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AN ANALYSIS OF SPEED LIMIT POLICIES FOR INDIANA

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July 2000

Indiana Department of Transportation

Purdue University

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16. Abstract

The repeal of the National Maximum Speed Limit law in 1995 enabled individual states to set their own speed limits. Speed limits are necessary to ensure mobility while preserving highway safety. It is important that states continually monitor and evaluate existing operating speeds in the context of changing patterns of travel, and changing characteristics of highways, vehicles, drivers, and land-use. Any efforts to review existing speed limits should be accompanied by evaluation of policy impacts such as safety and economic productivity. The goal of this research is to develop a framework for evaluating the impacts of speed limit changes in the State of Indiana and to use this framework to develop a set of speed limit policy guidelines for the state. The study reviews the historical trends in traffic speed in Indiana and recommends a detailed analysis of the impact of speed limit changes on safety and the trucking industry in Indiana. The report also presents a state-of-the-art practice review and a set of possible actions that may be considered for speed limits in Indiana.

17. Key Words

Maximum Speed Limit, state highway network, Indiana, safety, productivity

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INTRODUCTION

1.1 Background Information

Prior to 1974, Interstate highways through various states had different speed limits, with the exception of Montana and Nevada, which had none. A majority of states had a maximum speed limit of 70 miles per hour (MPH), some had 75 MPH, and a few had limits of 60 and 65 (MPH). In the wake of the 1973-74 oil crisis, the Federal government enacted a National Maximum Speed Limit (NMSL) legislation that set the maximum speed at 55 MPH, and all states were mandated to comply. This speed limit, however, was subsequently increased and almost all states adopted the 65 MPH speed limit by 1987, with the exception of Hawaii and a number of northeastern states. On December 8, 1995, Congress repealed the NMSL law, paving the way for states to set limits on highways within their jurisdiction.

Since the repeal of the NMSL, several states have revised speed limits on their highways. Most states have reverted to their respective pre-NMSL speed limits, and the new speed limits vary from state to state. A majority of states have raised their maximum speed limit to 70 MPH, and other states have increased to 75 MPH. The trend, in general, indicates that states located in the Plains have adopted 70 MPH, while others have seldom above 70 MPH. Another observed trend is that some states have different speed limits for different categories of vehicles and have different speed limits for different highway classes and land-use classes.

1.2 The Importance of Speed Limits

Speed limits are generally set to regulate vehicular operation on roads in order to ensure efficient travel on the roads. Efficiency, in this context, is a two-edged sword: speeds should be high enough to ensure mobility, but should not be so high as to pose safety hazards to highway users (and non-users). Setting a speed limit law is a delicate balancing act that should take into cognizance a gamut of input factors related to vehicular characteristics (e.g., vehicle classes or sizes, pavement tire interaction) the human operator (e.g., reaction time), roadway features (functional class, land-use class), and output factors such as speed-related pollution effects (emissions and dispersion, and noise), travel time, and other factors.

1.3 Problem Statement

The Indiana State legislature is responsible for setting appropriate speed limits on Indiana highways. The legislature, at its own discretion, may solicit technical assessment and recommendations from INDOT before finalizing speed limit related legislation. The repeal of the NMSL in 1995 makes it possible for INDOT to make appropriate recommendations for speed limit changes without conforming to a federal mandate, on the basis of rational criteria. However, any changes in existing speed limits should be preceded by a systematic and comprehensive study to determine the consequences of any such new policies. Any research effort in this direction must necessarily identify possible options for speed limit policies, evaluate the impacts of various options, and prepare policy guidelines for optimal speed limits for various classes of vehicles, roadway and land-use, for the State of Indiana.

1.4 Study Objectives and Benefits

The study was carried out with the following objectives:

- Make available to INDOT, and ultimately the Indiana legislature, a systematic and comprehensive account of all aspects of the current speed limit policy, and selected speed limit policy scenarios.
- Provide information about individual, interactive, and overall impacts of all factors involved in the evaluation process.
- Assist in formulating for any possible changes in speed limit policy for the state highway network in Indiana.

A carefully planned speed limit policy can reduce highway crashes, increase mobility, and enhance economic productivity. Given the large and ever-increasing usage of highways, the impact of such a study can be significant in terms of dollar savings.

1.5 Study Approach

The study began with a detailed information search regarding the historical trends in speed limit laws and the current status of speed limit policies and practices in Indiana as well as other states. The next step was to collect operating speed data made available by the Speed Monitoring Program of the Joint Transportation Research Program (JTRP), accident data from the Indiana State Police, and relevant data from other sources.

A detailed statistical analysis was conducted to evaluate the impact of past speed limit changes in Indiana in terms of safety and trucking industry productivity. The results of this analysis will help in the formulation of a set of policy guidelines for setting speed limits. The guiding principle in this exercise is to address all aspects of the change in existing speed limits, with the ultimate objective of maximizing benefits to road users and the economy in general, while minimizing any adverse impacts.

1.6 Organization of The Report

Chapter 1 provides a background to the study, and identifies the study approach. An in-depth literature review and discussion of the state-of-the-practice regarding speed limits is presented in Chapter 2. Chapter 3 presents an analysis of speed trends on various highways classes in the State of Indiana, as a prelude to studying the relationship between operating speeds and posted speed limits. Chapter 4 is specifically devoted to a discussion of the impact of previous speed limit changes on safety while Chapter 5 evaluates the impact of speed limit on trucking industry productivity. Finally, the conclusions and recommendations arising from the study results are provided in Chapter 6.

CHAPTER 2 SPEED LIMITS: STATE–OF–THE-PRACTICE

2.1 Introduction

A state-of-the-practice about speed limits and the impact of speed limits on factors of interest is presented here. Since speed limits have a direct bearing on all road users, this subject has been extensively studied in the past and yet continues to command considerable attention among researchers, professionals, decision makers and general public alike. Given the vast array of interests, the subject has been studied from a variety of angles. Among those interested in the subject in one way or the other are those working in the areas of safety, traffic engineering, transportation planning, highway design, transportation policy, transportation economics, transportation operation and law enforcement. Besides these professionals, decision-makers, politicians, and all road users in general are interested in the speed limit debate in one way or the other. A review of literature on the impact of speed limits on safety, productivity, environment and energy consumption is of particular interest for this research and is carried out in this chapter.

Research on the connection between safety and speed limit and the impact of speed limits on safety by far outnumbers that in productivity, environment and energy areas. Literature concerning the relationship between posted limits and actual operating speeds on the highways will be presented first in this chapter, followed by literature dealing with the impact of speed limits on safety, productivity, energy, and the environment.

2.1.1 Chapter Organization

Studies on the subject of speed limit impacts have been conducted both at state as well as national level. This chapter starts with an overview of the post-NMSL speed limit status in all states. This is followed by a review of literature on speed limits-operating speed linkage in the U.S. as well as abroad. Review of the U.S. literature in general is divided in three temporal phases: pre–1987, post–1987, and post–NMSL. For each of these phases, where applicable, speed limit policies and impacts for limited-access roads are discussed separately from the non-limited–access roads.

The speed-safety relationship literature review covers speed–crash probability relationship, followed by the speed–crash severity. The speed–crash probability discussion deals with correlational studies followed by causal studies. Limited-access and non-limited-access roads are discussed separately.

The speed limit–safety literature review section presents studies about the relationship between changes in speed limits and their effect on highway safety. The section briefly describes prominent studies dealing with the impact of the 55-mph speed limits (legislated in 1974) on safety. However, bulk of the literature deals with the post-1987 period. Studies about the safety effects of changes in speed limits in Indiana are presented first followed by those for neighboring states and then other states.

The discussion of the effect of speed limits on travel time and productivity follows that of safety. The chapter concludes with the presentation of available research work on the impact of speed limits on energy and environmental factors, particularly air quality.

2.2 Post-NMSL Speed Limits

Since the NMSL there have been two major changes in the speed limits in the USA. In 1987 Congress authorized states to raise maximum speed limits on eligible sections of rural interstates to 65 mph. Speed limits were raised in forty states after that. The second major change came in 1995 when Congress repealed the NMSL entirely. Eleven states raised speed limits in late 1995 or early 1996. By the end of 1996, the number had gone up to 32 [NHTSA 1998]. By June 1998, 49 states had changed maximum speed limits on one or the other part of their highway networks [TRB 1998]. Table 2.1 gives details of current (1999) speed limits in states. Most of the states have raised speed limits by 5 to 10 mph on rural interstates, and in some cases on other freeways and four-lane divided highways.

Table 2.1 Maximum Speed Limits by States as of April 30, 1999

State	Pre-NMSL Maximum (mph)	Current Maximum Speed Limit (mph) Interstate Highways	Primary Highways
Alabama	70	70	55
Alaska	70	65	55
Arizona	75	75	55
Arkansas	75	70 (65)	55
California	70	70 (55)	65 (55)
Colorado	70	75	55
Connecticut	60	65	55
Delaware	60	65	50
D.C.	60	55 (50)	50
Florida	70	70 (65)	55
Georgia	70	70	55
Hawaii	70	55	55
Idaho	70	75 (65)	65
Illinois	70	65 (55)	55
Indiana	70	65 (60)	55
Iowa	75	65	55
Kansas	75	70	70
Kentucky	70	65	55
Louisiana	70	70	65
Maine	70	65	55
Maryland	70	65	55
Massachusetts	65	65	55
Michigan	70	70 (55)	55
Minnesota	65	70	65
Mississippi	70	70	65
Missouri	70	70	65
Montana	Basic Law[a]	75 [b](65)	70[b] (60)
Nebraska	75	75	60

Table 2.1 (continued) Maximum Speed Limits by States as of April 30, 1999

State	Pre-NMSL Maximum (mph)	Current Maximum Speed Limit (mph) Interstate Highways	Primary Highways
Nevada	Basic Law[a]	75	70 (55)
New Hampshire	70	65	55
New Jersey	70	65[c]	55
New Mexico	70	75	60
New York	55	65	55
North Carolina	70	70	55
North Dakota	75	70	65
Ohio	70	65 (55)	55
Oklahoma	70	70	65 (55)
Oregon	75	65 (55)	55
Pennsylvania	65	65	65
Rhode Island	60	65	55
South Carolina	70	65	55
South Dakota	75	75	65
Tennessee	75	70	65
Texas	70	70 (60)	70 (60)
Utah	70	75	55
Vermont	65	65	50
Virginia	70	65	55
Washington	70	70 (60)	60 (55)
West Virginia	70	70	65
Wisconsin	70	65	55
Wyoming	75	75	65

Source: [TRB 1998], [MTDOT 1999]

Note: Figures in parentheses are speed limits for heavy trucks
Primary highways are part of federal-aid-highway system.
[a] Speed that is reasonable and prudent for the conditions, no numeric limit.
[b] Effective May 28, 1999.
[c] For an 18-month trial period since January 1998.

Only the District of Columbia and Hawaii still have a maximum speed limit of 55 mph on such roads. Indiana and 20 other states have a maximum speed limit of 65 mph Eighteen (18) states have a maximum speed limit of 70 mph for their (mostly rural) interstate system. Nine (9) states have raised the speed limit to 75 mph. Speed limits, in general, are higher in the western states. Montana experimented with non-numeric speed limits (December 1995 – May 1999) but enforced a maximum daytime speed limit of 75 mph for automobiles effective May 1999.

Maximum speed limits for the Primary Highways (non-interstate part of federal-aid highway system) in 31 states is still 55 mph or less. Nebraska, New Mexico and Washington have raised it to 60 mph. Speed limits for the Primary Highways in another 13 states have been raised to 65 mph. As of January 1998, the maximum speed limit for Primary Highways in Kansas, Nevada, and Texas is 70 mph. Six (6) states have differential speed limits for heavy trucks on their Primary Highways.

Twelve (12) states have retained or introduced differential speed limits with speed limits for trucks being 5-15 mph lower than those for automobiles. Some states have lower nighttime speed limits. Many of the states that did raise speed limits for rural interstates have retained lower speed limits for urban interstates and other freeways. The range of speed limits for urban interstates across states is 55 mph to 70 mph.

In general, the change in speed limits is affected through legislative action. Some states (California, Iowa) have legislated higher speed limits for specific road systems (e.g., rural interstates), but require safety studies and/or traffic or engineering surveys to be undertaken before extending the higher speed limits to other road classes. Some states have adopted the more cautious approach of raising speed limits on a temporary basis. In New Jersey, legislation was passed in January 1998 to raise speed limits to 65 mph for the state's limited-access highway network for an 18-month trial period [TRB 1998].

2.3 Speed Limits and Operating Speeds

Prior to a detailed analysis of the impact of speed limits on safety, productivity, environment and energy consumption, it is logical to establish if posted speed limits, or changes thereof, have any bearing on speed and speed distribution on highways. This subsection reviews literature about the relationship between speed limits and operating speeds, and the impact of changes in speed limits on changes in operating speeds. A detailed account of the speed trends in Indiana, over the 1981-95 time period, is given in Chapter 3.

Average traffic speeds, 85^{th} percentile speed and speed dispersion have been of primary interest to researchers who have analyzed the impact of changes in speed limits on travel speed characteristics. A commonly used definition of speed dispersion in such studies is the difference between average traffic speed and the 85^{th} percentile speed.

Studies in the U.S. regarding operating speeds and speed distribution for the pre-1987 period are discussed first, followed by those for the post-1987 period when speed limits for rural interstates in several states were raised to 65 mph. The speed trends for the post-NMSL period (1995 onwards) are then discussed. For each of these eras, studies about limited-access highways are discussed, followed by a review of studies for non-limited-access highways. International studies are discussed at the end of this sub-section.

2.3.1 Speed Limits and Operating Speeds – Pre 1987

Several studies about the connection between speed limits and operating speeds were conducted after the enactment of NMSL in 1974. A comprehensive review of these studies is given in a report of the Transportation Research Board [TRB 1994]. The report found that the lower (55 mph) speed limit had reduced both travel speeds and fatalities, although driver speed compliance had gradually eroded.

The 1987 Surface Transportation Uniform Relocation Assistance (STURA) Act primarily affected the rural interstates and hence most of the studies during the 1987-95 period concentrated on rural interstates. However, some studies analyzed the effects of change(s) in speed limit(s) on non-limited-access highways. Effects of change in speed limit on operating speeds on limited-access highways are discussed first, followed by a review of such effects for non-limited-access highways.

2.3.1.1 Speed Limits and Operating Speeds on Limited-Access Highways – Post 1987

Several studies have been conducted to analyze the impact of the 1987 change in the speed limits for rural interstate highways. The National Highway Traffic Safety Administration conducted studies in 1989, 1990 and 1992 to assess the impact of the change in speed limits. The 1989 study analyzed speed data for 21 states, 13 with 65 mph speed limits on Rural Interstates and 8 with 55 mph. The study used speed data collected by the states during 1982-1988. A before-and-after analysis using regression-based trend modeling was carried out as part of the data analysis. The study concluded that both the average speed and the 85th percentile speeds increased in the states that had increased speed limits to 65 mph [NHTSA 1989]. The study utilized a limited sample (data for only one year after the change in speed limit) and conclusions were made using an average across states.

McKnight et al. [1989] analyzed quarterly speed data collected from sixteen states (nine 65- mph states, seven 55-mph states) for the 1982-88 period. Employing ARIMA models they reported a 48.2 percent increase in the percentage of drivers exceeding 65 mph on rural interstates in 65-mph states. The corresponding number for the 55-mph states was 18 percent. The study also reported a 9.1 percent increase in the percentage of drivers exceeding 65 mph on roads with 55 mph speed limits in the 65-mph states. The corresponding number for the 55-mph states was 37 percent. This study also aggregated speeds over all states and did not control for differences across states or highway systems. Nor did the study offer any explanation for the increase in speed in the 55-mph states.

NHTSA [1990] updated its 1989 study in 1990, at which time data from 18 states (all with 65mph speed limits) were analyzed. Before-and-after analysis and regression techniques were employed for data analysis. The study, like the previous one, reported increase in both average and 85th percentile speeds.

Freedman and Esterlitz [1990] studied speed trends on rural interstates in Maryland, New Mexico and Virginia and urban interstates in New Mexico. They analyzed speed data for April 1987-July 1989 and reported an increase in both average and 85th percentile speeds on rural interstates in 65-mph states. Little change was observed on rural interstates in 55-mph state (Maryland). Similarly, little change was noted in speeds on urban interstates. The study also observed speed separately for trucks and reported similar speed trends for trucks. The study did not report any statistical tests and had no control for differences across states.

Mace and Heckard [1991] studied speed trends for 51 rural interstate speed sites in eight states. They did a before (1986) and after (1988/1989) analysis and reported 3.9 mph, 4.3 mph and 0.65 mph increase in average speeds, 85th percentile speeds and speed dispersion, respectively. The study observed little change in speed from 1988 to1989. Little local spillover effect was observed and there was no evidence of spillover onto urban interstates

The NHTSA study in 1992 was an update of its 1990 study. Data from eighteen (18) states and two periods (4th quarter of 1986 and 4th quarter of 1990) were used for the before-and-after analysis. The study reported that average speed during the analysis period increased by about 3.4 mph, 85th percentile speed increased by 4.1 mph and the speed dispersion increased by 0.7 mph [NHTSA 1992]. All three NHTSA studies relied on aggregating data from different states without controlling for differences across states.

Freedman and Williams [1992] studied speed trends in 11 northeastern states using speed data for Oct. 1989-Jan 1990 period. The study reported increase in speeds on rural interstates in 65-mph states but speeds on rural interstates in 55-mph states were unchanged. The study also reported comparatively lower truck speeds in states with differential speed limits. No statistical tests were reported.

The FHWA study [1995] reported that average speed on limited-access highways having 55 mph speed limit was 56.9 mph (range 49.4 – 59.6 mph). The 85th percentile speed was reported to be 64.0 mph (range 56.4-68.3). The study was based on speed monitoring data collected by states in 1993. No statistical analysis was reported.

Parker [1997] studied data from 10 interstate speed sites in four states during April 1989-August 1989. The sites included both experimental (where speed limits were changed) and comparison (where speed limits remain unchanged) sites. The study reported an increase (range 0.2 - 2.3 mph) in average speeds at experimental sites, and a decrease (range –0.9 mph to 0.2 mph) in speed standard deviation at 3 out of 4 experimental sites. Less than 0.5 mph change in average and 85th percentile speeds was reported for the comparison sites. The site selection for the study was non-random and the sample size was small. No control for differences across states or highway systems was applied.

2.3.1.2. Speed Limits and Operating Speeds on Non-Limited-Access Highways – Post 1987

There are fewer studies concerning speed limits and operating speeds on non-limited-access highways than there are for limited-access highways, perhaps due to the fact that unlike the later, speed limits were not changed system wide all over the country for non-limited-access highways in 1987. Some relevant studies are discussed here.

Ulman and Dudeck [1997] examined the effect of lowering the speed limit from 55 to 45 mph at six suburban highway sites, through selected rapidly developing areas in Texas. The study analyzed speed data for 1-year before and 1-year after the changes in speed limit and reported little change in average speed, 85th percentile speed, the proportion of drivers exceeding 60 mph, acceleration, or skewness (in the overall speed distribution). The authors, however, did not control for other confounding factors such as changes in population, traffic congestion and enforcement. The absence of these controls weakened the validity of the study's conclusion that lowering speed limits below the 85th percentile speed had no conclusive effect on absolute speeds, speed distributions or speed changing-activities.

Casey and Lund [1987] in two studies, analyzed the speed adaptation phenomenon. They studied and compared speeds of drivers continuing from high-speed roads on to low-speed roads with those not coming from high-speed roads. They studied three California locations (comprising 6 study sites) with urban and rural settings and alternative connecting roads and speed limits. ANOVA and multiple regression techniques were employed for data analysis. The study reported that drivers generally traveled slower on the connecting roads but on 5 out of 6 sites, drivers coming out of higher-speed roads had speeds 1.8 to 4.7 percent faster than those coming from lower-speed roads.

In a follow-up study state [Casey and Lund 1992], the authors re-tested the same sites to study the effect of 65 mph speed limits on California highways (none of the 6 sites had a change in speed limits). The study reported increase in average speeds at two of the three freeway sites and at three out of the four connecting roads. Speed adaptation continued to be observed but did not worsen post-65 mph speed limits in the state. The applicability of the findings elsewhere can, however, be questioned.

An important study by Parker [1997] included 100 experimental and 83 comparison sites, all non-limited-access, in 22 states between June 1986 and July 1989. The experimental sites were non-randomly selected and the comparison sites were selected to match the characteristics of the experimental sites as closely as possible. The sites were located both in rural as well as urban areas. Posted speed limits were lowered at 59 sites and raised at 41 of the 100 experimental sites. The change in speed limits ranged between 5 mph to 20 mph.

In general, the Parker study reported little evidence of a relationship between posted speed limits and speed distribution. The difference in the average speeds, 85^{th} percentile speeds and the standard deviations, before and after the changes in speed limits was generally less than 2-mph. These changes, though statistically significant, were interpreted as not being of practical significance. The study reported little spillover effect but did report significant change in driver compliance with respect to the posted speed limits. The non-random selection of sites gives rise to several questions about the findings of the study. It can be argued that because all the experimental sites in the study were scheduled for speed limit changes anyway, the posted speed limits may have simply rationalized observed behavior. If true, this could have biased the results significantly. Moreover, it also implies that the results of the study can not be generalized for the entire non-limited-access highway population and that inferences can only be drawn for the actual sites included in the study itself. Furthermore, the authors concluded that a statistically significant 2-mph change in speed distribution was not practically significant, but did not elaborate on the threshold level of change to merit practical significance.

2.3.2 Speed Limits and Operating Speeds – Post NMSL Repeal

Although after the repeal of NMSL, speed monitoring is no more federally mandated, several states that raised speed limits have continued collecting speed and crash data voluntarily, especially on roads where the limits were raised. Several studies have reported the impact of these changes. These studies are primarily focused on rural interstates since most of the post-NMSL initial changes in speed limits were on rural interstates.

The TRB study [TRB 1998], provides a comprehensive review of the impact of change in speed limits on operating speeds. After reviewing several studies on the subject that included [Retting and Greene 1997] (speed data from California, Montana, New Mexico, Nevada and Texas), [Pezoldt et al. 1997] (speed data from Texas), Davis [1998] (speed data from New Mexico), speed data from Montana [MNDOT & MNHP 1996], the report summarized the findings as follows:

> "Average speed typically increased 1 to 3 mph despite larger increases in the speed limit – a minimum of 5 mph. The relatively small changes in average speeds compared with the change in the speed limit may reflect poor driver compliance levels with the lower limit in effect before the change. Eighty-fifth percentile speeds also generally increased by 1 to 3 mph. Thus speed dispersion – at least as measured by the aggregate difference between the 85th percentile and the average speed – remained relatively unchanged 1 year after repeal of the NMSL."

The TRB study further reported that:

> "A few studies found a large percentage of drivers violating the new speed limits. This suggests that some drivers expect the same enforcement tolerance of 5 to 10 mph at the higher speed limits. For example, speed measurements taken on three urban freeways and one urban Interstate in Riverside, California, found that, 1 year after the speed limit was raised to 65 mph, 41 percent of drivers exceeded 70 mph – up from 29 percent immediately before the change [Retting and Greene 1997]. Thus, there is some evidence that, when speed limits are raised, the distribution of traffic speeds not only shifts rightward with higher average speeds but also outwards with a greater dispersion in speeds, at least at the high end of the speed distribution."

Similar trends for Montana were reported by the study where comparison of before and after (only 9 months) speed data revealed widening in the range of driving speeds (at least initially) and increase in average and 85th percentile speeds

[TRB 1998]. It needs to be noted, however, that Retting and Greene [1997] reported an increase of 6.2 to 6.5 mph in speed standard deviation on urban freeways (non-interstate) and one urban interstate in Riverside, California, immediately before and 1 year after the speed limit was raised to 65 mph for automobiles. They reported an even greater increase for Houston.

Nolf et al. [1997] studied speed trends in Michigan after speed limits were raised to 70 mph in the state in 1996. Speed data for the 9 test sites (8 rural interstate,1 non-interstate) and 9 control sites (3 urban interstates, 6 non-interstates) were analyzed. The data covered 17 days of before and approximately 3 months of after-period. The study reported an increase of 1 mph in average speed and 0.5 mph in 85th percentile speed after the increase in speed limit to 70 mph. No "meaningful" change was observed at the control sites and there was no spillover effect for sites located in proximity of test sites . The study relied on a small sample of speed data and reported no statistical tests. No control was employed for cross-site differences.

2.3.3 International Studies on Operating Speeds and Speed Limits

A number of international studies examined the linkage between speed limits and operating speeds. Unlike the United States, many of the international studies investigated the effect of speed limits on lower-speed roads (roads with speed limits below 50 mph). These studies represent conditions in European countries and Australia. Table 2.2 summarizes the findings of these international studies and is adopted from the TRB study [TRB 1998].

In general, the analyses are similar to those for the studies carried out in the United States and have similar questions raised about their findings. The studies report that speeds, in general, decrease when speed limits are decreased but not by the same amount. Many of the studies report changes in speed limits accompanied with other public information, traffic control and enforcement measures resulting in better results than those involving just a change in speed limit sign.

2.4 Effects of Speed on Safety

Studies about the relationship between driving speed and crash involvement date back to 1960s. Researchers have focused attention on two aspects of the speed-safety relationship: the relationship between operating/driving speed and probability of crash, and given a crash, the relationship between the severity of crash and driving speed. The issue of speed and probability of crash involvement is more complex than the speed-crash severity relationship.

The promulgation of NMSL in 1974 stimulated interest in the speed-safety relationship and several prominent studies were conducted on the subject during the 1970s. With the authorization to states to raise speed limits on rural interstates and some other roads in 1987, the speed-safety debate heated up again. By then two schools of thought could clearly be traced in the literature. One argues that higher speeds essentially result in higher number of crashes with increasing degree of severity. Higher speeds are more demanding from the driver perception and reaction point of view and that vehicular and roadway safety features are tested to (sometime beyond) limits at higher speeds.

Table 2.2 International Research on Speed Limits and Operating Speeds

Study	*Database for Study*	*Methodology*	*Findings*	*Comments*
Schleicher -Jester 1990	Germany, 19-mph speed zones, 1983-1986	Before/After analysis	General decrease in speeds and crashes	Prior speed limits were 31 mph. Decrease in speed limit combined with public information, traffic control, speed control and street design changes
Vis et al. 1992	Netherlands, 19 mph speed zones in 15 municipal areas, 1980	Before/After analysis Quasi-experimental	20 % reduction in speed, generally resulting in an 85th percentile speed of 19 mph. 5% to 30% fall in traffic volume. Decrease in crashes	No information on prior speed limits. Decrease in speed limit combined with engineering measures to slow traffic. Where did the decreased traffic go? No experimental site; changed only speed limit sign.
Cairney and Fackrell 1993	City of Unley, Australia 25-mph speed zone 1991-1993	Before/After analysis	25-mph limit led to permanent 3-mph reduction in speed. Initial temporary fall in traffic volume. Effect of increased enforcement ambiguous	No information on prior speed limits. Amount of speed reduction at experimental sites varied Examines effects of speed limit changes with and without speed camera enforcement
Nilsson 1990	Sweden 56-mph speed limit on 3400 miles of roads 1988-1989	Before/After analysis	Decrease in avg. speed less than speed limit decrease. Decrease in crashes not statistically significant	Assumes no effect on previous 56-mph roads. No control for accompanying changes in public information and enforcement.
Borsje 1995	Netherlands Introduction of a general 75-mph speed limit 1988-1991	Before/After analysis	Differentiated speed on motorways decreased average speed and had a non-increasing effect on speed dispersion Positive effect on crash incidence	75 mph on 80 % of motorways, 62 mph on 20% of motorways. Statistical significance of results not reported. Accompanied with greater enforcement, media campaigns and infrastructure changes

Source: [TRB 1998]

The other school of thought argues that large speed variance rather than higher speeds are responsible for higher crashes. If a change in speed limit results in narrowing the speed variance then, all else remaining constant, such a change will in fact improve the safety on roads. In fact, the 1984 TRB report indirectly supported this point of view by concluding that "if the average speed of the traffic stream could be increased without increasing the variance of the speed, then the adverse effects on safety might be comparatively small" [TRB 1984]. By having higher speeds on highways with safer design and better safety records some of the high speed traffic can be expected to divert to them from other, comparatively less safe, highways. This can help reduce the speed variance on the later, in turn reduce the probability of crashes on such highways.

