Cost-Benefit Evaluation of
Large Truck-Automobile Speed Limit Differentials
on Rural Interstate Highways

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Cost-Benefit Evaluation of Large Truck- Automobile Speed Limit Differentials on Rural Interstate Highways

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Speed differentials between large trucks and automobiles are due to both state regulated speed limits and commercial trucking company policies that restrict maximum truck speeds. The initial portion of this effort involved a review of the research and applications literature pertaining to absolute and differential truck speeds on traffic flow, highway safety, and operational costs. Speed data were collected for both heavy trucks and automobiles on rural interstate highways with four speed limit configurations: two with uniform speed limits (75 mph and 70 mph) and two with differential speed limits (70/65 and 65/55 mph). These highways were selected to represent the range of speed limits and posted speed differentials. Stakeholders were surveyed to obtain their opinions as to speed differentials and, more importantly, the basis of those opinions. Surveys were conducted of three stakeholder groups: commercial truck drivers, trucking company safety and operations personnel, and original equipment manufacturers. Using the information from the literature review, the empirical data collected and stakeholder surveys, a cost-benefit analysis was conducted that addressed the financial issues related to maximum truck speeds. The information collected, analyzed and documented in this report will assist both state regulatory agencies and trucking company decision makers when establishing policies related to maximum truck speed limits and speed differentials between heavy trucks and automobiles.

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1. Introduction

The setting of speed limits has been controversial since the first speed limits were set in 1901. Other than during the period of the National Maximum Speed Limit policy between 1973 and 1994, setting speed limits has historically been the responsibility of the states. Posted speed limits on United States highways are the product of both technical factors and politics. This is evident by the fact that different states have maximum speed limits that vary by as much as 20 mph on highways that have virtually identical physical, environmental, and traffic characteristics. The setting of speed limits for heavy trucks is an issue that has been found to elicit a particularly high amount of emotion by the many stakeholders that are affected (motorists, truck drivers, trucking companies, law enforcement agencies, etc.). Many states have speed differentials in which the maximum highway speed limit for heavy trucks is lower than for automobiles. These differential limits vary from uniform (no difference) to truck limits that are 15 mph lower than automobile limits on the same highway. The reported effort addresses the benefits and costs associated with both absolute and differential heavy truck speed limits. The focus of the effort is specifically rural, limited access interstate highways.

In addition to state-regulated maximum speed limits, traffic flow is affected by the fact that most commercial truck fleets and many owner-operators have speed limiters on their vehicles. These limiters result in speed differentials between many trucks and automobiles, even if the posted limits are not different. The primary reasons that trucking companies use speed limiters include safety and a reduction in operating costs associated with fuel efficiency. The potential financial benefits of increasing per-truck revenues versus the additional costs associated with higher speeds are discussed. The objective is to provide information for both regulatory agencies and commercial trucking operations in the decision process of setting maximum truck speeds on rural interstate highways.

The initial portion of the report reviews the research and applications literature related to the factors that are affected by vehicle speed. The empirical studies that have addressed the effect of changes in highway speed limits on traffic flow and the distribution of vehicle speeds are discussed. Understanding the causes of highway accidents that involve trucks is important in order to evaluate the effect of speed on highway safety. The causes of single and multiple vehicle accidents involving trucks were reviewed. The extensive literature that has dealt with the safety impact of increasing and decreasing speed limits at both the national and state levels is critically reviewed. In particular, the results of safety studies after the 1974 decrease in national speed limits to 55 mph and the subsequent increases in 1987 and 1995 are evaluated.

The methodological issues that help explain the many different conclusions drawn from this body of research are presented.

The effects of both absolute speed and differential speed limits are discussed in the context of traffic flow and speed variation. Whether being due to state regulated limits or company policies, the difference in speed between heavy trucks and automobiles results in more speed variance. The research literature that discusses the impact of speed variance on highway safety is presented.

There is a relationship between vehicle speed and the amount of time required to cover a particular distance. This is important for motorists, although it is particularly important for commercial transport operations. The effect of driving time has been an issue that has received a significant amount of attention from the trucking industry, governmental agencies, and the general public in the context of truck driver “hours of service.” The research literature that addresses the effect of driving time and driving speed is discussed with respect to driver fatigue.

In addition to the safety implications, the operational costs associated with truck speeds are important in a benefit/cost analysis. The research and applications literature that pertains to the costs of direct costs such as fuel, tires, and maintenance are discussed. In addition, the research that addresses the indirect costs such as emissions and road wear are presented.

The next portion of this research effort collected data in an attempt to fill some of the holes that were observed in the literature. For example, although there was a very large amount of research on speed limits, virtually none of the studies had recognized the impact of speed limiters on heavy commercial trucks. Even the studies that specifically analyzed increases in traffic speed when posted limits were increased (e.g., 1987 and 1995) did not account for the fact that the majority of heavy trucks, which often make up a large portion of the traffic on interstate highways, could not increase their speed.

To address this issue, empirical data were collected under four different speed limit configurations. Data were collected on Interstate I-44 where the speed limit is 70 mph for both automobiles and trucks. The Cherokee Turnpike in Oklahoma was chosen because of the higher, uniform speed limit of 75 mph. The traffic speeds of trucks and automobiles were measured on Interstate I-40 in Arkansas on which the automobile speed limit was 70 mph and the truck speed limit was 65 mph. Lastly, speed data were collected on I-57 in Illinois which had lower speed limits and a larger speed differential between automobiles and heavy trucks (65 and 55 mph, respectively). Multiple sites were selected under each of these configurations. The locations were selected to represent both high and low speeds, as well as speed differentials that exist on rural interstate highways. The objective of this portion of the study was to document the speed distributions for trucks and automobiles under the different conditions. By understanding how speed limits affect both the average speeds and speed variance, the effect of those limits on both traffic flow and safety can be addressed.

The empirical distributions for truck and automobile speeds that were observed at two of the locations (Missouri, 70/70 and Illinois, 65/55) were then used as the basis for a simulation model that evaluated the number of vehicle interactions as a function of travel speed. The objective of the simulation was to document the effect of traveling at a speed either slower or faster than the average traffic speed. The goal was to investigate how often a vehicle is involved in passing and being passed by another vehicle. In particular, the separate frequencies of passing and being passed by trucks and automobiles, respectively, were evaluated.

As previously stated, even in states that have uniform speed limits on the rural interstates, there is still a difference in the speeds of automobiles and heavy trucks due to company speed limitation policies. The next portion of the study collected data on the use of speed limiters by commercial trucking operations. The data were collected from 236 drivers at truck stops in seven different states (AR, IL, MO, OK, NM, AZ, TX). These drivers represented the full spectrum of owner-operators operating under their own authority, lease/contract drivers, and employees of large trucking fleets. The distribution of settings used by these different groups provides an important reference point for understanding how truck speed limiters affect traffic flow under different speed limit configurations.

Surveys were completed by the 236 drivers that addressed their opinions about speed limits on rural interstates and speed differentials between automobiles and heavy trucks. The surveys addressed perceived safety issues, as well as the drivers' judgments about the effect of truck speed on operational costs (fuel, tires, etc.) and psychosocial factors (driver fatigue, stress, and driver retention). The specific effects on drivers of speed differentials, whether due to posted limits or company policies, were documented.

In addition to collecting opinion data from the drivers, the opinion of commercial fleet management personnel were obtained through a combination of surveys, on-site visits, and communications at professional and trade meetings. In particular, the opinions of fleet safety and maintenance managers were collected, along with any data that the fleets had that pertained to the effects of truck speed and speed differentials. These opinions were then contrasted with the information that was obtained from the literature review and the opinions of the truck drivers.

The last group surveyed represented the original equipment manufacturers of the components that could be affected by the vehicle speed. In particular, manufacturers of commercial trucks, engines, and tires were surveyed with respect to the effect of truck speed on their products. These communications included both technical sales personnel and engineers in the various companies' technical and research centers.

Data from participating companies were used to conduct an analysis of "virtual" differential speed limits between automobiles and heavy trucks. The companies with fixed maximum speeds that were limited to either 62 or 65 mph operated in different states with different maximum speed limits for automobiles (65, 70 or 75 mph). By comparing the accident data from these different situations, the impact of a "virtual" speed differential between the fleets' trucks and the automobiles was analyzed.

