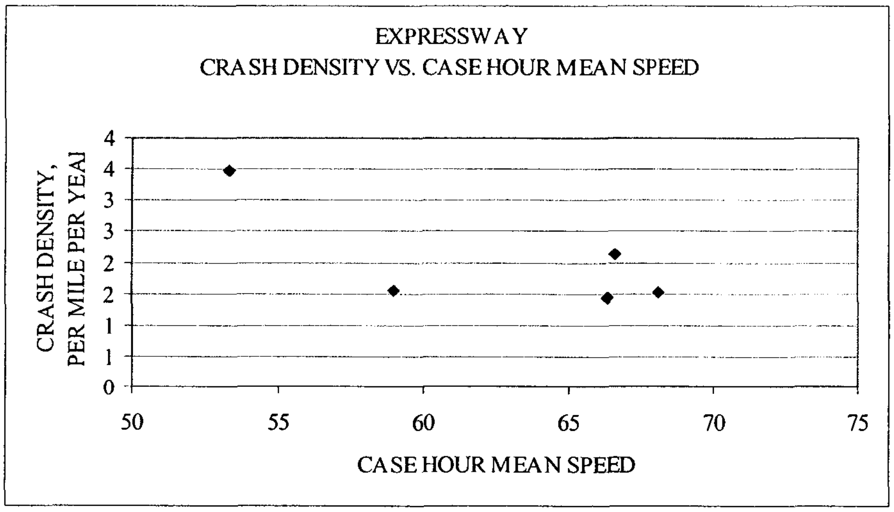

EXPRESSWAY
CRASH RATE VS. 85TH %ILE SPEED DIFFERENCE
CRASH RATE, PER MVM
1.0
0.8
0.6
0.4
0.2
0.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
85TH %ILE SPEED DIFFERENCE - CASE MINUS CONTROL HOUR

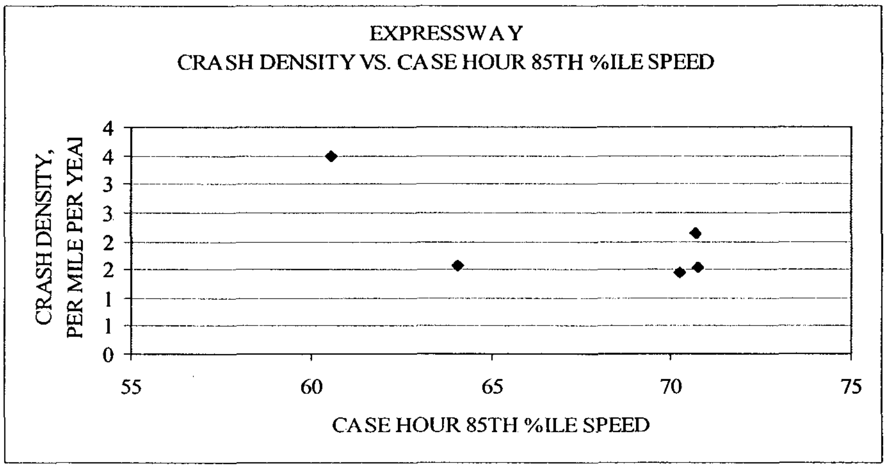

EXPRESSWAY
CRASH RATE VS. DEPARTURE
CRASH RATE
0.8
0.6
0.4
0.2
0.0
-5
0
5
10
15
20
CASE HOUR SPEED DEPARTURE

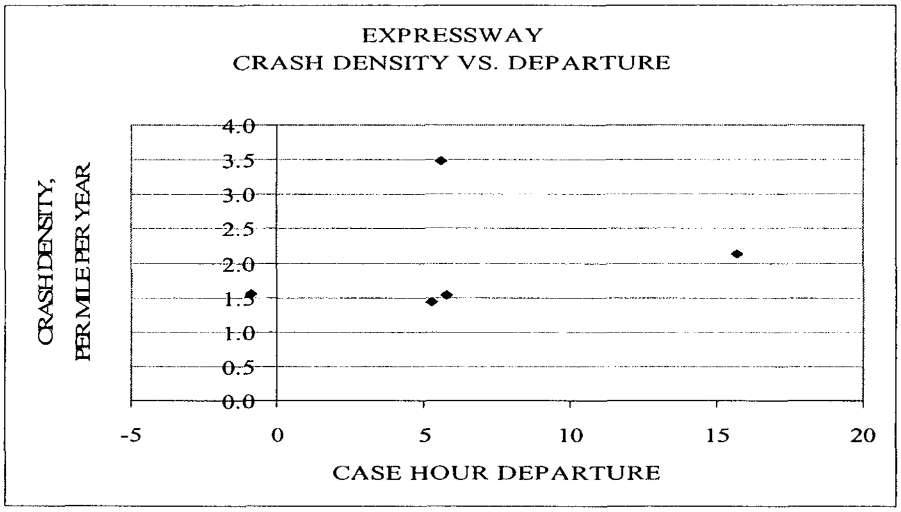

EXPRESSWAY
CRASH RATE VS. DEPARTURE DENSITY
CRASH RATE
0.8
0.6
0.4
0.2
0.0
-1000
0
1000
2000
3000
4000
5000
6000
7000
8000
DEPARTURE DENSITY

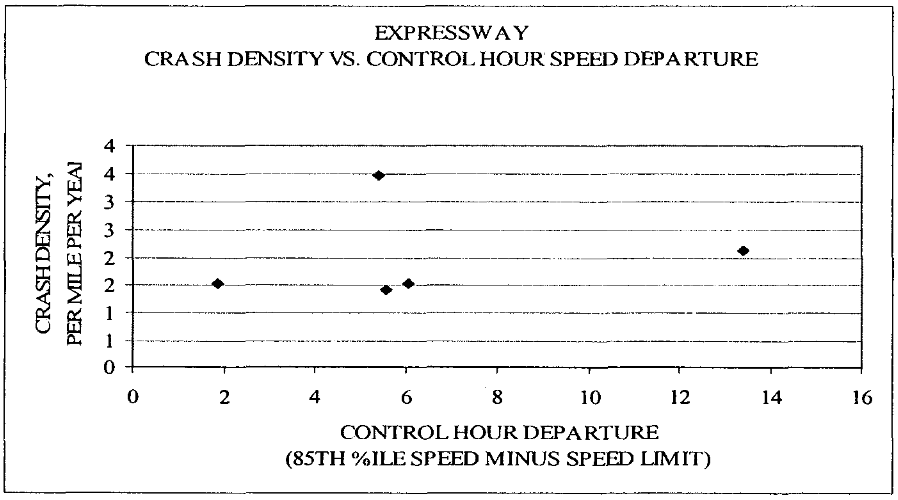

EXPRESSWAY
CRASH RATE VS. VOLUME
CRASH RATE
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
1000
CASE HOUR VOLUME

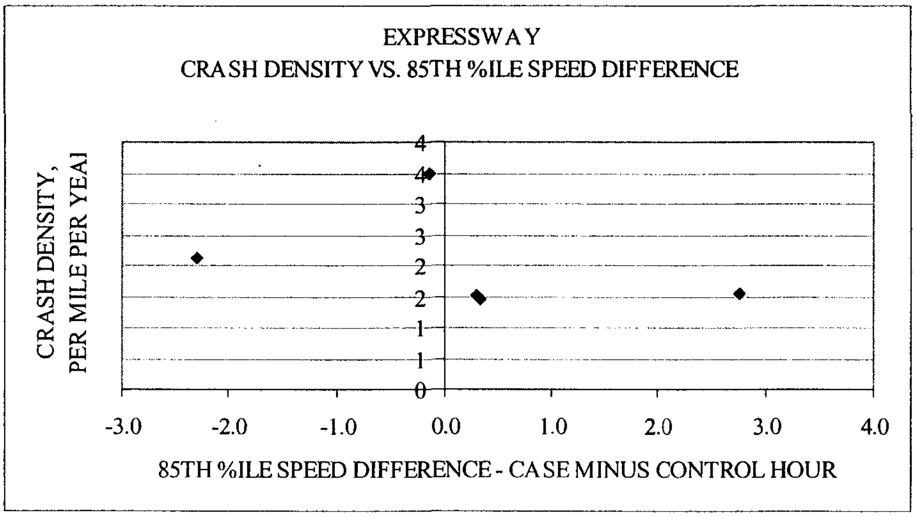

EXPRESSWAY
CRASH DENSITY VS. VOLUME
CRASH DENSITY,
PER MILE PER YEAR
4
4
3
3
2
2
1
1
0
0
200
400
600
800
1000
CASE HOUR VOLUME