Another point that could be offered in favor of realistic speed limits is that when speed limits reflect the desired speed of the drivers, enforcement of such a speed limit is less resource-intensive. Law enforcement personnel can then better concentrate on other safety aspects concerning the road travel such as driving under intoxication and use of seat belts.

2.4.1 Speed and Crash Probability

Three separate approaches, all aimed at providing a theoretical explanation of the relationship between speed and crash probability, could be traced in the literature.

- The risk-homeostasis motivational approach
- The traffic conflict approach, and
- The information processing approach

The risk-homeostasis motivational approach looks at speed and crash- involvement from the perspective of driver perception of risk and proposes that drivers adjust their speed according to the risk as perceived by them in order to maintain a subjectively acceptable level of risk [Taylor 1964; Wilde et al. 1985].

The traffic conflict approach assumes that crash probability is related to potential for conflict among vehicles in the traffic stream. This implies that the crash probability for a driver (to be involved in a multiple-vehicle crash) is a function of the deviation of the individual driver's speed from the speed of other drivers. Drivers with speeds much faster or slower than the median traffic speed are likely to encounter more conflict [Hauer 1971]. This is primarily applicable to 2-lane 2-way roads.

The information processing approach views driver as the information processor with a limited processing capacity. This approach theorizes that at higher speeds the pace of information processing required of the driver is higher and a crash is likely to happen when the information processing demands exceed the attention focussing or information processing abilities of the driver [Shinar 1978].

Researchers have attempted to establish the speed-crash involvement relationship in two different ways and depending on the approach the studies could be considered as correlation studies or causal/clinical studies. Correlation studies test the speed-crash involvement relationship by analyzing actual speed and crash data to find a correlation between the two. Causal or clinical studies, on the other hand, are aimed at establishing a cause-and-effect relationship between speed and crash involvement. Correlation studies are more frequent to find than clinical ones.

2.4.1.1 Non-Limited-Access Highways

Solomon [1964] studied travel speeds of vehicles involved in crashes with the average speed of free-flowing traffic on two- lane and four-lane, (35 out of 36 road sections) non-limited-access rural highways. Solomon reported that vehicles in the high and low speed areas of speed distribution had a greater crash involvement. He showed, through his well-known U-shaped curve, reproduced here as Fig 2.1, that crash involvement rates were the lowest at speeds slightly above average traffic speeds. The curve also showed that the rate of crash involvement goes up as the difference – both positive as well as negative - between the average speed and the individual motorist's speed increases. Hauer's traffic–conflict theory [Hauer 1971] provides a theoretical basis for Solomon's findings.

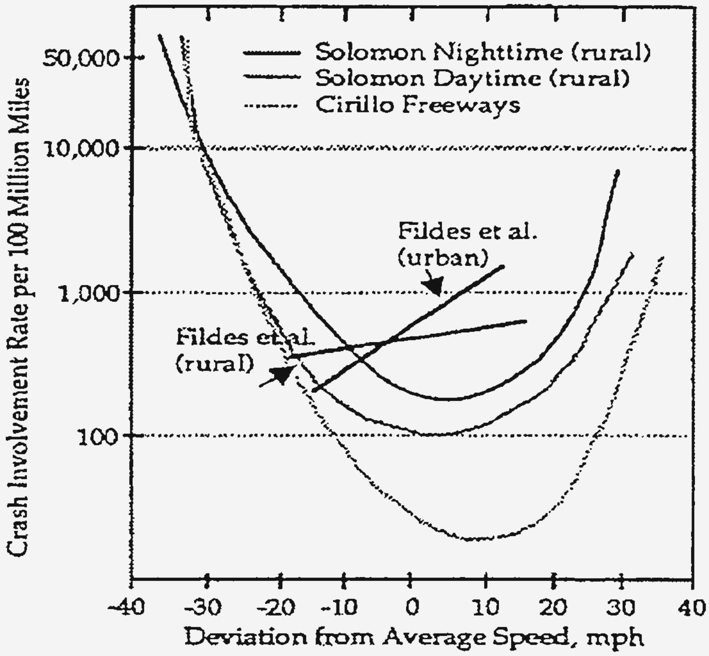

Figure 2.1 Vehicle Crash Involvement Rates as a Function Of Deviation from Average Traffic Speed

Source: [TRB 1998]

Several studies, conducted in the United States and elsewhere in different settings, have since reported findings similar to those of Solomon. Munden [1967] reported a similar relationship for rural roads in the UK. Cirillo [1968] replicated the U-shaped curve for interstates in the United States. Many of these studies have been criticized for the bias that might have been involved because of their dependence on police crash reports for the pre-crash speeds. These studies have also been criticized for unrepresentative comparative traffic speed data, lack of consistency between crash and speed data, and mixing of crashes of free-flowing with slowing vehicles, which would explain high crash involvement rates at low speeds [TRB 1998].

The Research Triangle Institute and Indiana University examined crashes on highways and county roads with speed limits of 40-mph and more. The study reported a similar but less pronounced U-shaped relationship between crash involvement and speed [RTI 1970 in TRB 1998]. West and Dunn [1971] studied the speed and crash relationship for rural roads in Indiana and reported results similar to Solomon's U-shaped relationship. However, when they removed crashes involving turning vehicles from the sample, the U-shaped relationship became weak. Moreover, unlike Solomon, they did not find any elevated rate of crash involvement for vehicles at the low end of speed distribution. These findings support the conclusion that road characteristics (e.g., frequent intersections and/or driveways) are as much a factor as those driving too slowly for the conditions.

Lave [1985] analyzed the relationship between crash involvement in terms of fatalities per 100 million vehicle miles), average speed, and speed dispersion (85^{th} percentile speed minus the average speed). Using data from 48 states he showed that, for most road types, speed dispersion is positively related to crash rates. He also reported that if speed dispersion is held constant (statistically), then the correlation of crash involvement with average speed, percentage of vehicles exceeding 55-mph and 65-mph, and 85^{th} percentile speed, are all insignificant. Lave's rural arterial model which attempted to control for more variables, found a weak but statistically significant relationship between traffic speed dispersion and fatality rates for only one of the two years of data. Similar results were reported for the urban arterial model [Lave 1985]. Commentators of Lave's analysis confirmed the relevance of speed dispersion to crashes but claimed that average speed is also a significant contributor [TRB 1998].

Garber and Gadiraju [1988] investigated the relationship between crash rates, speed dispersion (as a measure of speed variance), average traffic speed, design speed and speed limits for different classes of roads in Virginia. They found that crash rates declined with an increase in average traffic speed when data for all classes of roads were aggregated. The correlation, however, disappeared when the data were disaggregated by road class. Crash rates modeled as a function of speed dispersion for each road class, increased with increasing speed dispersion. The minimum speed dispersion occurred when the difference between the design speed and posted speed was small (less than 10 mph). For the rural arterial roads the authors found a high correlation between increasing speed dispersion and crash rates but found no significant relationship between average traffic speeds and crash or fatality rates.

Very little work has been done in the United States on the subject of speed and crash probability on urban streets and virtually none for residential streets. However, researchers in Europe and Australia have examined the relationship for urban streets and their findings are discussed under International Studies later in this section.

2.4.1.2 Limited-Access Highways

Cirillo [1968] investigated the speed-crash probability relationship for limited-access highways. She demonstrated that Solomon's U-shaped relationship between crash involvement and speed deviation applies to limited-access highways, with some differences. These differences pertain to the significantly lower crash involvement rates for the limited-access highways. The study reported a minimum crash involvement rate for limited-access highways at approximately 10 mph above the average traffic speed and goes up both above and below that speed. Cirillo also found that crash involvement rates are significantly higher in the vicinity of interchanges than in through sections. Since the approach was similar, Cirillo study had the same shortcomings as those mentioned earlier for Solomon's study.

Lave [1985], in addition to the non-limited-access highways also studied speed-crash involvement for limited-access highways. He found a statistically significant relationship between increasing traffic speed dispersion and fatality rates on rural but not on the urban interstate highways.

Garber and Gadiraju [1988], in their study, conducted a separate analysis for rural and urban interstates in Virginia. They found a significant, positive relationship between crash involvement and speed variance. Crash rates increased as speed variance increased. No significant correlation between average speed and crash involvement rates was reported.

2.4.1.3 Speed-Crash Probability Relationship - Causal Analyses

Most of the studies discussed above fall under what is known as the correlational approach of investigating the speed-crash probability relationship. This approach however cannot reveal the underlying causes of the relationship. It has been observed that older drivers, because of age-related and medical impairments, are slower to respond to emerging dangers even at low speeds compared to younger drivers. On the other hand, younger drivers often misjudge their vehicle handling limitations and the limitations of the vehicles and therefore travel at a speed too high to permit timely response to a change in the roadway or traffic conditions. These kinds of factors involved in crashes can be investigated by causal analyses.

Treat et al. [1977] in their clinical (causal) study analyzed the role of speeding as a cause of crash. The crashes dated from 1970 to 1975 and were confined to state, county, and municipal roads in Monroe County, Indiana. In their study, speed was defined as causal if it met two conditions: a) it deviated from the "normal" or "expected" speed of the average driver for the site condition, and b) it "caused" the crash, that is, the crash would not have occurred had the speed been as expected. Based on this definition, the study estimated "excessive speed" to be a definite cause in 7 to 8 percent of the crashes and a probable cause in an additional 13 to 16 percent of the crashes. Speed was identified as the second most common factor contributing to crash occurrence, second only to "improper lookout" (inattention) [TRB 1998].

Bowie and Wlaz [1994] combined a) the comprehensive causes of all fatal crashes in FARS, b) 1-year data from all police reported crashes from six states and c) some of the data analyzed by Treat et al. [1977]. Although the data came from different sources and were categorized using different methodologies, the three sources yielded similar estimates. Excessive speed was involved in approximately 12 percent of all crashes and more than 30 percent of fatal crashes.

Viano and Ridella [1996] analyzed data from 131 fatal crashes. The study reported "nothing to do" as the most common cause of crashes revealing that these crashes typically caused by circumstances where the driver was unable to do anything to avoid them. Single vehicle crashes that resulted in the vehicle leaving the road at a very high speed was reported to be the second most frequent cause, accounting for 11 percent of crashes. No crashes were attributable to slow driving although many of the crash scenarios involved maneuvers that required drivers to slow down (e.g., yielding, 6 percent; making left turns, 4 percent; and negotiating curves, 9 percent).

2.4.1.4 Speed-Crash Probability Relationship – International Studies

Several international studies were conducted in different countries to analyze the relationship between speed and rate of crash involvement. Munden [1996] studied the relationship between speed and crashes in the United Kingdom. He used speed ratio, defined as the ratio obtained by dividing the speed of the study vehicles by the speed of the four cars that preceded it and the four cars that followed it, to measure speed deviation. A U-shaped relationship was observed, but only for drivers habitually (more than once observed doing so during the study) driving at deviant – especially slow speeds.

Fildes et al. [1991] examined crash involvement rates as a function of speed on urban arterials as well as on two-lane rural roads in Australia. They found no evidence of the U-shaped relationship. Crash involvement rates rose linearly as a function of speed. Lowest crash involvement rates were observed at speeds below average traffic speeds and highest at speeds above the average with no advantage at the average.

Pasanen and Salmivaara [1993] measured both pre-crash speeds and traffic speeds at the time of the crash using a specifically calibrated video camera, placed above an intersection in Helsinki (Finland), for more than one year. They recorded 18 intersection collisions, 11 of them involving pedestrians. For eight (8) of these pedestrian crashes, the involved vehicles, in free flow conditions, were traveling much faster than the average speed of the traffic stream and the speed limit. Their work demonstrated that at least for urban intersections, there is a direct relationship between a vehicle's speed and crash probability.

Moore et al. [1995] and Kloeden et al. [1997] both studied the speed-crash probability relation ship for urban roads (speed limit in both cases was 37 mph) using the case control method to rule out as many non-speed factors as possible. For every injury crash they measured the speed of non-crashing control vehicles moving at free flow speeds at the same sites, at the same time, on the same weekday and under the same weather conditions. They also excluded from the study drivers with nonzero alcohol as well as those involved in illegal maneuvers. Moore et al compared the speed of 45 crash vehicles with 450 control vehicles and reported increased crash involvement for drivers exceeding speed limits but not for those below it. With 34 to 40 mph used as the reference speed, the relative risk of an injury crash for drivers traveling at 47 to 52 mph was approximately 8 (i.e., the probability of a crash was almost 8 times as high as that of a vehicle traveling at 34 to 40 mph). It rose to 39 for speeds exceeding 53 mph [Moore et al. 1995].

Kloeden et al compared the speeds of 151 crash vehicles with 604 non-crash vehicles and reported similar results. Casualty crash (a crash that causes someone to go to hospital by an ambulance) rate increased exponentially above the 37 mph speed limit, remaining relatively constant until that speed. For vehicles traveling at 47 mph the relative risk of an injury crash was 11 (i.e., the probability of a vehicle traveling at 47 mph being involved in an injury crash was 11 times as high as for those traveling at 37 mph). The relative risk rose to 32 for those traveling at 50 mph and to 57 for those traveling at 53 mph [Kloeden 1997].

All of the above international studies were correlational studies. Liu and Popoff conducted a causal (clinical) study to examine the crash data for 1990-95, in Saskatchewan, Canada. They defined a speed-related crash as one in which the police crash report noted that the driver was both "exceeding the speed limit and driving too fast for the conditions". Although conservative, the definition was considered to be appropriate since police reports are not as reliable as professional in-depth crash investigations. The study reported that speed was a causal factor in 9.2 to 10.5 percent of all crashes and in 11.9 to 15.2 percent of all casualty (injury or fatal) crashes [Liu et al. 1997 in TRB 1998].

2.4.2 Speed-Crash Severity

Crash severity is, in general, defined in one of the two ways:

a) The physical severity of impact speed or Delta-V (the change in velocity resulting from the crash)
b) The severity of injuries experienced by the occupant if the vehicle is involved in the crash.

Solomon, in his 1964 benchmark study, studied the speed-crash severity relationship using two measures of crash severity: 1) injury rates expressed as the number of people injured relative to the number of crash-involved vehicles and 2) property damage cost per crash-involved vehicle. Solomon reported a direct relationship: the higher the speed, the greater the cost, both in terms of injuries as well as property damages. He also calculated fatality rates from the data available to him. With a total of 235 fatalities he found that the odds of a fatality given a crash increased with speed, from a low of approximately 2 fatalities for every 100 crashes at speeds below 55 mph to more than 20 for speeds of 75 mph and above [Solomon 1964]

O'Day and Flora [1992] analyzed 10,000 crashes occurring between 1970 and 1979 and reported the speed – crash severity relationship as a power function. They showed that at speeds of 50 mph, the fatality rate – mostly for unbelted occupants – was slightly above 50 percent.

Joksch [1993], in an analysis of the National Analysis Sampling System (NASS) data, found a consistent relationship between the fatality risk for a driver in a car-car collision and Delta-V. He reported that the risk is closely related to Delta-V, and that the exponent varies between 3.9 to 4.1 for all types of crashes.

Bowie and Walz [1994] showed that the power relationship also holds well for nonfatal injuries. They calculated the relationship between Delta-V and injury rates for AIS Level 2+ injuries and AIS Level 3+ injuries and showed that the AIS 3+ injury rate increased significantly with increase in Delta-V. They also showed that the percentage of speed-related crashes increases with increasing injury level: from 10.2 percent for no-injury crashes, to 17.1 percent for incapacitating-injury crashes, to 34.2 for fatal crashes [Bowie and Walz 1994]. Table 2.3 shows distribution of injuries in speed-related crashes by injury severity level. The table is based on data from Bowie and Walz reported in TRB [1998].

Table 2.3 Distribution of Injuries in Speed-related Crashes by Injury Severity Level

Injury Severity Level	Number[a]	Speed-Related (percent)[b]	Total
No injury[c]	12,610,000	10.2	1,286,220
Possible injury	1,719,000	10.9	187,371
Non-incapacitating injury	943,000	14.6	137,678
Incapacitating injury	481,000	17.1	82,251
Fatal injury[d]	45,500	34.2	15,558

Source: [Bowie and Walz in TRB 1998]

Notes:

[a] National totals are from 1989 General Estimates System (GES)

[b] Speed-related percentage derived from Crash Avoidance Research Data File (CARDfile)

[c] The estimate for non-injured people is considered to be low because some states only list injured persons

[d] Fatal crash statistics are from Fatal Analysis Reporting System (FARS), 1989.

The effect of speed on pedestrian fatalities follows the same trend. The European Transport Safety Council (1995) concluded that in a 20-mph collision between a vehicle and a pedestrian, the probability of pedestrian death is 0.05; at 30 mph it rises to 0.45; and at 40 mph it is 0.85 [TRB 1998]. O'Donnell and Connor [1996] applied ordered multiple-choice models to all crash records of New South Wales for 1991. They showed that, relative to a benchmark crash with a 33-year old driver, a 1 percent increase in speed caused a 0.44 to 0.56 percent increase in the probability of death

In conclusion it can be said that all studies discussed above have found a consistent relationship between speed and crash severity showing that Delta-V and injury severity both increase as speed goes up. Shinar in [TRB 1998] summarized the findings of the work done to date about speed-crash probability and speed-crash severity relationship as follows:

> "1. There is ample, but not unequivocal, evidence to indicate that, on a given road, crash involvement rates of individual vehicles rise with speed of travel.
> 2. There are no convincing data to demonstrate that, across all roads, crash involvement rates rise with the average speed of traffic (i.e., that roads with higher average traffic speeds have higher crash rates than roads with lower average traffic speeds). This is probably because the average traffic speed is highly correlated with the design speed of different road classes (and other conditions).
> 3. The absolute speed deviation of crash-involved vehicles from the average traffic speed appears to be positively related to crash probability, especially for rural arterial highways and Interstate highways. There are insufficient data to demonstrate such a relationship for rural collector roads and urban streets.
> 4. The principal factor that accounts for the effects of speed deviation is the requirement to slow down to make turns and to enter and exit high-speed roads. Still, even when the effects of turning vehicles are removed from the data, some effects of speed deviation, especially at the extreme ends, remain.
> 5. The disparities in speed of the traffic stream may be positively related to crash probability, especially on Interstate highways. However, the data are not very consistent, and more data are needed.

6. On urban streets there appears to be a strong relationship between crash rates and the absolute speed of crash-involved vehicles. However, this conclusion is based mainly on small data sets from non-U.S. studies.

7. The data demonstrating the relevance of speed dispersion in the traffic stream and speed deviations of crash-involved vehicles are based on correlational effects and therefore cannot be used to indicate that if slow-moving drivers were to increase their speed, their crash probability would be reduced.

8. There are unequivocal data to indicate that the risk of injuries and fatalities increases as a function of pre-crash speed or Delta-V. This is true for all road types.

9. The overall cost of speed-related crashes is much greater than the relationship between speed and crash probability indicates. This is because high-speed crashes are associated with greater injury levels than are low speed crashes."

2.5 Speed Limits and Highway Safety

The speed limits-speed relationship and speed-safety relationship – in terms of speed-crash probability and speed-crash severity relationships – were discussed in the preceding sections. There is some evidence, though not consistent, that the lower speed limits under the NMSL did contribute in lowering the average and 85th percentile speeds. By the same token there is inconclusive evidence that the relaxed speed limits on rural Interstate highways, since 1987, have contributed in increased mean and 85th percentile speeds.

The next logical question is whether these effects of varying speed limits (which are believed to have an identifiable bearing on operating speeds) have any safety implications, and to identify any such implication) This aspect of the effects of speed limits, or changes in them, is the focus of this section. Fig 2.2 presents a framework of speed limit and highway safety relationship.

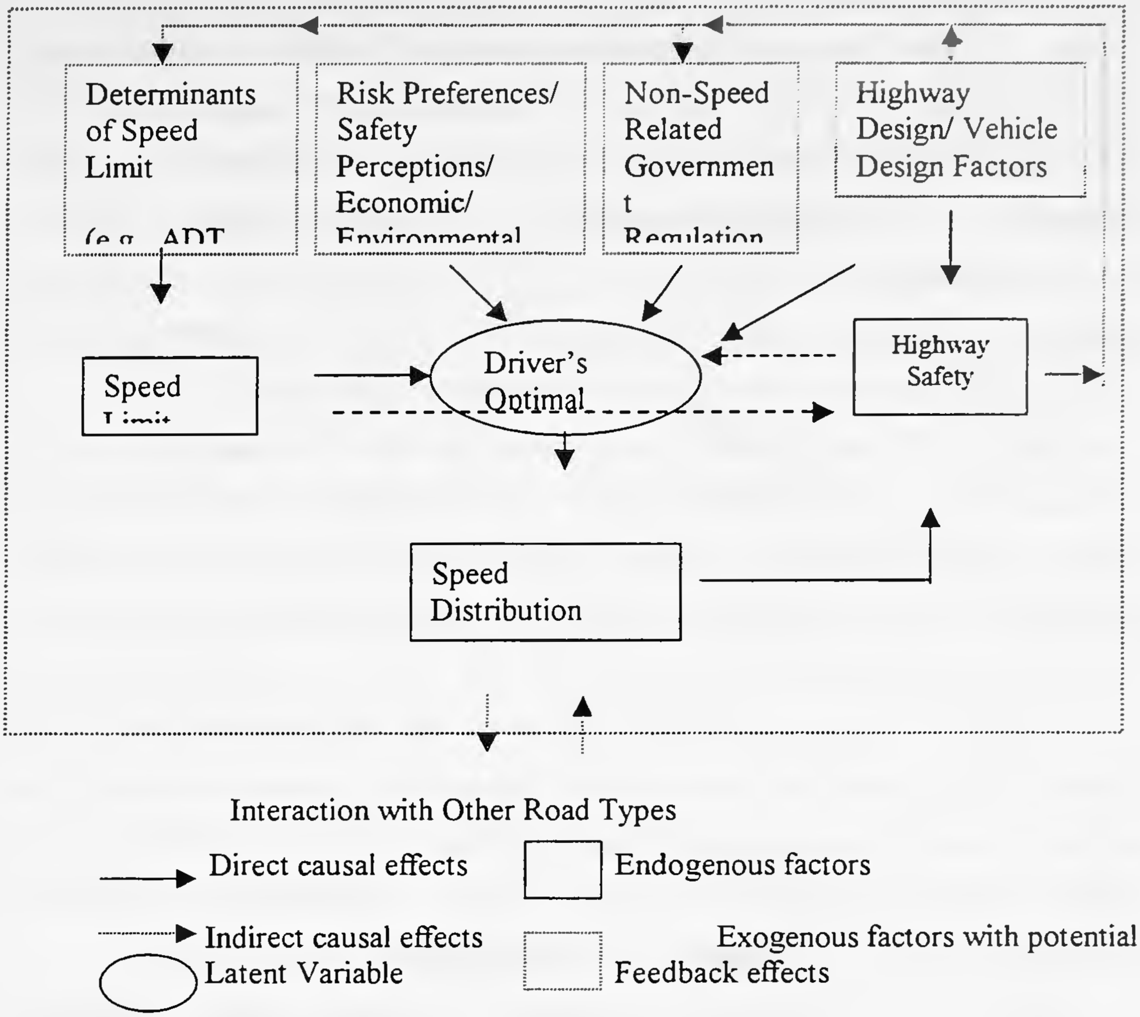

Figure 2.2 Relationship between speed limit and highway safety
Source:[McCarthy in TRB 1998].

The basic mechanism between speed limit and highway safety is shown in the middle of the figure. It indicates that speed limits, along with other factors, influence the choice of optimal speeds by drivers. Other important determinants include highway and vehicle design, traffic enforcement and other governmental interventions, environmental attributes and characteristics of the driving population. In addition to these, drivers have individual preferences for risk and a subjective view of traffic safety. All these objective and subjective factors collectively determine optimal speed for individual drivers, which in turn, produce a distribution of speeds and a set of safety outcomes.

Studies about highway safety generally fall into one of the three categories. The first category deals with setting speed limits and their effect on speed distribution and driver compliance. The second category of studies examines the relationship between attributes of speed distribution (average speed and speed dispersion) and highway safety. Most of the studies belonging to these two groups have been discussed in the previous sections with the exception of those dealing with setting of speed limits which will be discussed in the relevant sections elsewhere in this report. The third set of studies deals with the impact of changes in speed limits on safety. This section focuses on the third category. Although a large number of studies have been undertaken on this issue, there is yet no consensus on whether increasing speed limits decreases safety.

Researchers have tested several hypotheses concerning the effect of changes in highway speed limits. These hypotheses often focus on direct and indirect effects, as well as the effects by vehicle type, road type, time of travel, location, alcohol consumption and socioeconomic factors. Most of the studies have focussed on fatal crashes and fatalities.

Three methodological approaches have typically been used in the empirical literature to test hypotheses concerning the effect of changes in posted speed limits: paired comparison, regression analysis, and time series analysis. A more detailed explanation of these methodologies is presented elsewhere in this report.

U.S. studies about the impact of changes in speed limit are either national in their scope or concentrate on a single state. Studies that are national in scope are presented first followed by those that focus on a particular state. Then international studies are presented.

Only a few studies about the speed limit – safety relationship post NMSL are available and are discussed at the end of this section.

2.5.1 Speed Limit Changes and Highway Safety – National Studies

Following the enactment of the NMSL, numerous studies of the benefits and costs of that legislation were conducted. Expectedly, there is no consensus about the magnitude of the impact the 55-mph speed limits had on highway safety. However, there seems to be a broad agreement, in general, about its positive effect on safety.

A joint NHTSA and FHWA report [NHTSA & FHWA 1980] examined the effects of the lower speed limits on safety for the 1974-1978 period. The study concluded that while the "...determination of a precise, accurate estimate of lives saved by the NMSL is problematic, there were 20,000 to 30,000 lives saved by the NMSL during the 1974-1978 period".

The TRB special report [TRB 1984] presented a thorough and comprehensive examination of the impact of NMSL mandated 55-mph speed limit on safety. The TRB study reported that the lower speed limits did contribute to a reduction in average speeds and in a more uniform pace of travel (indicating less speed dispersion). The study further estimated that the 55-mph speed limit accounted for 3,000 to 5,000 fewer traffic fatalities in its first year, 1974. The study further estimated that on the average, for the 1974-1984 period the lower speed limit saved 2,000 to 4,000 lives per year.

Immediately after the passage of the STURA Act in 1987, 38 states raised speed limits on the eligible portions of their highway networks (mostly rural interstates), and 2 other states increased speed limits in 1988. Since the passage of the STURA law, NHTSA has completed a number of studies on the impact of that legislation.

In a before-and-after comparison in 1989, NHTSA [1989] reported that fatalities on rural Interstates in 65-mph states were 18 percent higher than they were in 1987 than 1986. The corresponding increase for the 55-mph states was 7 percent. Fatalities on urban interstates in the 65-mph states decreased by 7 percent in 1987 compared to 1986, while the corresponding decrease in 55-mph states was 10 percent.

An update of the 1989 NHTSA study [1990] employed before-and-after analysis using regression techniques, reported a 13 percent increase in rural interstate fatalities for the 1987-1988 period and a 2 percent decrease for 1988-1989. Rural interstates in the 55-mph states experienced a 12 percent decrease in fatalities between 1986 and 1989. Fatalities on the urban interstates in the 65-mph states increased by 7 percent for the 1987-1988 period, and decreased by 7 percent for 1988-1989. Urban interstate fatalities in the 55-mph states increased by 13 percent during 1986-1989.

In an update of its 1990 study, NHTSA [1982] employed the same analytical tools methodologies as in 1990. The study reported a 4 percent decrease in rural Interstate fatalities for the 1989-1990 period and a 27 percent increase for the overall 1987-1990 period in 65-mph states. The corresponding numbers for the 55-mph states were 17 percent increase and a 3 percent increase, respectively.