The last section of the report addresses the financial benefit-cost relationships associated with higher truck speeds. There is a trade-off between the benefits of increased company revenue that could be attainable with higher truck speeds and the increased operational costs incurred at higher truck speeds.

The issue of speed differentials between automobiles and heavy trucks is a complex combination of the impact on safety and financial considerations for both the truck drivers and the commercial trucking organizations. This report addresses the currently available published information, as well as the opinions of the various stakeholders with respect to the benefits and costs of limiting heavy truck speeds to below the traffic speed. This information is important for both public policy and company policy related to setting speed limits on rural interstate highways.

2. Review and Analysis of Literature

The objective of this effort was to investigate the costs and benefits related to speed differentials between heavy trucks and other vehicles on rural interstate highways. Truck speeds are limited by a combination of state regulated speed limits and company policies that limit truck speed with electronic control units on the trucks' engines. Both the effect of absolute speed and the speed of trucks relative to the other vehicles in the traffic flow are important to understand the impact of heavy truck speed policies. The initial phase of the effort involved a comprehensive review of the research and applications literature that pertains to the topic.

The first part of the literature review addresses the standard methods used to set posted speed limits and the impact of speed limits on the speed distributions of both heavy trucks and other traffic. The next section reviews the literature that has documented how speed limits and speed limit changes affect accident and fatality rates in the United States and internationally. The extensive number of studies that have investigated the safety impact of increases and decreases in speed limits has been reviewed. The last part of that section specifically addresses the causes and impact of heavy truck accidents and the impact of speed differentials between trucks and automobiles. The research literature pertaining to the relationship of vehicle speed and driver fatigue is discussed.

The last sections of the literature review address the research and applications literature on the operational impact of speed. In particular, the effects of truck speed on fuel consumption, tire costs, and maintenance costs are discussed.

2.1 Setting Speed Limits Based on the 85th Percentile

The geometric features of the roadway, such as horizontal and vertical alignment, sight distance, and cross-section determine the highway design speed. The original definition of design speed, coined by the American Association of State Highway and Transportation Officials (AASHTO) in 1938, was "the maximum approximately uniform speed which probably will be adopted by the faster group of drivers but not, necessarily, by the small percentage of reckless ones" (Krammes, Fitzpatrick, Blaschke, and Fambro, 1996). AASHTO's current definition of design speed is "the maximum safe speeds that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern" (AASHTO, 2001). This is the maximum speed prudent drivers would choose when environmental conditions are very good and traffic volumes are low. Subject to the constraints of environmental quality, economics, aesthetics, and social impacts, AASHTO recommends higher design speeds to promote safety, mobility, and efficiency. Design speed is highly sensitive to certain highway design features like curvature, sight distance, and roadside elements.

When speed limits are set based on design speed, the posted speed limit is generally lower than the design speed because it is known that some drivers will tend to drive faster and also that the road conditions are sometimes poorer than were used in the design standards (Persaud, Parker, Knowles and Wilde, 1997). However, according to Abraham and Abdulhai (2001), a speed limit that is set using this as a basis will often appear unrealistic to drivers since the limit is for an entire highway segment, even though is often reflects relatively few elements.

According to AASHTO (2001) posted speed limits are usually set to approximate the 85th percentile speed of traffic. For many rural highways, it is a common practice to establish the speed limit near the 85th percentile speed. The term "85th percentile speed" is the speed at or below which 85% of drivers travel in free-flow conditions at representative locations on the highway or roadway section (National Research Council, 1998). The 85th percentile speed is determined through spot speed studies of "free flowing" traffic (i.e., traffic unimpeded by other vehicles) (Krammes, Fitzpatrick, Blaschke and Fambro, 1996). According to AASHTO (2001) the 85th percentile speed is usually within the "pace" or the 10 mph speed range used by most drivers. In general, the speed limits for rural interstates are set below the 85th percentile speed limits. Harkey, Robertson and Davis (1989) collected data from urban and rural highways in North Carolina, Delaware, Colorado and Arizona, from 1985 to 1988, with posted speed limits ranging from 25 to 55 mph. The 85th percentile speeds ranged from 6 to 14 mph over the posted speed limits, or 4 to 7 mph above the mean speed.

The 85th percentile speed for a distribution of speed observations is shown in Figure 1. In most cases, the difference between the 85th percentile speed and the average speed provides a good approximation of speed standard deviation, which is another important factor that relates to the speed-safety relationship.

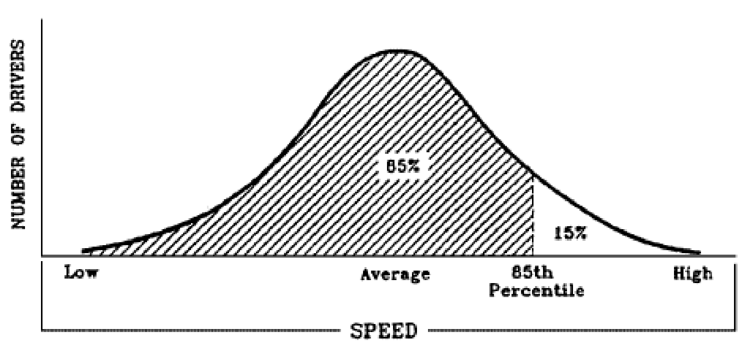

Figure 1. Representation of the Traffic Speed Distribution (Source. National Research Council, 1998)

The distribution of traffic speeds on any particular highway is affected by the posted speed limits and the enforcement of the limits. The observed 85th percentile speed on a highway with a 65 mph speed limit will be different than the 85th percentile speed on a highway with a 75 mph speed limit, even if they are both rural interstates with identical geometries.

For this reason, although it is discusses many times in the context of setting speed limits on rural interstate highways (Governors Highway Safety Association, 2005), the concept of "design speed as defined by the 85th percentile" does not appear to make apply. Safety, efficiency, and economics have played a significant part in the process of setting limits. This is shown by the large differences in speed limits set on similar highways in different states.

2.2 Effects of Speed Limits on the Distribution of Traffic Speed

The first speed limit in the United States was enacted in 1901 in Connecticut, and since then the practice of establishing speed limits has been both complex and controversial. As early as 1947, studies concluded that a high proportion of the drivers often ignore the speed limits and drive at speeds that they think are prudent, safe, and reasonable (Harkey, Robertson and Davis, 1989). The following sections review the research literature that addresses the effect of speed limits on traffic flow. The reviewed articles focus primarily on the research that applies to rural interstates.

2.2.1 Effects of Posted Limits on Means Speed and Speed Variance

The National Highway Traffic Safety Administration (1992) analyzed the speed data available from 18 of the 40 states that increased the automobile speed limits from 55 mph to 65 mph in 1987. The average speed of automobiles increased from 60.4 mph in 1986 to 64 mph in 1990. It was concluded that the increase in the speed limit significantly increased the average traffic speed. However, another way of looking at the same statistics is that the average driver's speed exceeded the posted speed limit by 5.4 mph in 1986, while in 1990 the average speed was actually 1 mph below the posted speed limit.

Freedman and Esterlitz (1990) measured the effect of increased speed limits on the traffic speed in Virginia and found that a 10 mph increase for automobiles speed limit, from 55 mph to 65 mph (leaving truck limits at 55 mph), resulted in an increase in the average speed of automobiles of 2.8 mph (63.1 to 65.9 mph) within one month of implementation. Later, as drivers "adapted" to the new speed limits, the average speed gradually increased, reaching 66.9 mph after one year. The authors contended that the percentage of automobiles "over speeding" (traveling above 65 mph) doubled from 32% to 69%. Again, however, another way of presenting the statistics is that the compliance rate increased and the average speed was reduced from 8 mph above the speed limit to only 0.9 mph above the speed limit. The conclusion as to the effect of a speed limit on "speeding" depends upon the definition. The average speed observed in this study was significantly lower than the average speed observed by the National Highway Traffic Safety Administration (1992) because the former study considered only the automobile speed, whereas the latter study included heavy trucks.

