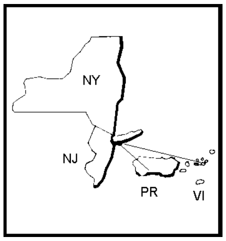

REGION II
UNIVERSITY TRANSPORTATION RESEARCH CENTER

CHARACTERISTICS OF TRAFFIC FLOW AND SAFETY IN 55 AND 65 MPH SPEED LIMITS: Literature Review and Suggestions for Future Research

FINAL REPORT

July 2002

Submitted by

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University Transportation Research Center, Region 2
City College of New York

New Jersey
Department of Transportation
Bureau of Research
and
U.S. Department of Transportation

DISCLAIMER STATEMENT

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA-NJ-2002-18	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Characteristics of Traffic Flow in 55 and 65 mph Speed Limits		5. Report Date August 2002 6. Performing
7. Author(s) Raghavan Srinivasan		8. Performing Organization Report No.
9. Performing Organization Name Region 2 University Transportation Research Center City College of New York New York, NY 10031		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and New Jersey Department of Transportation CN 600 Trenton, NJ 08625		13. Type of Report and Period Covered Final Report: 6/1/01-6/30/02 14. Sponsoring Agency Code
15. Supplementary In cooperation with Federal Highway Administration, U.S. Department of Transportation, Washington D.C.		

16. Abstract

Speed limits have been introduced for many reasons, e.g., to reduce gas consumption, to reduce the frequency and severity of crashes, and in some cases to reduce noise. The objective of this research effort was to conduct a literature review to assess the effect of increased speed limits on limited access roads regarding safety, travel speeds, and other unanticipated impacts including shifts in lane distribution, traffic diversions, and spillover effects. Following are the conclusions:

- In general, an increase in the speed limit does lead to an increase in average speeds, although the magnitude of this increase is less than the increase in the speed limit.
- Speed is directly related to the severity of crash injury. Probability of severe injury increases sharply with the increase in the impact speed of a vehicle.
- Studies that have tried to assess the impact of speed limit changes on speed dispersion have not produced consistent results.
- There seems to be a relationship between speed dispersion and safety. The safety effect of speed dispersion appears to most important for the fastest rather than the slowest drivers.
- Very little is known about the effect of changes in the speed limit on spillover and diversion of traffic to high-speed roads. Some of these issues will be addressed in an on-going NCHRP project that is expected to be completed in summer of 2004 (NCHRP Project 17-23).
- Further research is needed to develop appropriate methodologies that can be used to study the impact of changes in speed limits including the selection of appropriate statistical models.

17. Key Words Speed limit, speed, unanticipated impacts, speed dispersion, crashes, spillover effect		18. Distribution	
19. Security Classif (of this report): Unclassified	20. Security Classif. (of this page) Unclassified	21. No of Pages: 43	22. Price

Form DOT F 1700.7 (8-69)

Acknowledgments

This work was sponsored by the New Jersey Department of Transportation and the Region 2 University Transportation Research Center.

I am grateful to Karl Brodtman of the New Jersey Department of Transportation who was the project manager and provided valuable assistance, connections, and feedback. He was always helpful in answering my questions and finding out who could provide the information when he could not. I am also grateful to Mike Asson, Doug Bartlett, Greg Budholt, and other members of the Research Selection and Implementation Panel for their guidance and support.

TABLE OF CONTENTS

SUMMARY

Speed limits have been introduced for many reasons, e.g., to reduce gas consumption, to reduce the frequency and severity of crashes, and in some cases, to reduce noise. The overall objective of this research was to conduct a literature review to assess the effect of increased speed limits on limited access roads regarding safety, travel speeds, and other unanticipated impacts including the shifts in lane distribution, traffic diversions, and spillover effects (e.g., increase in average speeds and crashes in highway sections that did not increase speed limits). The final report also includes a discussion of issues to be addressed through future research. Following are the conclusions from this research:

- In general, an increase in the speed limit does lead to an increase in average speeds, although the magnitude of this increase in less than the increase in the speed limit. The percentage of drivers exceeding 65 mph seems to have increased following the 1987 speed limit legislation that allowed states to increase the speed limit on rural Interstates 65 mph. Local issues play an important role in how drivers respond to changes in speed limits.

- Speed is directly related to the severity of crash injury. Probability of severe injury increases sharply with the increase in the impact speed of a vehicle. The relationship between speed and frequency of multi-vehicle crashes is more complicated.

- Studies that have tried to assess the impact of speed limit changes on speed dispersion have not produced consistent results.

- There seems to be a relationship between speed dispersion and safety. The safety effect of speed dispersion appears to be most important for the fastest rather than the slowest drivers.

- Very little is known about the effect of changes in the speed limit on spillover or diversion of traffic to high-speed roads. Some of these issues will be addressed in an on-going NCHRP project that is expected to be completed in summer of 2004 (NCHRP project 17-23). There is very little evidence on any direct impact of the change in speed limit on lane distribution of traffic. However, if change in speed limits increase traffic volumes on these roads, this could in-turn affect the lane distribution of traffic.

- Further research is needed to develop appropriate methodologies that can be used to study the impact of changes in speed limits including the selection of appropriate statistical models. More work is needed to study local and system wide impacts of changes in speed limits.

INTRODUCTION

Background

Speed limits have been introduced for many reasons, e.g., to reduce gas consumption, to reduce the frequency and severity of crashes, and in some cases, to reduce noise [1]. In 1974, the national maximum speed limit (NMSL) of 55 mph was introduced to reduce the consumption of fuel. NMSL was followed by a dramatic reduction in the number of fatal crashes and Congress decided to continue with the 55 mph speed limit. In 1987, states were allowed to increase the speed limit to 65 mph on certain rural interstates. New Jersey did not change the 55 speed limit at that time since "very little mileage qualified as rural interstate" [2]. In 1995, the United States Congress suspended the NMSL and States were given the responsibility of setting appropriate speed limits. In May 1998, New Jersey designated 475.49 miles of roadway for a 65 mph speed limit for an 18 month study period [2].