EXPRESSWAY
CRASH DENSITY VS. CASE HOUR MEAN SPEED
CRASH DENSITY,
PER MILE PER YEAI
4
4
3
3
2
2
1
1
0
50
55
60
65
70
75
CASE HOUR MEAN SPEED


EXPRESSWAY
CRASH DENSITY VS. CASE HOUR 85TH %ILE SPEED
CRASH DENSITY, PER MILE PER YEA
4
4
3
3
2
2
1
1
0
55
60
65
70
75
CASE HOUR 85TH %ILE SPEED

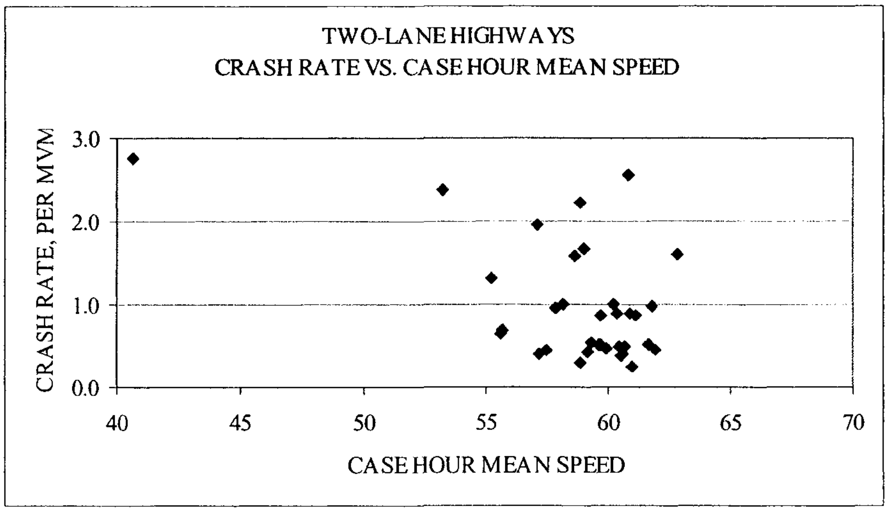

EXPRESSWAY
CRASH DENSITY VS. DEPARTURE
CRASH DENSITY, PER MILE PER YEAR
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-5
0
5
10
15
20
CASE HOUR DEPARTURE

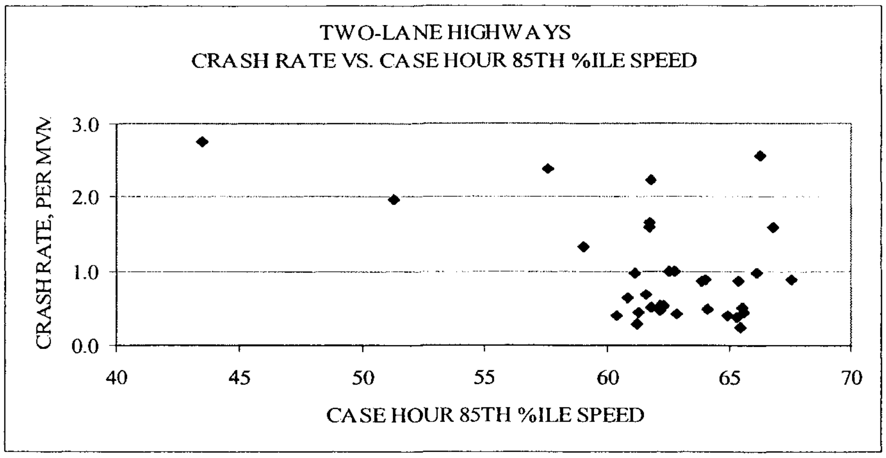

EXPRESSWAY
CRASH DENSITY VS. CONTROL HOUR SPEED DEPARTURE
CRASH DENSITY, PER MILE PER YEA
4
4
3
3
2
2
1
1
0
0
2
4
6
8
10
12
14
16
CONTROL HOUR DEPARTURE
(85TH %ILE SPEED MINUS SPEED LIMIT)

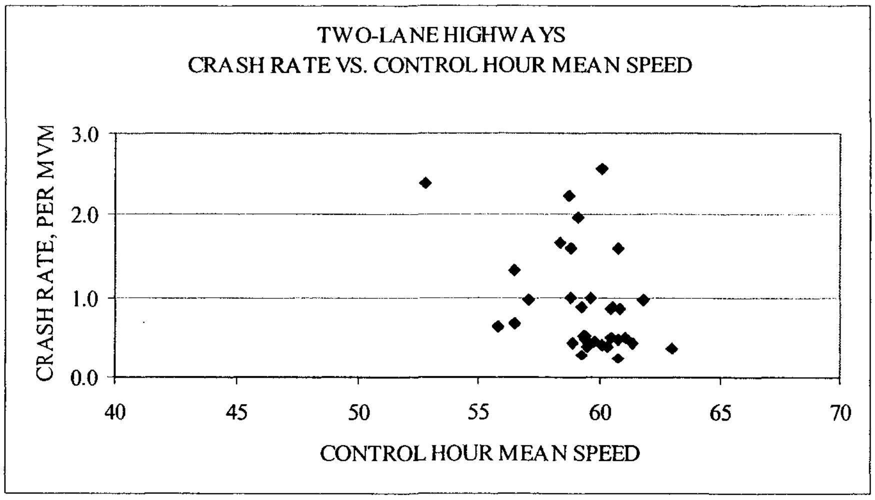

EXPRESSWAY
CRASH DENSITY VS. 85TH %ILE SPEED DIFFERENCE
CRASH DENSITY, PER MILE PER YEAI
4
4
3
3
2
2
1
1
0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
85TH %ILE SPEED DIFFERENCE - CASE MINUS CONTROL HOUR