Godwin (1992) found that an increase of 10 mph (55 mph to 65 mph) increased the average traffic speed by 3 mph (60.2 mph in 1986 to 63.2 mph in 1988). In the same period, the average speed in states that maintained the 55 mph speed limit increased by 0.9 mph (58.7 mph to 59.6 mph). Nakao (1989) found similar results for automobile speed data. A 10 mph speed limit increase (55 mph to 65 mph) resulted in 2.5 mph increase in average speed (62.4 mph to 64.9 mph) from April 1987 to September 1987. However, the observed speed change might have been greater if the data were collected later, when the drivers had "adapted" to the new speed limits. Any increase in the speed limit is followed by a "transition" period and then by "adaptation." During the initial "transition" period, the drivers' speed does not increase suddenly to the new higher speed, although it does increase gradually. After the transition period, they become "adapted" to the new higher speed limits and travel at the higher speeds. Ledolter and Chan (1996) found that after the 1987 increase in the speed limit in Iowa from 55 to 65 mph, the average speed increased by 7 mph, from 59 mph in 1985-1986 to 66 mph in 1990-1991. This comparison came be after the transition period.

McKnight, Klein, and Tippetts, (1989) analyzed nationwide data from 1983-1988 and found that the number of drivers spotted "speeding" increased by 48% for the states which had increased their maximum speed limit to 65 mph; whereas the number of drivers observed "speeding" increased by only 18% in the states that retained the 55 mph maximum speed limit. However, an important point to be noted is that the definition of "speeding" in this study was "anyone traveling at speeds higher than 65 mph" Obviously the number of people traveling above 65 mph in a 65 mph speed limit state will be much higher compared to the number in a state with a 55 mph speed limit. It will be observed that in many of the studies discussed, the researchers defined speeding as the percentage of drivers who exceeded 65 mph because it is widely assumed that high speeds are the primary contributors to fatal accidents. This definition of speeding does not consider the design speed of the highways, which is a major factor in determining the effects of traffic speed. Many of the highways included in the studies have design speeds that far exceed 65 mph.

Agent, Pigman, and Webber (1998) conducted a study to evaluate the effect of speed limits in Kentucky. From the speed data collected between 1994 and 1995 on the 65 mph rural interstate highways, the average speed of trucks was found to be considerably lower (64.2 mph) than the average speed of automobiles (68.0 mph). The non-compliance by automobiles was 70%; whereas, non-compliance by trucks was 37.3%. The speed limit increase of 10 mph led to a 1.1 mph increase in the 85^{th} percentile traffic speed. The authors found that when the speed limits were reduced by 10 mph, the 85^{th} percentile traffic speed increased by 0.4 mph, thus concluding that average speed of traffic generally follows an increasing trend, irrespective of the change in posted speed limits. These data also support the contention that drivers drive according to the roadway and environmental conditions and that the posted speed limits sometimes do not have a significant effect on the average speed of the traffic. Because the 85^{th} percentile speed for automobiles was found to be near 73 mph and the 85^{th} percentile speed for trucks was found to be near 69 mph, the authors recommended that the speed limits be increased from a 65 mph uniform speed limit to 70 mph for automobiles and 65 mph for trucks.

Similar results were obtained by Parker (1992); however, his study was limited to only rural and urban highways that were not limited access. Parker collected speed and accident data from 100 sites in 22 states before and after speed limits were altered. The average change in any of the percentile speeds (i.e., 90^{th}, 80^{th}, etc.) at the experimental sites was less than 1.5 mph, regardless of whether the speed limit was raised or lowered. This indicates that distribution of speed remains relatively constant and that the average speed of traffic generally follows an increasing trend, irrespective of the change in posted speed limits. The authors concluded that speed limits that are set close to the 85th percentile speed had a beneficial effect on the drivers' tendency to comply with the posted speed limits. It was concluded that lowering and raising the speed limits has relatively little effect on the traffic speed and that drivers travel according to the traffic conditions.

Binkowski, Maleck, Taylor, and Czewski (1998) studied the 1996 increase in speed limits for automobiles from 65 mph to 70 mph in Michigan. Speed data were compared for the month before the speed limit increase (July, 1996) and the three months after the speed limit increase (August, September, and October 1996). It was concluded that a 5 mph increase in speed limit (65 mph to 70 mph) increased the median speed by only 1 mph.

Najjar, Stokes, Russell, Ali, and Zhang (2000) studied the results of the 1996 increase in maximum speed limit from 65 mph to 70 mph in Kansas. The before-and-after comparison that was conducted using two years of after data indicated that the 5 mph increase the speed limit increased the 85^{th} percentile speed from 69.5 to 76.2 mph.

Davis (1998) examined the results of the 1996 increase in the New Mexico maximum speed limit from 65 mph to 75 mph. The average speed of traffic on the I-25 and I-40 interstate highways increased by 2.4 mph, (from 67.0 mph to 69.4 mph) and the 85^{th} percentile speed increased by 2.2 mph (76.1 to 78.3 mph). The increase in average speed and 85^{th} percentile speed on the I-10 interstate highway was observed to be just

0.7 mph and 0.9 mph, respectively. The reason for the lower values relate to the fact that heavy trucks dominate the traffic on I-10 and the enforcement levels were increased on I-10 after the increase in speed limits. Most of the commercial heavy trucks are governed by speed limiters that prohibit the trucks from traveling at higher speeds, thus an increase in the posted speed limit in the higher speed range has less of an effect on the average speed of trucks. Therefore, the proportion of trucks in the traffic and enforcement have significant impacts on the observed change in average traffic speed after an increase in posted speed limits.

Borsje (1995) studied the effects of having different speed limits on different highways within the same highway category (referred to by the authors as differentiated speed limits) in the Netherlands. In 1988, the Dutch government implemented differentiated speed limits on highways. The maximum automobile speed limits on 80% of the highways were increased from 100 kph to 120 kph (62.14 to 74.57 mph), while the remaining highways maintained a speed limit of 100 kph. For heavy vehicles, the speed limit remained at 80 kph (49.71 mph) for all highways. Along with differentiating speed limits, the government also undertook three additional measures: preventative measures, enlightening of the public regarding safety and increasing enforcement. It was observed that on 100 kph motorways, the mean automobile speed was reduced from 109.1 kph to 98.7 kph (67.79 mph to 62.33 mph) and the mean truck speed was reduced from 90.0 kph to 85.2 kph (55.93 mph to 52.94 mph). On the 120 kph motorways, the mean speed was also reduced from 113.1 kph to 108.5 kph (70.28 mph to 67.42 mph) and the mean truck speed reduced from 90.7 kph to 87.0 kph (56.36 to 54.06 mph). Even after increasing the speed limit, the average speeds of vehicles were observed to decrease. The reason for this decrease was attributed to the three additional measures which the government undertook. After four months, the average speed of automobiles and trucks increased by 2 to 6 kph (1.2 to 3.7 mph) on all the motorways.

In addition to the direct impact on traffic speed resulting from increases in posted limits on highways, there are two indirect effects on traffic: speed spillover and traffic diversion. Speed spillover results when an increase in the speed limit on one highway increases the average traffic speed on other highways that have not had an increased limit.

McKnight and Klein (1990) studied the nationwide impact of increasing the speed limits on rural interstate highways to 65 mph. It was found that for the states that raised speed limits to 65 mph, speeding on rural interstates and on non-rural interstates (highways still posted at 55 mph) increased by 48% and 9%, respectively. Whereas, in states that maintained the 55 mph limit on rural interstates, speeding increased by 18% and 37% on rural interstates and non-rural interstates, respectively. It is important to note that “speeding” was defined as the percentage of drivers who exceeded 65 mph for both the 55 mph and 65 mph highways.

Nakao (1989) analyzed the 1987 speed data from California. Speed data collected in April 1987 (the "before" period) was compared with data collected in July & September 1987 (the "after" period). Following the increase in speed limits on rural interstates, the average speeds on non-rural interstate highways, still posted at 55 mph, also increased by 1.1 mph, (62 mph to 63.1 mph).