All three of the NHTSA studies analyzed annual crash data for the thirty-eight (38) states with 65-mph speed limit and ten (10) states with 55-mph speed limit. The data for these studies spanned from 1975-1987, 1988 and 1990, respectively. Only in the 1992 study was the analysis explicitly controlled for the vehicle-miles-traveled (VMT). According to NHTSA the 20 percent increase in the VMT for rural interstates during 1986-1990 accounted for one-third of the increase in fatalities. Shortcomings of the NHTSA studies, pointed out by other researchers, include aggregation of data that led to disregard of the variability across states, and limited control for confounding factors.

Baum et al. used before and after analysis based on odd ratios for their three successive studies (1989, 1990 and 1991) to assess the effect of higher rural interstate speed limits on safety. The authors divided the states in 2 groups having 65-mph and 55-mph speed limits. They also defined two time periods, 1982-1986 versus the year of the respective study (1987, 1988 or 1989). Then they investigated whether the change in odd ratios (of fatalities on rural interstates to fatalities on other rural roads) was statistically significant between the two groups of states. In their 1989 study Baum et al. [1989] reported that relaxed speed limits increased the odds of a fatality on rural interstates significantly, but no significant effect was found in the 55-mph states. In the 65-mph states fatalities increased by 19 percent on rural interstates and by 4 percent on other rural roads. These results were similar to those reported by NHTSA. The authors found similar results for comparison of 55-mph states with and without differential speed limits, and for states with and without safety belt laws.

In their 1991 study Baum et al. [1991] controlled for changes in VMT and vehicle occupancy. The study reported that with no such adjustment, relative to 1982-1986, the odds of a rural interstate fatality in 65-mph states in 1989 increased 29 percent. After adjustment for VMT and vehicle occupancy, the percentage increase was 19 percent.

Garber and Graham [1989] estimated separate regression models based on monthly data for the 40 states that raised speed limits on rural Interstates. The authors controlled for some factors including economic performance, seasonal effects, weekend travel and safety belt law. The models also included a time trend to capture the influence of VMT. Similar to the trend in NHTSA's estimates Garber and Graham estimated that the median effect of the speed limit change was a 15 percent increase in fatalities on rural interstates, and a 5 percent increase for rural non-interstate roads. The authors also reported that: a) the 65-mph speed limit did not have uniform effects across all 40 states. All other factors being constant, fatalities increased in 28 states and either decreased or remain unchanged in 12 states; b) the higher speed limit generally increased rural non-Interstate fatalities, implying that spillover effects more than offset any traffic diversion effects.

McKnight et al. [1989] estimated an Autoregressive Integrated Moving Average (ARIMA) model to assess the impact of 65-mph speed limit on safety. They used data from January 1982 through July 1989, from 20 states with 65-mph speed limit and eight 55-mph states. The authors reported a significant increase in rural interstates fatal crashes in the 65-mph states but no effect on non-interstate rural roads in these states. This could be explained by a possible traffic diversion towards rural interstates in the 65-mph states. Controlling for use of safety belt and traffic density did not have any effect on these results. In the 55-mph states, the authors reported a significant increase in both rural Interstate and other rural non-interstate highway fatal crashes. This last result raised several questions about the time span of data series, the effect of aggregation, need to control for more confounding factors and the possibility of an unexplained spillover effect.

Chang et al. [1991] also used ARIMA methodology with a longer (January 1975 to December 1989) monthly crash data series to estimate fatality models for 32 states with a 65-mph speed limit and 6 states with a 55-mph speed limit. The authors tried several alternative formulations of the intervention and reported that the 65-mph speed limit had a statistically significant effect on fatalities initially, but after a "learning period" of 1 year, the effect decayed over time. They also reported similar trends for smaller states but found larger states to be insensitive to the change in speed limit. The authors also reported a significant rising trend in fatalities since 1986 prior to the speed limit change but attributed the same to some "unknown exogenous" factors.

Lave and Godwin [1992], in two separate studies investigated the effect of change in speed limits on safety. Both studied data from 38 states with a 65-mph speed limit and 8 states with a 55-mph speed limit. Both studies controlled for the VMT only and both reported an overall system-wide decrease in fatalities. Godwin indicated that such a system-wide fatality decrease resulted from an unreasonably high VMT shift from non-Interstate rural roads to rural Interstates [Godwin 1992]. Lave, however attributes the decrease to more efficient allocation of police resources in addition to the traffic diversion.

McCoy et al. [1993] studied data for 19 pairs of state highway urban speed zones for the 1985-1988 time period. They used a quasi-experimental approach and employed Poisson regression models. The authors concluded that speed zones with "reasonable" speed limits (based on the prevailing speed in the respective zones and the test run speed) have lower crash rates than zones with lower "unreasonable" speed limits. The models controlled for traffic volumes (AADT) and the presence of traffic generators (size and number of businesses). The study is important in that it is among the few studies that have focussed on roads other than rural interstates and provides it estimates of the effect of speed limit changes in the urban environment.

Studies by Lave and Elias [1994], like Lave's two previous works, analyzed annual (1986 and 1988) and monthly (January 1976 – December 1990) crash data from 44 states – 38 with a 65-mph speed limit and 8 with a 55-mph speed limit – using before-and-after and regression methodologies. This study updated Laves's 1992 work employing a systemwide approach. The models controlled for seasonal effects, safety belt law and the economy. The authors reported a 3.4 to 5.1 percent system-wide decrease in the fatality rate for the states.

Lave's 1992 study and the Lave and Elias study in 1994 represented another way of examining the speed limit-safety relationship. Unlike most of the other studies that focused on rural interstates, these two studies assessed the system-wide effects of the n speed limit changes. In his earlier study Lave found out that the fatality rate in the 65-mph states fell to 2.42 per 100 million VMT in 1988 from 2.57 per 100 million VMT in 1986. No change in fatality rates was observed for the 55-mph states. Lave estimated that additional 2206 fatalities would have taken place if the 1986 fatality rates were to continue. He attributed the savings in fatalities to the 65-mph speed limit since fatality rates in the 55-mph states did not change. In their later study Lave and Elias reported that system-wide fatality rates in 65-mph states fell between 3.4 and 5.1 percent. Reasons cited for the decline included traffic diversion, reallocation of enforcement resources, and possible declines in speed dispersion.

FHWA [1995], in its 1995 report on the subject examined data about the effect of speed limits on safety in all states. The report presented data for 1993. No statistical analysis was performed but a 2.4 percent increase in fatalities on rural interstates in the 65-mph states was reported. The 55-mph states were reported to have a 4.5 percent decrease in the rural interstate fatalities.

2.5.2 Speed Limit Changes and Highway Safety – State Level Studies

A large number of studies have examined the speed limit safety relationship for specific states, especially for the large and more populous states. Methodologies adopted for the data analysis in these state-specific studies are similar to those employed for the national studies. In general, these studies have reported increase in fatalities/fatality rates on rural interstates in the 65-mph states.

In this section studies about Indiana will be discussed first, followed by studies for the neighboring states. Finally, studies about other states will be discussed.

2.5.2.1 Indiana

Three studies have analyzed the impact of the 1987 change of speed limits for rural interstates in Indiana. McCarthy [1988] estimated a time series cross section regression model to analyze the speed, crash and other socioeconomic data for the 1981-1988 period. Only 7 months of the "after" data were available. The study reported a less than 1 percent increase in incidence and severity of crashes on rural interstates.

McCarthy [1991], in his second study on the subject, analyzed Indiana data for the 1981-89 period. This included 31 months of the post-1987 period. Using time series cross section (regression) models McCarthy analyzed speed, crash and other socioeconomic data for the state for 1981-1989. He reported that:

a) statistically significant increase was observed in total and injury crashes on rural interstates. No significant change was found on fatal crashes.
b) on other highways the trend was reverse, i.e., total and injury crashes decreased. No change in fatal crashes was found.

McCarthy explained the reduction in total and injury crashes on non-Interstate highways as an outcome of the change in speed limit, attributing this to a possible traffic diversion to rural Interstates. The (almost simultaneous) passage of the state's Mandatory Seat Belt Law, that was not controlled may have caused some confounding in the analysis.

In his third study, McCarthy [1993] investigated the effect of the speed limit change on a subset of crashes in Indiana i.e., alcohol-related crashes. He estimated a time series cross section (regression–fixed effects) model to examine the impact of change in speed limit on alcohol-related crashes in Indiana, while controlling for exposure, age distribution, population, economy, alcohol availability and enforcement. McCarthy reported that: a) On a statewide level, total, fatal, injury and property damage only crashes increased after the change in speed limits; b) alcohol-related crashes underwent a redistribution from higher-speed to lower speed roads after the change in speed limit; and c) similar trends as in 'a' and 'b' above were observed for most categories of alcohol-related crashes including daytime, single-vehicle and non-truck crashes.

2.5.2.2 Neighboring States

Three studies have been carried out to analyze the effect of the 65-mph speed limit on rural interstates in Illinois. Sidhu [1990] used a linear regression model to analyze the impact of speed limit change using data for a 5-year period before the 65 mph speed limit. He attempted to establish the impact of the change in speed limit on the probability of crashes in the state. The study concluded that there was no significant increase in fatalities due to increased speed limit and that most of the increase in rural interstate fatalities was due to an increase in crashes involving pedestrians as well as crashes involving drinking and driving.

In another study, Pfefer et al. [1991] used an ARIMA intervention analysis methodology to analyze the impact of the change in speed limits in Illinois. The authors examined monthly crash data for the rural Interstates in the state for the January 1983 – July 1988 period. The authors concluded that speed limit change had no significant effect on passenger car crash rates on the rural Interstates and that the fatal-injury car-truck crash rate decreased after the change in speed limit.

In a third study for Illinois, Rock [1995] compared the 65-mph rural interstates with those having a 55-mph speed limit. He estimated an ARIMA model using monthly rural highway crash data for the May 1982 - April 1991 time period. Rock reported a 40 percent increase in rural Interstate fatalities for the 65 mph Interstates. The 55 mph rural Interstates had a 25 percent increase in fatalities.

Three studies have been conducted about the effect of 65 mph speed limits on safety in Michigan. Wagenaar et al. [1989] used ARIMAX intervention analysis methodology and estimated separate models for rural interstates, urban interstates and other highways, using monthly crash data for January 1978 - December 1988 period. The authors also controlled for some confounding effects. They concluded that fatalities on 65-mph roads increased by 19 percent, serious injuries on the same roads increased by 40 percent. Fatalities on the 55 mph roads increased by 38 percent.

Streff and Schultz [1990], like Wagenaar et al., estimated ARIMAX models. Their data series included monthly crash data for Michigan for the January 1978 – December 1989 period. Like Wagenaar et al. they also estimated separate models for rural and urban interstates as well as other roads. The authors found that fatalities increased by 28 percent and serious injuries by 39 percent. These results were consistent with the findings of Wagenaar et al. with one difference. Unlike Wagenaar et al., who did find a significant increase in fatalities on 55 mph highways (urban interstate in particular) and attributed it to the "spillover" effect, Streff and Schultz found no significant impact on urban interstate fatalities.

A third Michigan study was conducted by Penfield et al. [1996] to analyze the effect of 55 mph speed limits mandated in 1974. The authors used (linear) regression models to analyze the 20-year (1968 – 1987) crash data for the state. The study did not find any significant change in the fatality crash trend. The authors also found out that while the crash rates for rural highways were/are in general higher, the impact of the 55 mph speed limit was more prominent on urban highways. Economic depression and higher unemployment at that time are claimed to be the reason for greater impact in urban areas.

Pent et al. [1991] studied the effect of 65 mph speed limit on safety in Ohio. They analyzed crash data for Ohio for an equal 36 months "before" (July 1984-June 1987) and "after" (August 1987 – July 1990) period employing a Poisson regression model. The authors found no statistically significant change in fatal crashes on rural Interstates. They however, did report significant increase in injuries and PDO crashes on rural Interstates. The authors reported significant increase in fatal, injury and PDO crashes on 55 –mph Interstates, injury and PDO crashes on non-Interstate 55-mph highways decreased.

2.5.2.3 Other States

Brown et al. [1990] studied the effect of 65-mph speed limit in Alabama. The authors analyzed crash data for 1-year before and 1-year after the change in speed limit. The study reported significant increase in average speed and daily traffic on rural interstates after the change. The study also reported a 1.9 percent increase in crash frequency but no increase in crash severity on rural interstates.

Upchurch [1989] studied the effect of 65-mph speed limit in Arizona. He compared crash data for 3-years prior to the change in speed limit with those for 1-year after the sped limit. The author while controlling for the VMT found that fatal crash rate on rural interstates after the change in speed limit was higher than that for any of the three years before. The fatal crash rate for the urban interstates that remain posted at 55-mph, declined. The authors, however, reported no statistical test.

Khorashdi [1994] studied the safety-speed limit relationship for California after the change in speed limit to 65 mph. Employing a before-and-after approach, Khorashdi estimated ANOVA models to compare crash data for 65 mph rural interstates, 65 mph rural non-interstates and 55 mph rural interstates. The study reported increase in fatal crashes on 65 mph highways, both rural interstates and rural non-interstates. Khorashdi also compared the crashes on 55-mph highways with those on 65-mph highways and found that while the trend for total, fatal, and injury crashes was declining on the 55-mph highways it was going up for the 65-mph highways.

McCarthy [1994] studied safety-speed limit relationship for California using a systemwide approach. He used specifications similar to those of Graber and Graham [Graber and Graham 1989], and utilized separate models for each category of roads to estimate the regression (time series cross section) models. The panel data set analyzed by him included monthly crash data (January 1981 – December 1989) McCarthy reported no systemwide effect on total, fatal, injury and PDO crashes. For individual road types, the change in speed limit had no effect on fatal or injury crashes on Interstates, U.S. highways, State highways and County roads. McCarthy also found a redistribution trend: crashes in counties with interstates experienced a declining trend while those without interstates had a rising trend.

Wright and Sarasua [1991] compared crash and speed data for 6 months before and after the implementation of the 65-mph speed limit in Georgia. The authors, in bid to define pattern of changes in crash and speed data performed a time series analysis. The study reported no significant increase in fatalities, but a significant increase in injuries was observed.

Two studies have examined the effect of speed limit change on highway safety in Iowa. Ledolter and Chan [1994] analyzed quarterly crash data for the 1981-1991 period. The authors used time series and seemingly unrelated regression models to estimate the effects on safety. The study reported a system-wide 18 percent increase in fatal crashes and a 2.4 increase in major injury crashes. For individual categories of roads the authors reported 45 percent increase in fatal crashes for rural interstate. A 17 percent increase in fatal crashes for rural primary roads and a 12 percent increase for rural secondary roads was also reported. The study did not control for confounding factors and suffered from the small sample size used for the analysis.

Maze et al. [1996] used a Bayesian dynamic model to estimate the effect of change in speed limit on safety in Iowa. The authors analyzed crash data for 1980-93 period and concluded that the 65 mph speed limit had caused a significant increase in fatalities on rural Interstates.

Jernigan et al. [1994] studied the effect of change in speed limit on safety in Virginia. They used a before-after approach and employed ANOVA models to analyze the data. The authors compared crash data for 1985-1987 (before) versus the data for 1989-1992 (after). The authors reported a decrease in system-wide fatalities but an increase in fatalities for the rural interstates. The authors also found that differential speed limits had no effect on car-truck crashes. The study had no control for confounding factors. The fatalities on rural interstates seems to have stabilized in the years 1990-1991.

2.5.3 International Studies

Speed limits and their effects on safety have been a topic of interest outside of the United States and a number of researchers have studied the subject, particularly in Europe and Australia. Most of these studies have used analysis approaches very similar to those adopted for studies conducted in the U.S. However, unlike the U.S. where attention has primarily been focussed on high-speed interstate highways, many international studies have analyzed the speed limit – operating speed – safety relationship for the low-speed roads. The following excerpt, adapted from the recent TRB study [TRB 1998] summarizes the salient features of the international studies on the subject. Table 2.4 gives a brief account of individual international studies.

> "In general the analysis in these studies is very similar to that used in many U.S. studies, namely quasi-experimental approaches dominated by a paired comparisons methodology. As such, these studies tend to generate similar effects

and suffer the same drawbacks. On the positive side, the imposition of speed limits in lower-speed environments is typically associated with a decrease in crashes and crash severity. However, these analyses generally suffer from not appropriately accounting for confounding factors and using a comparison series that may also be effected by the speed limit change.

Three European countries – Germany, the Netherlands and Denmark – have analyzed the effects of a 19-mph speed zone in urban areas. In each of these cases, the speed limit was part of an urban planning policy whereby traffic users shared the streets with other users. Complementing the reduced limit were other actions, including public information campaigns, increased enforcement, engineering speed measures, and so forth, intended to inform the public that the appropriate speed on the effected roads was lower than in the surrounding areas. In other words, in no cases did the speed limit change simply involve a speed limit sign change. Thus, it is not possible in these studies to draw any conclusions concerning the effect of a speed limit sign change only.

A second point of interest is that part of the decrease in crashes in some studies was due to a decrease in traffic volume, which raises the question of the traffic distribution effects of the speed limit" [TRB 1998].

Table 2.4 International Studies on Speed Limits and Highway Safety

STUDY	DATABASE FOR STUDY	METHOD-OLOGY	MAJOR FINDINGS	COMMENTS
Engel and Thomsen 1988	Denmark , urban areas, quarterly data, Oct.1985-Oct.1987	Logit Regression	9 % decrease in crashes 24 % decrease in fatalities	Prior speed limit was 37 mph Limited sample No control for confounding
Schleicher -Jester 1990	Germany 19 mph speed zones, 1983-86	Before/after analysis	General decrease in speeds and crash severity	Prior speed limits were 31 mph. Speed limit decrease combined with public information, traffic control, speed control, and street design change
Vis et al. 1992	Netherlands, 15 municipal areas, 19 mph speed zones 1980s	Before/after analysis Quasi-experimental	Traffic volume fell 5% to 30% 5% trend adjusted fall in crashes 25 % trend adjusted decrease in injury crashes	No information on prior speed limits Speed limit aimed to integrate road user categories Combined with engineering measures to slow traffic No experimental site; changed only the speed limit sign
Engel and Thomson 1992	Denmark, residential areas 19-mph speed zones, 44 experimental areas, 53 control sites, 1980s	Quasi-experimental Before/after analysis Regression analysis	18.4 %decrease in control group adjusted crashes 21.1% decrease in control group adjusted injuries 72% decrease in casualties per user in experimental areas No change in crash risk per user in experimental areas 96% increase in casualties per road user, just outside experimental areas	No information on prior speed limits 3 years of before data, 3 years of after data 139 miles of experimental group, 11766 miles of experimental group Speed-reducing measures also implemented No discussion of effect on casualties per road user in outer areas
Cairney and Fackrell 1993	City of Unley, Australia 25-mph speed zone 1991-93 data	Before/after analysis	Initial temporary fall in traffic volume Effect of increased enforcement ambiguous	No information on prior speed limits 2-miles by 660-ft study area in Unley Examines effects of sped limit changes with and without speed camera enforcement

Table 2.4 International Studies on Speed Limits and Highway Safety (Continued)

STUDY	DATABASE FOR STUDY	METHOD-OLOGY	MAJOR FINDINGS	COMMENTS
Newstead and Mullan 1996	Victoria, Australia 31-, 43-, and 50- mph speed limit zones 1992-93, 994-95	Before/after analysis Quasi-experimental	No systemwide effect 6.9 % increase in injury crashes for metropolitan Melbourne 32.9 % reduction in injury crashes in the rest of Victoria Both results are marginally significant	Speed limits increased on 1,1996 miles of roads, decreased on 342 miles. For Melbourne, 47% decrease in injury crashes when speed limit increased from 37 to 50 mph and a 10.5% increase when limit increased from 47 to 50 mph
Fieldwick and Brown 1987	Europe and the United States 1984	Regression cross-section analysis	Decrease in urban speed limit from 37 to 31 mph would decrease fatal and nonfatal injuries by 25% Similar but smaller effect if rural speed limits decrease from 62 mph to 56 mph	Confidence interval for predicted effects not given No control for cross-section heterogeneity Other excluded variables could reduce the beneficial effects found here
Nilsson 1990	Sweden 56-mph speed limit on 3400 miles of roads 1988, 1989	Before/after analysis	Relative to other 56-mph roads, 15% (11%) decrease in injury crashes (injuries) , neither statistically significant	Assumes that speed limit change had no effect on previ-ous 56-mph roads No control for change in public information and enforcement and other confounding factors
Sliogeris 1992	Victoria, Austalia Change in 65-mph speed limit 1985-1991	Before/after analysis Regression analysis	Statistically significant 24% increase in injury crashes per mile after 68-mph speed limit Statistically significant 19% decrease in injury crashes per mile after removal of 68-mph speed limit	Controlled speed limit was 62-mph No control for other factors All other 62-mph roads in Victoria are control group Similar results for rural and urban roads

Table 2.4 International Studies on Speed Limits and Highway Safety (Continued)

STUDY	DATABASE FOR STUDY	METHOD-OLOGY	MAJOR FINDINGS	COMMENTS
Borsje 1995	Netherlands Introduction of 75-mph speed limits 1988-1992	Before/after analysis	Positive effect on crash incidence	75 mph on 80 % of motorways, 62 mph on 20% of motorways Statistical significance of results not reported. Accompanied with greater enforcement, media campaigns and infrastructure changes
Johansson 1996	Sweden 56-mph speed limit Monthly 1982-91 crash data	Poisson time series analysis	No statistically significant effect on fatal or serious injury crashes Statistically significant decrease in minor injury and vehicle damage crashes	Methodology accounts for over-dispersion and serial correlation Controls for exposure, seasonal effects, safety belt law

Source: [TRB 1998]

2.5.4 Speed Limits and Safety – Post NMSL

Since the repeal of NMSL in 1995, researchers have attempted to study the effect of the changes in speed limits on safety. A number of state-specific studies and at least one national study have examined these effects.

NHTSA [1998] studied the effect of the repeal of NMSL at the national level. The study made a before-and-after comparison of fatalities in three groups of states using FARS data for 1995 (before) and 1996 (after). The three groups were: (1) the 11 states that raised speed limits in late 1995 or by the first quarter of 1996, (2) the 21 states that increased speed limits in late 1996, and (3) the 18 states (and the District of Columbia) that did not increase speed limits in 1996.

The study reported a less than 0.5 percent change in the system-wide fatalities and fatal crashes from 1995 to1996, while system-wide injuries and injury crashes increased by 4 percent. However, the states that increased their speed limits collectively experienced 350 more interstate fatalities than would have been expected based on historical trends.

Fatalities and fatal crashes on rural interstates both increased by 10 percent, while the corresponding increases on urban interstates were 6 percent and 7 percent. Fatalities and fatal crashes on non-interstates decreased by 1 percent. The number of injured persons increased 15 percent on Interstates in 1996, but increased by only 3 percent on all other highways.

The study analyzed data for only one year after the change and reported no statistical tests. A comparison of crash rates in 1995 and 1996, though more meaningful, could not be made since the VMT data were not available. Bulk of the increase reported for 1996 is accounted for by 3 or 4 states (Georgia, Oklahoma, Missouri and Texas). The aggregation of data across states concealed significant differences among them. It is interesting to note that fatalities on interstates increased in 6 out of 18 states that did not change speed limits, however fatalities and fatal crashes decreased for that. Similarly while fatalities on interstates increased for the group, 7 out of the 32 states that raised speed limits experienced decrease in fatalities.

Nolf et al. [1997] studied speed trends in Michigan, and made some preliminary investigations about effects on safety after speed limits were raised to 70 mph in 1996. Only one month of the post – 1996 mph data for the 9 test sites (8 rural interstate, 1 non-interstate) and 9 control sites (3 urban interstates, 6 non-interstates) were analyzed. The authors reported a 16.4 percent increase in total crashes for the test sites but cautioned that the results are preliminary and inconclusive. The study relied on a very small sample and reports no statistical tests. No control has been employed for cross-site differences.

Renski et al. [1998] examined the impact of post-NMSL speed limit increase on safety in North Carolina. In October 1996, North Carolina raised speed limits to 70 mph on 376 miles of interstate highways. In the following May, the speed limits were raised on an additional 316 miles of non-interstate highways. The authors used a quasi-experimental methodology and (among other data analysis techniques) estimated ordered probit models to analyze a subset of crashes (only single-vehicle crashes) on the Interstates. The data set included relevant crash data for the 1995-1997 period (roughly 1-year each before and after the speed limit change). The authors tested two hypotheses: 1) higher speed limits lead to higher crash injury severity and, 2) the higher the change in speed limit the greater the increase in crash injury severity.

Renski et al. concluded that higher speed limits did result in an increased likelihood of minor and non-incapacitating injuries where speed limits were raised from 55 mph to 60 mph or 65 mph. The highway segments where speed limits were raised by more than 10 mph resulted in a higher probability of increased severity than those raised by 5 mph. No significant changes in injury severity were found for the comparison segments or for highway segments where speed limits were raised from 65mph to 70 mph.

The authors controlled the analysis for number of occupants, alcohol involvement, presence of fixed objects along side the traveled way and vehicle type, among others. The study, by analyzing data representing the safest section of the roads may possibly have a selectivity bias which could have been avoided if the study sections had been selected randomly. A further limitation of the study is that it examines only one crash type (single-vehicle crashes) on one type of roadway (interstates) over a limited time period in one state.

2.6 Speed Limits, Travel Time and Productivity

In addition to operating speeds and consequently safety, speed limits also affect productivity. Particular groups of road users – commercial truckers and other business travelers may be more adversely affected by changes in speed limits that result in reduced driving speeds. These groups drive more miles than the average motorists and often use high-speed roads. The economic cost of travel time, particularly from lost productivity, can be substantial. No study, so far, has attempted to estimate explicitly the impact of speed limits on productivity, especially that for the commercial vehicles and trucking industry.

The importance and cost of travel time as a function of speed were illustrated by the experience during the 55-mph speed limit period. A TRB study [1984] estimated that in one year (1982) motorists spent about 1 billion extra hours on highways posted at 55 mph (because of slower driving speeds) compared to time spent on these highways in 1973. Most of this travel time was expended by passengers in personal vehicles.

To have a meaningful analysis of the time cost of travel, cost savings from reduced crashes and, fatalities and serious injures avoided, need to be considered. The 1984 TRB study compared cost of travel time with estimated lives saved and serious injuries averted by the 55-mph speed limit. The study reported the time cost to be of the order of 40 years of additional driving time per life saved and serious injury avoided. This came approximately close to the average remaining life expectancy of 41 years for the crash victims in 1982. It was concluded that making comparisons between the value of a year of life and the value of a year of driving time is not meaningful. However, it did provide one framework to assess the central trade-off between travel time and safety in making the speed limit related decisions. This study also examined another aspect of the travel time cost and speed limit relationship: the varying impact by road type and road users. The trucking industry is particularly and more adversely affected by lower speed limits. The 55-mph NMSL penalized rural interstate users the most. Lowering speed limits to 55-mph on rural interstates was estimated to cost both motorists and truckers 100 years of additional driving time per life saved – about four times as much as for other affected roads combined.

Among road users most of the additional travel time cost, attributed to NMSL, was borne by motorists engaged in personal travel. However, in view of the relatively short length of the more highly valued work-related travel, such trips are relatively insensitive to changes in speed limit. For many work trips congestion is more likely to affect driving speeds than speed limits. For trips other than work travel, the time value of trips is lower than for work travel, and by extension, the incremental cost of reduced driving speeds, or the savings to be derived from higher speeds, are low.

2.7 Speed Limits and Energy Consumption

The effect of speed on the vehicular fuel efficiency has been long established. In fact, fuel conservation was the primary motivation for the NMSL. Ever since, the situation has changed. With reliable and relatively plentiful low-cost fuel supply taken for granted, drivers concern for fuel economy is no more a primary factor in determining driving speeds. West et al. in TRB [1998] showed that for the 1988 to1995 model year, automobiles and light trucks, under steady-state, cruise-type driving conditions, fuel economy peaks at about 55 mph and then declines at higher speeds reflecting the effect of aerodynamic drag on fuel efficiency. At lower speeds, engine friction, tires, and accessories reduce fuel efficiency [West et al. in TRB 1998]. Little data on fuel economy as a function of speed for heavy trucks and older model automobiles are available. The available information suggests that fuel economy for heavy duty diesel trucks declines sharply at speeds above 50 mph, largely because of the effect of aerodynamic drag.