The suspension of NMSL has rekindled the debate over the effect of increased speed limits on frequency and severity of accidents. In addition to the direct effect of change in the speed limit on safety, it can lead to unanticipated impacts such as:

1. Diversion of traffic from low-speed roads to roads with higher speed limits,
2. Spillover effects – due to the higher speed limits on interstates, drivers may become acclimatized to driving at higher speeds on all roads,
3. Changes in lane distribution of traffic – this was postulated by New Jersey Department of Transportation based on anecdotal information [3].

One of the initial objectives of this research was to study the effect of the increase in speed limits on these unanticipated impacts. The initial research plan included a literature review and preparation of an RFP for data collection.

Objectives

The overall objectives of this research were to assess the effect of the increased speed limit on safety, travel speeds, and other unanticipated impacts including the shifts in lane distribution, traffic diversions, and spillover effects - such as, increase in average speeds and crashes in highway sections that did not increase their speed limits.

The specific objectives were to:

1. Conduct a comprehensive and critical review of the literature to assess the effect of increased speed limits.

2. Identify studies that have used a valid methodology by controlling for confounding factors and used appropriate statistical methods.

3. Determine if changes in speed limits have resulted in unanticipated impacts such as traffic diversions to faster routes, changes in the lane distribution, and spillover effects.

4. Develop a request for proposal (RFP) for data collection and analysis to determine if the increase in speed limit in New Jersey has resulted in unanticipated impacts.

When this project was proposed, it was intended that the results of the research could be used by the State of New Jersey on whether to continue with higher speed limits on the selected freeway segments. However, the State of New Jersey has since implemented 65 mph speed limits to additional freeway segments. Due to these developments, the Research Selection and Implementation Panel decided to eliminate the fourth objective, i.e., developing a request for proposal (RFP) for data collection. Hence, this report gives an overview of the results of the literature review and provides suggestions for future research in this area.

LITERATURE REVIEW

This section is a summary of the literature review that was conducted to study the effect of changes in speed limit on average speed, speed dispersion, accidents, and unanticipated impacts such as diversion of traffic, spillover effects, and changes in lane distribution of traffic. Appendix A gives a summary of selected studies that have studied the effect of the 1987 speed limit legislation and the abolition of the NMSL in 1995.

Effect on Average Speeds

Driver speed is a function of several factors apart from the posted speed limits, e.g., alignment, lane and shoulder width, design speed, surrounding land use, traffic volumes, percentage of trucks in the traffic stream, weather, time of day, enforcement[1], visibility, vehicle operating characteristics, and driver factors such as risk taking behavior (1,5). Hence, it is difficult to identify the effect of a single factor on speeds. To find out the effect of changes in speed limit on average speeds, most researchers have relied on a comparison of average speeds before the change in speed limit with average speeds after the change in speed limit.

In the early 80's, the Transportation Research Board conducted a study of the impacts of the 1974 NMSL legislation, leading to a special report (6). The study found that immediately following the introduction of the NMSL, there was a significant reduction in the average speed limit. Many drivers understood that lower speeds were associated with less fuel consumption. However, as gas became more easily available, speeds started increasing, although based on data until the early 80's average speeds in rural Interstate highways are well below the pre-NMSL values[2].

When Congress allowed rural interstate speed limits to be raised in 1987, most states found a 1 - 4 mph increase in the average speed, which is less than increase in the

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[1] The impact of enforcement is limited and transitory (see Reference 1)

[2] However, the special report also mentions that there have been changes in the collection of speed data over time – "equipment changes, sampling changes, and restrictions (before 1980) only to free-flow conditions". Hence, readers should exercise caution while comparing results over this time period.

speed limit [(7)]. However, the results were not consistent across the states. "Of the 13 states there were studied after the 1987 speed limit increase, average speeds increased in 8 states, fell in 4, and did not change in 1, between the first quarter of 1987 and the first quarter of 1988" [(8)]. In addition, among 9 States that kept the speed limits at 55 mph, average speeds increased in 5 states and decreased in 4 states, during the same time period. This indicates the importance of considering local factors and other confounding variables in the analysis[3].

According to the TRB special report 254 published in 1998, "average speeds typically increased 1 to 3 mph" following the abolition of the NMSL in 1995 [(9)]. Controlled before-after studies in Riverside, CA, and Houston, TX, have shown increases of 2-5 mph [(10)]. The New Jersey Department of Transportation (NJDOT) conducted a before-after study of speeds and accidents based on 36 months of data after the speed limit was increased to 65 mph on selected freeway segments [(11)]. Following the increase in the speed limit, "average travel speeds increased 1 mph on the various roadway sections in the 65 mph zones, with the exception of the Turnpike and Parkway which increased 3 to 4 mph on various segments". Again, this is reasonably consistent with results from other states, where an increase in the average speed was noted, although this increase was smaller than the increase in speed limit.

Effect on Speed Dispersion

In many studies, speed dispersion is expressed as the difference between the 85th percentile speed and the average speed, which has been found to be approximately equal to the standard deviation, the square root of the variance. If the dispersion is relatively low, speeds are more uniform. Speed dispersion is also a function of several factors in addition to the posted speed limit. In a study of urban and rural freeways in Virginia, speed variance was found to increase with an increase in the difference between the design speed and the posted speed limit [(12)]. In other words, if the posted

[3] Appendix A has summaries of selected studies that have looked at the effect of the 1987 speed limit legislation on average speeds.

speed limit is too low for a highway with high design standards, many drivers may not obey the posted speed limit.

Looking at the effect of the 1987 legislation on speed dispersion, the results are mixed. In some cases, there was an increase in speed dispersion, although the magnitude was small, approximately 1 mph. For example, in Washington, the difference between the 85th percentile speed and the mean speed was 5.5 mph before 1987, and 6.6 mph after 1987, an increase of 1.1 mph in the speed dispersion.