Mace and Heckard (1991) collected data between 1986 and 1988 from Illinois, Ohio, Texas and Alabama and found that the average traffic speed for states that increased their speed limit from 55 mph to 65 mph increased by 4 mph; whereas, on roads still having a 55 mph posted speed limit in these states, the average speed increased by only 0.8 mph. This study does not support a spillover effect.

A "traffic diversion" effect occurs when an increase in the speed limits on certain highways leads to an increase in traffic on the interstates that have a higher speed limit and a reduction of traffic on highways with lower speed limits. Lave and Elias (1994) observed the national traffic volumes before and after the 1987 speed limit increase. They observed that there was a 73% greater increase in vehicle miles traveled on the higher speed interstates compared to the statewide value. The non-interstate vehicle miles traveled decreased by 11%. These values illustrate that the speed limit increase resulted in traffic shifting from lower speed limit roads to higher speed limit roads.

Comparing the results of these studies indicates that the increase in speed limits does appear to increase the average speed and the 85th percentile. However, the magnitude of these increases has been found to vary significantly in different studies. One of the reasons for the differences is the time duration over which the studies were conducted. For example, the increase in average traffic speed observed by Ledolter and Chan (1996) was much higher than the increase observed by Nakao (1989). On possible reason for this difference is that Nakao took only six months of data into consideration (during the "transition" period), while Ledolter and Chan measured the speed increases over 10 years (when the drivers had adapted to the higher speed limits). Other factors, such as the geography of different states, that affects the highway design speeds and traffic volumes could account for the large differences in results of the different studies. Borsje (1995) and Davis (1998) concluded that enforcement can have an even greater effect on traffic speed than the posted limits. The level from which the speed limit increased, whether it was raised from 55 mph to 65 mph or from 65 mph to 75 mph, also caused differences in the magnitude of increases observed by the different studies.

One very important factor that most of the researchers failed to address, and may not even have realized, is that the speed of most of the commercial heavy trucks are restricted to below the posted speed limits by speed limiters, due to company policies. This obviously had a large effect on the magnitude of traffic speed increases when posted speed limits were raised, particularly for highways that have a relatively high proportion of heavy trucks.

2.2.2 Effects of Posted Differential Speed Limits on Truck Speed

As previously discussed, speed differentials between automobiles and heavy trucks occur due to two primary factors. First, many states impose lower posted speed limits on heavy trucks. These regulatory differentials range from 5 mph to 15 mph. The second factor that results in speed differentials between automobile and heavy trucks is the speed policy that is employed by commercial trucking companies. Many companies use speed limiters on the truck engines to restrict the maximum speed. These devices are becoming increasingly sophisticated in both their ability to control speed and record the speed that is driven. The literature discussed in this section relates to the effect of posted speed limits in that there is virtually no literature that addresses the effect of company speed policies on traffic speed in general, or truck highway speed, in particular. The notation will characterize speed limits in the format: 70/65 for differential limits of 70 mph for automobiles and 65 mph for trucks.

Mace and Heckard (1991) collected data between 1986 and 1988 in Illinois, Ohio, Texas and Alabama and found that the automobile speeds were 3.5 mph faster than truck speeds on interstates with a uniform 65 mph speed limit; whereas automobile speeds were 6 mph more than truck speeds on interstates with different speed limits of 65 mph for automobiles and 55 mph for trucks. Therefore, a 10 mph speed differential resulted in a change of 2.5 mph in the average speed difference between automobiles and trucks.

Baum, Esterlitz, Zador and Penny (1991) collected data in California and Illinois having differential speed limits (65/55) and their bordering states with uniform 65 mph speed limits. The results show that trucks traveled 2.73 mph slower in the states with differential speed limit than those with uniform speed limit.

Pfeffer, Stenzel, and Lee (1991) conducted a time series analysis to study the impact of differential speed limits for automobiles and trucks in Illinois. After the 55 mph national speed was raised in 1987, Illinois raised the speed limit on rural interstates to 65 mph for automobiles but retained the 55 mph speed limit for the trucks. The analysis found a statistically significant increase of 4 mph in the 85th percentile speed for automobiles. No significant change in the 85th percentile speed was observed for trucks.

In 1994, Harkey and Mera examined the impact of differential speed limit on average speed based on data from 11 states, all having the same speed limit for automobiles but different limits for trucks. The states were divided into three groups based on their speed limits: 65/65, 65/60 and 65/55 mph. The mean speeds for automobiles under these limits were 67.6, 67.8 and 67.4 mph, respectively, which were not statistically different. However, the average truck speeds in these states were 63.8, 63.6 and 61.1 mph, respectively, for the 65, 60 and 55 mph truck limits. The average truck speed in 65/55 states was significantly less than for the 65/65 and 65/60 mph states. According to this study, a speed differential of 5 mph (from 60 to 65) did not have a significant impact on the trucks' speed and a 10 mph speed differential decreased truck speed less than 3 mph. Furthermore, the percentage of automobiles traveling above the speed limit by more than 10 mph was significantly lower in the 65/55 mph (63.8%) states compared to the 65/65 mph and 65/60 mph states (68.7 and 66.6% respectively). Even though the automobile speed limit was uniform across all the states, it appears that the slower trucks in the 65/55 mph speed limit states had the effect of reducing the average speed of the automobiles. The non-compliance rate for trucks was much larger in the 65/55 and 65/60 speed limit group (89.4 and 76.5%, respectively) compared to that in 65/65 group (35.6%).

Garber and Gadiraju (1991) conducted a study in which they increased the speed limits from 55/55 to 65/55 on test sites and retained the uniform 55 mph speed limit on control sites in Virginia. It was found that the passenger automobile speed increased by 1 to 4 mph after the speed limit increase of 10 mph at test sites. No statistically significant difference was observed in the truck speeds after the increase. The speeds at control sites did not change.

In the Netherlands, den Tonkelaar (1994) studied the effect of lower speed limits of 80 kph (49.71 mph) for trucks and higher speed limits of 100 kph or 120 kph (62.14 mph or 74.57 mph) for automobiles. It was observed that trucks adhered poorly to the posted speed limits and were found to be traveling approximately 10 kph (6.2 mph) faster than their speed limits, while automobiles were observed to be traveling at or below their posted speed limits. The average speed of trucks was found to be 1.1 to 1.6 kph (0.68 to 1 mph) faster on roads with 120 kph posted automobile speed limit, compared to those on roads with 100 kph posted automobile speed limit. This indicates that truck drivers tend to adjust their speed according to the speed of traffic and tend to disregard the posted speed limits.

Freedman and Williams (1992) collected data from 11 northeastern states to estimate the effect of differential speed limits on the mean speeds and 85th percentile speeds. Six of these states had remained at 55/55 mph, three had increased to 65/65 mph and two employed differential speed limits of 65/55 mph. It was found that the average speed of automobiles in the states with 65 mph speed limit was 2 to 5 mph faster than those with 55 mph limits. For trucks, the mean speeds were 3 to 7 mph faster in states with a 65 mph speed limit than in states with 55 mph limits. The results indicated that the average truck speed was more sensitive to the posted speed limit than was the average automobile speed. This could have been due to the fact that the compliance rate of trucks was higher than the compliance rate of automobiles. For automobiles, there was no significant difference in the average speed or the 85th percentile speed in the 65/55 mph speed limit states (67.7 and 72.2 mph) compared to the 65/65 mph speed limit states (66.7 and 72.1 mph). However, the average and the 85th percentile automobile speeds for the 55/55 mph states were significantly lower (63.0

and 68.7 mph). The results indicated that the lower truck speed in differential speed limit states did not have any significant effect on the average speed of automobiles. The mean and the 85th percentile speeds of trucks were also not significantly different for states with 65/55 mph speed limit (61.6 and 66.3 mph, respectively) compared to those for the 55/55 mph limit states (60.2 and 65.3 mph, respectively). However, the mean and the 85th percentile truck speed for the 65/65 speed limit states were significantly higher (65.0 and 69.8 mph). The conclusion was that lower speed limits for trucks did reduce the average and the 85th percentile truck speeds. These results were in contrast to the opinions expressed by Ganote (1997), who believed that a differential speed limit does not really succeed in lowering truck speeds because the drivers takes into account the prevailing road conditions.