The rapidly changing vehicular cross-section with growing share of sports utility vehicles, minivans and pickup trucks presents yet another aspect of fuel economy for the entire fleet of active vehicles. The sports utility vehicles, minivans and pickup trucks, in general have poor fuel economy, than all but the heaviest automobiles for a wide range of speeds, and their fuel economy peaks at lower speeds than that of most passenger vehicles [Davis in TRB 1998]. Other vehicle operating costs are likely to increase with increasing speeds. However, relative to fuel costs these are small and less sensitive to speed changes.

2.8 Speed Limits and Environment

Evidence suggesting clear links between speed and air quality in terms of vehicular emission has been proved by previous research. Such studies suggest that volatile organic compound (VOCs) and carbon monoxide (CO) are highest at very low speeds frequently experienced in congested urban areas with stop-and-go traffic flow pattern. The VOC and CO emission rises again with high-speed, free flow traffic condition. Increased power demands on the engine, at higher speeds, cause VOC and CO emission to increase. However, the exact optimal emission speeds, and the emission rates at those optimal speeds are not exactly known. Emissions of oxides of Nitrogen (NO_X), are thought to increase gradually at speeds well below free-flow highway conditions, but like the VOC and CO there is uncertainty about the speeds at which this increase begins and the rate of increase [TRB 1995].

Little data are available about emission-speed linkage for heavy trucks. The available data suggest that VOC and NO_X emissions from heavy trucks increases at higher speeds. Despite the fact that particulate concentration is known to pose significant health risk, and heavy trucks are the primary source of particulate emission, no data are available about speed-diesel particulate emission from heavy trucks [TRB 1998].

In addition to causing air pollution, motor vehicles are the single largest source of Carbon dioxide (CO_2) emission, one of the principal green house gases associated with global warming. CO_2 emissions are closely linked with fuel economy and in turn with speed. At higher speeds, when fuel economy is poor, vehicle emit more CO_2 [TRB 1995]

Mullen et al. [1997] examined the impact of higher speed limits on vehicular emissions one year after the repeal of NMSL. The authors estimated that VOC emission nation-wide, increased by 2 percent. The corresponding increase in CO and NO_x emission was 7 percent and 6 percent, respectively. The increase was more prominent in western states where increases in speed limits are generally greater.

Another possible environmental impact of speed limits is noise. Higher noise levels are associated with higher speeds. Noise pollution is of greater concern to those living near highway facilities that allow high-speed travel. However, no data are available about the impact of changes in speed limits on noise levels.

CHAPTER 3 INDIANA SPEED TRENDS

3.1 Introduction

Studying the relationship between operating speeds and the posted speed limits is an important aspect of speed limit related research work. Since all impacts of speed limits stem from this primary effect, it seems logical to establish first, how do operating speeds vary with changes in speed limits. In this chapter speed data collected on Indiana highways during 1981-1995 will be used to analyze the speed trends in the state. In 1987, speed limits on rural interstates in Indiana were raised to 65-mph (60-mph for heavy trucks). The speed data analysis presented here primarily deals with the assessment of the impact of that change on operating speeds on rural interstates as well as other highways in the state highway network.

3.2 Chapter Organization

This chapter starts with the background information about speed monitoring program in Indiana. This is followed by presentation of statewide speed data and trends. This is essentially an aggregate approach of dealing with the data, combining data from individual stations representing different classes of highways to come up with statewide trends. The analysis was conducted for seven distinct road classes: 1) rural interstates, 2) urban interstates, 3) four-lane rural arterials, 4) two-lane rural arterials, 5) urban arterials, 6) rural collectors and 7) urban collectors. Speed data about these road types are presented in the same sequence. Effects of the 1987 change in speed limits for rural interstates are presented next followed by the effects on other highways

3.3 Background Information

The Joint Transportation Research Program (JTRP), formerly known as the Joint Highway Research Project (JHRP), at Purdue University has conducted annual speed studies for the Indiana Department of Transportation (INDOT) since 1956. The early studies were of free flowing traffic on rural highways and they were conducted only during summer months.

In 1974, in the wake of the oil crisis, the U.S. Congress passed a law that among other measures set the National Maximum Speed Limits (NMSL) at 55-mph. The Federal-Aid Amendment of the 1974 Highway Act made annual state enforcement certification a prerequisite for approval of Federal-Aid highway projects. Federal procedural manuals were issued to keep monitoring practices consistent in all states [U.S. DOT 1975].

The JTRP speed-monitoring program, in response to the NMSL compliance, started with a total of 14 speed stations – 4 stations each on rural interstates, rural 4-lane arterials, rural 2-lane arterials and 2 stations on urban interstates. These stations were all located on highway sections with the maximum posted speed limits for the relevant highway class.

The next major change came in 1980 when FHWA issued Speed Monitoring Program Procedural Manual (SMPPM) [U.S. DOT 1980]. Among other important changes, it required the number of statewide speed monitoring stations to be increased to 35, and a minimum duration of 24-hours for the speed monitoring sessions using standardized equipment.

In 1987, the Congress passed the Surface Transportation Uniform Relocation Assistance (STURA) Act, which gave states the right to increase speed limits up to 65-mph on the eligible portions of the interstate system. Indiana raised speed limit on rural interstates to 65-mph in June 1987. Highways posted at 65-mph were no longer required to be included in the federally mandated speed-monitoring program. Indiana continued to monitor speeds on some of its rural interstates till 1990 although the results were not included in its speed reports to the Federal Highway Administration (FHWA). The total number of speed-monitoring stations stayed at 35 with adjustments in their distribution across other highway types. No speed data for the rural interstates were collected during 1991-1993. Speed data collection for rural interstates resumed in 1994 and continues to date. However, the statewide speed trend reported (to FHWA) for Indiana for the post-1987 period continued to exclude speed data from rural interstate.

The amendments in the SMPPM in 1992 and 1993 required some of the speed monitoring locations to be taken from the Highway Performance Monitoring System (HPMS) and re-inclusion of the rural interstates in the speed-monitoring program. In Indiana the changes became effective in October 1994. Twenty-four (24) of the 35 original locations were retained and 22 HPMS stations were added, increasing the total number of speed monitoring stations in Indiana to 46.

These latest changes also regrouped the highways in Indiana into three (3) following categories for the purpose of speed monitoring:

1- Freeways posted at 55-mph including:
   a) Rural Interstates
   b) Rural Arterials
   c) Rural Others
   d) Urban Interstates
   e) Urban Arterials
   f) Urban Others

2 - Freeways posted at 65-mph including:
   a) Rural Interstates
   b) Rural Arterials
   c) Rural Others

3 - Non-Freeways posted at 55-mph including:
   a) Rural Arterials
   b) Rural Others
   c) Urban Arterials
   d) Urban Others

No highways in Indiana, except the rural interstates, fall under the 65-mph category.

With the passage of the National Highway System Designation Act of 1995, among other measures, Congress allowed states to set speed limits within their jurisdictional boundaries. Since then, states are no more required to report speed trends to the federal government. Indiana, however, continues to monitor speeds on its highways, although changes have been proposed to the speed-monitoring program to better suit the state requirements [Jorgenson and Sinha 1998].

3.3.1 Current Speed Monitoring Program in Indiana

There were 46 speed stations in Indiana in 1995. These speed stations were distributed over the state highway network based on the functional classification of highways, the VMT and spatial considerations. Of the 46 statewide speed measuring stations, fifteen (15) were located on rural/urban interstates, eighteen (18) on 2-lane or 4-lane US routes, and thirteen (13) were located on 2-lane or 4-lane state roads. Speed in Indiana continues to be monitored, to this date, at the same number of speed stations. Figure 3.1 shows speed monitoring stations in Indiana in service since 1995.

Prior to 1995 speed stations were divided into control and standard locations. Speed at control locations was monitored every quarter while the standard locations were monitored once a year. In 1995 there were 24 control and 22 standard speed stations in the state. Since 1995 all sites have been control stations.

Speed data were collected for one direction of travel only covering all travel lanes in that direction. Data were collected for all vehicles without regard to vehicle class, *i.e.*, truck speeds were not monitored separately. Speeds monitoring sessions lasted for a minimum of 36 to 72 hours, and data for 24-hours duration for the selected day were extracted from these data. Speed monitoring sessions were scheduled to eliminate any weekday bias. Automated equipment was used for all data collection operations.

The data collected, after necessary analysis, were reported in a specific format. Typically speed data in these reports were presented in a 1-35mph and then 5 mph steps. The data in the reports included number of vehicles monitored, average and 85^{th} percentile speed, percentage of vehicles exceeding the speed limit and percentage of vehicles exceeding speed in 5-mph increments of speed limits.

Figure 3.1 Speed Monitoring Stations Layout, 1995

3.4 Statewide Speed Trends

The statewide speed trends represent data aggregated from individual stations representing different classes of highways to come up with statewide trends. The JTRP speed-monitoring program reports statewide speed data on quarterly and annual basis. Since the speed-monitoring program in Indiana does not cover roads under local jurisdiction, the statewide trends reported by the program do not represent speed on these roads.

When referring to the distribution of speed in a traffic stream, three measures of speed are of interest: the average (mean) speed, the 85th percentile of the speed distribution, and the dispersion in travel speeds. Speed dispersion, in turn, can be quantified by the variance, standard deviation, 10-mph pace, or range (high minus low) of a sample of speed measurements. The standard deviation is commonly approximated as the difference of 85th percentile speed and the average speed [TRB 1998]. Table 3.1 presents the JTRP reported statewide speed data for the 1981-1995 period. The table includes average speed, 85th percentile speed and speed dispersion in terms of difference between the 85th percentile speed and the average speed.

The speed data presented in Table 3.1 are based on data collected from speed stations located on state highways posted at 55-mph. This means that while data for the 1981-1987 period, before speed limits were increased for rural interstates, include speed data from all speed stations, data for the post-1987 period exclude speed data from rural interstates. This is because FHWA exempted states from reporting speed on highways posted above 55 mph. Although Indiana did continue to monitor speeds on its rural interstates through 1990, the data were neither reported to FHWA nor included in the estimation of the statewide speed trends. Moreover, speed monitoring on rural interstates remained suspended altogether during the 1991-1994 period. Speed monitoring on rural interstates resumed in 1995.

Unreported (to FHWA) data from the speed monitoring stations on rural interstates, for the 1988-1990 period, were extracted from the JTRP record and were used for the analysis to estimate statewide speeds, presented here, for that period. However, rural interstate speed data for the 1991-94 period did not exist and had to be estimated using time series forecasting techniques. The results are presented in Table 3.2.

Table 3.1 Indiana Statewide Speeds –Highways posted at 55-MPH

	SPEED MEASURE		
YEAR	MEAN	85^{TH} PERCENTILE	DISPERSION
1981	56.1	61	4.9
1982	56	62.4	6.4
1983	55.5	63	7.5
1984	56.5	63.7	7.2
1985	55	62.7	7.7
1986	57	63.3	6.3
1987	57.1	63.5	6.4
1988	57.6	63.9	6.3
1989	57.5	63.6	6.1
1990	57.5	64.1	6.6
1991	57.5	64.2	6.7
1992	57.5	64.2	6.7
1993	58.3	64.4	6.1
1994	58.1	64.3	6.2
1995	60.9	68	7.1

Source: JTRP Speed Reports
Note: Includes data only for highways posted at 55 mph, no rural interstates after 1987.

The statewide mean speed data presented in Table 3.1, in general, indicate an observable trend (not statistical) of increasing mean speeds over time. The mean speed increased from 56.1 mph in 1981 to 58.3 mph in 1993, an increase of 2.2 mph over a span of 13 years. However, the mean statewide speed rose to 60.9 mph in 1995, an increase of

2.6 mph in just two years, more than the increase in the previous 13 years. Interestingly enough, as already stated, these data exclude speed data from rural interstates that have the highest speed limits. Data for the 85th percentile speed reveal a similar trend – a gradual increase during 1981-1993 and then a significant increase in 1994-95.

Speed dispersion on the other hand does not reveal any systematic trend – it peaked at 7.7 mph in 1985 from a low of 4.9 mph in 1981- and has been fluctuating in between these values since then. In 1995, although the mean and 85th percentile speed both reached to their peak values, the speed dispersion still did not exceed the peak observed in 1984 and 1985.

Gradual increase in operating speeds under relatively less congested flow conditions is a commonly observed phenomenon on highway networks. Significant and/or sudden increase in operating speed is generally associated with some policy intervention (e.g., change in speed limits) or capital improvement (e.g., additional lanes, widening, resurfacing etc.). In the absence of any system-wide policy change or capital improvement, the significant increase in speeds observed in 1995 could be because of the drivers' anticipation of higher speed limits in the wake of the speed limit related debate that culminated in the repealing of the NMSL by Congress by the end of 1995.

Speed data presented in Table 3.2 incorporates speed data for the rural interstates. Like the statewide speeds in Table 3.1, a gradually increasing trend could be observed here as well. However, the 1987 increase in speed limit for rural interstates did have a significant impact on the statewide speed in the subsequent years. Statewide speeds, inclusive of 65-mph rural interstates, are higher than those without them. However, the difference narrows down gradually over the years. For example, the difference between the two statewide mean speeds came down to 1.0 mph, in 1995, from a high of 2.1 mph in 1988. The 85th percentile speeds follow a similar trend. The difference between the with-rural interstates and without-rural interstates 85th percentile speeds was 3.8 mph in 1988 but only 1.6 mph in 1995. Statewide speed dispersion values for the with-rural interstates case are also slightly higher than those (for the without-rural interstates case) given in Table 3.1.

Table 3.2 Indiana Statewide Speeds – Highways posted at 55/65 MPH

YEAR	SPEED MEASURE		
	MEAN	85^{TH} PERCENTILE	DISPERSION
1981	56.1	61	4.9
1982	56	62.4	6.4
1983	55.5	63	7.5
1984	56.5	63.7	7.2
1985	55	62.7	7.7
1986	57	63.3	6.3
1987	57.1	63.5	6.4
1988	59.7	66.1	6.4
1989	59.9	66.7	6.8
1990	60.2	66.8	6.6
1991	60.2	67.2	7.0
1992	59.9	67.0	7.1
1993	60.9	67.2	6.3
1994	60.5	67.2	6.3
1995	61.9	69.6	7.2

Source: JTRP Speed Reports
Note: Rural interstates speed used for 1991-1994 are estimated

Distribution of travel speeds is another important speed feature. Figure 3.2 presents the distribution of statewide travel speeds for Indiana. Data for four years, 1984, 1986, 1988 and 1994 are plotted to show speed distribution trends before and after the change in speed limits for rural interstates in 1987. The speed distributions in Figure 3.2 show a shift towards higher average traffic speeds and somewhat wider distribution, an indication of more vehicles traveling at higher speeds.

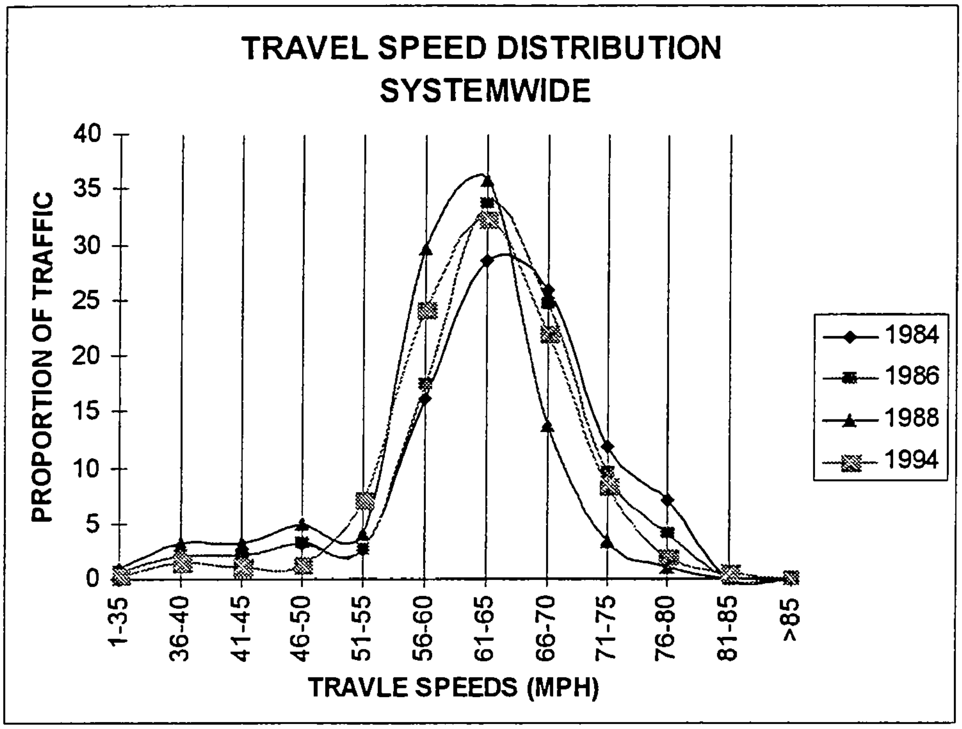

Fig 3.2 – Indiana Travel Speed Distribution – Systemwide – 1984-1994

3.4.1 Speed Trends for Rural Interstates

In 1995 there were 863 miles of rural interstates in the state highway network with eight (8) speed-monitoring stations. Speed trends on rural interstates are of particular interest here because, in general, the highest travel speeds are observed on them, and it is on the rural interstates that a system-wide change in speed limit was made in 1987.

Table 3.3 shows mean speed, 85th percentile speed and speed dispersion, on yearly basis, for the rural interstates for the 1981-1995 period. The speed data for the 1981-1990 period and then for 1995 are taken from the speed monitoring data collected by JTRP. However, since Indiana temporarily discontinued speed monitoring on rural interstates, no actual speed data for the rural interstates exist for the 1991-1994 period. Mean and 85th percentile speeds for the rural interstates given in Table 3.3 are estimated using time series forecast techniques.

Table 3.3 Rural Interstates Speeds

YEAR	SPEED MEASURE		
	MEAN	85^{TH} PERCENTILE	DISPERSION
1981	59.1	63	3.9
1982	59.2	64.6	5.4
1983	60.3	66.3	6
1984	62.2	68.6	6.4
1985	60.4	66.2	5.8
1986	60.6	66.5	5.9
1987	61.6	66.9	5.3
1988	64	70.6	6.6
1989	65.6	73.9	8.3
1990	65.8	72.5	6.7
1991	65.9	73.5	7.6
1992	65.2	73.1	7.9
1993	66.4	73.2	6.8
1994	65.8	73.4	7.6
1995	66.7	73.1	6.4

Source: JTRP Speed Reports
Note: Speeds for 1991-1994 are estimated.

Rural interstates in Indiana have differential speed limits – 65-mph for automobiles and 60-mph for heavy trucks. However, the JTRP speed-monitoring program, did not monitor speed by vehicle class on a regular basis. Figures 3.3 and 3.4 present mean speed, 85^{th} percentile speed and speed dispersion for the rural interstates graphically.

Distribution of travel speeds on rural interstates is shown in Fig 3.5. Like that for the statewide speed distribution, trend for rural interstate showed a shift towards higher average speeds and a wider speed distribution indicating an increasing proportion of traffic

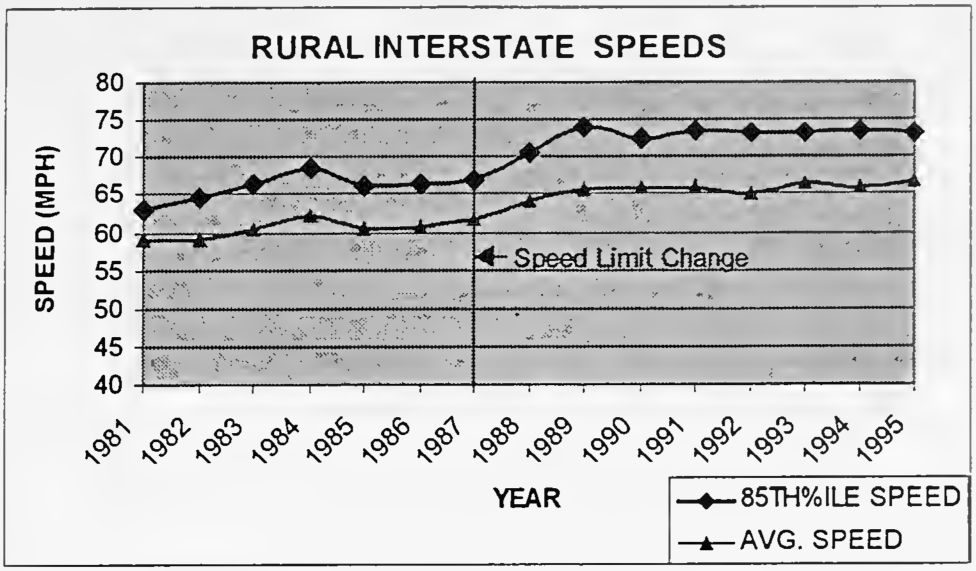

Fig 3.3 – Indiana Rural Interstate Speed Trends – Average and 85^{TH} %ile Speed, 1981-95

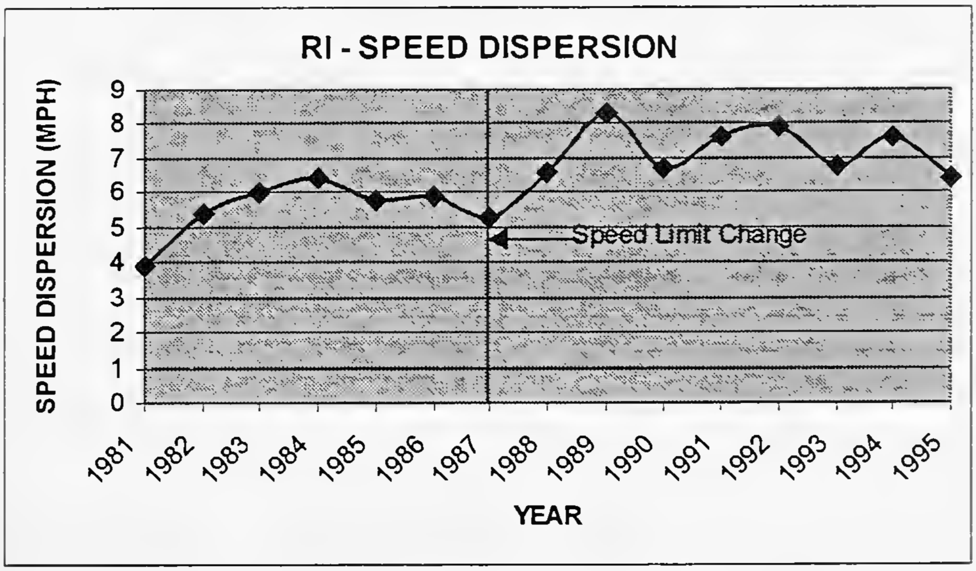

Fig 3.4 – Indiana Rural Interstate Speed Trends – Speed Dispersion, 1981-95

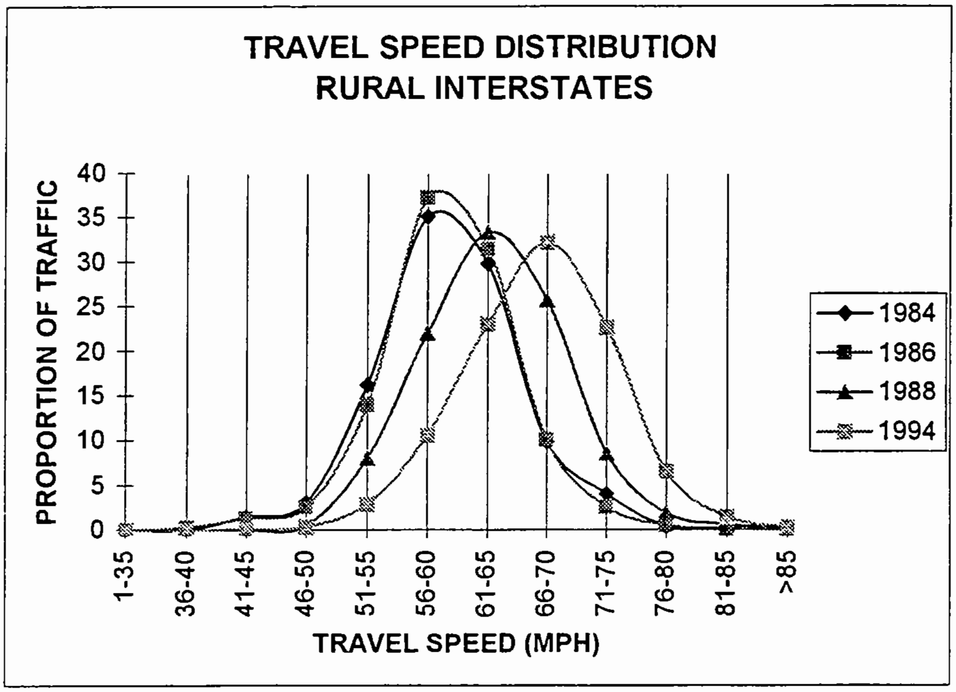

Fig 3.5 – Indiana – Travel Speed Distribution – Rural Interstates – 1984-1994

traveling at high speeds. The effect for rural interstates, however, is significantly more prominent than for the statewide travel speeds. The mean speed for rural interstates remained above the posted speed limits most of the time but the difference narrowed down

3.4.2 Speed Trends for Urban Interstates

Urban interstates remained posted at 55 mph throughout the 1981-1995 period. However, the travel speed on urban interstates continued to increase gradually over the years. In 1995, there were 337 miles of urban interstates and freeways posted at 55 mph in Indiana with 7 speed-monitoring stations located on these highways. Table 3.4 presents summarized speed data for urban interstates.

The speed data for the urban interstates shown in Table 3.4 reveal a trend of increasing mean speeds and 85^{th} percentile speeds. The mean speed increased from 56.8 mph in 1981 to 61.7 mph in 1995, an increase of 4.9 mph over a span of 15 years. The 85^{th} percentile speed, in the same period, increased from 61.5 mph to 68.7 mph, an increase of 7.2 mph. This indicated an increase in the speed dispersion on urban interstates. In terms of the relationship with speed limits, the mean speed on urban interstates remained above the 55-mph speed limit throughout the 1981-1995 period.

Table 3.4 Urban Interstates Speeds

YEAR	SPEED MEASURE		
	MEAN	85TH PERCENTILE	DISPERSION
1981	56.8	61.5	4.7
1982	57	62.7	5.7
1983	57.5	63.8	6.3
1984	59	64.1	5.1
1985	59	64.4	5.4
1986	58.7	64.3	5.6
1987	60.9	66.4	5.5
1988	62.2	68.3	6.1
1989	61.5	67.8	6.3
1990	60.8	68.4	7.6
1991	61.8	68.6	6.8
1992	61	67.7	6.7
1993	60.9	67.5	6.6
1994	61.7	67.6	5.9
1995	61.7	68.7	7

Source: JTRP Speed Reports

3.4.3 Speed Trends for Urban Arterials

The data for this category came from 2 monitoring stations located on non-limited-access urban arterials and one station located on an urban collector highway. All highway sections were posted at 55mph. Table 3.5 presents summarized speed data for these highways for the 1981-1995 period.

The data in Table 3.5 indicate a trend of increasing speeds on these highways, similar to that on interstates. However, while mean speed on urban interstates increased by 4.9 mph during the 1981-1995 period, it went up by 6.3 mph – from 53.2 mph to 59.5

Table 3.5 Speed Trends for Urban Arterials

YEAR	SPEED MEASURE		
	MEAN	85^{TH} PERCENTILE	DISPERSION
1981	53.2	58.9	5.7
1982	54.9	62.1	7.2
1983	57	64.2	7.2
1984	57	64.8	7.8
1985	56.8	63.3	6.5
1986	56.5	62.9	6.4
1987	57.3	63.6	6.3
1988	56.8	63.1	6.3
1989	56.8	63.8	7
1990	57.5	63.9	6.4
1991	57.8	64.2	6.4
1992	58.3	65.1	6.8
1993	59	66.1	7.1
1994	57.9	64.7	6.8
1995	59.5	67.7	8.2

Source: JTRP Speed Reports

mph – on urban arterials, during the same period. 85^{th} percentile speed also increased significantly on these highways, going up to 67.7 mph in 1995 from a low of 58.9 in 1981. The speed dispersion increased from 5.7 mph in 1981 to 8.2 in 1995 – an increase of 2.5 mph – slightly larger than that observed on urban interstates. There were some fluctuations before 1987 but the speeds showed an almost consistently upward trend since then. The mean speed was 54.9 mph in 1982 and since then has remained above the 55-mph speed limit on these highways.