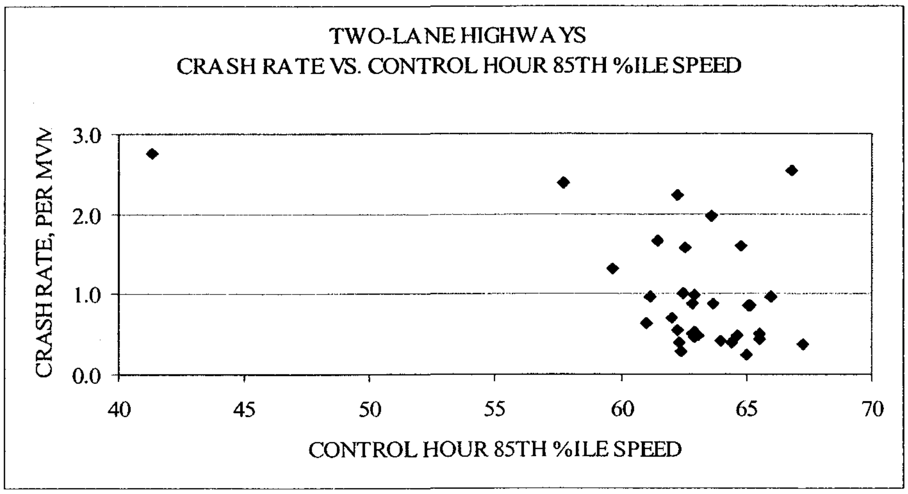
TWO-LANE HIGHWAYS

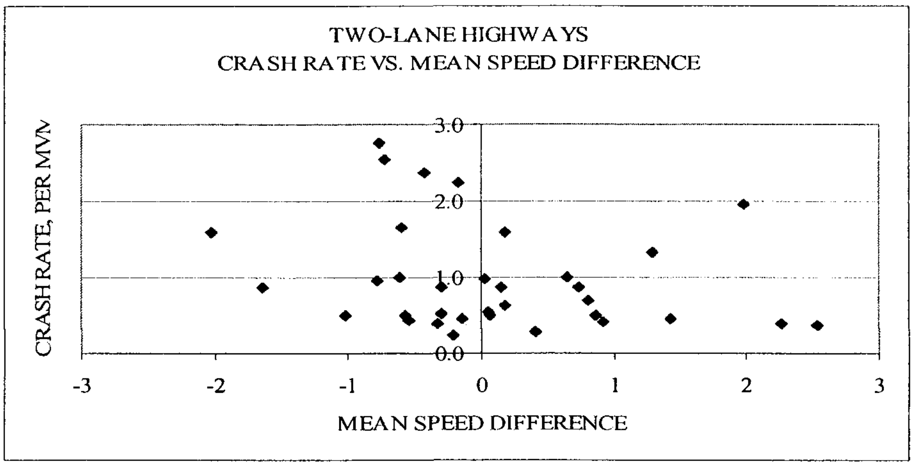
	AVG SPEED		85TH %ILE SPEED		CRASH						DEPARTURE		
ATR	CASE	CONT	CASE	CONT	RATE	DENS	LIMIT	VOL	ADT	VOL/ADT	CASE	CONT	DISP
201	58.98	58.38	61.72	61.45	1.66	1.81	55	132	2990	0.044	6.72	6.45	2.74
202	57.48	58.92	61.25	62.91	0.45	0.58	55	197	3550	0.055	6.25	7.91	3.77
203	59.59	60.46	61.78	62.86	0.51	0.88	55	279	4710	0.059	6.78	7.86	2.19
207	60.45	59.44	64.11	63.05	0.49	0.61	55	194	3420	0.057	9.11	8.05	3.66
208	53.21	52.79	57.61	57.71	2.38	3.31	55	133	3810	0.035	2.61	2.71	4.40
209	55.24	56.52	59.00	59.66	1.32	2.20	55	174	4420	0.039	4.00	4.66	3.76
210	57.23	59.49	60.40	62.30	0.40	0.59	55	256	4030	0.064	5.40	7.30	3.17
211	59.66	59.36	62.33	62.92	0.52	0.62	55	137	3290	0.042	7.33	7.92	2.67
219	55.64	55.81	60.81	60.97	0.64	1.17	55	232	4960	0.047	5.81	5.97	5.18
220	57.85	57.06	61.15	61.18	0.96	0.62	55	88	1770	0.050	6.15	6.18	3.31
221	59.93	59.78	62.18	62.92	0.46	0.30	55	85	1780	0.048	7.18	7.92	2.24
224	60.47	63.01	65.32	67.22	0.38	0.33	55	170	2370	0.072	10.32	12.22	4.85
226	60.68	60.76	64.08	64.67	0.49	0.53	55	141	2970	0.047	9.08	9.67	3.39
228	61.89	61.35	65.59	65.56	0.44	0.39	55	56	2380	0.024	10.59	10.56	3.70
229	62.78	60.76	66.78	64.82	1.59	0.47	55	46	800	0.058	11.78	9.82	4.00
230	61.76	61.79	66.13	65.99	0.97	0.77	55	116	2150	0.054	11.13	10.99	4.37
231	59.69	60.42	63.90	65.15	0.86	0.50	55	38	1600	0.024	8.90	10.15	4.21
233	58.82	59.23	61.20	62.43	0.28	0.13	55	68	1310	0.052	6.20	7.43	2.38
234	58.65	58.84	61.74	62.53	1.58	1.04	55	93	1810	0.051	6.74	7.53	3.09
235	59.18	60.10	62.83	63.96	0.42	0.14	55	65	880	0.074	7.83	8.96	3.64
238	60.95	60.73	65.45	64.99	0.24	0.10	55	54	1150	0.047	10.45	9.99	4.50
240	60.36	60.51	64.06	63.64	0.88	0.63	55	87	1950	0.045	9.06	8.64	3.70
244	60.20	59.60	62.76	62.46	1.00	2.33	55	400	6400	0.063	7.76	7.46	2.56
248	60.60	60.27	64.90	64.44	0.40	0.20	55	55	1340	0.041	9.90	9.44	4.30
300	60.77	60.06	66.25	66.81	2.55	0.27	55	30	290	0.103	11.25	11.81	5.48
301	60.91	59.26	67.50	62.87	0.88	0.33	55	66	1040	0.063	12.50	7.87	6.59
307	55.69	56.49	61.55	62.06	0.69	0.33	55	81	1320	0.061	6.55	7.06	5.86
309	58.87	58.70	61.77	62.25	2.23	0.76	55	48	930	0.052	6.77	7.25	2.90
310	57.12	59.10	51.30	63.61	1.96	0.34	55	18	470	0.038	-3.70	8.61	
311	61.12	60.82	65.38	65.10	0.86	0.25	55	56	800	0.070	10.38	10.10	4.27
312	61.64	61.07	65.55	65.53	0.51	0.27	55	56	1440	0.039	10.55	10.53	3.91
314	58.18	58.84	62.53	62.92	0.99	0.24	55	38	670	0.057	7.53	7.92	4.35
501	59.31	59.37	62.14	62.27	0.54	0.64	55	175	3280	0.053	7.14	7.27	2.82
804	40.65	39.88	43.53	41.33	2.76	3.76	30	126	3740	0.034			2.89
AVG.	58.69	58.79	62.19	62.66	0.96	0.79		117		0.052	7.759	8.31	3.78

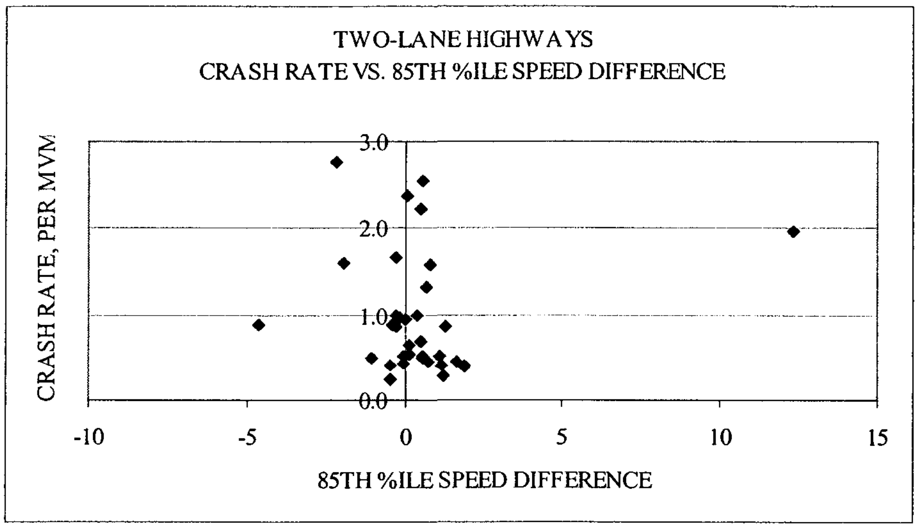

TWO-LANE HIGHWAYS
CRASH RATE VS. CASE HOUR MEAN SPEED
CRASH RATE, PER MVM
3.0
2.0
1.0
0.0
40
45
50
55
60
65
70
CASE HOUR MEAN SPEED