Most of the studies have concluded that a 10 mph posted speed differential does not produce a 10 mph difference in the average speed of the automobiles and trucks. In addition, even under uniform speed limits, the average speed of trucks is 3 mph to 4 mph slower than the average speed of the automobiles. It was also observed by Harkey and Mera (1994) that the average speeds of automobiles and trucks are similar in 65/65 mph and 65/60 mph states, indicating that a speed differential of 5 mph does not have any significant impact on the truck speed.

2.3 Effects of Speed Limits on Rural Interstate Highway Safety

The literature available on impact of speed limits on accidents and fatalities is reviewed in this section. It has been indicated in literature that vehicle speed is only one of the factors that affect the probability and type of accidents. The type of roadway and the design speed of the highway are also important factors affecting the number and type of accidents. Preston (1996) studied the accident records of Minnesota and found that the most common type of accident on Minnesota's rural freeways was single vehicles running off the road or hitting a deer, accounting for almost 70% of all accidents. The most common type of accidents on urban freeways involved multiple vehicles (i.e., rear end and sideswipe), which accounted for almost 70% of the accidents. One reason for the high frequency of multiple vehicle accidents on urban freeways was the high density of vehicles on these roads. Higher vehicle density leads to increased interaction among vehicles and more multiple vehicles accidents; whereas, the very low number of interactions among vehicles can contribute to the driver becoming inattentive or drowsy on rural roads. The report did not separate the proportion of accidents in which leaving the rural interstate roadway was due to excess speed. The results obtained by Preston after dividing the accident types on rural and urban freeways were are shown in Table 1.

Table 1. Distribution by Accident Type on Rural and Urban Freeways (Source. Preston 1996)

Accident Type	Rural	Urban
Rear End	12.90 %	50.50 %
Sideswipe	7.30 %	17.40 %
Right Angle	8.40 %	2.40 %
Head On	1.50 %	0.80 %
Ran Off Road	33.70 %	17.80 %
Hit Deer	25.10 %	0.40 %
Other	11.10 %	10.70 %

2.3.1 The General Trends in Highway Safety

Figure 2 illustrates the amount of variation in the number of highway fatalities over the last 40 years. To evaluate the effect of speed limits on highway safety, it is important to consider the amount of exposure experienced by drivers in terms of the vehicle miles traveled. Figure 3 illustrates that, although speed limits have increased, the fatality rate (fatalities per 100 million miles traveled) has been consistently improving. This is the result of improved safety characteristics of both vehicles and roadways.

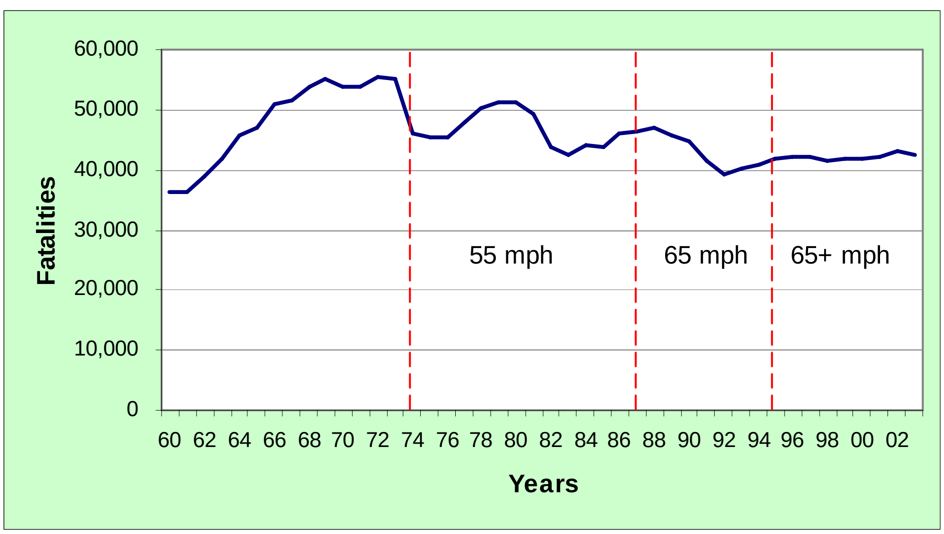

Figure 2. Trends in National Fatalities (Source. Federal Highway Administration)

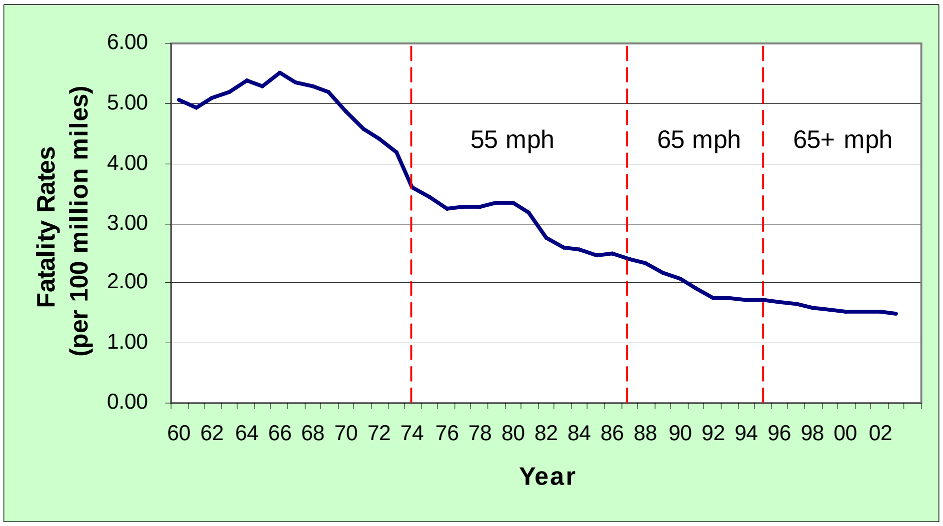

Figure 3. Trends in National Fatality Rates (Source: Federal Highway Administration)

Figure 4 shows both the number of fatalities on rural interstates and the vehicle miles traveled. The trend in fatalities is upward; however, the trend in vehicle miles traveled is also increasing. Figure 5 illustrates that the trend in the fatality rate on rural interstates was actually improving during that period.

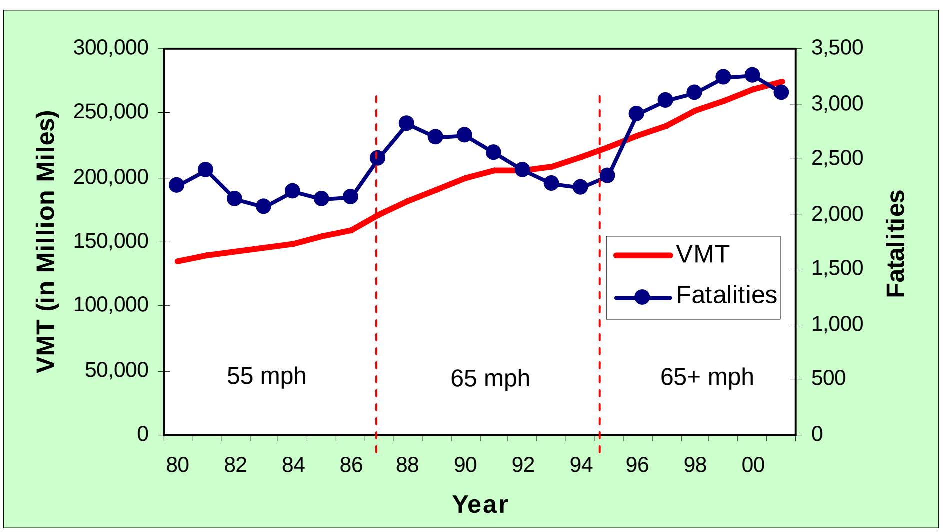

Figure 4. Trends in Rural Interstate Fatalities and Vehicle Miles Traveled (Source: Federal Highway Administration)