Higher geometric design standards and access control for urban interstates may have contributed to relatively higher mean speed and 85th percentile speed observed on urban interstates compared to the urban arterials with the same 55 mph speed limits. On the other hand the greater speed dispersion and steeper upward trend for mean speed and 85th percentile speed on urban arterials may be the result of greater variation in vehicular mix in the traffic stream and less effective speed enforcement, respectively.

3.4.4 Speed Trends for 2-Lane Rural Arterials & Others

This category includes 2-lane rural arterials and collector highways, posted at 55 mph. In 1995, there were 11 speed-monitoring stations located on these highways. The summarized speed data for 2-lane rural arterials are presented in Table 3.6. Mean and 85th percentile speeds both indicated an increasing trend over the 1981-1995 period. Mean speed increased from 51.9 mph in 1981 to 57.4 mph in 1995. The 85th percentile speed, over the same period, increased from 58.4 mph to 63.2 mph. The trend for these highways showed more fluctuations than that for other highway types discussed so far. Speed dispersion on these highways ranged from a low of 4.9 mph in 1983-1985, to a high of 6.5 mph observed in 1981 and again in 1994. This trend revealed that more drivers were driving at higher speeds. Interestingly, since 1985 the mean speeds on 2-lane rural arterials had been consistently higher than the 55 mph posted speed limit.

3.4.5 Speed Trends for 4-Lane Rural Arterials

This category comprises 4-lane rural arterials posted at 55 mph. In 1995, there were 11 speed-monitoring stations located on these highways. Table 3.7 presents summarized speed data for these highways. Like all other highway categories, the 4-lane rural arterials also exhibited a trend of increasing speeds. Mean speed for these highways increased from 55.6 mph in 1981 to 60.2 mph in 1995 and the 85th percentile speed increased from 60.7 mph to 66.4 mph. The speed dispersion ranged from 4.4 mph in 1982 to 6.2 mph in 1995. The trend here is more fluctuating than any other type of roads.

Table 3.6 Speed Trends for 2-Lane Rural Arterials

YEAR	SPEED MEASURE		
	MEAN	85^{TH} PERCENTILE	DISPERSION
1981	51.9	58.4	6.5
1982	53.3	59.1	5.8
1983	55.1	60	4.9
1984	54.7	59.6	4.9
1985	55.7	60.6	4.9
1986	56.5	62.2	5.7
1987	57.5	63.2	5.7
1988	56.3	61.9	5.6
1989	56.9	62.6	5.7
1990	57.4	63.3	5.9
1991	57	62.8	5.8
1992	57.2	62.8	5.6
1993	57.4	63	5.6
1994	56.6	63.1	6.5
1995	57.4	63.2	5.8

Source: JTRP Speed Reports

Table 3.7 Speed Trends for 4-Lane Rural Arterials

YEAR	SPEED MEASURE		
	MEAN	85^{TH} PERCENTILE	DISPERSION
1981	55.6	60.7	5.1
1982	56.6	61	4.4
1983	54	59.1	5.1
1984	55.2	59.7	4.5
1985	54.4	59.4	5
1986	55	59.7	4.7
1987	54.5	59.4	4.9
1988	55.8	60.2	4.4
1989	57.3	62.4	5.1
1990	58	63.7	5.7
1991	57.8	63.6	5.8
1992	57.8	63.5	5.7
1993	58.5	64.1	5.6
1994	57.9	63.9	6
1995	60.2	66.4	6.2

Source: JTRP Speed Reports

3.5 Effect of 65-mph Speed Limit

The speed limit on rural interstates in Indiana was increased to 65-mph in June 1987. What effect did this change have on operating speeds in the state is the matter of interest here. In general, vehicular speed on all highway types showed an increasing trend during the 1981-1995 period. Two aspects of the change in speed limit need to be investigated: 1) did the change result in a statistically significant effect on speeds in the post-1987 period or not, and 2) was the effect only limited to rural interstates or did it have some spill-over on other highways in the state.

Speed data were available for individual speed stations in terms of average speed and percentile of vehicles with various speeds. The data were analyzed using Analysis Of Variance (ANOVA) models for each highway class (rural interstates, urban interstates, rural arterials, urban arterials, rural collectors/others and urban collectors/others). The hypothesis tested was that there was no difference in speeds before and after the change in speed limit over and above what could be explained by the temporal (yearly and quarterly) and spatial (speed station locations) changes.

Speed measures used for the hypothesis testing included average speed, 85th percentile speed and speed dispersion. Speed data from speed-stations spread all over the state and spanning over the 1981-1995 period were analyzed to evaluate the speed trends. Number of speed stations and their locations for the different road classes varied over the years. Only data from speed stations that had at least one observation per year at the same, or practically similar, location were considered. Table 3.8 summarizes the number of speed stations and number of observations in the data sets analyzed for the respective road types.

Table 3.8 Speed Stations and Observations

ROAD CLASS	SPEED STATION	NUMBER OF OBSERVATIONS
Rural Interstates	10	190
Urban Interstates	3	165
Rural Arterials	5	252
Urban Arterials	2	109
Rural Collectors & Others	7	219
Urban Collectors & Others	2	107

The ANOVA models employed were of the form:

$Y_{ijkl} = \mu + \tau_i + \beta_j + \gamma_k + \theta_l + (\textit{Interaction terms}) + \varepsilon_{ijkl}$

where

Y_{ijkl} = Speed measure (average speed, 85th percentile speed or speed dispersion)

μ = Overall mean

τ_i = Class variable representing Pre-1987 and Post-1987 speed observations $\{i = 1, 2\}$

β_j = Class variable representing speed station location $\{j = 1, 2,..10\}$

γ_k = Class variable representing year of speed observation $\{k = 1981, 1982, \ldots 1995)$

θ_l = Class variable representing quarter of speed observation $\{l = 1, 2, 3, 4\}$

ε_{ijkl} = Error term

Only two factor interactions were considered in the final models. Three and higher order interactions were found to be insignificant.

3.5.1 Model Adequacy Checking

Model adequacy checks and residual analysis revealed that the data were normally distributed. The normal univariate plots showed that the data points fell on a straight line approximately and that all data points were within three (3) standard deviations from the mean. The Shapiro-Wilks test also showed that the normality assumption was not violated for any of the models.

The plot of residuals indicated that the equality of variance assumption was not seriously violated. No positive or negative runs were detected implying that the independence of error terms assumption was not violated. The plot of residual versus predicted (fitted) values showed that the data points were randomly scattered with no significant patterns.

3.5.2 Discussion of Speed Model Results

All models seem to explain the variation in the dependent variable (speed measures) reasonably well. This is evident from the R^2 values that the models yielded. The R^2 for the various models ranged from approximately 0.75 to 0.95. Table 3.9 summarizes the results of the analysis.

Table 3.9 Summary of ANOVA Models Results

HIGHWAY CLASS	NO. OF OBS.	R^2	F – VALUE (P – VALUE) GROUP	LOCATION	YEAR	QTR
Rural Interstates	190					
Avg. Speed		0.949271	368.7 (0.0001)	5.37 (0.0001)	7.07 (0.0001)	0.53 (0.6616)
85th%ile Speed		0.966569	812.03 (0.0001)	17.41 (0.0001)	6.78 (0.0001)	1.78 (0.1637)
Speed Dispersion		0.882651	198.07 (0.0001)	2.39 (0.0248)	2.48 (0.0204)	1.03 (0.3892)
Urban Interstates	165					
Avg. Speed		0.773729	51.63 (0.0001)	15.79 (0.0001)	4.18 (0.0001)	2.41 (0.0737)
85th%ile Speed		0.849009	171.28 (0.0001)	21.15 (0.0001)	4.50 (0.0001)	4.57 (0.0054)
Speed Dispersion		0.895564	265.74 (0.0001)	37.02 (0.0001)	11.22 (0.0001)	3.18 (0.028) Contd.
Rural Arterials	252					
Avg. Speed		0.842928	96.94 (0.0001)	49.38 (0.0001)	14.88 (0.0001)	1.18 (0.3207)
85th%ile Speed		0.843335	157.31 (0.0001)	58.85 (0.0001)	9.00 (0.0001)	2.04 (0.1111)
Speed Dispersion		0.818957	47.19 (0.0001)	16.34 (0.0001)	12.54 (0.0001)	11.74 (0.0001)
Urban Arterials	109					
Avg. Speed		0.822167	15.42 (0.0004)	27.35 (0.0001)	5.38 (0.0001)	1.31 (0.2869)
85th%ile Speed		0.920738	86.18 (0.0001)	72.35 (0.0001)	13.06 (0.0001)	4.71 (0.0070)
Speed Dispersion		0.828599	30.94 (0.0001)	5.89 (0.0202)	3.25 (0.0029)	2.90 (0.0477)
Rural Collectors	219					
Avg. Speed		0.94407	414.21 (0.0001)	91.85 (0.0001)	15.72 (0.0001)	0.27 (0.8494)
85th%ile Speed		0.913161	389.19 (0.0001)	31.26 (0.0001)	9.18 (0.0001)	3.39 (0.0214)
Speed Dispersion		0.856216	4.61 (0.0345)	20.83 (0.0001)	7.93 (0.0001)	7.24 (0.0002)
Urban Collectors	107					
Avg. Speed		0.746251	0.92 (0.3428)	38.80 (0.0001)	1.08 (0.4059)	0.88 (0.4588)
85th%ile Speed		0.783571	9.70 (0.0036)	40.11 (0.0001)	1.14 (0.3608)	1.71 (0.1822)
Speed Dispersion		0.810668	24.86 (0.0001)	0.53 (0.4706)	1.23 (0.3143)	0.85 (0.6126)

The class variable GROUP that represents pre-1987 and post-1987 speed observations was significant for all road classes and for all speed measures except for average speed in case of urban collectors. This indicated a statistically significant difference in speed measures for the pre-1987 and the post-1987 periods. This was the case for essentially all highway types. The difference between rural interstates and other highways was that the GROUP variable accounted for a much greater and the largest proportion of the change in speed measures for the rural interstates while that was not the case for other type of highways. For almost all other types of roads, although GROUP was significant, it accounted for smaller proportion of the total variation with other factors accounting for a larger share. It seems that the 1987 change in speed limit on rural interstates caused the already existing trend of increasing speeds on Indiana highways, in general, to get somewhat more pronounced, more so for rural interstates than for other highways. The following sub-sections discuss the results of the ANOVA models for rural interstates in greater detail. A brief summary of results for all other highways follows.

3.5.2.1 Rural Interstates

The ANOVA models for the rural interstates had the highest R^2 values (compared to all other highway types analyzed here). For the average speed model three of the four class variables (GROUP, LOCATION, YEAR) in the model were significant in explaining variations in the speeds observed on rural interstates. With 190 observations from 10 speed stations the data set for the rural interstates was reasonably large. However, there were no observations for the 1991-1993 period as no speeds were monitored on rural interstates during this period.

The GROUP variable was by far the most significant one in the model and it alone accounted for a significantly large proportion of the variation in average speed, followed by LOCATION and YEAR. The variable QTR representing quarterly variations in speed was not significant in case or rural interstates. Among the interaction terms only LOCATION*YEAR was significant. Together the three significant class variables and the significant interaction term accounted for about 95 percent of the total variation in the model. Interestingly, the results also indicated that the other two factors (LOCATION, YEAR) and the only significant interaction term (LOCATION*YEAR) in the model collectively accounted for more variation than GROUP. This implied that while the 1987 change in speed limit did have a statistically significant impact on speed, it was not the only factor affecting speed. In fact the collective impact of the yearly and location related changes on speed was more prominent than that accounted for by the speed limit change in 1987. In other words even if there were no change in speed limit in 1987, there would have been (an upward trend of) statistically significant yearly and location related speed variation.

The trend was essentially the same for all three speed measures on rural interstates with minor variations. Variable GROUP accounted for increasingly greater proportion of the total variation observed by the models for the 85th percentile speed and speed dispersion ANOVA models than was the case for the average speed model. However, the overall results – GROUP, LOCATION, YEAR and LOCATION*YEAR were significant and QTR was not – were the same as for the average speed model. Trend for the speed dispersion model was somewhat different. No interaction was significant for this model. In other words, the 1987 change in speed limit had a more pronounced impact on the 85th percentile speed on rural interstates than was the case for the average speed. Since speed dispersion here was the difference of 85th percentile speed and average speed, the impact on speed dispersion was similarly more pronounced. This implied that while speed, in general, did go up after 1987 the trend for the fastest moving vehicles was even steeper.

3.5.2.2 <u>Other Highways</u>

Results for the ANOVA models for other highways, with some variations, were similar to those for rural interstates. Variables GROUP, YEAR and LOCATION, and interaction term YEAR*LOCATION were significant for all the models with the exception of urban collectors. Similarly variable QTR, representing quarterly variation in speed measures though not significant for average speed on any highway type, was significant for 85th percentile and speed dispersion models for urban interstates, rural and urban arterials and rural collectors. The trend indicated that traffic speed on arterials and collectors - highway types of comparatively lower geometric design standards than interstates - was more sensitive to seasonal and weather changes. Similarly there appeared to be more seasonal variation in speed for relatively short trips experienced on urban interstates and other non-interstate type highways.

In summary the results indicated that:

- The 1987 change in speed limit did have a statistically significant effect on (implying increase in) average speed, 85th percentile speed and speed dispersion on the entire state highway network, with the exception of average speed on urban collectors.
- Among the highway types the impact was, understandably, most prominent (the highest increase) on rural interstates.
- Rural highways, in general, had a greater impact than comparable urban highways, *e.g.*, rural arterials had a greater impact (sharper increase) than urban arterials.
- For non-rural interstate highways the impact (i.e., increase in speed) diminished in its significance depending on the functional hierarchy of the highway, *i.e.*, higher impact on urban interstates than urban arterials and the least on urban collectors
- Change in speed limit alone did not explain all the variation observed in speed measures over the analysis period. Variations related to location (rural versus urban) of speed stations and yearly speed changes (speed in current year minus speed in the previous year) were also statistically significant, and explained what was not accounted for by the speed limit change alone. For example, rural stations had greater increase in observed speeds and most yearly speed changes indicated an increase.
- Quarterly changes while not significant (though still positive), implying increase) for the average-speed are significant for the 85th percentile speed and for the speed dispersion (summer speeds are higher than other quarters) observed on highways other than rural interstates.

It should be noted that although the results have demonstrated that the 1987 change in speed limit did have a statistically significant impact on speed characteristics of rural interstates and most other highways in the state highway network, the change in speed limit was not the sole factor accounting for all the variations in speed. Yearly and location related changes also contributed significantly to the change in speed characteristics.

CHAPTER 4 SPEED LIMITS AND SAFETY

4.1 Introduction

Impact on safety is perhaps the most sensitive issue to be addressed while analyzing effect of change in speed limits. Given its safety implications it is not surprising that the relationship has been, and continues to be, widely debated. A number of studies at national as well as state level have examined the impact of speed limits on safety. Findings of these studies, including those about Indiana, have been discussed in a separate Chapter 2. A review of the chapter would reveal the existence of two schools of thought. One school of thought essentially believes that speed kills. They argue that the higher the speed the higher the probability of crash, and given a crash, the higher the speed the greater is the degree of severity. The other school challenges the approach of drawing unqualified conclusions about the impact of higher speed limit on safety. They argue that the impact of change in speed limits depends on the way it affects the speed variance. They also argue that while evaluating the impact on safety a system-wide approach should be employed.

4.2 Chapter Organization

This chapter starts with a brief introduction of the speed limit and highway safety relationship. Following the chapter organization an overview of the available methodologies for safety analysis is provided. The next section discusses the selected time series cross section models and their adequacy for the intended analysis in detail. This is followed by the description of the data collection efforts and the details of the dataset. Results of the data analysis employing the selected models are presented and discussed next. The chapter concludes with a summary of the results.

4.3 Overview of Available Methodologies

A brief overview of the available and relevant analytical approaches is presented here before describing the methodology employed for the data analysis. In the literature on speed limits and their effects, three methodological approaches – paired comparison, regression analysis and time series analysis - have typically been used to test hypotheses.

4.3.1 Paired Comparison

Ideally the paired comparison approach would require an experimental design involving randomly selected set of homogenous (roads that are physically identical and have an identical user profile). The set is then randomly divided in two subsets, a control group and an experimental group. The speed limit for the roads in experimental group is altered and the outcome is analyzed. The analysis typically involves comparing the outcome (in terms of speed distribution and impact on safety) for the two groups and testing if the outcome for the experimental group is statistically different from that for the control group. A benefit of this approach is that it enables drawing conclusion for the population of roads under study. However, the approach is, in general, not feasible as transportation agencies are reluctant to participate in such experiments for various reasons.

An alternative to the experimental design approach is a quasi-experimental methodology. In quasi-experimental approach, the set of roads to form experimental and control groups are not chosen randomly. After taking into account the effect of confounding factors that vary across the roads and road users, the results for the two groups are compared for statistically significant differences between speed distribution and safety outcomes on the affected and unaffected roads. Other variations of the approach compare impact of change in speed limit across roads at a given point in time (e.g., a comparison between states that did and did not increase speed limits on rural interstates) or across time (a comparison of affected states before and after the change in speed limits).

A common approach in such cases is the use of odd ratios. In the odd ratio approach the odds for the outcome of interest (e.g., fatal crashes) before and after the change (in speed limit for the affected roads with respect to the unaffected roads) are compared.

The primary advantage of the paired comparison approach, including the before and after approach, is that the data needs are not large. The main drawback of the approach is in the underlying hypothesis that relating outcomes in the experimental group to those in the control group accounts for all differences in the two groups. Whether these techniques provide sufficient control for confounding factors that may influence the variable of interest, and accordingly, affect the test results and the associated policy implications, is an important empirical issue [TRB 1998]. Stratification of the sample based on other variables (e.g., highway exposure, socioeconomic characteristics) to control for other factors is often employed with some success.

4.3.2 Interrupted Time Series Analysis

Another methodology to analyze the effect of change in speed limit is time series intervention models. Typically time series data represent an overall trend in addition to a cyclical seasonal variation. The objective is to develop a model, commonly referred to as Autoregressive Integrated Moving Average (ARIMA) model, that accounts for the trend of the series, seasonal patterns and any serial dependencies that exist in the series itself or in the error term.

The model is initially estimated for the pre-intervention period (e.g., in a time series for rural interstates in Indiana for the period 1981-1995, only 1981-1987 is used to develop a pre-intervention model as the speed limit was changed in 1987). Assuming that the process, in the absence of intervention, would continue in accordance with the pre-intervention model, the model is then estimated with an additional function to identify the effect of the intervention. The model can be forumulated several ways depending upon the hypothesis about the potential nature of the impact of the intervention.

A significant advantage of the ARIMA models is data economy. These models only require data about dependent variable and the knowledge of when the intervention occurred. The main disadvantage of ARIMA models is the underlying assumption that the effect of other determining factors is captured and that there are no disruption in these series over the analysis period. This is a rather strong assumption that may not hold well in many cases. ARIMAX, a variation of ARIMA model, requires other variables, in addition to the dependent variable, to be included in the model and explicitly tests the hypothesis that other factors have no effect on the series.

4.3.3 Regression Models

One of the most commonly used methods for analyzing the effect of change in speed limits on highway safety is to develop a statistical model that not only includes the relevant policy variable but also controls for other confounding factors. This is the regression approach. The general form of the regression model employed for safety analysis is of the form:

$$H_{it} = \sum_{i=1}^{N} \alpha_i + \sum_{j=1}^{k} \beta_j x_{itj} + \varepsilon_{it}$$

where

H_{it} = highway outcome (e.g., fatal crashes, fatality rate, injury crashes, injury rate) for cross section i and time period t (i = 1,2,…., N and t = 1, 2, … , T),

x_{itj} = jth explanatory variable for cross section i and time period t (i = 1,2,…., N and t = 1, 2,…., T, j = 1,2, …, k),

α_i = parameter reflecting the marginal effect of the ith cross section on the highway safety outcome

β_j = parameter reflecting the marginal effect of the jth explanatory variable on the highway outcome (j = 1,2, …, k), and

ε_{it} = error term for cross section i and time period t (i = 1,2,…., N and t = 1, 2, … , T).

The data for this regression are cross sections over a period of time, called a pooled data (also known as panel data). An example of such a data set would be the number of fatal crashes in each of the 92 counties in Indiana from 1981 through 1995.

The pooled data formulation is a general specification that, depending on the available data set, collapses to simpler econometric models. There are two most common form of time series regression model. First, an analysis can be done with a single cross section (e. g., annual nationwide fatal crashes from 1981 through 1995, or the monthly fatality rate from January 1980 through December 1992). Further, if the model included only a constant term and a time trend as the only explanatory variable, then the regression equation would model historical trends. Alternatively, a cross-section model is based on a cross section of observations at a single point in time (e.g., fatal crashes in each county in Indiana for 1994, or total crashes for each state in the nation in 1996).

If reliable data about other confounding factors that affect the dependent variable are available, a well-specified regression model, by controlling for the statistical influence of the confounding factors, better isolates the independent effect of the policy. This is the main advantage of regression models. However, there are two difficulties in using the regression approach. First, regression models become increasingly data intensive as the number of confounding factors to be controlled increases. Second problem with the regression approach are the statistical pitfalls associated with the estimation of regression models. For example, in time series analysis error terms may be serially correlated, which if not corrected invalidates hypothesis tests. Similarly, regression models using highly collinear data are generally unable to isolate the independent effects of the collinear variables. The potential advantages of the regression model approach could only be realized if the data are tested for the presence of statistical problems and, where possible, such problems are corrected.

4.3.4 Selection of Methodology

The selection of methodology for the purpose of safety analysis in this study was made with careful consideration about several aspects including, among others, desired hypotheses to be tested, data availability, availability of software and extent of computational efforts.

Since the hypotheses to be tested were primarily aimed at evaluating the impact of the change in speed limit, it was essential to control for other confounding factors that might affect the dependent variable. Such confounding factors included the degree of exposure as indicated by vehicle miles traveled (VMT), level of law enforcement and several socioeconomic factors. While regression models can be readily employed for such an analysis, the paired comparison approach (before and after analysis) and interrupted time series analysis (ARIMA models) are not suitable for the purpose.

Since regression models were to be used for controlling statistical influence of other confounding factors, it is implied that these models were going to be data intensive. Fortunately, most of the data required for the analysis were known to be available, though not in directly usable form. A more detailed account of the data collection efforts and their outcome is given later in this chapter.

Several software for statistical analysis are available. While many of them are capable of analyzing simple regression models, their capabilities vary when the analysis becomes complex and the level of details desired by the analyst becomes more demanding. The software chosen for this work – LIMDEP - has been widely used by econometricians and is becoming increasingly popular with analysts in other professions as well including transportation engineering. While it is capable of estimating a multitude of statistical and econometric models, LIMDEP is particularly favored for panel data analysis. That the data set to be analyzed here was also a panel data set reinforced the choice of the LIMDEP software for this study.

4.4 The Selected Model

In view of their capability to offer control for confounding factors, regression models were targeted as the prime candidate for the safety analysis in this study. Time series cross section models, a more sophisticated class of regression models commonly used in econometric analyses, offer an opportunity to capture most of the underlying trends that the panel data set could reveal. In addition to sorting out the statistical influence of other confounding factors on highway safety these models can also capture the time trend, commonly observed in safety data, and the sensitivity of safety outcome with respect to cross-sectional variations.

Statistical models combining cross-section and time-series data have become increasingly popular in econometric research over the last thirty years. With their success in better modeling many problems in the area of econometrics such data sets are also being used in other areas, including transportation. The major factors explaining this development are:

- the availability of disaggregated data often in the form of panel data sets,
- advances in computer technology and software programs, and
- progress in the elaboration and implementation of appropriate statistical methods covering a larger spectrum of potential situations.

A panel data set (also known as longitudinal survey) is one in which a given set of individuals – or more precisely a basic statistical unit – is repeatedly sampled at different point in times. Such a data set offers a certain number of advantages over traditional pure cross-section or pure time-series data sets.

First and the most obvious advantage is that the number of observations is typically much larger in panel data. This is likely to produce a more reliable parameter estimate and enable the analyst to specify and test more sophisticated models incorporating less restrictive assumptions.

Second advantage of a panel data set is that it may alleviate the problem of multicollinearity. Multicollieanty is the phenomenon observed in many multivariate models where some of the explanatory variables are linearly related. This could seriously alter the results making it difficult to interpret them correctly. When the explanatory variables vary in two dimensions – as in a panel data set – they are less likely to be highly correlated.

A third advantage of these data sets is that they make it possible to identify and measure effects that are simply not detectable in pure cross section or pure time series data. It is sometimes argued that cross section data reflect long-run behavior while the time series data emphasize short-term effects [Balestra 1996]. By combining the two sorts of information, a distinctive feature of panel data, a more general and comprehensive dynamic structure can be formulated and estimated.

Finally, the use of panel data may eliminate or reduce estimation bias. For example, in a simple production model the output (dependent variable) for a cross section of firms is explained by capital, labor and managerial ability (explanatory variables). This last variable is typically non-observable. If the data are analyzed as a regression model for the pure cross section of firms, the estimate of factor elasticities will be biased since an important variable (managerial ability) has been omitted. In a panel data context the analyst could control for this latent variable by introducing into the model a fixed individual effect (assumed to remain constant through time) thus eliminating the bias in the elasticity estimates.

Up to six (6) different models for panel data have been used in econometric literature [Matyas & Sevestre 1996]. The principal step (in all these models) is to model heterogeneous behavior in an appropriate manner. Heterogeneity may appear in the regression coefficients (which may vary across individual and/or time) and in the structure of the residuals. These models include: the ordinary regression model; individual regression model; the seemingly unrelated regression (SUR) model; the covariance model; the error component model and the random coefficient model. A detailed discussion of all these models is not attempted here. Out of these six models the covariance model was selected for the analysis in the present study.

The covariance model assumes that the reaction coefficients are the same for all individuals, except for a generic individual (fixed) effect and a similar generic time effect. This can be accomplished by allowing a different intercept for each individual cross-section and time unit in the model. The resulting model, also known as individual dummy variables model, is:

$$H_{it} = \sum_{i=1}^{N} \alpha_i + \sum_{t=1}^{T} \gamma_t + \sum_{j=1}^{k} \beta_j x_{itj} + \varepsilon_{it}$$

where

γ_t = parameter reflecting the marginal effect of time *t* on the highway safety outcome, and all other terms are as defined in sub-section 4.3.3.

The individual cross-section differences and the time trend are uniquely reflected in the coefficients α_i and γ_t. This model is easy to estimate, treats individual differences in a simple systematic way and allows for tests of them.

The generic individual cross-sectional effect of the covariance model is probably the result of a multitude of individual cross-sectional factors (constant over time). Similarly the generic time effect is probably the result of several individual factors (constant over cross-sections). It may be more realistic to treat theses effects as random effects as is the case in a classic regression model where the influence of all the omitted variables is summarized in the error term. However, the question of knowing whether an effect is fixed or random is extremely delicate. A fixed effects model has been selected for this study in view of the following:

- Underlying causes. Random effect models are better suited if the individual cross-section and time effects are believed to be related to a large number of non-observable random causes.
- The number of statistical units. When the number of cross sectional units (N) is large and the number of time units (T) is small, the number of parameters to be estimated in a fixed effects model is large relative to the total number of available data points, hence the resulting estimates of all parameters can be unreliable. For the model estimated here, although N (92) was larger than T

(15), the difference was not large enough to warrant using an error components model.