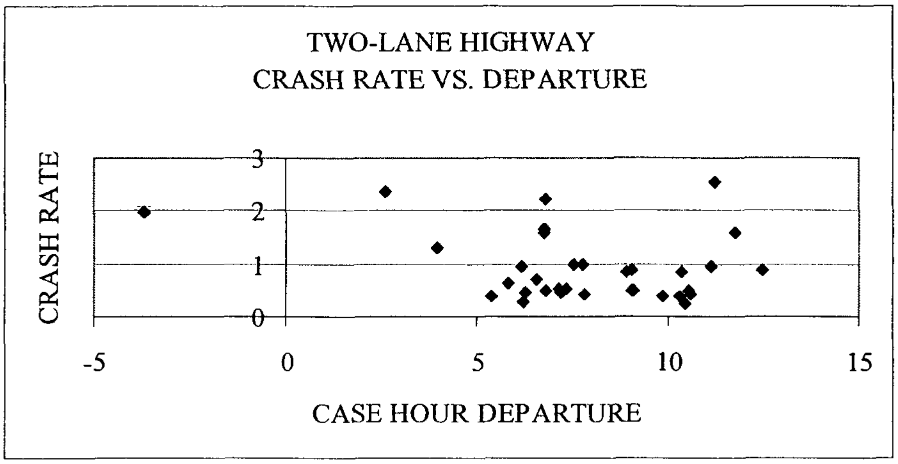

TWO-LANE HIGHWAYS
CRASH RATE VS. CASE HOUR 85TH %ILE SPEED
CRASH RATE, PER MVM
3.0
2.0
1.0
0.0
40
45
50
55
60
65
70
CASE HOUR 85TH %ILE SPEED

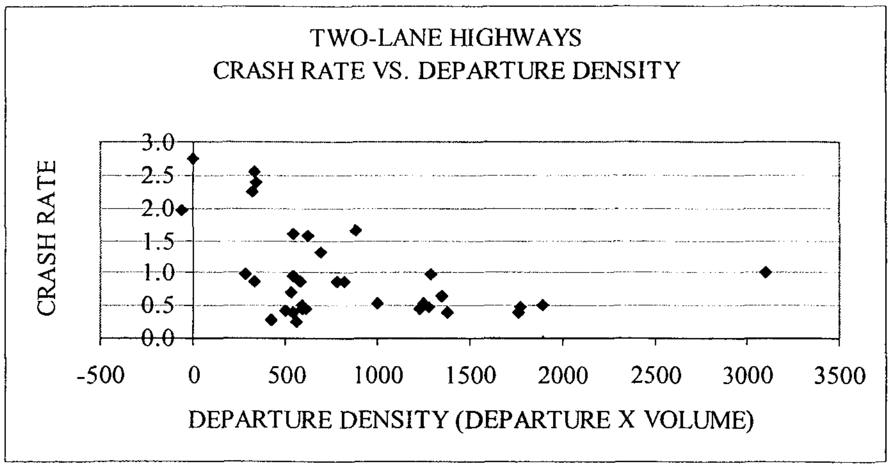

TWO-LANE HIGHWAYS
CRASH RATE VS. CONTROL HOUR MEAN SPEED
CRASH RATE, PER MVM
3.0
2.0
1.0
0.0
40
45
50
55
60
65
70
CONTROL HOUR MEAN SPEED

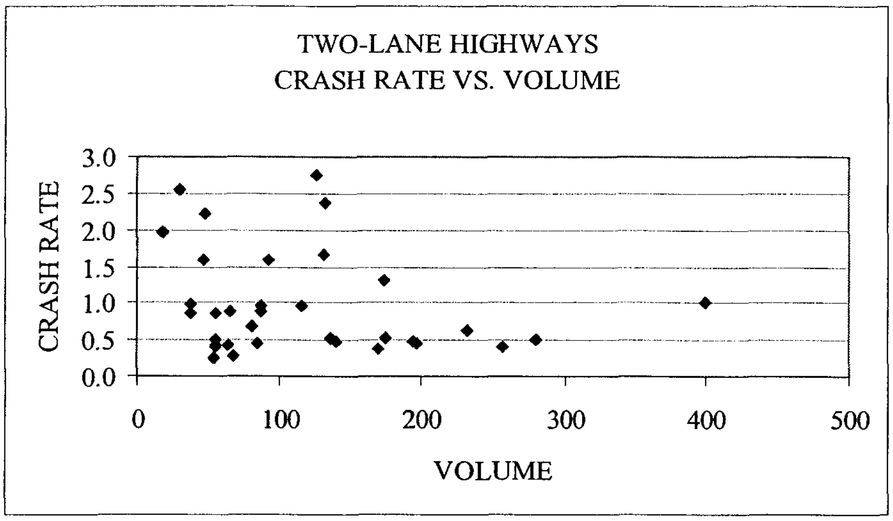

TWO-LANE HIGHWAYS
CRASH RATE VS. CONTROL HOUR 85TH %ILE SPEED
CRASH RATE, PER MVM
3.0
2.0
1.0
0.0
40
45
50
55
60
65
70
CONTROL HOUR 85TH %ILE SPEED

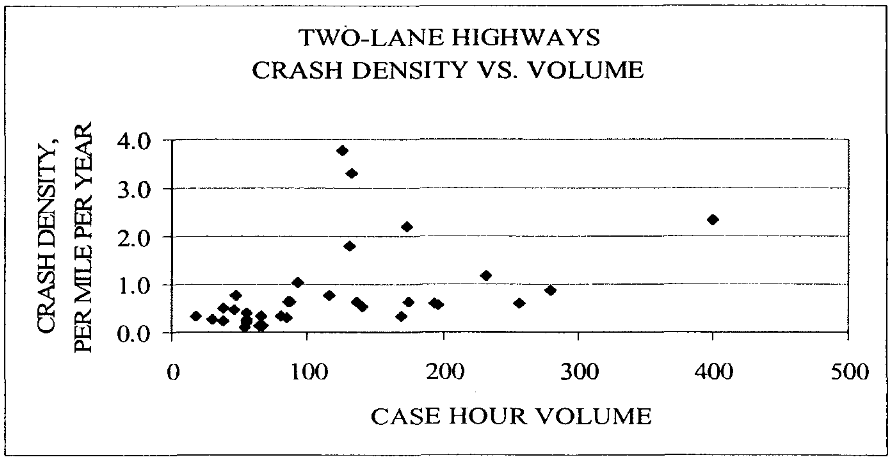

TWO-LANE HIGHWAYS
CRASH RATE VS. MEAN SPEED DIFFERENCE
CRASH RATE, PER MVM
3.0
2.0
1.0
0.0
-3
-2
-1
0
1
2
3
MEAN SPEED DIFFERENCE