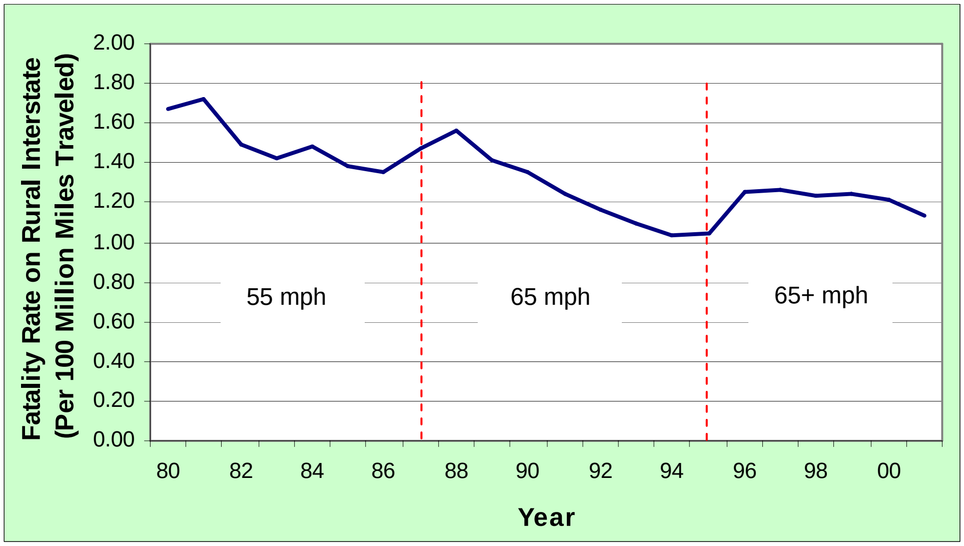

Figure 5. Trend in Rural Interstate Fatality Rates (Source: Federal Highway Administration)

2.3.2 Methodological Issues Contributing to Different in Study Results

Over the past 40 years, the relationship between highway speed limits and safety has received an extraordinary amount of attention in both the research and popular literature. There have often been conflicting conclusions reported in this literature. Some studies have found positive effects of higher speed limits, some found very negative effects and many have not found there to be a relationship. There are a number of reasons for these differences. It is apparent from a cursory review of the literature that much of the public comment and even a significant amount of the research is biased by the entities conducting the research. In addition, there are serious methodological issues that need to be considered when interpreting the research presented in the following sections.

The first explanation for the differing results from different studies is simply the natural variation that affects accident rates. Figure 6 indicates the amount of variation in the number of fatalities on rural roads in Arizona, and illustrates that there are large differences in monthly fatality data. (Balkin and Ord, 2001.)

The results of speed limit studies can also be affected by the states or regions compared. Figure 7 shows data from a study by Ashenfelter and Greenstone (2004). They documented the fatality rates for the states that adopted the 65 mph limits versus the states that retained the 55 mph limits. It is apparent that the states that increased e speed limits had a higher fatality rate both before and after the speed limit increase.

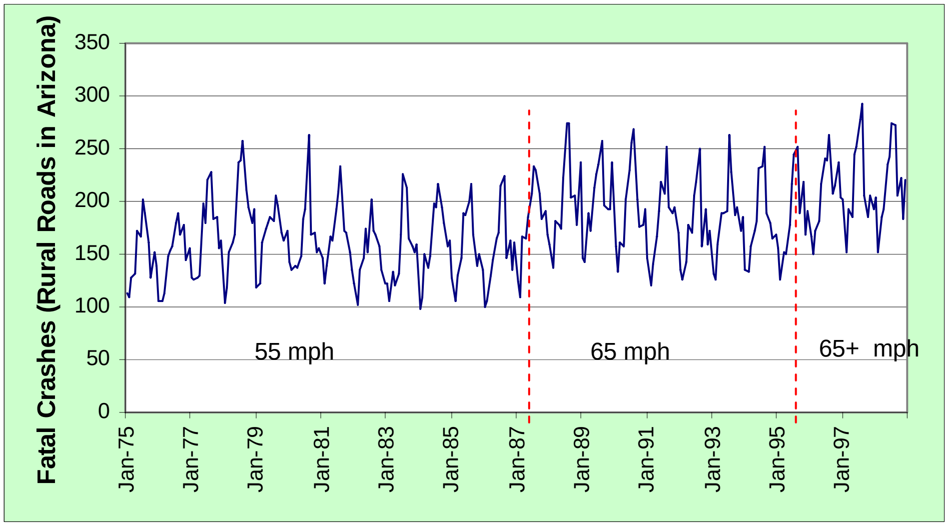

Figure 6. Fatal Crashes on Rural Roads in Arizona (Source: Balkin and Ord, 2001)

If the studies compared the two groups after the change, without correcting for this difference, the results would not represent the actual effect of the speed limit increases. The time frame that is selected for the analysis can also significantly affect the interpretation of the research results. Some of the studies compare the before-and-after accident data to evaluate the effect of the speed limit increase. Notice in Figure 7 that there was a significant drop in the fatality rate in 1989 for the states that maintained the

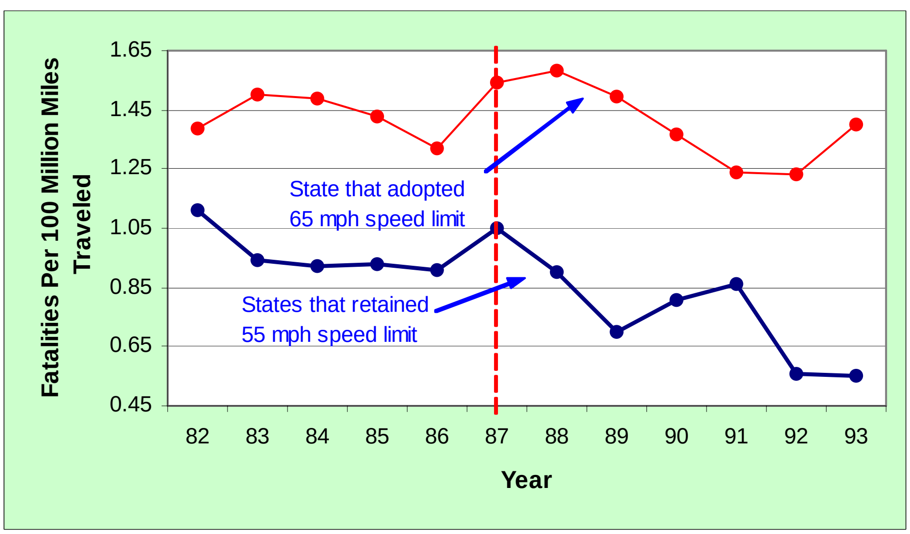

Figure 7. Trends in Rural Interstate Fatality Rates (Source: Ashenfelter and Greenstone, 2004)

55 mph limit. Subsequently, in 1990 and 1991 the fatality rate increased. By comparison, the fatality rates for the states that increased their speed limits decreased steadily from 1989 to 1992. If the relative rate of each group was used in the analysis and the study compared 1986 to 1989 the conclusion could have been that there was a large increase in the relative fatality rates for the states that increased their limits. However, if the study had compared the data from 1986 to 1991, the conclusion could have been that there was no effect of the increase in speed limits.

Another aspect of the time frame issue is the adaptation that occurs when a speed limit is changed. There is inertia to traffic speed when the limits are changed. The average speed and the 85^{th} percentile speed do not change very much initially. In particular, when limits are changed, a few drivers will adapt rapidly, moving at new speed limit or even faster; whereas most drivers will increase their speed gradually as they become more comfortable with the increased speed. The result is that there is initially an increase in the speed variance among vehicles. The negative effect of speed variance is potentially confounded with the effect of the speed limit increase.

As previously discussed, the amount and severity of enforcement also has a large effect on traffic speed behavior. If enforcement was relatively lax when the speed limits were lower and became more strict with new, higher limits, the actual effect of the change on traffic speed might be minimal. In this case, the impact of increased "posted" speed limits might have no effect on traffic behavior and, therefore, accident rates.

The effect of having highway types with very different design speeds is also important to the interpretation of the speed limit studies. The current study is focused on rural interstates. Most of the research combined all highways, some with low design speeds and others (i.e., rural interstates) with design speeds that are significantly above the posted speed limits. Even for the studies that specifically address the speed limits on interstate highways, most do not differentiate between urban and rural interstates. It is often difficult to extrapolate the results of these studies to rural interstates, in particular.