- The nature of the sample. When the sample is closed and exhaustive (as is the case here, all 92 Indiana counties are included in the sample), fixed effect models are natural candidate.
- The type of inference. The choice of model also depends upon the inferences to be drawn from the results. If inferences are to be drawn with respect to population characteristics, then a random specification is desirable. Since the sample here is exhaustive (the sample is the same as population) this issue is irrelevant here.

4.5 The Data Set

Extensive efforts were made to collect data for building and estimating time series cross section models described above. Table 4.1 summarizes the types of data collected for the safety analysis. The data set contains data for all the variables for the 15-year analysis period, 1981 to 1995. The analysis period was determined considering several factors. First, it allowed having a fairly balanced data set before and after the 1987 change in speed limit for rural interstates. Second, by cutting off in 1995, the potential impact of the 1995 relaxation of the national speed limit law on some of the data was avoided. Some of the adjoining states (e.g. Michigan) revised speed limits after 1995 and operating speeds on highways continuing to and from such states are believed to have some spill-over effect in Indiana.

Table 4.1 Type and Sources of Data

TYPE OF DATA	SOURCE OF DATA
Crash data	Indiana State Police
Enforcement data	Indiana State Police
Population data	i) US Bureau of Census ii) Indiana Department of Health
Employment data	US Department of Labor
Vehicle registration data	Indiana Bureau of Motor Vehicles
Driver data	Indiana Bureau of Motor Vehicles
Alcohol sale outlets data	Indiana Alcohol Beverage Commission
Vehicle Miles Traveled (VMT)	Indiana Department of Transportation

4.5.1 Crash Data

Indiana State Police (ISP) maintains an excellent crash database that has observations covering all reported crashes in the state. The database actually comprises relational databases including environmental record, vehicle record, driver record, injury record, pedestrian record and trailer record, besides the master record. Crash data for the 1981-1989 period were already available from a previous project. Data for the 1990-1995 period became available in June 1998 from ISP. The data files were later parsed into an usable, comma separated, format by a C program. These data were eventually converted into a SAS database where all queries on the data were run. Typically these queries were made to extract data about crashes of varying severity (ISP database reports three degrees of severity: fatal, injury and property damage only) that occurred on various types of roads. Since county was the cross-section unit for the adopted model, all data were extracted at the county level. The database also allows data to be extracted by vehicle type (automobile, truck etc.) and area type (urban, rural).

Actual dataset used in the analysis typically consists of 1380 observations (15 observations for each of the 92 counties in Indiana). Tables 4.2 through 4.5 present annual crash data for: the entire state; rural interstates; urban interstates and non-interstate highways in Indiana, respectively. The annual crash data for the entire state, presented in Table 4.2, reveal an increasing trend for fatal crashes for 1981-1991 that peaked in 1987-1988. Number of fatal crashes came down significantly in 1992-1993 before witnessing an upsurge again in 1994-1995. Injury crashes increased between1981 and 1985, then showed a cyclical pattern, reversing trend every 2-3 years. PDO crashes also showed an increasing trend between 1981 and 1989. After reaching a peak in 1989, PDO crashes followed a decreasing trend for the 1990-1994 interval before showing an upward sign again in 1995.

Annual crash data for rural interstates are presented in Table 4.3. Number of fatal crashes on rural interstates in Indiana kept fluctuating for the 1981-1989 period, peaked in 1990, stabilized in 1991-1994 but went significantly up in 1995. Injury and PDO crash data, in general, showed an upward trend during the 1981-1989 period, had a downward trend in 1990-1992 and then started edging up again, with a significant increase in 1995.

Crash data for urban interstates are presented in Table 4.4. Fatal crashes on urban interstates, ranging between a low of 11 crashes in 1985 and a high of 25 in 1989, did not reveal any specific trend. Injury and PDO crashes on urban interstates showed an increasing trend, in general, but the trend experienced a significant increase after 1987.

Annual crash data for non-interstate highways are presented in Table 4.5. Fatal crashes on non-interstate highways in Indiana showed a rising trend for the 1981-1987 period with the peak observed in 1987. Since 1987, the trend has, in general, been downward with a notable increase in 1994. Trend for injury and PDO crashes had been fluctuating with the peaks observed in 1985 and 1989, respectively.

4.5.2 Enforcement Data

ISP, like the crash database, maintains an excellent enforcement database. The database has data about all traffic related incidents that required issuing a citation by ISP. The information available from the database includes date of incident, county, area type and road type where the citation was issued, speed observed and the speed limit at the location of the incident. Data for 1981-1995 were converted into a SAS database. Queries to extract required data were run on the SAS database.

Data about the number of tickets issued by Indiana State Police in Indiana each year during 1981-1995 are presented in Table 4.6. The data showed a consistent increase in the number of tickets issued for the 1981-1996 period. The number went down slightly in 1987 but again followed an increasing trend during 1988-1992. The trend has been fluctuating

Table 4.2 Annual Total Crashes Statewide

Year	Fatal Crashes	Injury Crashes	Property Damage Only (PDO) Crashes
1981	827	36,357	90,292
1982	877	37,557	93,774
1983	937	41,741	92,204
1984	898	46,663	101,808
1985	920	47,995	106,673
1986	973	43,392	106,211
1987	992	43,834	109,923
1988	992	46,911	138,241
1989	917	47,524	143,951
1990	971	45,396	131,883
1991	950	42,463	124,601
1992	843	42,135	110,157
1993	835	44,345	116,340
1994	935	45,595	119,033
1995	921	47,194	125,711

Source: Indiana State Police

Table 4.3 Annual Rural Interstate Crashes

Year	Fatal Crashes	Injury Crashes	Property Damage Only (PDO) Crashes
1981	63	1,700	3,777
1982	70	1,842	4,031
1983	82	1,855	4,139
1984	88	2,070	5,095
1985	77	2,258	5,468
1986	82	1,953	5,135
1987	74	2,082	5,339
1988	94	2,812	9,008
1989	74	2,836	9,723
1990	101	2,655	8,850
1991	89	2,601	8,567
1992	87	2,279	8,129
1993	89	2,503	8,931
1994	89	2,788	9,772
1995	101	2,844	9,832

Source: Indiana State Police

Table 4.4 Annual Urban Interstate Crashes

Year	Fatal Crashes	Injury Crashes	Property Damage Only (PDO) Crashes
1981	21	630	1,344
1982	21	660	1,410
1983	15	673	1,534
1984	14	690	1,948
1985	11	734	1,824
1986	18	728	1,952
1987	17	720	1,717
1988	15	955	3,153
1989	25	999	3,805
1990	22	924	2,949
1991	16	862	2,957
1992	13	816	2,794
1993	20	893	3,294
1994	22	975	3,538
1995	24	1033	3,472

Source: Indiana State Police

Table 4.5 Annual Non-Interstate Crashes

Year	Fatal Crashes	Injury Crashes	Property Damage Only (PDO) Crashes
1981	743	34,027	85,171
1982	786	35,055	88,333
1983	840	39,213	86,531
1984	796	43,903	94,765
1985	832	45,003	99,381
1986	873	40,711	99,124
1987	901	41,032	102,867
1988	883	43,144	126,080
1989	818	43,689	130,423
1990	848	41,817	120,084
1991	845	39,000	113,077
1992	743	39,040	99,234
1993	726	40,949	104,115
1994	824	41,832	105,723
1995	796	43,317	112,407

Source: Indiana State Police

Table 4.6 Annual Number of Tickets issued by ISP

Year	Number of Tickets
1981	187,482
1982	201,805
1983	201,872
1984	208,001
1985	249,607
1986	262,922
1987	244,597
1988	273,735
1989	315,181
1990	317,931
1991	318,398
1992	327,910
1993	310,351
1994	319,800
1995	314,485

Source: Indiana State Police

between 1993-1995. It must be noted here that these statewide data mask significant variations in the enforcement levels (as represented by the number of tickets issued) experienced at the county levels that were actually used in the models employed for the safety analysis.

4.5.3 Socioeconomic Data

Socioeconomic data collected for the safety analysis included population data, employment data, vehicle registration data, number of young drivers (age equal to or less than 24 years) and number of alcohol sale outlets. US Bureau of Census was the primary source of population data. Indiana Department of Health updates its population estimate annually for all counties in the state and was a good secondary source of population data. Population data for Indiana are presented in Table 4.7. The state population after showing a declining trend in 1981-1984 has been rising at a varying rate with the exception of 1990 when it fell slightly. However, population data at the county level (not shown in Table 4.7) showed greater variation.

Employment data (percentage unemployed) were obtained from the U.S. Department of Labor database. The primary source of vehicle registration and driver data was Indiana Bureau of Motor Vehicles (BMV). BMV maintains record of all vehicles registered with the bureau including data about the year, make and model of the vehicle. BMV also maintains data about all licensed drivers in the state. The data about drivers include age, gender and the type of operating license issued. Vehicle and driver data for the 1981-93 were already obtained for previous projects. Data for 1994-1995 were obtained from BMV.

Table 4.8 presents statewide vehicle registration data for Indiana. The data revealed that the total number of vehicles registered followed the same trend as the state population – a downward trend for 1981-1983, then a consistent increase each year, with the exception of 1987 when the number subsided slightly.

Table 4.7 Total State Population

Year	Population
1981	5,489,800
1982	5,485,100
1983	5,475,700
1984	5,493,100
1985	5,500,600
1986	5,503,600
1987	5,530,700
1988	5,556,600
1989	5,566,142
1990	5,544,156
1991	5,602,878
1992	5,651,855
1993	5,706,561
1994	5,749,033
1995	5,796,948

Source: US Bureau of Census & Indiana Department of Health

Table 4.8 Number of Registered Vehicles

Year	Number of Registered Vehicles
1981	4,374,321
1982	4,336,170
1983	4,276,264
1984	4,388,881
1985	4,450,974
1986	4,533,362
1987	4,427,800
1988	4,550,450
1989	4,693,634
1990	4,724,758
1991	4,755,882
1992	4,787,006
1993	4,818,129
1994	4,849,253
1995	4,880,377

Source: Indiana Bureau of Motor Vehicles

Data about the number of young drivers were also obtained from Indiana BMV. Table 4.9 presents data on the number of young drivers in the state for each year during1981-1995. The data, in general, indicated a declining trend for the young driver population, with the exception of 1986, 1988 and 1995 when the number of young drivers actually increased from that in the previous years, respectively. The declining trend is perhaps a consequence of aging of the state population and migration of younger people out of Indiana.

Data for alcohol sale outlets were obtained from the Indiana Alcohol Beverage Commission. The commission maintains record of alcohol sales licenses issued to vendors in the state at county level. This was used as a proxy for alcohol consumption in the model. The available data, however, showed no variation for some of the years during the analysis period 1981-1995. The statewide data are presented in Table 4.10.

4.5.4 VMT Data

Data about vehicle miles traveled in the state, disaggregated to county level, were critical for estimating the model while controlling for exposure. The Indiana Department of Transportation (INDOT) provided the VMT data. The source of these data is the traffic survey for estimating Average Daily Traffic (ADT) on the state highway network that INDOT undertakes every other year. The data, however, do not include vehicle miles traveled on local roads not included in the state highway network.

The VMT data for Indiana are presented in Table 4.11. The DVMT data in Table 4.11 were aggregate statewide data for all highway classes in the state highway network. The data indicated an almost 55 percent increase in DVMT during 1981-1995. The trend, however, had been far from consistent, especially during 1981-1990 when it fluctuated considerably from year to year. However, since 1990 the DVMT for Indiana has been rising, in general, at a varying yearly rate. DVMT data at the county level indicated much wider ranges of variations depending upon the population, size, economic condition, and location of the county. It also varied with the number of lane miles of different classes of highways in the county.

Table 4.9 Number of Young Drivers

Year	Number of Young Drivers*
1981	834,924
1982	781,925
1983	771,930
1984	733,448
1985	713,249
1986	755,107
1987	743,875
1988	756,256
1989	750,045
1990	653,441
1991	599,518
1992	524,695
1993	522,020
1994	513,611
1995	621,291

* - Drivers 24 years of age or younger
Source: Indiana Bureau of Motor Vehicles

Table 4.10 Number of Alcohol Sale Outlets

Year	Alcohol Sale Outlets
1981	11,352
1982	11,352
1983	9,459
1984	9,459
1985	9,374
1986	9,387
1987	9,387
1988	9,450
1989	9,452
1990	9,479
1991	9,506
1992	9,533
1993	9,560
1994	9,582
1995	9,603

Source: Indiana Alcohol Beverage Commission

Table 4.11 Daily Vehicle Miles Traveled (DVMT)

Year	DVMT
1981	109,810,958
1982	104,320,548
1983	108,895,890
1984	112,227,397
1985	111,726,027
1986	113,548,000
1987	119,572,000
1988	139,684,000
1989	153,953,000
1990	147,115,000
1991	149,714,000
1992	155,938,767
1993	164,455,080
1994	167,504,715
1995	169,852,819

Source: Indiana Department of Transportation (INDOT)

4.6 Data Analysis

The basic aim of this study was to determine the impact of change in speed limit on safety, among other factors. The 1987 change in speed limit for rural interstates in Indiana provided a good opportunity to model the impact on safety on rural interstates as well as systemwide. The data set used for the analysis was extensive, covering a 15-year long period from 1981 to 1995. The data set included safety data, enforcement data, socioeconomic data and the data about vehicle miles traveled. With county being the cross sectional unit of analysis here, all of these data were collected at the county level.

The methodology used for the data analysis, as described in the previous section of this chapter, is the widely used econometric model, commonly known as the time-series cross-section model. The model allowed not only estimating the impact of the change in explanatory variables, it also enabled estimation of the cross section effect and the time effect on the dependent variable. Several models were estimated to analyze the impact of the 1987 change in speed limit on various safety aspects. These included models to estimate the impact on:

1. Statewide highway safety
2. Safety on rural interstates
3. Safety in counties with and without rural interstates
4. Truck involvement in rural interstate crashes

Highway safety parameters, for each one of the above groups of models, included fatal crashes, injury crashes, PDO crashes, total crashes and some variations of one or more of these parameters. In terms of regression analysis, all models described above were linear models, i.e., a linear relationship was assumed between the dependent and explanatory variables.

Since it was desired to be able eventually to prepare recommendations about the speed limit policy on statewide basis, it was essential to analyze the impact of varying speed limits on other highway classes in the state highway network as well, besides the interstates. A slightly different approach was used to study the impact of varying speed limits on US highways and State highways, where no systemwide changes in speed limits were made. Sections of these highways with different speed limits (55 mph, 50 mph and 45 mph) were selected from those in the Highway Performance Monitoring System (HPMS). These sections were considered because they were randomly selected for being included in the HPMS. Safety data for the relevant sections were analyzed to determine the impact of different speed limits after controlling for variations in location, access control and geometric design features. Since the number of crashes (especially fatal crashes) for the sections of US highways and State Roads that were analyzed were small (often as low as 0 or 1), Poisson regression models (instead of the linear regression models used for other models) were used for these roads. Poisson regression models assume that the dependent variable (number of crashes) is Poisson distributed. For situations where the number of crashes is low, Poisson models have been found to perform well and are widely used for safety analyses in such conditions.

The approach for the analysis typically consisted of having one observation for the dependent variable and each explanatory variable for each county for each year in the analysis period. The data, besides the dependent variable and the explanatory variables, also included dummy (0,1) policy variables. For example, the change in speed limit variable (a dummy variable) for the rural interstate model had a value of 0 for 1981-1987 and then became 1 from 1988 onwards.

A number of variants of the original models were tried to determine the best fit. These variants essentially had the dependent variable divided by one of the explanatory variables like VMT, population or number of registered vehicles. This resulted in converting the dependent variable from absolute numbers to crash rates that are easier to compare and control the results for exposure (e.g., amount of travel).

In as much as the models were treated as regression models they fall in one of the two categories: linear regression model or Poisson regression model. In terms of panel data analysis, the models were analyzed as fixed-effects models. These models estimate the effect of explanatory variables on the dependent variable like other regression models. In addition, the models also estimate the effect of cross-sections on the dependent variable (assuming that the effect does not change over time) as well as the effect of time on dependent variable (assuming that the effect does not change across cross-sections). A detailed discussion about the adequacy of these models for the intended analysis is given earlier in this chapter.

4.7 Discussion of Results

The answers to the following questions were investigated through the relevant models:

- Did the 1987 change in speed limit have a statistically significant effect on rural interstate crashes?
- Did the 1987 change in speed limit have a statistically significant effect on statewide crashes and was that effect statistically different in counties with rural interstates than those without them?
- Did the 1987 change in speed limit have a statistically significant effect on crashes involving trucks on rural interstates?
- Did different speed limits on sections of US highways have a statistically significant effect on crashes experienced on the relevant sections of the US highways?
- Did different speed limits on State roads (SR) have a statistically significant effect on highway crashes experienced on the relevant sections of the State roads?

The software used to analyze the models was LIMDEP. Results provided by LIMDEP include those estimated for the models with:

- Constant term only
- Cross section effects only
- Explanatory variables only
- Explanatory variables and cross section effects
- Explanatory variables and time effects
- Explanatory variables, cross section effects and time effects

In general, it is the model with explanatory variables, cross-section effects and time effects that gives the most comprehensive results. However, results from other models described here are used for hypothesis testing and comparing the marginal effects of analyzing the data as an ordinary regression model to that for the panel data model. LIMDEP also computes R^2 and the log likelihood values for each model. In addition, LIMDEP performs test to check for the adequacy of a fixed-effects model versus random-effects model. Although fixed-effects model had already been selected for estimation, the LIMDEP allows comparison confirmation of the adequacy of the selected model. Results of the analysis to address the above questions, employing fixed-effects time series cross-section models, are presented in the following sub-sections.

4.7.1 Results for Rural Interstates

Rural interstates were the only roads where speed limit was raised for the entire network in 1987. The effect of this change on safety on rural interstates was, therefore, believed to be direct. Fifty (50) out of 92 Indiana counties have rural interstates passing through them. Models for rural interstates analyzed crash data for only these 50 counties. Models for actual crashes as well crash rates were estimated. Tables 4.12 and 4.13 summarize results of actual crashes and crash rates models for rural interstates, respectively. While models for actual crashes were used to estimate the effect of change in speed limit on the number of crashes, models for crash rates estimated the effect on crash rates by controlling for exposure in terms of crashes per 100 million vehicle miles traveled.

Separate actual crash models were estimated for fatal crashes, injury crashes, PDO crashes and total crashes. However, since the PDO crashes, in general, far outnumber fatal and injury crashes, results for the PDO crashes are virtually the same as for total crashes and hence not reported here. Most of the results are intuitive. The results indicate that the 1987 change in speed limit (represented by a dummy speed limit change variable in the model) had a statistically significant effect on injury (and PDO) and total crashes on rural interstates. The positive sign indicated that the number of injury (and PDO) and total crashes increased after the change in speed limit. However, the effect on fatal crashes was not significant. This result is intuitive and reveals that, as expected, while the probability of crashes after the change in speed limit did increase, the severity of crashes, to the extent that crashes become fatal, did not.

The effect of enforcement on safety was estimated by the variable "per vehicle tickets" obtained by dividing the number of tickets issued in the county by the number of vehicles registered in the county. This is considered to be as appropriate representative of enforcement level proportional to the level of activity and yielded satisfactory results for the models. Per vehicle tickets was marginally significant only for total crashes where, intuitively, it had a negative sign. The enforcement level did not have a statistically significant effect on injury crashes but retained its negative sign. For the fatal crashes however, not only the effect was

Table 4.12 Estimation Results-Rural Interstate Crashes

Explanatory Variable	**Dependent Variable** Total	Fatal	Injury
Speed Limit Change	486.628 (14.604)	0.1257 (0.332)	54.028 (8.989)
Per Vehicle Tickets	-882.715 (-1.963)	8.3299 (1.629)	-67.924 (-0.838)
Population Density	3.809 (7.73)	-0.03592 (-.641)	0.615 (6.925)
Per Vehicle Young Drivers	-1416.351 (-3.278)	8.5716 (1.744)	-116.201 (-1.491)
Unemployment	-6.505	0.01092	-0.50233275
Per Vehicle Alcohol Licenses	-61594.867 (-1.842)	293.28 (.771)	-13085.2127 (-2.169)
Per Vehicle Miles Traveled	0.3078 (4.692)	-.0017 (-2.289)	0.0381 (3.221)
Cross-Section Effect (α_i)	Significant	Significant	Significant
Period (Time) Effect (γ_t)	Significant	Not significant	Significant
Constant	-2628.037 (-16.921)	1.845 (1.045)	-305.590 (-10.908)
R^2	0.9320	0.7976	0.9646

Values in parentheses are t-statistics

Table 4.13 Estimation Results-Rural Interstate Crash Rates (Per 100 Million VMT)

Explanatory Variable	Dependent Variable		
	Total	Fatal	Injury
Speed Limit Change	-1.4662 (-0.212)	0.9708 (0.237)	-5.0639 (-2.14)
Per Vehicle Tickets	194.4172 (2.082)	1.7853 (0.323)	16.5268 (0.518)
Population Density	0.48169 (4.706)	-0.0116 (-0.192)	0.9793 (2.798)
Per Vehicle Young Drivers	-15.1971 (-0.169)	5.6256 (1.06)	20.1984 (0.658)
Unemployment	-0.28168 (-0.29)	0.0238 (0.041)	-0.247 (-0.074)
Per Vehicle Miles Traveled	-0.00068 (-0.05)	-0.00144 (-1.785)	0.00079 (0.17)
Per Vehicle Alcohol Licenses	-1361.27 (-0.196)	505.3403 (1.23)	-2414.26 (-1.017)
Cross-Section Effect (α_i)	Significant	Significant	Significant
Period (Time) Effect (γ_t)	Significant	Significant	Significant
Constant	26.1468 (0.811)	0.9765 (0.512)	30.4246 (2.758)
R^2	0.8741	0.3259	0.8024

Values in parentheses are t-statistics

not statistically significant, it had a counter intuitive positive sign. This is perhaps an indication of the extra attention fatal crashes get from the enforcement point of view. Typically higher level of enforcement is maintained for a spot, stretch of road or county, known to be sensitive from the fatal crashes point of view. Fatal crashes, however, do not reveal sensitivity to time (Table 4.12, time effect is not significant). What it essentially means is that while more tickets are issued in the years following higher fatal crashes experienced in a county, the number of fatal crashes does not, in general, change proportionally in the following years.

Most of the socioeconomic explanatory variables had intuitive results and expected signs. Population density (number of residents per square mile) was significant and had positive signs for injury and total crashes. The result confirmed what was expected; the more densely populated a county, the higher the probability of crashes. However, population density was not significant for fatal crashes, perhaps indicating that drivers traveling on stretches of rural interstates passing through relatively densely populated areas exhibited greater caution to avoid crashes of high severity.

Per vehicle young drivers - number of young drivers in a county divided by the number of registered vehicles in the same county - was significant for total crashes with an unexpected negative sign. It was expected that a higher per-vehicle-young-drivers number would tend to increase the number of crashes. The variable was not significant for injury and fatal crashes but had opposite signs, negative for injury crashes and positive for fatal crashes. The result indicated that at least while traveling on interstates, in general, young drivers are more alert and in better control of their vehicles.

However, young drivers perhaps trust their abilities to control vehicles more than they should in critical situations that lead to fatal crashes. Results from studies conducted in other states also indicate that young drivers have a much larger representation in single vehicle fatal crashes than their proportion in the total driver population.

Unemployment was significant for total crashes and had an expected negative sign across the board. The result is intuitive. Higher rates of unemployment are known to have reduced the amount of travel thus reducing the exposure and number of crashes. Unemployment was not significant for injury and fatal crashes.

Per vehicle alcohol licenses - number of alcohol sale outlets divided by number of registered vehicles in a county - was used as a measure of alcohol consumption. It had a negative sign and was significant for injury and (marginally significant for) total crashes. A possible explanation for the negative sign may be that with the increase in number of outlets the amount of travel involved to get to such outlets perhaps also reduced and less travel to and from alcohol sale outlets could cause a negative effect on crashes. The effect for fatal crashes, however, was not significant.

Per vehicle miles traveled was calculated by dividing the county VMT with the number of vehicles registered in the county and was used in the model as a measure of the level of exposure. The variable was significant for fatal, injury and total crashes. It had a positive sign for injury and total crashes and a negative sign for fatal crashes. These results were intuitive. Higher levels of exposures are, in general, expected to result in higher number of crashes, explaining the positive sign for total and injury crashes. Similarly, higher levels of exposures, inevitably leading to congestion, are expected to have relatively less fatal crashes.

Estimating the effects of cross-section (county is the cross-section unit for this analysis) and time (year) on crashes is the feature that sets this analysis apart from ordinary regression analysis. Results indicted that cross-section had a significant effect on all types of crashes for most of the counties. Typically, the signs were negative for smaller counties and positive for larger (highly populated) counties.

Effect of time was significant for all but fatal crashes. For injury (as well as PDO) and total crashes time effect was significant and had a positive sign for 1981-1987. While still significant, the sign for injury and total (and PDO) crashes became negative from 1988 onward. Fatal crashes were the only type of crashes for which effect of time was not significant. These results captured the effect of all omitted variables and indicated a declining yearly trend for injury and total crashes. It should be recalled that the dummy speed limit change variable was also significant for all but fatal crashes, with an opposite (positive) sign. However, the two results do not necessarily indicate opposite trends. While the dummy speed change variable compared the pre-1987 crashes to the post-1987 crashes as a group, the time effect considered crashes on yearly basis. A downward trend for injury (PDO) and total crashes, after peaking in 1987, was observed (Table 4.3). This result confirmed the observed trend. However, the time effect was only marginal compared to that of the explanatory variables and/or cross-sections.

Results for the crash rate models for rural interstates are presented in Table 4.13. The model for fatal crashes had a low R^2 value indicating that fatal crash rates on rural interstates did not seem to be sensitive to the variables (explanatory variables, cross section and time trend) included in the model. One reason for the result could be the very low fatality rate observed on rural interstates. Fatal crash models typically are better specified using count data models like Poisson regression model. Unfortunately, the Poisson model cannot be used for estimating the crash rates, since it (Poisson model) requires dependent variable to have integer values (0, 1, 2...etc.), not the case for crash rates.

The injury and total crash rate models have reasonably high R^2 values. The speed limit change was significant, with a negative sign, indicating a lower injury crash rate after the 1987 change in speed limit. The effect on total crash rate was statistically not significant. Enforcement (per vehicle tickets) was significant, but with a positive sign for total crashes. The explanation for the result is that counties with higher crash rates, in general, had higher enforcement levels. Population density was significant with positive signs for both injury and total crash rates. This result is intuitive. Cross-section and time effects were both significant. While cross-section was significant for almost two-third of all counties, signs for cross-section were almost equally divided in positives and negatives indicating the significance of the local, otherwise unobserved factors, which could affect crash rates on rural interstates and that the effect was not uniform. Results for the time effect are in a way similar to those for the actual number of crashes model (Table 4.12) – significant or marginally significant for each of the 15 years in the model, negative sign pre-1987 and positive post-1987 - and hence the explanation for them is also the same as given previously. Interestingly, the time effect for crash rate models is relatively less marginal than was the case for the actual number of crashes model. One reason for this could be the fact that only a few explanatory variables were significant in the crash rate model.

4.7.2 Results for Statewide Crashes

The effect of the change in speed limits for rural interstates has been studied extensively and several studies addressing the issue are available in the literature. In general, such studies have found that the 1974 decrease in speed limit had a positive impact on safety and that the 1987 increase in speed limit on rural interstates had a negative effect on rural interstate safety. However, some researchers have argued about the validity of the approach used for analyzing the impact of the speed limit change, particularly at a system wide level. The argument is that while the impact on safety for rural interstates might be negative, the impact on system wide safety may or may not be the same. Studies conducted to evaluate the system wide effect of speed limit change on rural interstates have, in general, concluded that the impact on system wide safety was not always negative. Several reasons are offered to explain these results. It is argued that with the increase in speed limit some of the fastest traffic diverted from other, relatively less safe highways, to rural interstates, thus reducing the conflict and probability of crashes on non-interstate highways. Another explanation is that with the increase in the speed limit for rural interstates the resources available for traffic law enforcement were perhaps better utilized by concentrating on areas with poor safety records rather than monitoring speeds on rural interstates. The purpose of estimating the statewide models in the present study is to verify the validity of these findings in Indiana's context.