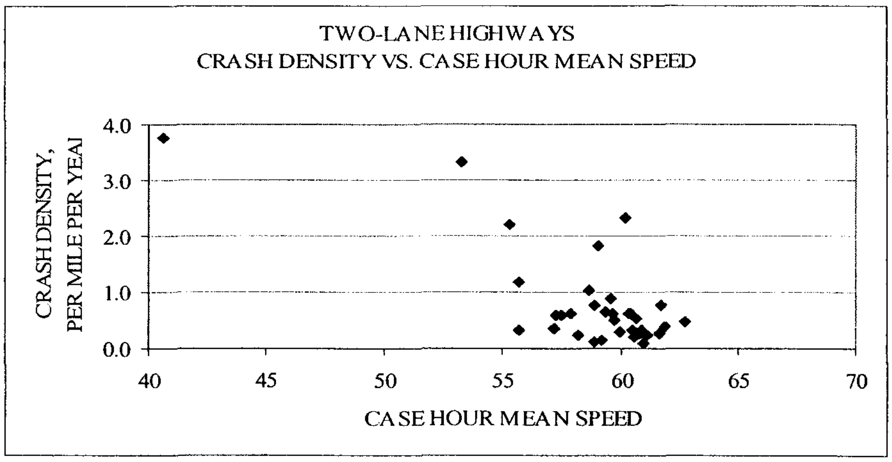

TWO-LANE HIGHWAYS
CRASH RATE VS. 85TH %ILE SPEED DIFFERENCE
CRASH RATE, PER MVM
3.0
2.0
1.0
0.0
-10
-5
0
5
10
15
85TH %ILE SPEED DIFFERENCE

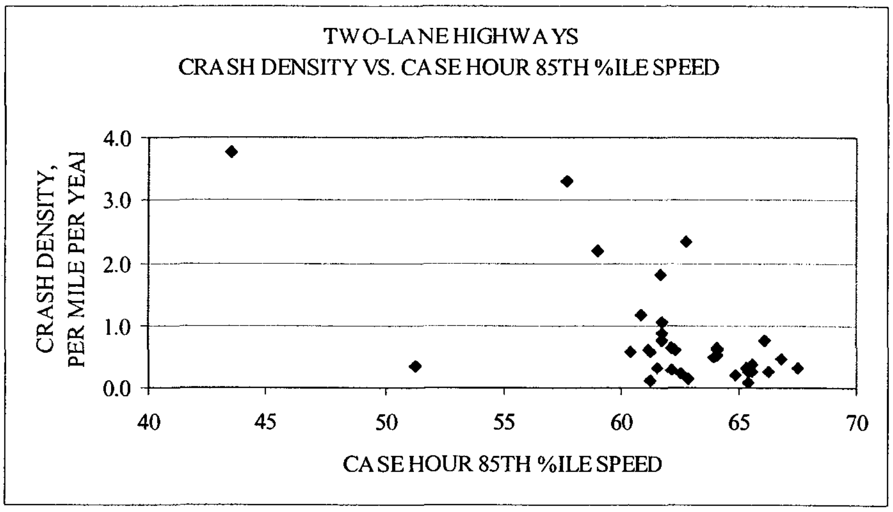

TWO-LANE HIGHWAY
CRASH RATE VS. DEPARTURE
CRASH RATE
3
2
1
0
-5
0
5
10
15
CASE HOUR DEPARTURE

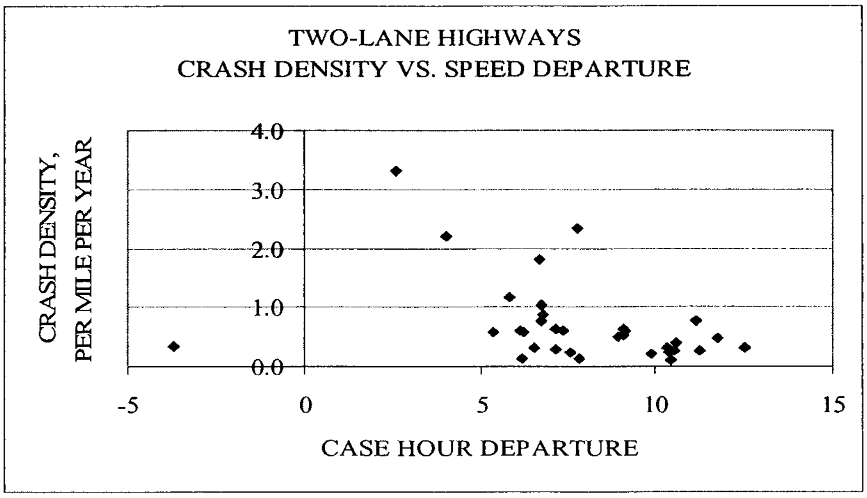

TWO-LANE HIGHWAYS
CRASH RATE VS. DEPARTURE DENSITY
CRASH RATE
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-500
0
500
1000
1500
2000
2500
3000
3500
DEPARTURE DENSITY (DEPARTURE X VOLUME)

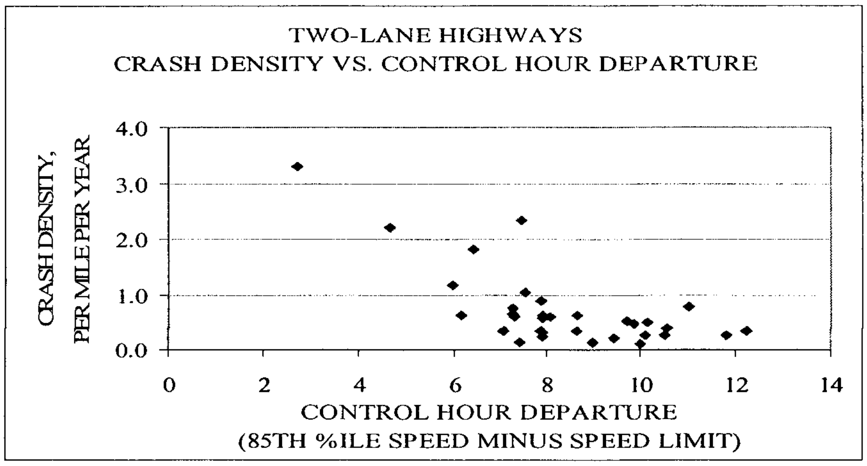

TWO-LANE HIGHWAYS
CRASH RATE VS. VOLUME
CRASH RATE
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
VOLUME

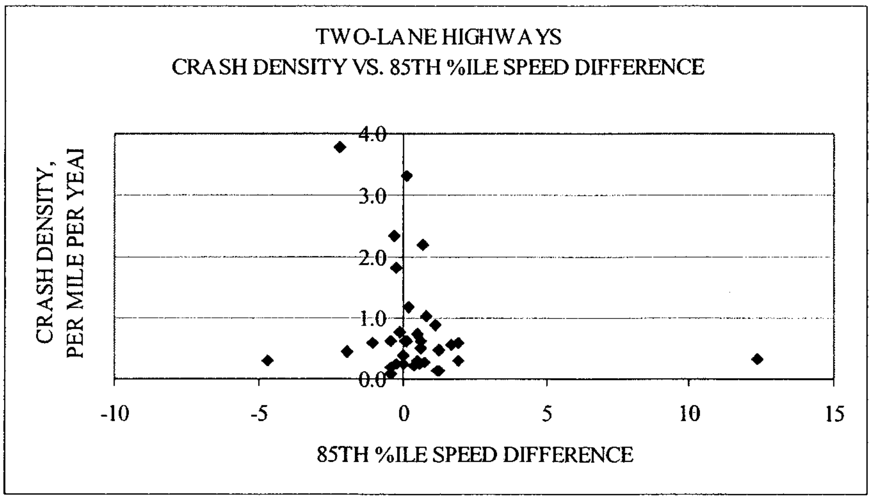

TWO-LANE HIGHWAYS
CRASH DENSITY VS. VOLUME
CRASH DENSITY, PER MILE PER YEAR
4.0
3.0
2.0
1.0
0.0
0
100
200
300
400
500
CASE HOUR VOLUME


TWO-LANE HIGHWAYS
CRASH DENSITY VS. CASE HOUR MEAN SPEED
CRASH DENSITY, PER MILE PER YEAI
4.0
3.0
2.0
1.0
0.0
40
45
50
55
60
65
70
CASE HOUR MEAN SPEED