The fact that trucks have limiters that often do not allow them to go the posted speed limit also has an effect on the interpretation of speed limit studies. When limits were increased from 65 mph in 1995, many, if not most, of the commercial heavy trucks on the interstate highways were restricted to a speed of 62 or 65 mph. As previously discussed, this is the reason that the average vehicle speed generally increases much less than the amount of the increase in the posted speed limits. The volume of heavy trucks on the highway can have an effect on the traffic speed. This issue has not been addressed in studies that have investigated the safety impact of speed limits changes.

The archival databases that many studies have used for their analyses include only fatalities and do not include accidents that do not involve a fatality. The effectiveness of passive safety systems (i.e., seat belts, air bags, etc.) have improved the "crash worthiness" of vehicles that are involved in an accident. The result is that the relationship between fatalities and total accidents changes as a function of time. This is particularly the case for speed limit studies. The simple physics of higher speed accidents could have a proportionately larger impact on fatalities than on the number of accidents. Studies that only address fatalities can come to very different conclusions about the safety implications of speed limits compared to studies that include non-fatal accidents.

The last methodological issue that makes the interpretation and comparison of studies in this area difficult is the use of the number of fatalities or accidents, rather than the fatality or accident rates. As previously discussed, studies that simply look at the number of fatalities or accidents, without considering the vehicle miles traveled, can come to different conclusions than those that include vehicle miles traveled. This again is particularly the case for speed limit studies. There is an inverse relationship between speed and exposure time on the highway. That is, for a given mileage driven, a driver (truck or automobile) is exposed to the potential of a collision longer at lower speed limits.

The objective of this section was to introduce some of the methodological issues that limit the interpretability of much of the vast amount of research literature on the relationship between safety and posted speed limits. In particular, many of these issues make it difficult to extrapolate the research findings to truck speeds on rural interstates. As the safety research is reviewed in the following sections, these methodological issues should be kept in mind.

2.3.3 Cause and Impact of Speed Variation

Although there has been a debate as to the impact of speed limits on accidents, one aspect on which most of the research is consistent is that speed variance can have a significant impact on the probability of accidents. There are four primary methods of calculating speed variance reported in the literature: (a) the standard deviation of the individual vehicle speeds, (b) the difference between the 85th percentile speed and the median speed (50th percentile), (c) the difference between the 85th percentile speed and the mean speed, and (d) the difference between the 85th percentile and the 15th percentile speed. However, for the data analysis section of this report, only the first two of the above four methods were used to calculate the speed variance.

It has been widely acknowledged that an increase in speed variance is often associated with an increase in the probability of accidents. According to the National Research Council (1998), the narrower the speed distribution (e.g., less spread between the average speed and the 85th percentile speed), the greater the safety benefits.

Garber and Gadiraju (1988 and 1989) found that the level of safety on any highway is related to the characteristics of the traffic stream and the geometry of the highway. It was found that the major factor that affected speed variance was the difference between the posted speed limit and the design speed of the highway. Speed variance was observed to be the lowest when the posted speed limit was 6 to 12 mph lower than the design speed of the highway. The accident rates were observed to increase with increasing speed variance for all classes of roads. For average speeds up to 70 mph, speed variance decreased with increased average speed. The authors also concluded that the accident rates on a highway do not necessarily increase with an increase in average speed.

Lave (1985) collected nationwide average speed and 85th percentile speed data for 6 different types of highways (rural and urban interstates, arterials and collectors) from 48 states for 1981 and 1982. Speed dispersion was calculated as the difference between 85th percentile speed and the mean speed. Speed, by itself, was not found to have a significant effect on fatality rates. However, when using speed variance as the metric, 10 out of 12 road types indicated a statistically significant positive relationship. This result indicated that it is not absolute speed, but the speed variance that increases fatality rates. It was also observed that, speed variance decreased with increases in the average speed. A series of responses to Lave's models by Levy and Asch (1989), Fowles and Loeb (1989) and Synder (1989) confirmed the negative effect of speed variance, but also suggested that there is also an impact of average speed on fatality rates. One common potential drawback in all of the above models is that the speed data and accident data do not belong to the same highway types. The fatality data for all road types were combined and then used with interstate average speeds in their models. Therefore, the results must be interpreted with care (Monsere, Newgard, Dill, Rufolo, Wemple, Bertini and Miliken, C., 2004).

Graber and Gadiraju (1991) studied the impact of a speed limit increase on speed variance in Virginia. After the 1987 speed limit increase, the posted speed limits in Virginia were raised from a 55/55 mph uniform speed limit to a 65/55 mph differential speed limit. Speed variance among the automobiles decreased when the speed limits were increased to 65 mph. One explanation was that the new higher speed limit was closer to the design speed. However, the overall speed variance among all vehicles (including trucks) was observed to be significantly higher for Virginia compared to the speed variance of all vehicles in West Virginia (which increased speed limits from 55/55 to 65/65). This indicated that the implementation of DSL tended to increase the speed variance.

Baxter (1999) and Addis (1999) also held a similar opinion of the relationship between speed and safety. According to Baxter, accidents will increase only if speed increases beyond the design speed of the highway; whereas, if the posted speed remains below the design speed of the highway, there will not be a significant increase in accidents as speed limit increases. Addis (1999), also stressed, although with no data to support his claim, that speed variance has a significant effect on the fatality rate and that speed, alone, has no effect on fatality rate.

Garber and Ehrhart (2000) conducted a study of traffic speed, traffic flow and geometric characteristics on the crash rates for Virginia highways. The crash rate (number of crashes/hr/km/lane) increased as the standard deviation of speed increased. It was also noted that the changes in crash rates were not necessarily caused by any one independent factor, but rather by the combined effects of independent factors including speed, standard deviation and traffic flow.

A study conducted by Rajbhandari and Daniel (2002) examined the effects of increase in speed limits from 55 mph to 65 mph in New Jersey in 1998. The data were collected from 1997-2000. The increase in speed limit to 65 mph caused more speed variance between automobiles and trucks and increased the accidents that involved trucks by 19% (772 per year to 919 per year). There was also a 27% increase in total accidents in the same period.

Fitzgerald (1989) studied the increase in the speed limit of trucks from 80 kph to 90 kph, while retaining the 100 kph speed limits for automobiles in Australia. The average speed difference between trucks and automobiles was reduced from 10 kph to 8 kph, thus reducing the speed variance. It was also found that there was no significant change in the accident rate that could be attributed to the change in the truck speed limit.

Liu (1998) examined accident data from 1969 -1995 in Canada and observed that on roads with higher speed limits, as the average speed increased both the speed variance and the fatality rates decreased. It was concluded that for every 1 kph increase in speed, speed differential decreased by 0.8 kph and, for every 1 kph increase in speed differential, the casualties increased by 270.

Godwin (1992) studied the impact of a 1987 speed limit increase on the speed variance. The standard deviation of traffic speed increased by 0.8 mph (6.1 to 6.9 mph) for the states that retained the 55 mph speed limit. For the states that increased their speed limits, the standard deviation increased by only 0.2 mph (6 to 6.2 mph). Similar conclusions were drawn by Binkowski, Maleck, Taylor and Czewski (1998), who studied the 1996 increase in speed limits for automobiles from 65 mph to 70 mph in Michigan. The 5 mph increase in the speed limit increased the median speed by 1 mph and increased the 85^{th} percentile speed by 0.5 mph for the initial three months, indicating that the speed variance (difference between 85^{th} percentile and median speed) decreased with the increased speed limit. However, the results were based on only four months.

Pfeffer, Stenzel and Lee (1991) conducted a time series analysis to examine the impact of differential speed limits on speed variance in Illinois, where the speed limits were raised from 55/55 to 65/55 mph in April 1987. Although the average speed of automobiles increased significantly, there was no significant change in the speed variance of automobiles or trucks, considered separately. In this study, when it was reported that the speed variance remained the same for automobiles and trucks after the implementation of DSL, it should be noted that the automobiles were traveling at much higher speeds than the trucks. Therefore, the overall speed variance of the traffic actually increased after the implementation of DSL.