Some have argued that in addition to looking at average speed and speed dispersion, one should also look at the number or percentage of vehicles driving at very high speeds, e.g., look at the percentage of vehicles that 65 mph, and how this number has changed after the change in the speed limit. Based on the limited evidence that is available, this percentage seems to have increased with an increase in the speed limit. For example, in Michigan, the percentage of vehicles exceeding 65 mph increased from 30% when the speed limit of 55 mph to 42% when the speed limit was increased to 65 mph in 1987[(13)]. Similarly, a multi-state analysis conducted in 1990 by McKnight and Klein [(14)] concluded that, “there was a 48.2% increase in the percentage of drivers who exceeded the 65 mph speed limit in rural interstates in the 65 mph states. In 55 mph highways in 65 mph states, there was a 9% increase in the percentage of drivers who exceeded 65 mph”.

Effect on Safety

Speed is directly related to the severity of crash injury. Probability of severe injury increases sharply with the increase in the impact speed of a vehicle [(15)]. In terms of crash rates, single vehicle crashes have been shown to increase with travel speed [(16)]. Some studies have shown an association between crash involvement rates and deviation from average speed [(12, 17, 18, and 19)]. These studies argue that speed dispersion is a more important factor than average speed with respect to crash involvement.

After a detailed literature review on the relationship between crashes and speed dispersion, McCarthy [8] concluded the following:

- “There is a positive relationship between crash severity and speed dispersion, particularly for rural Interstate roads. Also, evidence suggests that minimum speed dispersion occurs when the difference between a road’s design speed and the posted speed limit lies between 5 mph and 10 mph.

- The safety effect of speed dispersion appears to be most important for the fastest rather than the slowest drivers.”

McCarthy [8] also indicated that more research and disaggregate data are required to better understand the relationship between average, speed dispersion, and highway safety. For example, some studies have tried to relate aggregate measures of speed dispersion with crash frequency, and this measure may not necessarily correspond to the speed dispersion at the time of the crash. In addition, many studies do not control for other confounding factors.

Godwin and Kulash [20], and others, have argued that lower speeds lead to safer driving, because:

- “When traveling at a higher speed, the car moves a greater distance during the fixed period of time that it takes for the driver to react to a perceived problem.

- On highways lacking adequate super-elevation, a driver’s ability to steer safely around curves diminishes with speed.

- The distance required to stop a vehicle by braking increases with speed.”

Effect of the NMSL

The fatality rate dropped significantly after the implementation of NMSL. Several factors may have played a role in this drop [6, 20]. The shortage of fuel during the Arab oil embargo reduced the amount of total traffic. It is also possible that accident intensive recreation travel may have also been reduced. There were also some technological changes: "1974 was the first year that new cars were required to have interlock that did not permit the car to start unless the driver's seat belt was fastened (a short lived provision)".

Despite these issues, most researchers have argued that decline in the number and rate of fatalities in 1974 is larger than can be explained by these factors. For example, Godwin and Kulash [20], indicate that, "highway travel declined by 1.5% between 1973 and 1974, and long-term improvements in the rate of fatalities per mile driven averaged around 3%. The sudden drop in the fatality rate in 1974 measured 15% - more than 3 times the combined effect of these two factors. Further the greatest declines in fatality rates occurred on these roads where the speed limit reductions were largest."

Effect of the 1987 and 1995 Speed Limit Legislations

Most researchers argue that the increase in speed limit on rural Interstates in 1987 and the abolition of the NMSL in 1995 led to an increase in fatalities[4]. NHTSA [7] estimated that after the 1987 speed limit increase, the 1990 fatality toll on rural interstates in the 38 states with 65 mph speed limits was "30% greater than might have been expected". Many of the studies discussed in Appendix A come to similar conclusions, although the magnitude of change in crashes / fatalities after the 1987 speed limit increase varied in different States probably due to differences in the local conditions and the methodology that was adopted in the particular study.

Regarding the effect of the 1995 legislation, according to preliminary results published by NHTSA in 1998 [21], "states that increased speed limits after the 1995 suspension of

[4] It should be noted that several studies have only looked the number of fatalities and not the fatality rate. Readers should have caution when interpreting these results.

NMSL experienced approximately 350 more fatalities than would have been expected based on historical trends – about 9% above expectations". Another study conducted by the Insurance Institute for Highway Safety (IIHS), concluded that on Interstates, fatalities increased by 15% and fatality rates increased by 17% after speed limits were raised [(22)]. The study did not find any significant change in fatalities on non-interstate roads.

In New Jersey, the 36 month study report on the 65 mph speed limit found that "fatal accidents and fatalities remained about the same as a similar 36 month period prior to the study period. Reported accidents increased 27% in the 65 mph zones over a similar 36 month period prior to the study. Adjacent 55 mph zones had slightly higher increases in the number of reported accidents than the 65 mph zones during a similar time period" [(11)].

Unlike other researchers, Lave and Elias [(23)] have argued that the 65 mph speed limit actually saved lives. Their article argues that, "overall state fatality rates fell by 3.4 to 5.1% for the group of states that adopted the 65 mph speed limit". Their results are based on the following observations:

- "Most studies have looked at the number of fatalities, before and after the increase to 65 mph. The numbers usually increased since traffic usually increased – but we should be looking at rates, i.e., fatalities per vehicle miles traveled (VMT)". It is true that some earlier studies did look only at frequency of fatalities, in some cases because VMT data were not reliable. However, subsequent studies, e.g., the one conducted by IIHS [(22)] did look at rates.

- "Enforcing the 55 mph speed limit on the Interstate highways required a substantial amount of highway patrol resources: the new 65 mph limit allows highway patrols to shift these resources to other safety activities and other highways – something they wished to do". Lave and Elias, discuss about anecdotal evidence from Nevada, California, Montana, West Virginia, and

Wyoming, indicating that some reallocation did occur. Again, one would expect this to be local issue depending on the needs and resources of the State and local communities.

- The new 65 mph speed limit on rural Interstates in 1987 produced a shift of traffic from rural roads to rural Interstates, which are safer. Based on travel data, Lave and Elias indicate that traffic on the rural Interstate highways in the 65 mph states grew 1.73 times faster than the overall growth in those states, supporting their argument of a shift in travel towards the high speed rural Interstates. Godwin [(24)] argues that even if there was a shift in traffic to the higher speed rural Interstates, it was not sufficient enough to justify the reductions in fatalities that Lave and Elias estimated.