TWO-LANE HIGHWAYS
CRASH DENSITY VS. CASE HOUR 85TH %ILE SPEED
CRASH DENSITY, PER MILE PER YEAI
4.0
3.0
2.0
1.0
0.0
40
45
50
55
60
65
70
CASE HOUR 85TH %ILE SPEED


TWO-LANE HIGHWAYS
CRASH DENSITY VS. SPEED DEPARTURE
CRASH DENSITY,
PER MILE PER YEAR
4.0
3.0
2.0
1.0
0.0
-5
0
5
10
15
CASE HOUR DEPARTURE


TWO-LANE HIGHWAYS
CRASH DENSITY VS. CONTROL HOUR DEPARTURE
CRASH DENSITY,
PER MILE PER YEAR
4.0
3.0
2.0
1.0
0.0
0
2
4
6
8
10
12
14
CONTROL HOUR DEPARTURE
(85TH %ILE SPEED MINUS SPEED LIMIT)


TWO-LANE HIGHWAYS
CRASH DENSITY VS. 85TH %ILE SPEED DIFFERENCE
CRASH DENSITY,
PER MILE PER YEAI
4.0
3.0
2.0
1.0
0.0
-10
-5
0
5
10
15
85TH %ILE SPEED DIFFERENCE

APPENDIX C – SAS INPUT & OUTPUT PRINTOUTS

Freeways – Input File to SAS

```
PROC IMPORT OUT= WORK.fifth
            DATAFILE= "C:\ATR\SAS_Freeways2.xls"
            DBMS=EXCEL REPLACE;
     SHEET="'Input data$'";
     GETNAMES=YES;
     MIXED=NO;
     SCANTEXT=YES;
     USEDATE=YES;
     SCANTIME=YES;
RUN;
data sixth; set fifth;
      if C = 0 then D = 1;
      if C = 1 then D = 0;
run;
proc logistic data=sixth ;
      class T W;
      model D = MeanSpeed Variance Volume T1 T2 T3 Dispersion Departure
VolADT W / stepwise;
      output out=set1 L=lower95 P=phat U=upper95 / alpha=0.05;
      title 'Logistic analysis';
run;
```

Freeways – Using all input data – Output File

```
Logistic analysis      13:40 Friday, September 9, 2005   1

                        The LOGISTIC Procedure

                          Model Information

             Data Set                          WORK.SIXTH
             Response Variable                 D
             Number of Response Levels         2
             Model                             binary logit
             Optimization Technique            Fisher's scoring


                Number of Observations Read        2275
                Number of Observations Used        2275

                           Response Profile

                   Ordered                          Total
                     Value            D         Frequency

                         1            0              1156
                         2            1              1119

                      Probability modeled is D=0.


                      Stepwise Selection Procedure


                        Class Level Information

                                                 Design
                     Class      Value         Variables

                     T1         0                     1
                                1                    -1

                     T2         0                     1
                                1                    -1

                     T3         0                     1
                                1                    -1

Step  0. Intercept entered:

                        Model Convergence Status

             Convergence criterion (GCONV=1E-8) satisfied.

                          -2 Log L = 3153.218
```

The LOGISTIC Procedure

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
131.9254	9	<.0001

Step 1. Effect MeanSpeed entered:

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	3155.218	3045.066
SC	3160.948	3056.526
-2 Log L	3153.218	3041.066

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	112.1518	1	<.0001
Score	105.1453	1	<.0001
Wald	94.5824	1	<.0001

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
34.6054	8	<.0001

NOTE: No effects for the model in Step 1 are removed.

Step 2. Effect Departure entered:

The LOGISTIC Procedure

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	3155.218	3029.134
SC	3160.948	3046.323
-2 Log L	3153.218	3023.134

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	130.0838	2	<.0001
Score	116.5137	2	<.0001
Wald	98.1386	2	<.0001

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
16.4880	7	0.0210

NOTE: No effects for the model in Step 2 are removed.

Step 3. Effect VolADT entered:

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

The LOGISTIC Procedure

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	3155.218	3023.443
SC	3160.948	3046.362
-2 Log L	3153.218	3015.443

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	137.7745	3	<.0001
Score	122.1878	3	<.0001
Wald	101.6564	3	<.0001

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
8.8662	6	0.1812

NOTE: No effects for the model in Step 3 are removed.

Step 4. Effect Dispersion entered:

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	3155.218	3017.569
SC	3160.948	3046.217
-2 Log L	3153.218	3007.569

The LOGISTIC Procedure

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	145.6491	4	<.0001
Score	130.4524	4	<.0001
Wald	108.1139	4	<.0001

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
1.1633	5	0.9483

Step 5. Effect MeanSpeed is removed:

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	3155.218	3016.584
SC	3160.948	3039.503
-2 Log L	3153.218	3008.584

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	144.6340	3	<.0001
Score	129.9010	3	<.0001
Wald	108.1305	3	<.0001

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
2.1805	6	0.9024

The LOGISTIC Procedure

NOTE: No effects for the model in Step 5 are removed.

NOTE: No (additional) effects met the 0.05 significance level for entry into the model.

Summary of Stepwise Selection

Step	Effect Entered	Effect Removed	DF	Number In	Score Chi-Square	Wald Chi-Square	Pr > ChiSq	Variable Label
1	MeanSpeed		1	1	105.1453		<.0001	MeanSpeed
2	Departure		1	2	17.9497		<.0001	Departure
3	VolADT		1	3	7.6828		0.0056	VolADT
4	Dispersion		1	4	7.7381		0.0054	Dispersion
5		MeanSpeed	1	3		1.0129	0.3142	MeanSpeed

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Dispersion	1	24.6293	<.0001
Departure	1	78.6437	<.0001
VolADT	1	8.0841	0.0045

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.0431	0.1646	0.0687	0.7933
Dispersion	1	0.1523	0.0307	24.6293	<.0001
Departure	1	-0.1141	0.0129	78.6437	<.0001
VolADT	1	5.2652	1.8518	8.0841	0.0045

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
Dispersion	1.165	1.097	1.237
Departure	0.892	0.870	0.915
VolADT	193.483	5.133	>999.999

The LOGISTIC Procedure

Association of Predicted Probabilities and Observed Responses

percent Concordant	60.8	Somers' D	0.224
percent Discordant	38.3	Gamma	0.226
percent Tied	0.9	Tau-a	0.112
Pairs	1293564	c	0.612

Freeways – non-weather crashes input file – output

```
                         18:31 Tuesday, October 4, 2005
                   The LOGISTIC Procedure

                     Model Information

        Data Set                       WORK.SIXTH
        Response Variable              D
        Number of Response Levels      2

        Model                          binary logit
        Optimization Technique         Fisher's scoring


           Number of Observations Read        1517
           Number of Observations Used        1517


                      Response Profile

              Ordered                         Total
                Value              D      Frequency

                    1              0            762
                    2              1            755

                Probability modeled is D=0.


                Stepwise Selection Procedure


                  Class Level Information

             Class      Value     Design Variables

             W          0           1
                        1          -1

             T          0           1      0      0
                        1           0      1      0
                        2           0      0      1
                        3          -1     -1     -1

Step  0. Intercept entered:


                  Model Convergence Status

        Convergence criterion (GCONV=1E-8) satisfied.

                     -2 Log L = 2102.976
```

Freeways Logistic Analysis No Weather
18:31 Tuesday, October 4, 2005

The LOGISTIC Procedure

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
237.5541	9	<.0001

Step 1. Effect W entered:

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	2104.976	1826.775
SC	2110.301	1837.424
-2 Log L	2102.976	1822.775

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	280.2015	1	<.0001
Score	228.7184	1	<.0001
Wald	93.3863	1	<.0001

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
10.5621	8	0.2278

NOTE: No effects for the model in Step 1 are removed.