The results, presented in Table 4.14, indicated that while the speed limit change for rural interstates had a significant effect (at a confidence level of 95%, t-value being greater than 1.96) with a positive sign on total crashes statewide (i.e., total crashes went up as the speed limit did), it had a significant effect on fatal crashes but with a negative sign. The effect on injury crashes was not significant. The impact was, however, different in counties with and without interstates.

Table 4.14 Estimation Results- Statewide Crashes

Explanatory Variable	Dependent Variable Total	Fatal	Injury
Speed Limit Change	462.3272	-1.0686	1.4924
	(16.792)	(-3.985)	(0.181)
Per Vehicle Tickets	-638.9670	-7.0066	-112.0412
	(-1.415)	(-1.593)	(-0.831)
Population Density	5.822	-0.1892	-2.3785
	(4.709)	(-1.571)	(-6.440)
Per Vehicle Young Drivers	1567.1248	18.9153	864.4941
	(2.124)	(2.633)	(3.923)
Unemployment	-19.9951	-0.2284	1.9204
	(-2.378)	(-0.279)	(0.764)
Per Vehicle Alcohol Licenses	-14703.1373	319.7754	-3689.1196
	(-.759)	(1.694)	(-0.637)
Per-Vehicle Miles Traveled	-0.14551	-0.0025	-0.0999
	(-1.423)	(-2.505)	(-3.272)
Rural Interstate Dummy	-258.8148	1.8926	95.3598
	(-2.066)	(1.551)	(2.549)
Cross-Section Effect (α_i)	Significant	Significant	Significant
Period (Time) Effect (γ_t)	Significant	Significant	Significant
Constant	-1236.5309	4.9114	-162.6307
	(-1.032)	(.421)	(-0.455)
R^2	0.9872	0.9231	0.9870

Values in parentheses are t-statistics

The presence of rural interstates had a significant effect on total number of crashes with a negative sign, was significant with a positive sign for injury crashes and was not significant for fatal crashes. These results revealed the following important points:

- Overall the number of total crashes statewide increased after 1987, fatal crashes decreased and there was no statistically significant change in injury crashes.
- The trend was not uniform across the counties. Compared to those without, the counties with rural interstates had fewer total crashes but higher injury crashes. The effect on fatal crashes was statistically not significant.
- The increase in speed limit on rural interstates possibly resulted in shifting of faster vehicles from other highways to rural interstates and thus in turn causing a spill-over effect of higher speeds on other adjacent highways. The first trend explains decrease in total crashes while the other explains increase in injury crashes in counties with rural interstates.

Socioeconomic variables, in general, had intuitive results and signs. Population density had a significant positive effect on total crashes statewide but a significant negative effect on injury and fatal crashes. Young drivers had a significant positive effect for all types of crashes. Unemployment had a significant negative effect on total crashes only. Alcohol sale outlets had a marginally significant effect, with a positive sign, on fatal crashes. Number of traffic tickets was not significant for any type of crashes but had the intuitive negative sign for each one of them. Vehicle miles traveled was significant with a negative sign for injury and fatal crashes and had no significant effect on total crashes. Cross-section and time effects were both significant for all the models.

Results for the crash rate (per million vehicle miles traveled) models are presented in Table 4.15. Results for the socioeconomic variables were virtually the same as for the actual crashes model. The results for tickets and VMT were also similar. However, results for the speed change variable and the rural interstate variable were of greater interest. Both of these were included in the model as dummy variables. The speed limit change variable had a very significant effect, with a negative sign, for the total and injury crashes. It was only marginally significant for fatal crashes retaining its negative sign. The rural interstate variable had a very

Table 4.15 Estimation Results- Statewide Crash Rates (Per 100 Million VMT)

Explanatory Variable	Dependent Variable		
	Total	Fatal	Injury
Speed Limit Change	-21.6324	-0.1226	-8.7876
	-7.785	-1.646	-10.049
Per Vehicle Tickets	18.5781	2.288	-1.9726
	0.408	-1.872	-0.138
Population Density	0.7255	0.0396	0.0712
	5.814	1.185	1.815
Per Vehicle Young Drivers	311.2833	3.302	74.3115
	4.181	1.654	3.172
Unemployment	0.8189	-0.03785	0.1672
	0.965	-1.663	0.626
Per Vehicle Alcohol Licenses	1842.3902	46.2328	287.4915
	0.942	0.882	0.467
Per Vehicle Miles Traveled	-0.0051	-0.0003	-0.0010
	-4.700	-1.099	-3.280
Rural Interstate Dummy	75.008	0.5339	20.4377
	5.933	1.575	5.137
Cross-Section Effect (α_i)	Significant	Significant	Significant
Period (Time) Effect (γ_t)	Significant	Significant	Significant
Constant	-371.157	-2.42584	-52.9558
	-3.070	-0.748	-1.392
R^2	0.891314	0.330023	0.864835

Values in parentheses are t-statistics

significant effect, with a positive sign, for the total and injury crashes. It was not significant for fatal crashes while still having a positive sign.

These results revealed that the counties with rural interstates had higher rates for total crashes and injury crashes, compared to those without rural interstates. The rate for fatal crashes was also higher; however, the difference was not statistically significant. The results also indicated that the crash rates for total and injury crashes statewide went down after the change in rural interstate speed limit in 1987. The rate for fatal crashes went down only marginally. These results are similar to those found in other states.

4.7.3 Results for Crashes on Rural Interstates Involving Trucks

Since 1987 Indiana, like a few other states, has a differential speed limit policy enforced for its rural interstates. Speed limit for trucks on rural interstates in Indiana is 60 mph and that for automobiles is 65 mph. The effect of these differential speed limits has also been a matter of debate in the literature. Some safety researchers argue that these differential speed limits have caused a negative impact on safety by increasing the speed variance on rural interstates. In the present study, the models for truck crashes on rural interstates were estimated to identify the effect of the differential speed limit in Indiana.

Results for the number of crashes model are presented in Table 4.16. Table 4.17 shows results for the crash rate model involving trucks. Results for the actual number of crashes model indicated that the change in speed limit did have a significant effect on total and injury crashes involving trucks on rural interstates. The positive sign showed that the number of such crashes went up after the differential speed limit was enforced in 1987. The effect on fatal crashes was statistically not significant but still had a positive sign indicating a weaker upward trend. Results for other socioeconomic variables, enforcement variable (tickets per vehicle) and VMT were all intuitive.

Table 4.16 Estimation Results-Rural Interstate Crashes Involving Trucks

Explanatory Variable	**Dependent Variable**		
	Total	**Fatal**	**Injury**
Speed Limit Change	48.001 (12.536)	0.1251 (1.136)	7.4869 (8.406)
Per Vehicle Tickets	-258.3942 (-2.140)	4.0994 (1.180)	-51.4816 (-1.833)
Population Density	0.1476 (0.149)	-0.0184 (-0.646)	0.2728 (1.184)
Per Vehicle Young Drivers	-190.6687 (-1.378)	6.3527 (1.597)	-14.4762 (-0.450)
Unemployment	-2.7886 -2.215	-0.533 (-1.472)	-0.4984 (-1.702)
Per Vehicle Alcohol Licenses	-14131.1815 (-1.495)	637.081 (2.343)	-2673.9734 (-1.216)
Per-Vehicle Miles Traveled	0.2987 (1.900)	-0.0095 (-2.107)	0.0393 (1.075)
Cross-Section Effect (α_i)	Significant	Significant	Significant
Period (Time) Effect (γ_t)	Significant	Not Significant	Significant
Constant	-401.8437 (-7.071)	-0.2406 (-0.147)	-62.1250 (-4.700)
R^2	0.9226	0.5433	0.9276

Values in parentheses are t-statistics

Table 4.17 - Estimation Results-Rural Interstate Crash Rates (Per 100 Million VMT) Involving Trucks

Explanatory Variable	Dependent Variable		
	Total	Fatal	Injury
Speed Limit Change	3.5718 (2.795)	0.4391 (0.368)	0.4786 (0.879)
Per Vehicle Tickets	-103.2988 (-2.563)	1.4723 (0.391)	-40.9181 (-2.384)
Population Density	0.0250 (0.076)	-0.1048 (0.7340)	0.04586 (0.326)
Per Vehicle Young Drivers	45.4628 (0.984)	4.7797 (1.109)	18.2944 (0.930)
Unemployment	-0.8524 (-2.028)	-0.4494 (-1.146)	-0.2865 (-1.601)
Per Vehicle Alcohol Licenses	1408.4672 (0.446)	1028.9206 (3.494)	-338.27 (-0.252)
Per-Vehicle Miles Traveled	-0.1490 (-2.841)	-0.01487 (-3.038)	-0.0451 (-2.020)
Cross-Section Effect (α_i)	Significant	Significant	Significant
Period (Time) Effect (γ_t)	Significant	Not Significant	Not Significant
Constant	24.7571 (1.305)	0.798 (.451)	12.668 (1.568)
R^2	0.801618	0.2467	0.5945

Values in parentheses are t-statistics

Results for the crash rate model revealed that the differential speed limits did have a significant effect on the rate for total crashes with a positive sign. However, the effect on injury and fatal crashes was not significant. The effects of all other socioeconomic variables, enforcement variable, VMT and time and cross section effects were intuitive.

The results essentially confirmed increase in the number of total crashes and injury crashes involving trucks on rural interstates since 1987 when the differential speed limit became effective. In terms of crash rates, however, the increase is statistically significant only for all crashes taken together. These results are similar to those found in studies undertaken in other states.

4.7.4 Results for Non-Interstate Highways

Unlike the interstates where uniform speed limits are enforced system wide, the non-interstate highways have speed limits ranging from 30 mph to 55 mph (some sections of state roads have even lower speed limits), typically with 5 mph increments. The modeling of the effect of changes in speed limits on these non-interstate highways was not straightforward. Data about the extent of different speed limits on these highways were not readily available. In addition, it was difficult to get data about geometric characteristics and the (traffic) operational features for all of the highway stretches with different speed limits. To circumvent this obstacle it was decided to randomly select sections of US highways and State highways with 55 mph, 50 mph and 45 mph speed limits and analyze the effect of the different speed limits on crashes experienced on these highways. The highway sections were selected from the HPMS database. To minimize the impact of different geographical locations, sections of highways with different speed limits were selected within the same counties. Forty-nine (49) such sections in 9 counties were selected for the State highway models and thirty (30) sections in 6 counties for the US highway models. The variables in the data sets included number of lanes, area (rural/urban), and access control (besides socioeconomic, enforcement and VMT variables) to account for variations in the geometric design and traffic operational features. Results for the US highways and State roads are presented in Tables 14.18 and 4.19, respectively.

Results for the US highways indicated that compared to 55 mph sections (of the same road and in the same county) 50 mph and 45 mph sections had higher total and injury crashes as both the speed limit variables were significant and had a positive sign. The effect was not significant for fatal crashes. The speed limit change variable (1987 speed limit change for rural interstates, included in the model to check for spill over effect on non-interstate road sections) was not significant for any crash type. The socioeconomic variables had intuitive results except for the young drivers variable, which was significant for total and injury crashes, but with a negative sign. This result was similar to that observed for rural interstates. The effect of the young drivers variable was not significant for fatal crashes. Another important but somewhat counter intuitive result was for the tickets per vehicle variable. The variable had a significant positive effect on total and fatal crashes but was not significant for injury crashes. However, the variable had shown similar results for the statewide and rural interstate models as well. The effect and its possible explanation given in the discussion for the relevant models are applicable here as well and hence not repeated. Alcohol sale outlets per vehicle were not significant for any of the models and the same was true for the VMT variable.

Section-specific variables showed intuitive results. The dummy variable for area type was significant and had a negative sign indicating fewer total and injury crashes on urban sections of roads compared to rural sections. The variable had no significant effect on fatal crashes. This was expected since more sections with lower speed limits were in rural areas and operating conditions in rural areas are, in general, believed to be less forgiving. The effect of number of lanes was significant with a positive sign. This result indicated higher number of crashes on four-lane sections compared to the two-lane-two-way roads since the former are more heavily traveled and have a higher number of intersections and other conflicting movements. Access control was significant with a negative sign for the total and injury crashes. The effect on fatal crashes was not significant. The results indicated fewer total and injury crashes on sections with access control than those without it. Cross-section and time effects were not significant for fatal crashes; only cross-section was significant for injury and total crashes.

Table 4.18 Estimation Results–US Highway Crashes
(55 mph, 50 mph & 45 mph Sections)

Explanatory Variable	Dependent Variable		
	Total	Fatal	Injury
Speed Limit Change (Dummy variable)	-0.4983 (-0.820)	-0.6492 (-1.636)	-0.1598 (-0.771)
50 MPH Speed (Dummy variable)	0.7946 (2.921	0.0933 (1.101)	0.2787 (3.005)
45 MPH Speed (Dummy variable)	0.2609 (2.653)	-0.03123 (-1.041)	0.1241 (3.700)
Per Vehicle Tickets	0.6948 (2.035)	0.03355 (3.130)	0.1358 (1.167)
Population Density	157.927 (2.942)	2.2503 (1.315)	50.04056 (2.734)
Per Vehicle Young Drivers	-38.055 (-3.492)	-0.2872 (-0.838)	-8.7285 (-2.350)
Unemployment	2.2463 (-3.258)	-0.1496 (-0.728)	-0.7818 (-3.326)
Per Vehicle Alcohol Licenses	-0.3681 (-0.095)	-0.0926 (-0.761)	-0.4674 (-0.353)
Per Vehicle Miles Traveled	-8.9410 (-1.130)	-0.5834 (-1.184)	-2.1923 (-0.812)
Area (Dummy variable)	-0.0067 (-4.195)	0.00026 (0.519)	-0.0027 (-5.060)
Number of Lanes (Dummy variable)	9.6918 (2.418)	0.6339 (0.507)	3.5617 (2.607)
Access Control (Dummy variable)	-11.6568 (-2.459)	-0.1386 (-0.938)	-3.5414 (-2.192)
Cross-Section Effect (α_i)	Significant	Not Significant	Significant
Period (Time) Effect (γ_t)	Not Significant	Not Significant	Not Significant
Constant	-556.7738 (-1.427)	-1.8435 (-0.140)	194.0159 (-1.458)
R^2	0.905643	0.4232	0.897108

Values in parentheses are t-statistics

Table 4.19 Estimation Results–State Roads Crashes
(55 mph, 50 mph & 45 mph Sections)

Explanatory Variable	**Dependent Variable**		
	Total	**Fatal**	**Injury**
Speed Limit Change (Dummy variable)	4.455 0.863	0.2976 0.947	0.625 0.383
50 MPH Speed (Dummy variable)	0.0909 2.430	0.0351 1.541	0.2416 2.042
45 MPH Speed (Dummy variable)	-0.193 -0.850	0.0013 1.004	-0.687 -0.958
Per Vehicle Tickets	-2457.741 -4.176	-138.811 -3.885	-730.013 -3.923
Population Density	0.0763 0.153	0.00217 0.740	-0.2916 -1.844
Per Vehicle Young Drivers	16.144 1.123	-0.529 -0.614	8.768 1.928
Unemployment	-0.3864 -1.921	0.8698 0.709	-0.1673 -2.630
Per Vehicle Alcohol Licenses	-861.958 -1.072	-26.234 -0.540	-145.627 -0.573
Per Vehicle Miles Traveled	-0.0232 -0.378	0.0091 2.451	-0.4062 -2.096
Area (Dummy variable)	-0.000063 -0.973	-0.000018 -0.456	-0.0000013 -0.006
Number of Lanes (Dummy variable)	0.7585 0.262	-0.2835 -0.162	0.9027 0.988
Access Control (Dummy variable)	0.9980 0.226	-0.1531 -0.569	2.0285 1.453
Cross-Section Effect (α_i)	Significant	Significant	Significant
Period (Time) Effect (γ_t)	Significant	Significant	Significant
Constant	3.0306 0.7708	0.04037 0.064	0.983 0.299
R^2	0.680731	0.306989	0.664553

Values in parentheses are t-statistics

Results for the State highway models were similar to those for the US highways. There was no significant effect of the speed limit on 45 mph sections, however, it was significant for the injury and total crashes on sections with 50 mph speed limit. Most of the socioeconomic variables had intuitive results and signs. Number of tickets issued was significant and had an intuitive negative sign for all type of crashes. None of the section-specific variables were however significant.

Crash rate models were also estimated for the two non-interstate highway types. The results did not reveal any significant difference from the number of crash models except that for the State roads number of lanes and access control became significant with intuitive negative and positive signs, respectively. Since the number of fatal crashes was small, Poisson models were also estimated. The results, however, did not reveal any significant deviation from those discussed above.

4.7.5 Summary of Results

Salient important results of the above analyses and their implications for highway safety are summarized below.

- The number of total and injury crashes on rural interstates did go up after the 1987 change in speed limit. However, when controlled for the level of exposure (by dividing the number of crashes by vehicle miles traveled), there was no increase in crash rates. The injury crash rates actually went down after 1987. There was no significant effect on either the number or rate of fatal crashes.
- Statewide, the number of total crashes went up after 1987, fatal crashes went down and no significant change was observed for the injury crashes. In terms of crash rates, however, total and injury crash rates declined. Fatal crash rates showed no significant change.
- The differential speed limit in Indiana did have an impact on crashes involving trucks on rural interstates as both the number and rate for total crashes went up. There was no evidence of any significant effect on fatal crashes. Injury crash numbers did go up but not the rate.

- For non-interstate highways there was evidence that, all else being constant, highway sections with lower speed limits, in general, had higher total and injury crash numbers and rates. There was no significant difference for fatal crashes. Highway sections with lower speed limits are generally those with less than ideal geometric features.
- Better enforcement, in general, was followed by decreasing crashes; however, fatal crashes seemed to be less sensitive to enforcement levels than injury or total crashes.
- Young drivers had a greater representation in fatal crashes on practically all types of facilities than their proportion in the total driver population. That was not the case for total and injury crashes.
- The number of alcohol sale outlets, in general, had a significant effect on injury and fatal crashes in a county but the evidence was neither very strong nor universally valid for all highway types.
- There was strong evidence of spatial (cross-section) and temporal (year) effects influencing crashes on highways, especially the injury and total crashes.
- Results for most of the models are more conclusive for total and injury crashes then for fatal crashes. A probable reason for this was the low number of fatal crashes.

There was some evidence of collinearity among the socioeconomic data. While that does not affect the overall findings, results about the effects of individual socioeconomic variables should be viewed with caution.

CHAPTER 5: SPEED LIMITS AND PRODUCTIVITY

5.1 Introduction

In addition to operating speeds and associated safety, speed limits also affect productivity. Particular groups of road users – commercial truckers and other business travelers - may be more adversely affected by changes in speed limits that result in reduced driving speeds. These groups drive more miles than average motorists and often use high-speed roads. The economic cost of travel time, particularly from lost productivity, can be substantial. No study, so far, has attempted to estimate the impact of speed limits on productivity, especially for commercial vehicles and the trucking industry as a whole.

The importance and cost of travel time as a function of speed were illustrated by the experience during the 55-mph speed limit period. A TRB study estimated that in one year (1982) only, motorists spent about 1 billion extra hours on highways posted at 55 mph because of slower driving speeds compared with travel time associated with speeds on these highways in 1973. Passengers in personal vehicles accounted for most of this travel time [TRB 1984].

Another aspect of the travel time cost and speed limit relationship is the varying impact by road type and road users. The trucking industry is particularly and adversely affected by lower speed limits. The 55-mph speed limit enforced in 1974 affected the rural interstate users the most. Lowering speed limits to 55-mph on rural interstates was estimated to cost motorists and truckers almost 100 years of additional driving time per life saved – about four times as much as all other affected roads [TRB 1984].

While all road users are affected by speed limits and travel time can be related to economic productivity, the impact is most directly felt by the trucking industry, as a large part of trucking cost is related to truck driver wages. For many truckers, time saved is money saved. In the present study it was therefore decided to elaborate on the impact of speed limits on trucking industry's productivity. Simply put, when speed limits are reduced, it takes longer to travel specific distances thus increasing the cost of operation and in turn, causing a negative or unfavorable impact on the productivity of the trucking industry.

5.2 Chapter Organization

This chapter begins with a brief introduction of the issue at hand. A discussion about productivity in the context of trucking industry follows the chapter organization. A description of data collected for analysis comes next followed by the methodology adopted for the analysis. Results of the analysis are presented at the end of the chapter.

5.3 Productivity and Trucking Industry

Economic productivity is the relationship between the output of goods and services and the inputs of resources used to produce them. Productivity for the trucking industry can be defined in two ways. These are:

- Output per employee
- Output per hour

Output per employee is defined as the gross output of the industry, in dollar terms, produced per employee. It is obtained by dividing the total dollar value of the output (also known as gross product) by the number of employees working in the trucking industry.

Output per hour is defined as the output, in dollar terms, produced by the industry per hour. This is computed by dividing the gross output of the industry by the total number of man-hour input by the employees.

Out of the two measures of productivity, output per hour would have been desirable in representing the effect of change in speed limits as it could directly reflect the impact on travel time. However, data about output per hour are not easily available, especially at the state level. The trucking industry employs both full time and part time employees whose input in number of hours varies but details for which are not readily available. As output per employee is the only productivity measure for which reliable and continuous data series are available, the present study used this indicator for the analysis.

5.4 Existing Trucking Industry Productivity Data

Bureau of Economic Analysis (BEA) is the main source of labor productivity data for all industries including the trucking industry. BEA maintains databases about output for a large number of industries in the USA. It also maintains data on the number of employees in each industry, wage levels in each industry and other data series related to productivity. BEA uses these data to come up with what it calls "the productivity index". The data are available for the trucking industry in terms of output per employee since 1954.

Table 5.1 presents the productivity index for the trucking industry. The BEA's trucking industry productivity index has a value of 100 for the output per employee in 1987. The data provide a good historical prospective of the yearly changes in the industry's productivity at the national level. The data, in general, indicated an almost consistent trend of increasing productivity over the years. Starting from the lowest value of 41.1 in 1954, the index continued to rise till it reached the peak value of 133.3 in 1994, indicating a more than three-fold increase. However, there have been some exceptions, notably those in 1974-1975, 1980-1985 and then in 1995 when the productivity index for the trucking industry went down. Advancement in vehicle technology, improvement in highway infrastructure and better managerial techniques played a major role in the productivity improvement. However, the decline in productivity in 1974-1975 coincided with the introduction of the reduced 55 mph maximum speed limits in 1974. Similarly, there has been a noticeable upward trend in productivity all along the 1987-1994 period, again coinciding with the introduction of higher speed limits for rural interstates. This evidence suggests some relationship between speed limit and trucking industry productivity, at least at the national level.

Table 5.1 Trucking Industry Productivity Index at the National Level

Year	Productivity Index
1954	41.0
1955	43.1
1956	43.4
1957	44.0
1958	45.3
1959	47.8
1960	47.8
1961	48.5
1962	49.9
1963	52.3
1964	53.7
1965	55.6
1966	58.4
1967	56.3
1968	59.8
1969	61.3
1970	60.1
1971	63.8
1972	68.1
1973	69.5
1974	67.2
1975	64.2
1976	72.2
1977	71.9
1978	82.9
1979	83.9
1980	77.5
1981	83.6
1982	77.7
1983	94.3
1984	97.3
1985	93.8
1986	96.8
1987	100.0
1988	105.2
1989	109.3
1990	111.1
1991	116.9
1992	123.4
1993	128.6
1994	133.3
1995	125.4

Source: Bureau of Economic Analysis

5.5 Methodology

National trends are often significant indicators of state trends. For the purpose of the present study the impact on the productivity of trucking industry was evaluated specifically for Indiana. Because BEA does not compile productivity indices for states, it was decided to undertake the exercise from scratch and estimate the trucking productivity in terms of output per employee for Indiana. Annual data for the gross product of the trucking industry and the number of employees working for the industry were available for individual states from BEA.

Because the objective here was to analyze the impact of change in speed limits on trucking industry's productivity, the impact of other factors affecting productivity also required to be considered to avoid confounding of results (crediting speed limits for impacts that might have been caused by other factors if not specifically analyzed).

A number of such factors, both quantitative and qualitative, were identified. The quantitative factors included the gross domestic product (GDP) of the state, state highway spending, truck VMT, (variations in) revenue rates and fuel consumption levels. The qualitative or policy factors that were considered to affect productivity included the change in speed limits (one each in 1974 and 1987) and the deregulation of the trucking industry (in 1980).

The timeline for the availability of the data related to the above mentioned factors varied considerably. The earliest year in which common data for all of the factors became available from was 1969. It could have been possible to estimate a classic/simple regression model with Indiana data only. However, it was considered desirable to have a model with more data points in order to come up with more convincing results. To achieve that objective it was decided to develop and analyze a model with data for Indiana and four neighboring states – Illinois, Michigan, Ohio and Wisconsin. The reason to include these states is that the BEA treats them all part of what it calls "the Great Lakes Economic Region" and reports data for them accordingly.

With data for 5 states spanning over 1969-1995, the resulting dataset took the form of a typical time series cross-section model dataset. The general form of the time series cross-section model employed for the productivity analysis was of the form:

$$P_{it} = \sum_{i=1}^{N} \alpha_i + \sum_{j=1}^{k} \beta_j x_{itj} + \varepsilon_{it}$$

where

P_{it} = Productivity measure (e.g., output per employee, output per hour, etc.) for cross section i and time period t ($i = 1,2,\ldots, N$ and $t = 1, 2, \ldots, T$),

x_{itj} = jth explanatory variable for cross-section i and time period t ($i = 1,2,\ldots, N$ and $t = 1, 2,\ldots, T$, $j = 1,2, \ldots, k$),

α_i = parameter reflecting the marginal effect of the ith cross-section on the productivity measure,

β_j = parameter reflecting the marginal effect of the jth explanatory variable on the productivity measure ($j = 1,2, \ldots, k$), and

ε_{it} = error term for cross section i and time period t ($i = 1,2,\ldots, N$ and $t = 1, 2, \ldots, T$).

Cross-sectional units for the model were the states of Illinois, Indiana, Michigan, Ohio and Wisconsin. The time series extended from 1969 to 1995. The quantitative explanatory variables included state GDP, state highway spending, truck VMT (in each state), revenue per ton-mile, and fuel consumption.

5.6 Data for the Productivity Model

Data for the variables in the model came from two sources, BEA and Bureau of Transportation Statistics (BTS). Most of the economic data came from BEA, while the data about functional performance of the trucking industry (VMT, revenue per ton-mile and fuel consumption levels) became available from BTS. While most of the data were available for the states, only national data were available about revenue per ton-mile, fuel consumption and ton-miles carried per gallon of fuel.

Data for state GDP, gross product/output of the trucking industry, number of employees in the trucking industry and state highway spending for Indiana, Illinois, Michigan, Ohio and Wisconsin are presented in Tables 5.2 through 5.6, respectively.