Due to these reasons, Lave and Elias argue that the analysis and comparisons should be done at the State level and not at the highway level.

Unanticipated Impacts

Changes in speed limits can have some unanticipated impacts such as:

1. Change in the speed distribution and crashes on roads that did not alter the speed limit (i.e., spillover effect);
2. Diversion of traffic from roads with lower speed limits to roads with higher speed limits;
3. Change in the lane distribution. It has been postulated that the increase in speed limits may have caused a shift in lane distribution to the right [(3)]. This shift may make it more difficult for vehicles to enter and exit the freeway especially in locations with limited speed-change lanes.

Spillover Effect

In most states, speed limits have been increased only on Interstates, which are the highways designed for the highest standards. If spillover effect exists, it can lead to increase in average speeds on roads where the speed limit was not raised and are not designed to handle high-speed traffic. Sometimes, this can lead to an increase in crashes. Some studies have tried to specifically study this issue by comparing the change in average speed in nearby roads where the speed limit was not changed. For example, in Alabama, the introduction of 65 mph speed limit in 1987 was followed by a 2.43 mph increase in average speeds in the road segments where the speed limit was increased [(25)]. There was no change in the average speed in the control sites where the speed limit was not changed, indicating no evidence of spillover. On the other hand, a study in California [(26)] did find some evidence of speed spillover and concluded that, "relaxation of speed limits on some roadways, and the accompanying public awareness of this issue may have significant impact on other roads geometrically remote to those with the increased limits". Another study using accident data from California did not find any evidence of increase in crashes in areas where the speed limit was not raised [(27)]. More research is required to study if the spillover effect is indeed real.

Diversion of Traffic

One could argue that diversion of traffic is dependent on local conditions, especially whether the roads with higher speed are really viable alternative routes. For example, Ossiander et al., [(28)] in their study of data from Washington State concluded that diversion of traffic is relatively low because "the geography of rural freeways in Washington State is such that drivers rarely have a choice between using the freeway or using other highways". On the other hand, Brown et al., [(25)] based on their study of ADT data in Alabama, concluded that "shifts to the interstate were occurring from non-interstate roads, and this shift seem to be accelerating after the intervention (increase in the speed limit)". Clearly more research is required in this area.

Lane Distribution of Traffic

Lane distribution is a function of several factors including traffic volume, percentage of trucks, presence of differential speed limits (between cars and trucks), presence of toll plazas, and the location of exit and entrance ramps. It is not clear if speed limit has any effect on lane distribution. Verv few studies have even discussed this issue[5]. Pigman and Mayes [(29)] conducted a study to identify the factors influencing lane distribution of traffic. Traffic data in rural multilane highways in Kentucky during 1968, 1973, and 1975 (after NMSL), were collected and analyzed. The authors concluded that the “addition of any variable other than the hourly traffic volume, did not contribute significantly to the accuracy of predicting lane distribution of traffic”. A recent study found that the lane distribution is related to several factors including the ratio of speed and the ratio of density between adjacent lanes [(30)], which again is probably more a function of traffic volume rather than the speed limit.

[5] If we assume that traffic diversion is a significant phenomenon and the 65 mph speed limit has led to an increase in traffic volume on these roads, then this increase in volume can lead to a change in the lane distribution. However, at this time, sufficient data are not available to test this hypothesis.

DISCUSSION AND CONCLUSIONS

There is a lot of interest among researchers and policy makers to study the effect of changes in the speed limit. As discussed earlier, several published studies have been conducted, although several questions remain answered. Here is an overview of the conclusions along with some of the issues that have to be addressed:

Conclusions

- In general, an increase in the speed limit does lead to an increase in average speeds, although the magnitude of this increase in less than the increase in the speed limit. The percentage of drivers exceeding 65 mph seems to have increased following the 1987 speed limit legislation that allowed states to increase the speed limit on rural Interstates 65 mph. Local issues play an important role in how drivers respond to changes in speed limits.

- Speed is directly related to the severity of crash injury. Probability of severe injury increases sharply with the increase in the impact speed of a vehicle. The relationship between speed and frequency of multi-vehicle crashes is more complicated.

- The impact of the increase in speed limit on speed dispersion is not consistent across studies.

- There seems to be a relationship between speed dispersion and safety. The safety effect of speed dispersion appears to be most important for the fastest rather than the slowest drivers.

- Very little is known about the effect of speed limit on spillover or diversion of traffic to high-speed roads. Some of these issues will be addressed in an on-going NCHRP project that is expected to be completed in summer of 2004[6]. There is very little evidence on any direct impact of the change in speed limit on lane distribution of traffic. However, if change in speed limits increase traffic volumes on these roads, this could in-turn affect the lane distribution of traffic.

Issues to be addressed

Frequency of Crashes versus Crash Rates

Some studies in this area study the difference between the frequency of crashes (say, fatal crashes or fatalities) before the change in the speed limit with the frequencies after the change in the speed limit. This has some intuitive appeal because in general the overall objective is to reduce the number of crashes on public roads. However, many have argued that it is more appropriate to study crash rates, which can be defined as the ratio of the number of crashes to the vehicle miles traveled (VMT). The argument here is that the number of crashes will increase with more vehicle miles all other things being equal. However, using crash rates makes an implicit assumption that crash frequency is linearly related to VMT. Recent studies have shown that this not a valid assumption. One way to address this problem is to include VMT or ADT as an independent variable with crash frequency as the dependent variable. This way the effect of the VMT or ADT on crash frequency can be studied along with the other variables.

How many of years of data to include?

Looking at the several studies that have been conducted to study the impact of speed limits, there is a wide variation in the number of years of data that have been included, both before the implementation of the speed limit, and after the implementation of the speed limit. If only fatal crashes are being considered, more years of data (from FARS[7])

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[6] This is NCHRP Project 17-23, "Safety Impacts and Other Implications of Raised Speed Limits on High-Speed Roads"

[7] FARS is Fatality Analysis Reporting System. This is a database that provides detailed information about fatal crashes in the United States, and has been operational since 1975. More information can be found at: http://www-nrd.nhtsa.dot.gov/departments/nrd-01/summaries/FARS_98.html

are available. However, if the analysis intends to study non-fatal crashes, then the number of years may be limited by the availability of accurate data in different states. Some states have modified the reporting requirements for these crashes, especially for PDO only crashes, and this needs to be carefully considered in any analyses.