Step 2. Effect Variance entered:

Freeways Logistic Analysis No Weather

18:31 Tuesday, October 4, 2005

The LOGISTIC Procedure

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	2104.976	1823.500
SC	2110.301	1839.473
-2 Log L	2102.976	1817.500

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	285.4767	2	<.0001
Score	233.2443	2	<.0001
Wald	98.2334	2	<.0001

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
5.2889	7	0.6248

NOTE: No effects for the model in Step 2 are removed.

NOTE: No (additional) effects met the 0.05 significance level for entry into the model.

Summary of Stepwise Selection

Step	Effect Entered	Removed	DF	Number In	Score Chi-Square	Wald Chi-Square	Pr > ChiSq	Variable Label
1	W		1	1	228.7184		<.0001	W
2	Variance		1	2	5.2939		0.0214	Variance

Freeways Logistic Analysis No Weather

18:31 Tuesday, October 4, 2005

The LOGISTIC Procedure

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Variance	1	5.1524	0.0232
W	1	94.1028	<.0001

Analysis of Maximum Likelihood Estimates

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept		1	1.3272	0.2187	36.8175	<.0001
Variance		1	0.00598	0.00264	5.1524	0.0232
W	0	1	-1.8834	0.1941	94.1028	<.0001

Odds Ratio Estimates

Effect		Point Estimate	95% Wald Confidence Limits	
Variance		1.006	1.001	1.011
W	0 vs 1	0.023	0.011	0.050

Association of Predicted Probabilities and Observed Responses

percent Concordant	64.4	Somers' D	0.317
percent Discordant	32.7	Gamma	0.326
percent Tied	2.8	Tau-a	0.159
Pairs	575310	c	0.659

Expressways – input files to SAS

```
PROC IMPORT OUT= WORK.fifth
            DATAFILE= "C:\ATR\SAS_expressways2.xls"
            DBMS=EXCEL REPLACE;
     SHEET="'Input data$'";
     GETNAMES=YES;
     MIXED=NO;
     SCANTEXT=YES;
     USEDATE=YES;
     SCANTIME=YES;
RUN;
data sixth; set fifth;
      if C = 0 then D = 1;
      if C = 1 then D = 0;
run;
proc logistic data=sixth ;
      class T W;
      model D = MeanSpeed Variance Volume T Dispersion Departure VolADT W
/ stepwise;
      output out=set1 L=lower95 P=phat U=upper95 / alpha=0.05;
      title 'Logistic analysis';
run;
```

Expressways – all data in input file – output file

```
Logistic analysis      08:24 Friday, September 9, 2005   1

                           The LOGISTIC Procedure

                             Model Information

              Data Set                        WORK.SIXTH
              Response Variable               D
              Number of Response Levels       2
              Model                           binary logit
              Optimization Technique          Fisher's scoring


                 Number of Observations Read        1633
                 Number of Observations Used         334


                              Response Profile

                    Ordered                       Total
                      Value            D      Frequency

                          1            0            168
                          2            1            166

                        Probability modeled is D=0.

NOTE: 1299 observations were deleted due to missing values for the
response or explanatory variables.


                        Stepwise Selection Procedure


                          Class Level Information

                                            Design
                      Class       Value    Variables

                      T1          0               1
                                  1              -1

                      T2          0               1
                                  1              -1

                      T3          0               1
                                  1              -1


Step  0. Intercept entered:
```

The LOGISTIC Procedure

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

-2 Log L = 463.010

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
1.9865	9	0.9917

NOTE: No (additional) effects met the 0.05 significance level for entry into the model.

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	0.0120	0.1094	0.0120	0.9129

Expressways – No Weather Crashes Included – Output file

1

08:28 Tuesday, October 4, 2005

The LOGISTIC Procedure

Model Information

Data Set	WORK.SIXTH
Response Variable	D
Number of Response Levels	2
Model	binary logit
Optimization Technique	Fisher's scoring

Number of Observations Read	259
Number of Observations Used	259

Response Profile

Ordered Value	D	Total Frequency
1	0	130
2	1	129

Probability modeled is D=0.

Stepwise Selection Procedure

Class Level Information

Class	Value	Design Variables
W	0	1
	1	-1

Step 0. Intercept entered:

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

-2 Log L = 359.046

The LOGISTIC Procedure

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
46.5298	7	<.0001

Step 1. Effect W entered:

Model Convergence Status

Quasi-complete separation of data points detected.

WARNING: The maximum likelihood estimate may not exist.
WARNING: The LOGISTIC procedure continues in spite of the above warning. Results shown are based on the last maximum likelihood iteration. Validity of the model fit is questionable.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	361.046	304.147
SC	364.603	311.261
-2 Log L	359.046	300.147

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	58.8991	1	<.0001
Score	44.1914	1	<.0001
Wald	0.0023	1	0.9618

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
2.7613	6	0.8382

Step 2. Effect W is removed:

Expressways Logistic Analysis No Weather

08:28 Tuesday, October 4, 2005

The LOGISTIC Procedure

WARNING: The validity of the model fit is questionable.

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

-2 Log L = 359.046

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
46.5298	7	<.0001

NOTE: Model building terminates because the last effect entered is removed by the Wald statistic
criterion.

Summary of Stepwise Selection

Step	Effect Entered	Effect Removed	DF	Number In	Score Chi-Square	Wald Chi-Square	Pr > ChiSq	Variable Label
1	W		1	1	44.1914		<.0001	W
2		W	1	0		0.0023	0.9618	W

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	0.00772	0.1243	0.0039	0.9505

Two-Lane Highways – input files to SAS

```
PROC IMPORT OUT= WORK.fifth
            DATAFILE= "C:\ATR\SAS_2lanes.xls"
            DBMS=EXCEL REPLACE;
     SHEET="'Input data$'";
     GETNAMES=YES;
     MIXED=NO;
     SCANTEXT=YES;
     USEDATE=YES;
     SCANTIME=YES;
RUN;
data sixth; set fifth;
      if C = 0 then D = 1;
      if C = 1 then D = 0;
run;
proc logistic data=sixth ;
      class T W;
      model D = MeanSpeed Variance Volume T Dispersion Departure VolADT W
/ stepwise;
      output out=set1 L=lower95 P=phat U=upper95 / alpha=0.05;
      title 'Logistic analysis';
run;
```

Two-Lane Highways – all data in input files – output file

Logistic analysis 08:19 Friday, September 9, 2005 1

The LOGISTIC Procedure

Model Information

Data Set	WORK.SIXTH
Response Variable	D
Number of Response Levels	2
Model	binary logit
Optimization Technique	Fisher's scoring

Number of Observations Read	685
Number of Observations Used	683

Response Profile

Ordered Value	D	Total Frequency
1	0	345
2	1	338

Probability modeled is D=0.

NOTE: 2 observations were deleted due to missing values for the response or explanatory variables.

Stepwise Selection Procedure

Class Level Information

Class	Value	Design Variables
T1	0	1
	1	-1
T2	0	1
	1	-1
T3	0	1
	1	-1

Step 0. Intercept entered:

Model Convergence Status
Convergence criterion (GCONV=1E-8) satisfied.

The LOGISTIC Procedure

-2 Log L = 946.767

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
18.6282	9	0.0285

Step 1. Effect Departure entered:

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	948.767	941.565
SC	953.294	950.618
-2 Log L	946.767	937.565

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	9.2026	1	0.0024
Score	9.0801	1	0.0026
Wald	8.8649	1	0.0029

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
9.6342	8	0.2916

NOTE: No effects for the model in Step 1 are removed.