Table 5.2 Trucking Industry Productivity Related Data - Indiana

YEAR	GDP[1] (Mill. $)	GDPTRCK[2] (Mill. $)	TRCKEMP[3] (Number of employees)	STHWYSP[4] (Mill. $)	Truck VMT (Mill. Miles)
1969	21790	534	38915	8905	1799
1970	22530	530	38034	9140	1858
1971	24073	562	37806	9391	1977
1972	27224	645	39309	9696	2154
1973	31187	779	42551	9914	2368
1974	33926	843	43762	10038	2371
1975	34582	773	40763	10178	2429
1976	39889	909	43044	10409	2586
1977	47324	1020	46017	10519	2838
1978	53162	1159	49368	10536	3158
1979	57750	1250	50245	10574	3255
1980	58423	1206	47466	10620	3240
1981	63841	1271	47426	10619	3246
1982	63337	1231	45685	10558	3192
1983	67587	1349	46538	10482	3379
1984	77086	1579	52037	10533	3701
1985	80528	1748	55959	10567	3780
1986	85137	1982	59253	10587	3886
1987	91350	2143	64285	10653	4044
1988	98270	2350	66669	10714	4222
1989	105830	2503	70662	11143	4429
1990	109552	2608	73021	11215	4474
1991	112937	2724	74133	11373	4501
1992	122097	2902	75147	11532	4687
1993	129667	3037	77737	11577	4814
1994	141358	3300	80019	11657	5083
1995	148801	3382	83991	11767	5320

Sources: Bureau of Economic Analysis & Bureau of Transportation Statistics

1: GDP – State Gross Domestic Product
2: GDPTRCK - Gross Product of the trucking industry
3: TRCKEMP - Number of employees in trucking industry
4: STHWYSP – State highway spending

Table 5.3 Trucking Industry Productivity Related Data - Illinois

YEAR	GDP[1] (Mill. $)	GDPTRCK[2] (Mill. $)	TRCKEMP[3] (Number of employees)	STHWYSP[4] (Mill. $)	Truck VMT (Mill. miles)
1969	59291	454	88155	1081	1924
1970	63300	460	82179	1157	1986
1971	67490	688	84177	1287	2113
1972	73424	901	85518	1314	2302
1973	81532	1191	89444	1403	2532
1974	89650	1336	90775	1474	2535
1975	93927	1275	83847	1580	2596
1976	103438	1608	85214	1770	2765
1977	115442	1974	89478	1803	3033
1978	128792	2234	92458	1915	3376
1979	140479	2446	93745	2059	3480
1980	146275	2398	86084	2162	3463
1981	160083	2482	84480	2319	3470
1982	163180	2432	80467	2392	3412
1983	171952	2665	80178	2570	3613
1984	191988	3070	86047	2917	3956
1985	204833	3267	88359	3347	4041
1986	218362	3509	89425	3587	4155
1987	230199	3807	100927	3548	4323
1988	246971	4080	101448	3701	4514
1989	260915	4142	104980	3974	4735
1990	273359	4275	106754	4119	4783
1991	281930	4316	105214	4428	4812
1992	298747	4469	102248	4741	5011
1993	312349	4833	111932	4837	5146
1994	336867	5373	119497	5001	5434
1995	352932	5485	125560	5225	5687

Sources: Bureau of Economic Analysis & Bureau of Transportation Statistics

1: GDP - Gross Domestic Product (million of current dollars)
2: GDPTRCK - Gross Product of the trucking industry (million of current dollars)
3: TRCKEMP - number of employees in trucking industry (million of current dollars)
4: STHWYSP – State highway spending (million of current dollars)

Table 5.4 Trucking Industry Productivity Related Data - Michigan

YEAR	GDP[1] (Mill. $)	GDPTRCK[2] (Mill. $)	TRCKEMP[3] (Number of employees)	STHWYSP[4] (Mill. $)	Truck VMT (Mill. miles)
1969	44860	488	48922	822	2009
1970	46419	474	46437	885	2075
1971	50292	583	46744	964	2208
1972	55247	705	49039	972	2405
1973	61269	891	52020	1042	2645
1974	64136	902	51363	1096	2648
1975	66875	815	46103	1176	2712
1976	75733	1017	47830	1306	2888
1977	87684	1278	51876	1319	3169
1978	97658	1494	55671	1406	3526
1979	103637	1587	56228	1512	3635
1980	102049	1423	49372	1580	3618
1981	112503	1471	47753	1672	3625
1982	112249	1429	45148	1716	3564
1983	124499	1585	45392	1817	3774
1984	140389	1807	49835	2034	4132
1985	150308	1982	53727	2285	4221
1986	160363	2164	55159	2410	4340
1987	166298	2123	56883	2342	4516
1988	175695	2236	57255	2412	4715
1989	184552	2267	58073	2653	4946
1990	188016	2314	59608	2729	4996
1991	189876	2321	59079	2911	5027
1992	201635	2469	58194	3093	5234
1993	217347	2619	60686	3131	5375
1994	240645	2954	65218	3213	5676
1995	251794	3053	67813	3330	5941

Sources: Bureau of Economic Analysis & Bureau of Transportation Statistics

1: GDP - Gross Domestic Product (million of current dollars)
2: GDPTRCK - Gross Product of the trucking industry (million of current dollars)
3: TRCKEMP - number of employees in trucking industry
4: STHWYSP – State highway spending (million of current dollars)

Table 5.5 Trucking Industry Productivity Related Data - Ohio

YEAR	GDP[1] (Mill. $)	GDPTRCK[2] (Mill. $)	TRCKEMP[3] (Number of employees)	STHWYSP[4] (Mill. $)	Truck VMT (Mill. miles)
1969	47821	466	87313	1084	2090
1970	50281	520	85688	1181	2158
1971	53137	748	87813	1294	2297
1972	58514	950	90641	1285	2502
1973	66562	1263	95039	1357	2751
1974	72709	1373	96813	1417	2755
1975	75026	1271	86896	1499	2821
1976	84448	1601	88500	1644	3005
1977	97772	2079	95570	1636	3296
1978	108803	2370	101998	1736	3668
1979	118919	2587	102965	1857	3781
1980	123285	2541	95633	1921	3764
1981	134400	2594	91609	2021	3771
1982	135528	2375	82913	2069	3708
1983	145333	2522	82514	2199	3926
1984	164412	2862	90122	2499	4299
1985	175070	2940	91365	2829	4391
1986	183530	3074	91121	3011	4515
1987	192429	3183	99733	2945	4698
1988	204870	3449	101043	3046	4905
1989	216820	3555	102672	3182	5145
1990	227102	3665	102711	3257	5197
1991	232337	3732	102820	3455	5229
1992	245726	3998	102061	3651	5445
1993	256593	4299	108410	3675	5592
1994	276742	4731	114672	3749	5905
1995	292103	4880	118309	3863	6180

Sources: Bureau of Economic Analysis & Bureau of Transportation Statistics

1: GDP - Gross Domestic Product (million of current dollars)
2: GDPTRCK - Gross Product of the trucking industry (million of current dollars)
3: TRCKEMP - number of employees in trucking industry
4: STHWYSP – State highway spending (million of current dollars)

Table 5.6 Trucking Industry Productivity Related Data - Wisconsin

YEAR	GDP[1] (Mill. $)	GDPTRCK[2] (Mill. $)	TRCKEMP[3] (Number of employees)	STHWYSP[4] (Mill. $)	Truck VMT (Mill. miles)
1969	19705	250	29441	444	1836
1970	20988	274	29794	480	1895
1971	22420	342	29736	525	2017
1972	24844	418	30732	527	2197
1973	28279	512	31707	566	2416
1974	31195	568	32871	594	2419
1975	32838	554	31872	630	2478
1976	36443	658	32095	696	2639
1977	40709	728	34018	699	2895
1978	45548	839	36094	743	3221
1979	50364	958	37917	801	3321
1980	52969	975	37427	840	3305
1981	57555	1030	37081	901	3312
1982	59225	1013	36603	944	3256
1983	62841	1130	37888	1009	3447
1984	70161	1334	42331	1140	3775
1985	74001	1422	44333	1292	3856
1986	78078	1572	44884	1376	3965
1987	82078	1627	46901	1361	4126
1988	88865	1776	48788	1409	4308
1989	94522	1882	50902	1506	4518
1990	99246	2022	53478	1555	4564
1991	103223	2116	55183	1666	4592
1992	110618	2317	56151	1777	4782
1993	117651	2501	60198	1806	4911
1994	125831	2801	63807	1860	5186
1995	132704	2949	67546	1935	5427

Sources: Bureau of Economic Analysis & Bureau of Transportation Statistics

1: GDP - Gross Domestic Product (million of current dollars)
2: GDPTRCK - Gross Product of the trucking industry (million of current dollars)
3: TRCKEMP - number of employees in trucking industry
4: STHWYSP – State highway spending (million of current dollars)

The data revealed an almost consistent upward trend in the GDP for all states for the entire 1969-1995 time period. The trucking industry's gross product also, in general, followed an upward trend. However, there were exceptions when the industry's output went down. For all five states the output of the trucking industry showed a decline in 1975 compared to its output in 1975. This coincided with the enforcement of the reduced speed limit (55 mph) in 1974. The impact, however, was short lived and the industry quickly regained its growth trend in the following years. The next dip in the otherwise upward growth trend of the trucking industry could be observed in 1980-1982. This one coincided with the deregulation of the trucking industry in 1980. The 1987 increase in speed limit for rural interstates was followed by a steeper than previous upward growth in the total output of the trucking industry. Figure 5.1 shows these changes graphically.

The number of employees in the trucking industry also showed similar trends. Figure 5.2 graphically shows the trend in annual employment over the years. The 1974 change in speed limit (and of course the oil crisis) caused commotion in the industry and it took the industry several years to recover from that. The impact of the deregulation of the trucking industry was also followed by a decline in the number of employees working in the trucking industry. Although the trend was similar in all five states, the larger states (Illinois and Ohio) took longer to recover from the impact than the smaller ones (Indiana, Wisconsin).

Annual state highway spending, in general, showed an upward trend for all states all through 1969-1995. However, the rate of increase was somewhat steeper in Illinois, Indiana, and Wisconsin than in Michigan and Ohio.

Vehicle miles traveled (VMT) by trucks in all 5 states showed a consistent upward trend during the entire analysis period, 1969-1995. However, the 1974 oil crisis and the enforcement of 55 mph speed limit did reduce the rate of growth in truck VMT. The impact was short lived and dissipated by 1976.

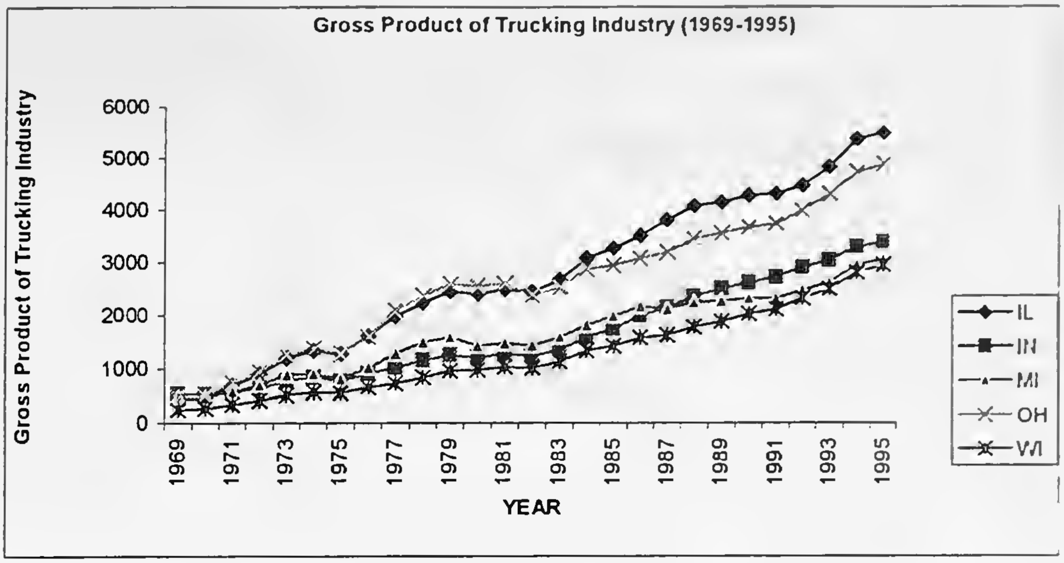

Figure 5.1 Annual Gross Product of Trucking Industry

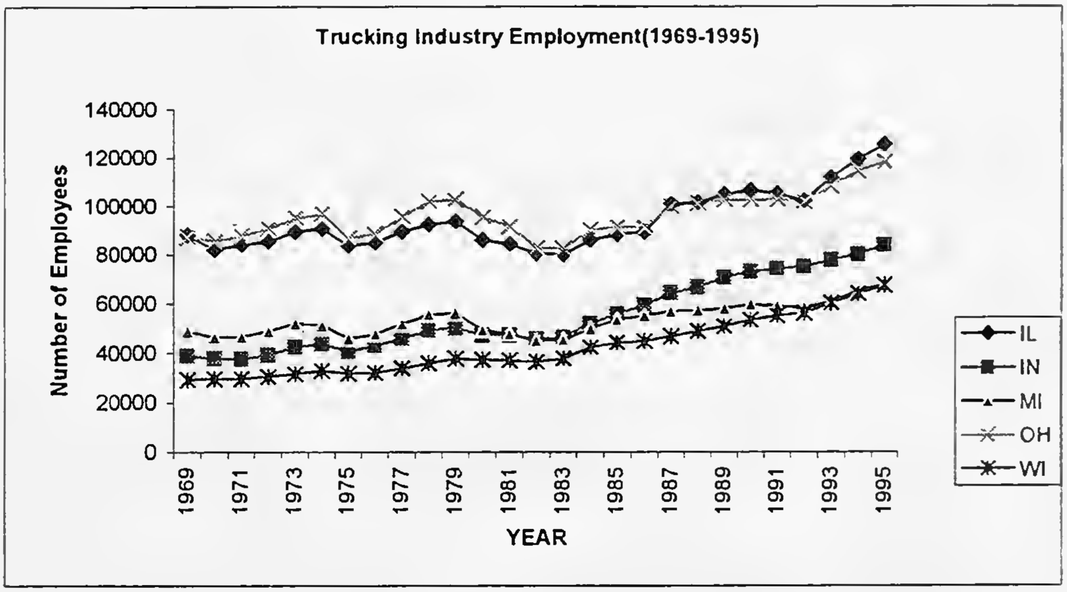

Figure 5.2 Annual Employment in Trucking Industry

Deregulation of the trucking industry in 1980 also had a negative impact on truck VMT and the impact lasted longer than that of the 1974 changes. The truck VMT values were back on their upward trend by 1983 and have remained so ever since then, with a little higher growth rate after 1987.

Average revenue per ton-mile data and fuel consumption data for the trucking industry became available from BTS. The data were available only at the national level. Revenue per ton-mile data (in cents per mile) are presented in Table 5.7. The data revealed a trend of increasing revenue over the entire 1969-1996 period, however, the rate of increase slowed down during the later years. Fuel consumption data are given in terms of vehicle-miles traveled per gallon of fuel consumed. It can be seen that the fuel efficiency of the trucking industry has had an improving trend over the years.

The aggregate fuel efficiency levels for all vehicles in the trucking fleet mask an important change the industry has undergone during these years. The number of single unit trucks that obviously were more fuel efficient in terms of miles traveled per gallon of fuel consumed has been dwindling over the years and larger combination trucks have replaced these trucks. The combination trucks might not be as fuel efficient in terms of miles per gallon, they are believed to offer better economy in terms of ton-miles per gallon of fuel consumed.

Although the ton-miles per gallon data were not directly available the data about ton-miles traveled and total fuel consumption by the trucking industry were used to compute the same. Data on average ton-miles per gallon of fuel consumed are presented in Table 5.9. The data did indicate increase in ton-miles per gallon during early 1970s and the value had been fluctuating since then falling in1974-1983, gradually going up in 1984-1991 and then going down again in 1991-1995.

The policy variables - speed limit change of 1974, trucking industry deregulation in 1980, the1987 change in speed limit, and the differential speed limits in some states were all introduced in the model as dummy, 0-1 variables.

Table 5.7 Average Revenue Per Ton-Mile

Year	Average Revenue Per Ton-Mile (Cents per mile)
1969	8.1
1970	8.5
1971	9.0
1972	9.6
1973	10.2
1974	10.9
1975	11.6
1976	12.7
1977	13.8
1978	15.1
1979	16.5
1980	18.0
1981	18.9
1982	19.8
1983	20.8
1984	21.8
1985	22.9
1986	23.2
1987	23.5
1988	23.8
1989	24.1
1990	24.4
1991	24.8
1992	23.1
1993	25.0
1994	25.0
1995	25.1

Source: Bureau of Transportation Statistics

Table 5.8 Average Fuel Consumption by Trucking Industry

Year	Average Fuel Consumption by trucks (Miles per gallon)
1969	5.90
1970	5.50
1971	5.51
1972	5.53
1973	5.54
1974	5.55
1975	5.57
1976	5.54
1977	5.52
1978	5.49
1979	5.46
1980	5.44
1981	5.50
1982	5.57
1983	5.63
1984	5.70
1985	5.77
1986	5.81
1987	5.85
1988	5.89
1989	5.93
1990	5.97
1991	5.98
1992	6.03
1993	6.09
1994	6.15
1995	6.15

Source: Bureau of Transportation Statistics

Table 5.9 Average Ton-Miles Hauled per Gallon of Fuel

Year	Ton-Miles per Gallon
1969	44.55
1970	52.14
1971	54.20
1972	55.94
1973	53.98
1974	51.02
1975	46.58
1976	47.94
1977	45.82
1978	46.47
1979	44.54
1980	40.15
1981	38.97
1982	38.67
1983	41.77
1984	44.99
1985	43.76
1986	43.21
1987	44.48
1988	46.10
1989	46.17
1990	45.72
1991	46.03
1992	44.04
1993	43.62
1994	42.18
1995	41.08

Source: Bureau of Transportation Statistics

5.7 Discussion of Results

A fixed-effects time series cross-section model was specified for analyzing the impact of the change in speed limits on the productivity of the trucking industry in terms of output per employee. The dataset contained data for Indiana and four neighboring states in the Great Lakes region for 1969-1995. The results of the analysis are presented in Table 5.10. The model seems to be well specified. This is evident from the high R^2 value (0.996).

The results indicated that three of the four policy variables – speed limit change of 1974, trucking industry deregulation, and the 1987 change in speed limit - did have a significant positive effect on the productivity of the trucking industry measured in terms of output per employee. While the results for the deregulation and the 1987 increase in speed limit are intuitive, the positive effect of the 1974 reduced speed limit is not that straight forward. Intuitively, the impact would have been negative.

It seems that the industry adjusted itself rapidly to minimize the impact of more than one factors that affected it in 1974. Evidence for this comes from the data that revealed significant decrease in number of employees in 1974 and 1975 and a considerable improvement in the ton-miles per gallon value. Both of these measures indicated the industry's effort to adjust to the change. Perhaps the collective impact of all these factors, taking place simultaneously, resulted in increasing productivity despite the perceived negative impact of reduced speed limits.

The deregulation of the trucking industry had a significant positive effect on productivity. This result is intuitive and similar to the impact of deregulation on the aviation industry.

Table 5.10 Estimation Results-Trucking Industry Productivity Model

Explanatory Variable	Dependent Variable Output per employee
Speed Limit Change 1974	0.8474E-08 (6.319)
Trucking Industry Deregulation 1980	0.2063E-08 (1.976)
Speed Limit Change 1987	0.6430E-08 (3.130)
Differential Speed Limits	-0.4329E-03 (-0.507)
State Gross Domestic Product	-0.1312E-06 (-8.429)
State Highway Spending	0.787 E-05 (5.405)
Vehicle Miles Traveled Per Employee	0.8264 E-01 (1.026)
Revenue Per Miles Traveled	0.4158 E-07 (0.86)
Miles Traveled Per Gallon	0.103 E-05 (0.933)
Ton-Mile Per Gallon	0.1529E-02 (1.00)
Cross-Section Effect(α_i)	Significant
Period (Time) Effect (γ_t)	Not Significant
Constant	-0.6136 E-01 (-1.05)
R^2	0.99644

Values in parentheses are t-statistics

Indiana and Ohio had differential speed limits with a lower 60 mph speed limit for trucks. The result indicated that the effect of this policy variable on productivity was not statistically significant. However, this was the only policy variable that did have a negative sign. Another implicit indication of the effect of differential speed limits came from the result that had Indiana and Ohio as having a negative effect on productivity in terms of the cross-section effect.

State GDP was included in the model to control for the influence state economic condition had on the trucking industry performance. The result revealed that the state GDP had a negative impact on trucking industry's productivity. The result is intuitive. When the state economy is flourishing (GDP increasing), there is increased activity experienced by the trucking industry, but it is also accompanied by an increase in wages and salaries taking the cost of operation upward, thus resulting in a negative impact on productivity.

State spending on highways was significant with a positive sign. This result is also intuitive. Higher state spending on highway infrastructure results in lower vehicle operating costs and that in turn improves trucking industry productivity.

Vehicle Miles Traveled Per Employee, Revenue Per Mile Traveled, Miles Traveled Per Gallon and Ton-Miles Per Gallon all had positive signs but were not significant. These results revealed that all the above factors contributed to improve productivity of the trucking industry but their effect was not statistically significant.

The cross-section effect was significant indicating that individual states had considerable influence on results. While all states were significant, the effect was not unidirectional for all states. Indiana, Michigan and Ohio had a negative sign, while Illinois and Wisconsin had positive signs. As already stated, both Indiana and Ohio had differential speed limits that may have caused the negative effect. Also, Michigan had the largest fluctuation/prolonged stagnation in its highway spending of all the five states. Illinois and Wisconsin did not have differential speed limits and their highway spending more or less consistently kept an upward trend. Lastly, the output per employee did not reveal any statistically significant time trend.

5.7.1 Summary of Results

Salient important features of the above results and their implications on speed limit policy are summarized below.

- There is strong evidence that change in speed limits had a statistically significant impact on the productivity of the trucking industry defined in terms of output per employee (higher speed limits coincide with higher productivity).
- While the result for the 1974 change in speed limit could have some confounding involved (as the recession slowed economic activity across the board and was also indicated by lower truck miles traveled), the results for the 1987 change in speed limit were free from such an ambiguity.
- There is no statistically significant evidence to indicate that differential speed limits in Indiana have had a negative impact on the productivity of the trucking industry.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

Speed limits represent trade-offs between risk and travel time for a road class or specific highway section reflecting an appropriate balance between the societal goals of safety and mobility. The process of setting speed limits is not merely a technical exercise. It involves value judgments and trade-offs that are in the arena of the political process.

The fact that road conditions vary a great deal and that a "one-size-fits-all" approach should not be adopted for speed limits cannot be over emphasized. There is no single right answer in setting appropriate speed limits because policy makers may legitimately disagree on the priority given to factors like safety, travel time, enforcement and community concerns. Technical input on how these factors should be weighed in different situations can help guide the decision.

6.2 Rationale and Purpose of Speed Limits

It can be argued that if most drivers operate their vehicles at speeds that are safe and prudent for the conditions, then the issue of speed control should be left to the motorists rather than posting speed limits. In support of the contrary, reasons for regulating drivers' speed choices are summarized below [TRB 1998]:

- Externalities – risks and uncompensated costs imposed on others because of individual speed choices.
- Inadequate information – that limits driver's ability to determine appropriate driving speed.
- Driver misjudgment – of the effects of speed on crash probability and severity.

The primary purpose of speed limits is to regulate driving speeds to achieve an appropriate balance between travel time and risk for the road it is intended for. Safety, both in terms of crash avoidance as well as mitigation of crash outcomes, is the most important reason for imposing speed limits. A secondary purpose of imposing speed limits is to provide motorists with a common set of rules about appropriate driving speeds.

6.3 Speed Limit Setting Practice in Indiana

The approach used in Indiana, and most other states, is to set speed limits legislatively for broad road classes (e.g., interstate highways) and geographic area (e.g., urban/rural). When statutory speed limits do not fit specific road or traffic or road condition, speed zones are established administratively. Speeds limits in these speed zones may be reduced from the statutory limit for that road class.

Currently the statutory speed limits in Indiana by road class and geographic area are as follows:

Road Class and area	Speed Limit (mph)
Rural interstates	65 60 for trucks
Urban interstates	55
All other roads not in speed zones	55

6.4 Recommendations for Future Speed Limits

A set of possible recommendations is presented here for future speed limits, based on the interpretation of study results. These recommendations have been made with due regard given to the following considerations:

- Existing operating speeds,
- Perceived safety impact,
- Design features of the respective highway class, and
- Enforcement experience.

On a system-wide basis (excluding rural interstates) the average speed in the state for the entire analysis period of 1981-1995 remained above the 55 mph and the 85th percentile speed was still higher. The trend has continued beyond 1995.

Data for individual road classes indicated similar speed trends. The average speed for rural interstates has remained above 65 mph since 1989 and the 85th percentile speed had started to exceed 65 mph even before the 1987 rise in speed limits. There could be differences in the amount by which the average speed and 85th percentile speeds exceed the speed limits on the respective highway classes, but the trend is unmistakably the same – operating speeds are higher than speed limits- irrespective of the highway class or geographic location.

In terms of safety, statewide total and injury crashes have generally gone up gradually, while the number of fatal crashes did not change significantly. This is, however, only one perspective of the issue. Crash rates, which take into consideration the amount of travel on highways, indicated a declining trend for total and injury crashes while the fatal crash rate witnessed no significant change.

The case of rural interstates was of particular interest since the speed limit on rural interstates was raised in 1987. Safety data for rural interstates in Indiana were put to rigorous analysis. The results were no different from statewide trends. The number of total and injury crashes went up after 1987, but the fatal crashes did not. The crash rates, however, went down for injury crashes and the total and fatal crashes had no significant change. Safety data for randomly selected sections of US Highways and State Roads were also analyzed and generally indicated the same trends.

The above discussion reveals two important aspects of highway safety. First, the crash rates, in general, did not go up during the past two decades, even during the 1981-1995 period for which data were analyzed. Secondly, the change of speed limits on rural interstates in 1987 did not have any statistically significant impact on the safety trends.

Summing up, it is clear that previous upward changes in speed limits in Indiana did increase operating speeds. However, there is statistically significant evidence that such increases did not result in a significantly negative impact on safety. It must be pointed out that this does not imply that future changes would produce the same trend, because a very critical component of the entire issue is the role of enforcement.

Along with safety, the issue of productivity was also analyzed. The analysis for the effect of speed limit changes on trucking industry productivity revealed (though not unequivocally) that higher speed limits actually increased productivity.

Given the above results, recommendations for future speed limits for the various highway classes can be made as follows:

- Rural Interstates – Design features are not a constraint for most of the total length of the rural interstates in the state, and current and historic average and 85th percentile speed trends are significantly above the posted speed limit. Furthermore, crash rates have not shown upward trends, and some neighboring states have already raised speed limits on such highways. Therefore, an increase of 5 mph in speed limit is feasible, provided an effective enforcement program can be pursued.
- Differential Speed Limits For Trucks – There is some evidence that differential speed limits have a negative impact on safety in terms of crashes involving trucks; however, the evidence is not very strong. Also, differential speed limits did not have any significant effect on trucking industry productivity. It would be prudent therefore to retain the speed differential, pending further investigation.
- Urban Interstates – Because design features for urban interstates are often a controlling factor, and operating traffic conditions are relatively complex and demanding, no change in speed limit for urban interstates is considered appropriate. It is worth noting that since 1995, a majority of states that did raise speed limits for highways other than urban interstates maintained current speeds for this class of highways. However, many of the highway sections currently included in urban interstates may not be properly classified and should be reviewed for possible reclassification.

are free of specific safety problems, can be recommended to have speed limits up to 60 mph.

- Maximum speed limit for all other highways in the state network should remain at 55 mph.

As mentioned earlier, effective enforcement is a critical factor in speed limit policy consideration. Enforcement is critical to achieving compliance with speed limits and achieving the intended objectives of any change in speed limit policy. Merely posting a speed-limit sign does not guarantee a certain level of operating speeds. Even if some motorists complied, enforcement would still be necessary to ensure the conformity of other drivers who comply only if they perceive a credible threat of detection and punishment for noncompliance.

The effects of traditional enforcement methods in deterring speeding or other unwanted behavior tend to be short-lived. The effectiveness and longevity of deterrence can be achieved by combining enforcement with high profile public information and education campaigns. The use of automated enforcement – for example, photo radar – can be used to complement traditional enforcement methods, particularly where roadway geometry or traffic volume makes traditional enforcement difficult.

Furthermore, for speed enforcement to be effective, it is essential that the police and traffic court judges perceive that speed limits are reasonable and enforceable. Development of sentencing guidelines and training for judges who handle speeding violations can help ensure consistent and fair treatment of violators.

Finally, the State of Indiana should continue to monitor speed trends, highway usage patterns, and other relevant vehicular, roadway and human factors that are necessary inputs for any future review of speed limits. A periodic review (3-5 years) of speed limits and effects of speed limit policies should be carried out.

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