Regarding the number of years of data to include after the implementation of the speed limit, that may partly depend on when the study is conducted. There have been several published studies that have included just 1 or 2 years of data, and one has to be cautious in interpreting the results from these studies.

Functional form and serial correlation

The functional form of the dependent variable and the correlation of observations over time are important issues to consider [(31)]. If the frequency of crashes are being modeled as the dependent variable, the consensus is to use poisson, negative binomial, and / or Zero-inflated poisson (ZIP) models [(32)], that specifically account for the fact that crash frequency is a non-negative integer variable (i.e., a count variable). When crash data after the implementation of the speed limit are compared with crash data before the implementation of the speed limit, data over time are being included. If these data are assumed to be independent, then the estimated results from the statistical model may be biased. One solution is to estimate time series models, such as ARIMA, or variations of ARIMA [(33)]. However, estimation of poisson and other count variable models in a time series context is complicated, and very few software packages are capable of handling these. Recent studies have begun to address this issue (for example, see Balkin and Ord [(34)]).

Confounding Factors

In any statistical model, it is important to reduce the bias that may be created due to the omission of confounding factors. In the context of the studying the impact of speed limits, examples of confounding factors include: changes in seat belt laws, state of the economy, population growth and change in the demographics, percentage of trucks in the traffic stream, changes to the highway safety, and enforcement of speed limit and other public safety laws. There is wide variation between different studies on the number of independent variables that have been included in a statistical model. Inclusion of more relevant independent variables will reduce the bias in the results as long as accurate data are available for these variables.

System Wide vs. Local Effects

This issue was initially raised by Lave and Elias [23], and is related to whether the change in speed limits lead to diversion of traffic to higher speed facilities and diversion of resources away from monitoring speed limits to other safety related projects. Based on the argument that these diversions are significant, Lave and Elias indicate that increases in speed limit could reduce crashes on other roads, even if they lead to a smaller increase in crashes on Interstate roads where the speed limit was increased. Hence, they suggest that before-after comparisons in this context should look at changes in crashes (or fatal crashes or fatalities) at the system level, e.g., at the State level, instead of only at the route / section where the speed limit was changed. However, based on current data, it is not clear to what extent traffic is diverted and resources are diverted. One approach is to make comparisons at both the route level and as well as the system level, and include all relevant confounding variables. To some extent, McCarthy [27] did address this issue by analyzing the effect of the increase in speed limit on counties where the speed limit was altered, and in addition, estimating the net effect on the State. Again, more work is necessary.

Type and Location of Crashes

Changes in the speed limit could affect how fast drivers exit or enter a freeway segment. So far, very few studies have addressed this issue in detail, although it is recognized that the design of entrance and exit areas including ramps are a function of the speeds on the mainline [35, 36]. In addition, although many studies have concluded that the increase in speed limits have resulted in more crashes / fatal crashes, very little of this discussion has focused on how many of these crashes are of a particular type or whether excessive speeds / speeding was a causal factor in these crashes. More research is required in this area.

APPENDIX A:

Summaries of selected studies on the impact of changes in speed limits

Michigan (1988)

Source: Olson, P.L., (1988), “Effect of the 65 mph speed limit on vehicle speeds in Michigan”, University of Michigan Transportation Research Institute, UMTRI-88-52, December.

Objective:
Study changes in vehicle speeds following the increase in speed limits to 65 mph following the 1987 legislation

Approach and Methodology:
This was a before-after study that looked at the change in speeds following the 1987 government legislation to allow states to raise the speed limit to 65 mph on selected rural freeways. Study was conducted in two stages – stage 1 was conducted in summer and fall of 1987, prior to the speed limit change in 1987. Stage 2 consisted of two rounds of measurements, which were carried out in the spring and in late summer-early fall of 1988, after the speed limit was increased. The study looked at rural interstates, urban interstates, rural freeways, and two and four-lane rural highways.

Results:
Rural Interstates – Speed limit was raised to 65 mph on November 29, 1987. With the exception of a site near the Indiana border, mean speeds were found to be 2 to 3 mph higher in the spring of 1988. In the third round of measurements, taken in the late summer of 1988, except for one section, mean speeds were found to be 1 to 2 mph lower than in the second round, but still generally higher than before speed limits were increased.
Urban Interstates – Speed limits were not raised on these roads. However, many sections of urban interstates are indistinguishable from rural interstates. There was only one urban interstate site. Before the increase in speed limit on the rural interstates, the average speed in this section was 64.2 mph. In the first post-change period, speeds were virtually the same, at an average speed of 64 mph. In the second post-change period, speeds were somewhat higher, at an average of 65.5 mph.
Rural freeways – Speed limits increased to 65 mph on rural portions of these roads on January 1, 1988. There was one site for which data were collected. In this site, speed limits were increased to 65 mph in January before the second measurement period. Before the increase in the speed limits, the overall mean speed was 63.4 mph. In the second measurement period, mean speeds increased to 64.8 mph. In the third measurement period, the mean speed dropped again to 63.8 mph.
Two and four-lane rural highways – Of the four two-lane roads included in the study after the speed limit change, only one recorded higher average speeds after the speed limit change.

Arizona (1989)

Source: Upchurch, J. (1989), "Arizona's experience with the 65-mph speed limit", *Transportation Research Record* 1244, pp. 1-6.

Objectives:
To study the impact of the 65 mph speed limit on speeds and accidents in Arizona.

Methodology and Data:
The studies utilized a before-after comparison of speeds, accidents, and accident rates.