Step 2. Effect Dispersion entered:

The LOGISTIC Procedure

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	948.767	933.174
SC	953.294	946.754
-2 Log L	946.767	927.174

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	19.5930	2	<.0001
Score	17.5624	2	0.0002
Wald	13.2945	2	0.0013

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
1.2400	7	0.9900

NOTE: No effects for the model in Step 2 are removed.

NOTE: No (additional) effects met the 0.05 significance level for entry into the model.

Summary of Stepwise Selection

Step	Effect Entered	Number Removed	DF	In	Score Chi-Square	Wald Chi-Square	Pr > ChiSq	Variable Label
1	Departure		1	1	9.0801		0.0026	Departure
2	Dispersion		1	2	8.5203		0.0035	Dispersion

The LOGISTIC Procedure

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Dispersion	1	5.1408	0.0234
Departure	1	9.0422	0.0026

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	0.3930	0.1274	9.5139	0.0020
Dispersion	1	-0.0457	0.0202	5.1408	0.0234
Departure	1	-0.0573	0.0190	9.0422	0.0026

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
Dispersion	0.955	0.918	0.994
Departure	0.944	0.910	0.980

Association of Predicted Probabilities and Observed Responses

percent Concordant	54.2	Somers' D	0.096
percent Discordant	44.6	Gamma	0.097
percent Tied	1.3	Tau-a	0.048
Pairs	116610	c	0.548

Two-Lane Highways – No Weather Crashes in input file – output file

08:26 Tuesday, October 4, 2005

The LOGISTIC Procedure

Model Information

Data Set	WORK.SIXTH
Response Variable	D
Number of Response Levels	2
Model	binary logit
Optimization Technique	Fisher's scoring

Number of Observations Read	575
Number of Observations Used	573

Response Profile

Ordered Value	D	Total Frequency
1	0	290
2	1	283

Probability modeled is D=0.

NOTE: 2 observations were deleted due to missing values for the response or explanatory variables.

Stepwise Selection Procedure

Class Level Information

Class	Value	Design Variables
W	0	1
	1	-1

Step 0. Intercept entered:

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

-2 Log L = 794.261

The LOGISTIC Procedure

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
8.8374	7	0.2645

Step 1. Effect Dispersion entered:

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	796.261	788.640
SC	800.612	797.342
-2 Log L	794.261	784.640

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	9.6210	1	0.0019
Score	8.0060	1	0.0047
Wald	4.5156	1	0.0336

Residual Chi-Square Test

Chi-Square	DF	Pr > ChiSq
0.8132	6	0.9917

NOTE: No effects for the model in Step 1 are removed.

NOTE: No (additional) effects met the 0.05 significance level for entry into the model.

Two-Lane Highways Logistic Analysis No Weather
08:26 Tuesday, October 4, 2005

The LOGISTIC Procedure

Summary of Stepwise Selection

Step	Effect Entered	Effect Removed	DF	Number In	Score Chi-Square	Wald Chi-Square	Pr > ChiSq	Variable Label
1	Dispersion		1	1	8.0060		0.0047	Dispersion

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Dispersion	1	4.5156	0.0336

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	0.2262	0.1202	3.5411	0.0599
Dispersion	1	-0.0483	0.0227	4.5156	0.0336

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
Dispersion	0.953	0.911	0.996

Association of Predicted Probabilities and Observed Responses

percent Concordant	47.9	Somers' D	-.004
percent Discordant	48.4	Gamma	-.004
percent Tied	3.7	Tau-a	-.002
Pairs	82070	c	0.498

APPENDIX D – ATR SITE DESCRIPTIONS

				CRASH COUNT			
ATR	HWY NO.	LENGTH	COUNTY	NON-WEATHER	WEATHER	ALL	WEATHER %
100	I-29	3.98	Pottawattamie	39	11	50	22
102	I-29	7.32	Mills	23	15	38	39
104	I-35	5.57	Hamilton	28	48	76	63
105	I-29	6.44	Monona	38	13	51	25
106	I-35	4.53	Decatur	14	5	19	26
109	I-35	5.34	Cerro Gordo	42	30	72	42
110	I-80	4.39	Pottawattamie	37	40	77	52
111	I-80	4.38	Iowa	37	22	59	37
113	I-380	5.86	Benton	37	16	53	30
115	I-80	2.47	Cass	30	15	45	33
116	I-80	3.73	Dallas	55	35	90	39
117	I-80	1.96	Polk	85	74	159	47
201	US 65	1.93	Franklin	18	3	21	14
202	US 71	3.14	Audubon	11	4	15	27
203	US 63	3.03	Bremer	16	5	21	24
204	US 75	5.61	Plymouth	52	13	65	20
205	US 218	3.05	Henry	28	8	36	22
206	US 30	1.58	Story	17	4	21	19
207	US 18	2.73	Kossuth	10	2	12	17
208	US 6	2.57	Iowa	51	5	56	9
209	US 67	0.83	Scott	11	5	16	31
210	US 18	1.96	Osceola	7	4	11	36
211	US 20	2.69	Calhoun	10	5	15	33
217	Iowa 122	3.02	Cerro Gordo	63	15	78	19
219	US 34	1.14	Clarke	8	2	10	20
220	US 52	3.77	Allamakee	14	8	22	36
221	Iowa 9	3.92	Emmet	7	1	8	13
224	US 59	4.05	Shelby	8	1	9	11
226	US 18	3.47	Fayette	11	2	13	15
228	Iowa 117	3.01	Jasper	7	1	8	13
229	Iowa 78	2.50	Henry	7	3	10	30

ATR	HWY NO.	LENGTH	COUNTY	CRASH COUNT NON-WEATHER	WEATHER	ALL	WEATHER %
230	US 69	2.61	Madison	12	0	12	0
231	Iowa 148	2.98	Cass	9	0	9	0
233	Iowa 110	3.78	Buena Vista	3	1	4	25
234	Iowa 12	4.80	Plymouth	30	6	36	17
235	Iowa 143	4.94	O'Brien	4	3	7	43
236	Iowa 196	2.10	Sac	2	2	4	50
238	Iowa 149	3.30	Keokuk	2	1	3	33
240	Iowa 2	3.72	Fremont	14	1	15	7
242	US 61	4.02	Scott	74	0	74	0
243	US 30	3.12	Clinton	27	9	36	25
244	Iowa 1	2.00	Johnson	28	6	34	18
245	US 20	2.15	Blackhawk	22	8	30	27
246	Iowa 141	1.02	Dallas	13	1	14	7
247	US 20	4.33	Hamilton	48	16	64	25
248	Iowa 21	2.55	Iowa	3	1	4	25
249	US 218	3.52	Johnson	40	13	53	25
250	US 65	2.72	Polk	21	18	39	46
300	Co Rd P14	3.10	Greene	5	2	7	29
301	Co Rd S14	2.50	Story	5	3	8	38
307	Co Rd S38	1.00	Wright	2	2	4	50
309	Co Rd K 52	1.98	Sioux	9	2	11	18
310	Co Rd Y 52	1.49	Clinton	3	2	5	40
311	Co Rd W 12	4.00	Benton	6	1	7	14
312	Co Rd E 26	5.00	Boone	8	5	13	38
314	CO 105	2.05	Worth	3	1	4	25
501	Iowa 5	4.67	Monroe	18	6	24	25
701	I-380	0.33	Linn	9	4	13	31
704	I-29/I-80	0.87	Pottawattamie	59	24	83	29
705	I-74	0.54	Scott	22	3	25	12
804	Iowa 4	0.31	Pocahontas	7	0	7	0
Polk I35	I-35	5.32	Polk	38	0	38	0
Wright	I-35	2.45	Wright	14	0	14	0
				1381	556	1937	29