Results and Conclusions:
Actual speeds driven by motorists on Arizona's rural interstates increased by about 3 mph or less during the four quarters after the increase in the speed limit. Speed dispersion was found to be 'slightly' higher in the after condition compared to the before condition. The number of accidents on rural interstates was higher during the after condition compared to the before condition. The fatal accident rate on the rural interstates was higher in the 1-year after-period than in any of the years between 1983 and 1986.

Comments:
This study did not use statistical techniques to test the significance of the changes from the before to the after period.

Michigan (1990)

Source: Streff, F.M. and Schultz, R.H. (1990), "The 65 mph speed limit in Michigan: a second year analysis of effects on crashes and crash casualties", University of Michigan Transportation Research Institute, UMTRI-90-37, September.

Objective:
Study the effect of the 65 mph speed limit introduced in 1987 on crashes, injuries, and fatalities

Approach and Methodology:
Monthly time series data from January 1978 through December 1989 were used. The time series statistical models included several covariates, such as unemployment rate and alcohol consumption. Effects of other policy changes such as the compulsory safety belt law were statistically controlled. The comparisons were made between changes in the outcome measures for road segments where the limit was raised to 65 mph with: (1) limited access highway segments where the limit remained at 55 mph, and (2) all other roads.

Results:
Crashes and Injuries: Increasing the speed limit on rural interstates and other limited access highways to 65 mph resulted in increased fatal, serious, and moderate injuries resulting from motor vehicle crashes on those roads. Deaths on roads with the 65 mph speed limit increased 28.4%, severe injuries on these roads increased 38.8%, and moderate injuries on these roads increased 24%. The major effect of the 65 mph speed limit on Michigan highways has been the increased severity of injuries among crash involved persons.
Speeding: The proportion of drivers exceeding 65 mph on roads with 65 mph speed limits increase dramatically from 30% prior to the 65 mph to 42% after the 65 mph was implemented.

Comments:
This study did not seem to include traffic volume or VMT as a variable in the analysis. Changes in these variables may have influenced the results.

Alabama (1990)

Source: Brown, D.B., Maghsoodloo, S., and McArdle, M.E. (1990), "The safety impact of the 65 mph speed limit: a case study using Alabama accident records", *Journal of Safety Research*, 21(4), pp. 125-139.

Objective:
Study the safety impact of the 1987 legislation that increased speed limits on speeds and crashes in Alabama.

Approach and Methodology:
A before-after analysis was conducted. 'Before' was defined as the 12 month period preceding the effective date of the change in speed limits. The 'after' period was the 12 month period after the new speed limit was implemented. Time series trend analysis was conducted to study changes in speed. Chisquare tests were conducted to study changes in crashes.

Results:
Speed: Average speeds increased by 2.43 mph after the intervention. There was very little change in the speed dispersion. There was no significant change in the average speeds in the control sites, and the authors concluded that speed spillover was negligible.
Traffic Volume: Comparison of ADT data indicated that shifts to the interstates were occurring from the non-interstate roads, and this shift seemed to be accelerating after the intervention.
Safety: Chi-square tests did not indicate significant changes in the proportion of fatal, injury, or PDO accidents in the after period, although the authors feel that these may have been partially due to changes in the number of people wearing seat belts. However, the frequency of accidents on the rural interstates increased significantly by 19%.

Comments:
One year before and one year after is probably not a sufficient sample to study changes. More long-term historical data would have provided more insight.

Multi-State Analysis (1990)

Source: A.J. McKnight and T.M. Klein (1990), "Relationship of 65-mph limit to speeds and fatal accidents", *Transportation Research Record* 1281, pp. 71-77.

Objective:
Study accidents, VMT, and vehicle speeds after the increase in rural interstate speed limits to 65 mph in 1987.

Approach and Methodology:
Accident and speed data for 65 mph versus 55 mph states for the 5 years preceding the increase in the speed limit and the year following the increase were compiled. Rural interstates in those states that did not the change the speed limit and other 55 mph highways were selected as control groups. Intervention time series analysis was utilized. For crashes, fatal accidents were used as the primary dependent variable. The percentage of drivers who exceeded 65 mph was the speed variable of interest.

Results:
Crashes: A statistically significant increase in fatal accidents was found. The increase was estimated to be a 27% increase over those that would have occurred if there had been no change in speed limit. There was very little change in the fatal crashes that occurred on 55 mph highways in 65 mph states. However, there was also a statistically significant increase of 10% in the fatal crashes among rural interstates in the 55 mph states.
Speed: There was a 48.2% increase in the percentage of drivers who exceeded the 65 mph speed limit in rural interstates in the 65 mph states. In 55 mph highways in 65 mph states, there was a 9% increase in the percentage of drivers who exceeded 65 mph.

Virginia (1991)

Source: J.D. Jernigan and C.W. Lynn (1991), "Impact of the 65 mph speed limit on Virginia's rural interstate highways through 1989", *Transportation Research Record* 1318, pp. 14-21.

Objective:
Study changes in speeds and crashes after the increase in rural speed limits in Virginia to 65 mph in July 1988.

Approach and Methodology:
Data from 1987 were compared with 1989. A regression model was calculated, estimating the number of rural interstate fatalities from annual average speed and VMT. The years 1966-1987 were used as the baseline data for the model, and projections were made for 1988 and 1989 on the basis of this model.

Results:
Speed: Actual speeds on Virginia's rural Interstates increased after the implementation of the 65 mph speed limit, but substantially less than the 10 mph increase in the legal limit. Average speeds on rural interstates increased from 59.9 mph in Spring 1987 to 63.5 mph by Spring 1999. The 85th percentile speed increased from 65 mph to 70 mph during the same period. At survey sites on the rural interstates, speed variance increased an average of 36.4% after the speed limit was raised. However, speed variance also increased by 39.3% at urban Interstate survey sites even though the speed limit had stayed at 55 mph.
Crashes: Fatal crashes increased from 40 in 1987 to 59 in 1989, and fatalities increased from 44 to 63. The percentage of all crashes that involved speeding as a contributing factor remained relatively constant between 1987 and 1989. However, accidents involving run off the road and driving the wrong way increased between 1987 and 1989.

California (1992)

Source: S.M. Casey and A.K. Lund (1992), "Changes in speed and speed adaptation following increase in national maximum speed limit", *Journal of Safety Research*, Vol. 23, pp. 135-146.

Background and Objectives:
Speed adaptation is a phenomenon experienced by automobile drivers, and one that might result in an underestimation of speed. The objective of this study is to empirically test the extent of this phenomenon.

Methodology and Data:
Freeway speeds were measured in 1988 on two sites on U.S. 101 at San Luis Obispo and Ventura, and one site on California Highway 1, just south of Oxnard. Data were collected for both drivers traveling on the freeways and drivers that exited the freeways. Speed limits on these highways remained at 55 mph even though the speed limits on other roads were increased to 65 mph. Speed data were collected and compared to data from a similar study that was conducted in 1985.

Results:
Travel speeds in 1988 in the same location were higher than in 1985, although the speed limits in these roadway segments were not changed. Significant speed adaptation was observed at all observation stations in the three areas. The authors argue that the "relaxation of speed limits on some roadways, and the accompanying public awareness of this issue, may have significant impact on impact on other roads geometrically remote to those with the increased limits".

Comments:
It is not clear how much of the increase in travel speeds is due to national trend that was observed in many parts of the country during the 1980's. It would have been useful if this data were compared to the changes in the average speeds on those roads where the speed limit was increased to 65 mph.

Multi-State Analysis (1993)

Source: Chang, G-L, Chen, C-H, and Carter, E.C. (1993), "Intervention analysis for the impacts of the 65 mph speed limit on rural interstate highway fatalities", *Journal of Safety Research*, Vol. 24, pp. 33-53.

Background and Objectives:
To study the impact of the 1987 speed limit legislation on rural interstate highway fatalities

Methodology and Data:
Monthly rural interstate fatality data were obtained for each state using the FARS system maintained by NHTSA. Data from January 1975 until December 1989 were utilized. Different hypothesis were tested within the context of ARIMA time series intervention models. The analysis did not include traffic volumes or VMT because they were not considered sufficiently reliable by the authors.

Results and Conclusions:
Based on the results of the time series model, the increased speed limit had significant initial impacts on highway fatalities at the nationwide aggregate level. However, these impacts appear to decay over time after remaining stable for about a 1-year learning period for drivers. Large states such as Texas, California, or Florida, seemed less sensitive to the speed limit change compared to the smaller states. The analysis indicated unknown exogenous factors that caused the increase in fatality numbers since 1986 one year before the speed limit was raised to 1987.

Comments:
Although the statistical analysis used in the study was very sophisticated, only 2 years of data the speed limit increase were utilized. Hence, as acknowledged by the authors, the appearance of decay over time of the impacts will have to be examined by subsequent studies. In addition, McCarthy [31], argues that "driver anticipation of higher speeds, rather than changes in exogenous factors, generated the fatality increases in the months preceding the 65-mph speed limits".

California (1994)

Source: P.S. McCarthy (1994), "An Empirical Analysis of the Direct and Indirect Effects of Relaxed Interstate Speed Limits on Highway Safety", *Journal of Urban Economics*, 36, pp. 353-364.

Objective:
Evaluate the safety impacts of the increase in speed limit to 65 mph on rural interstates in California in May 1987.

Approach and Methodology:
Countywide crash data for a 9 year period from 1981 to 1989 were obtained. The number of crashes, by level of severity, was the dependent variable. Time series cross-section analysis technique was utilized. The independent variables included, a variable to represent when the speed limit was altered, dummy variable to represent if a county had a 65 mph road or not, traffic citations, per capita wine consumption, per capita distilled spirits, number of alcohol licenses in a county, VMT in a county, per capita young drivers, population density, unemployment rate, county wide per capita income, dummy variable to represent metro / non-metro area, gas price, proportion of truck VMT, and linear time trend.

Results
In counties with 65 mph roads, the higher speed limit produced a strong positive and statistically significant effect that resulted annually, in 845, 14, and 278 additional total, fatal, and injury related accidents, respectively, per county. However, the predicted net effect on the state from increased rural interstate speed limits was minor and not statistically significant.

Multi-State Analyses (Lave and Elias, 1994)

Publication: C. Lave and P. Elias, “Did the 65 mph speed limit save lives? ”, *Accident Analysis and Prevention*, 26(1), pp. 49-62, 1994.

Background and Objective:
Study the effect of the increase in speed limit on fatalities. Lave and Elias argue that total fatality rates for the entire state should be looked at instead of just the highways that had the speed limits changed. Based on anecdotal evidence from Nevada, California, Montana, West Virginia, and Wyoming, the authors argue that the increase in speed limit would allow the police to allocate more resources to other more critical safety issues and hence reduce crashes. They also postulate that more drivers will switch to the safer 65 mph roads from the relatively unsafe non-interstate routes with lower speed limits.

Approach and Methodology:
This study analyzed the effect of the new speed limit using two independent methodologies. First, the experience of the entire group of states that raised speeds were compared against the experience of the states that did not. Second, data were analyzed on a state-by-state basis using regressions on monthly time-series data. Both methodologies used the statewide fatalities divided by statewide VMT as the dependent variable.
First Methodology: For each group of states, the total fatality rate, defined as the sum of overall statewide fatalities across the entire group, divided by the sum of statewide VMT, was calculated. This was done for 1986, the last full year of data before the change in the speed limit. The change in fatality rates for the 65 mph states, were compared against the change in fatality rates in the 55 mph states.
Second Methodology: Authors also fit a ‘restricted’ model to the combined data sets that restricted the speed limit coefficient to be identical across states; and also fit an “unrestricted” model that allowed the coefficients to vary.

Results:
Fatality Rates: Taken as a whole, the analyses showed that overall statewide fatality rates fell by 3.4% to 5.1% for the group of states that adopted the 65 mph limit.
Changes in VMT: Traffic on the rural interstate highways in the 65 mph states grew 1.73 times faster that the overall VMT growth. Traffic on the non-interstate highways grew at only 89% of the overall VMT growth rate for these states. Authors argued that these results supported their hypothesis that drivers had switched from relatively unsafe non-interstate highways to safer interstate highways.

Kentucky (1997)

Source: Agent, K.R., Pigman, J.G., and Weber, J.M. (1997), "Evaluation of Speed Limits in Kentucky", Kentucky Transportation Center, KTC-97-6, April.

Objectives:
Study speeds and crashes associated with 55 and 65 mph speed limit in Kentucky.

Approach and Methodology:
Speed Data: Four types of speed data were collected: moving speeds, speeds for specific locations at speed monitoring stations, data at specific locations taken before and after changes in speed limit, and speeds in construction zones where the regulatory speed limit was reduced.
Accident Data: Characteristics of speed-related accidents – Accidents in which unsafe speed was identified as a contributing factor on the police report were identified from 1993 through 1995. The accident rate involving unsafe speed was calculated by highway type for 1992 through 1994. These data were used to obtain a critical number and rate of accidents for each highway type. For a sample of locations where the speed limit was changed, the date of the change, and the mile-point range for the change, were determined. Before and after accident data were identified at these locations. In addition, the mile-points of the sections of interstate where the speed limit was under 65 mph were obtained and accident rates were calculated for these sections and compared to adjacent sections where the speed limit was 65 mph.

Results:
Speed data before and after speed limit change: The change in the 85^{th} percentile speeds was much less than the change in the speed limit. These changes were not significant.
Accident data before and after speed limit change: The average number of accidents increased slightly at locations where the speed limit was decreased 10 mph as well as locations where it was increased 10 mph. Using the chi square statistical test, none of the categories of speed changes showed a statistically significant change in the number of before and after accidents.
Accident rates for 65 mph versus 55 mph interstates: The accident rates for the 65 mph sections were not higher than the 55 mph locations. Considering all locations, the total rate was 122 ACC/100 MVM (accidents per 100 million vehicle miles) for 55 mph locations compared to 74 ACC/100 MVM at 65 mph locations. The fatal accident rate was slightly higher for the 65 mph locations (0.44 compared to 0.39 ACC/100MVM) but the injury rate was lower (23 compared to 30 ACC/100 MVM).

North Carolina (1999)

Source: H. Renski, A.J. Khattak, F.M. Council, (1999), "Impact of Speed Limit Increases on Crash Injury Severity: Analysis of Single-Vehicle Crashes on North Carolina Interstate Highways", *Transportation Research Board Annual Meeting*, January.

Objective:
Study the impact of speed limit increases in North Carolina on crash injury severity in single vehicle crashes

Approach and Methodology:
Two separate statistical techniques were utilized: ordered probit model and the more traditional paired-comparison before / after evaluation. Three years of accident data (1995 to 1997) collected one year before and after the speed limit change, were utilized. For the paired comparison analysis, each road segment where speed limits were increased was identified and paired with a comparison road segment where the speed limit was not raised. Comparison sites were selected taking into consideration the similarity to study sites in ADT, road type, rural/urban environment, and geographic proximity.

Results:
Segments where speed limits were increased from 55 mph to either 60 mph or 65 mph were associated with an increased likelihood of Class B and Class C injuries. Highway segments where speed limits were raised by 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 highway segments where speed limits were raised from 65 mph to 70 mph.

Multi-State Analyses (Farmer et al., 1999)

Source: Farmer, C.M., Retting, R.A., and Lund, A.K. (1999), "Changes in motor vehicle occupant fatalities after repeal of the national maximum speed limit", *Accident Analysis and Prevention*, 31, pp. 537-543.

Objective:
Study changes in fatalities following the repeal of the national maximum speed limit using data from several states

Approach and Methodology:
Data on motor vehicle occupant deaths in each state for each month beginning January 1990 and ending December 1997 were extracted from the FARS. Data on vehicle miles of travel for the same time period by monthly were obtained from the Federal Highway Administration. Monthly estimates of the number of employed people in the US Civilian population were obtained from the Bureau of Labor Statistics. Separate analyses were conducted for fatalities occurring on interstates and freeways, roadway function classes 1, 11, and 12 (in FARS), fatalities occurring on other roads, and total motor vehicle occupant fatalities. Logarithms of fatality counts and rates for each quarter during 1990-1997 were modeled as a function of time, number employed, and type of state (four study groups and one comparison). The model included an indicator variable equal to zero for all quarters prior to the speed limit increase and equal to one for all quarters thereafter.

Results:
Fatalities on interstates increased by 15%, and fatality rates increased by 17% after speed limits were raised. No significant change in fatalities on non-interstate roads. The authors argue that although an increase in speed limits may have resulted in a small change in mean speed, it should not be ignored, because it can signal a major increase in the proportion of vehicles traveling at higher speeds.

Washington (2002)

Source: Ossiander, E.M. and Cummings, P. (2002), "Freeway speed limits and traffic fatalities in Washington State", *Accident Analysis and Prevention*, Vol. 34(1), pp. 13-18.

Objective:
Study changes in speed and crashes as a result of the 1987 speed limit increase from 55 to 65 mph.

Approach and Methodology:
Crash data from 1970-1994 were used. Poisson and negative binomial regression models were estimated. The natural logarithm of vehicle miles traveled was entered as an independent variable. Time was represented as a linear term. A variable to describe rural / urban area was included.

Results:
Safety: Fatal crashes more than doubled compared with what would have been expected if there had been no speed limit increase. The frequency of crashes did not change significantly.
Speed: The average rural interstate speed for the 5-year period preceding the speed limit increase, 1982-1986, was 58.5 mph. During the first 5 years after the speed limit change, 1988-1992, the average was 64 mph, an increase of 5 mph. Over the same time periods, the 85th percentile rural interstate speed increased from 64 to 70.6 mph, an increase of 6.6 mph.
Travel: The authors argue that the geography of rural freeways in Washington State is such that drivers rarely have a choice between using the freeway or using another highways. VMT on rural freeways dropped in the 2 years following the speed limit increase, and increased 11% in the 5 years after the speed limit increase, compared with the 5 years before, while VMT on urban freeways increased by 23% in the same time period.

APPENDIX B: REFERENCES

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APPENDIX C

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