Freedman and Esterlitz (1990) measured the effect of increased speed limits on traffic speed and found that in Virginia, the 10 mph speed limit increase from 55/55 to 65/55 mph, had no significant effect on the standard deviation (a measure of speed variance) of automobiles and trucks, even after one year of speed limit change.

To analyze the impact of the increase in speed limits on the speed distribution of vehicles, Nakao (1989) compared California automobile speed data in April 1987 (55 mph maximum speed limit) with July and September 1987 data (65 mph maximum speed limit). The 10 mph increase in speed limit resulted in a 2.5 mph increase in the average speed of automobiles (62.4 mph to 64.9 mph) and the 85^{th} percentile speed increased by 2.4 mph (66.9 mph to 69.3 mph). It was concluded that even though the speeds have increased, the speed distribution had not changed.

Zlatoper (1991) analyzed nationwide data in 1987 and found average speed, speed variance, and traffic volume to be directly related to accidents. Other factors, such as spending on highway police and safety, income levels , inspection laws, and seat belt laws were found to be inversely related to the number of accidents.

Radwan and Sinha (1978) studied the effect of the decrease in speed limit from 70 mph to 55 mph on truck crashes in Indiana after the 55 mph National Maximum Speed Limit was implemented in 1974. Significant decreases in heavy truck accident rates and severity were observed. On interstates, all accident rates (fatal, personal injury and property damage only) decreased significantly when the average truck speed decreased from 61 mph in 1972 and 1973 to 57 mph in 1974 and 1975. One possible contribution to the decrease in accident rates could have been that the average speed of automobiles and trucks became more uniform. The difference between the average speed of automobiles and trucks on the Indiana interstate highway system before the 55 mph speed law was introduced was 10 mph compared to 2 mph after the reduction.

Agent, Pigman and Webber (1998) conducted a study to evaluate the impact of increasing speed limits from 55 mph to 65 mph on rural interstates in Kentucky. For the 65 mph rural interstate highways, the average speed of trucks (64.25 mph) was found to be considerably lower than the average speed of automobiles (68.04 mph). However, the difference between the average speed of trucks and automobiles was less for the rural interstates with 55 mph posted speed limit. The average speed of trucks and automobiles on these highways was 59.4 and 61.5 mph respectively. One possible reason for the larger difference between the average automobile and truck speeds on higher speed limit interstates was that many, or even most, of the trucks were equipped with speed limiters set below the speed limit.

Harkey and Mera (1994) examined the impact of differential speed limits on traffic speed variance based on an investigation of speed data from 12 states (26 sites) divided into four different speed limit groups (65/65, 65/60, 65/55 and 55/55 mph). The variance of truck speeds was higher than for automobile speeds when the truck speed limit was higher. Due to the speed limiters on trucks, not all trucks could travel at the higher speeds, resulting in more speed variance for trucks. They found differences in truck speed variance for ten of thirteen pair-wise comparisons between uniform and differential speed limit sites. No significant differences were found in the automobile speed variances at the sites.

From the studies reviewed it appears that differential speed limits increased the amount of speed variance among vehicles because trucks travel at lower speeds than the automobiles. When considering automobiles and trucks individually, different results were observed. Increases in the speed limits decreased the speed variance among automobiles. However, due to the presence of speed limiters on trucks, most of the trucks can not travel at speeds above 70 mph. Therefore, if the speed limit for trucks is raised to 75 mph the speed variance among trucks increases. Regarding the impact of speed variance on traffic safety, most of the studies have agreed that increases in speed variance increases the probability of accidents.

2.3.4 Effects of Speed on Individual Vehicle Risk

In the previous sections, the effect of traffic speed and speed limits on traffic safety was discussed. This section focuses on the role of an individual vehicle's speed on the probability of being involved in an accident. It has been argued that an increase in speed will increase the probability of accidents if the number of interactions with other vehicles increases. Similarly, if a vehicle moves slower than the traffic speed, the number of interactions will also increase. Solomon (1964) conducted a comprehensive study on crashes and how other roadway, driver, and vehicle characteristics affect the probability of being involved in a crash. Approximately 600 miles of rural two-lane and four-lane highways were studied using a spot speed sampling procedure. Interviews with 290,000 drivers were collected over a two-year time period. The travel speed prior to the crash was collected from 10,000 crash records, as reported by the police or by the driver. The estimated travel speeds from the accident records were compared to the speeds measured at representative sites within each study section. The comparisons indicated that vehicles involved in crashes were over-represented in both high and low speed categories within the speed distribution. The crash involvement rate was represented by a U-shaped curve as a function of the amount of deviation from the average speed. The accident-involvement, injury, and property damage rates were found to be highest at speeds significantly below the average traffic speed. The accident rates were least at the average traffic speed and increased with increasing speed above the average traffic speed (Figure 8).

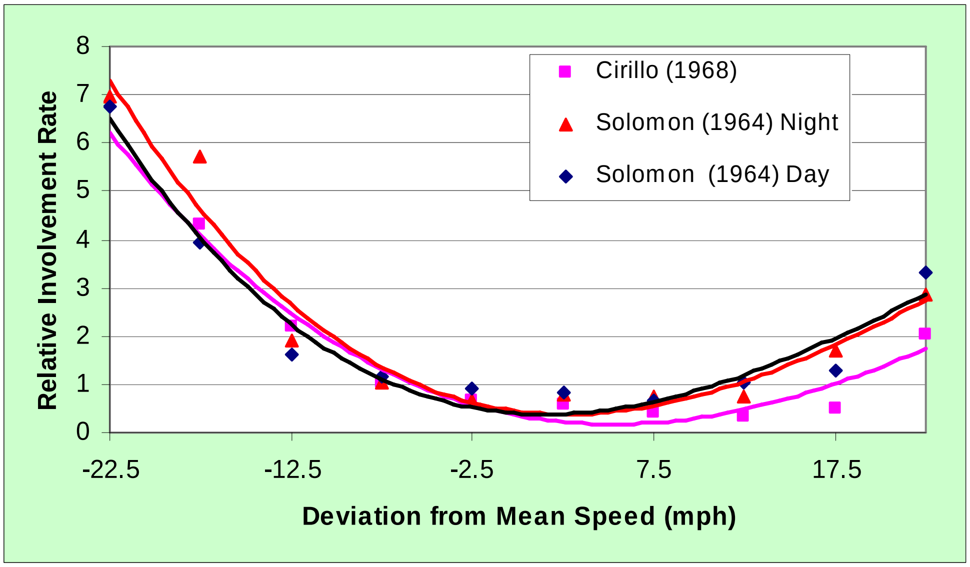

Figure 8. Accident Involvement Rate by Variation from Average Speed (Source: Solomon, 1964 and Cirillo, 1968 in Coffman, 1998)

Cirillo (1968) also conducted a study that addressed speed variation. Two thousand vehicles involved in daytime crashes on interstate highways were analyzed. The data represented a U-shaped curve similar to the Solomon data. The analysis took into consideration only the crashes that involved two or more vehicles (rear end, same direction sideswipe or angle collisions). Data were collected on rural and urban section of interstate highways from twenty state highway departments. The type of collision was controlled since the focus was on how the differences in speeds of vehicles in the same traffic stream contributed to crashes. The U-shaped curve obtained by Cirillo is shown Figure 8. According to the Insurance Institute of Highway Safety (1991), one of the main concerns regarding the validity of the results obtained by Cirillo is that only two- vehicle accidents were considered while single vehicle crashes were not included.

To address the average speed of sections of highway not directly related to the crash location, the Research Triangle Institute (1970) used a combination of trained on-scene crash investigators and a system of automated continuous speed monitoring sensors embedded in the roadway pavement to measure the speed of crash-involved vehicles and their traffic speeds at the time and location of the crash. Data were collected on 114 crashes involving 216 vehicles on state highways in Indiana with posted speed limits of 40 to 65 mph. The investigators were able to differentiate the vehicles that slowed down to negotiate a turn from vehicles that were moving slowly in the flow of traffic. West and Dunn (1971) reported the results of the Research Triangle Institute studies. As shown in Figure 9, the overall crash data were similar to the U-shaped curve.

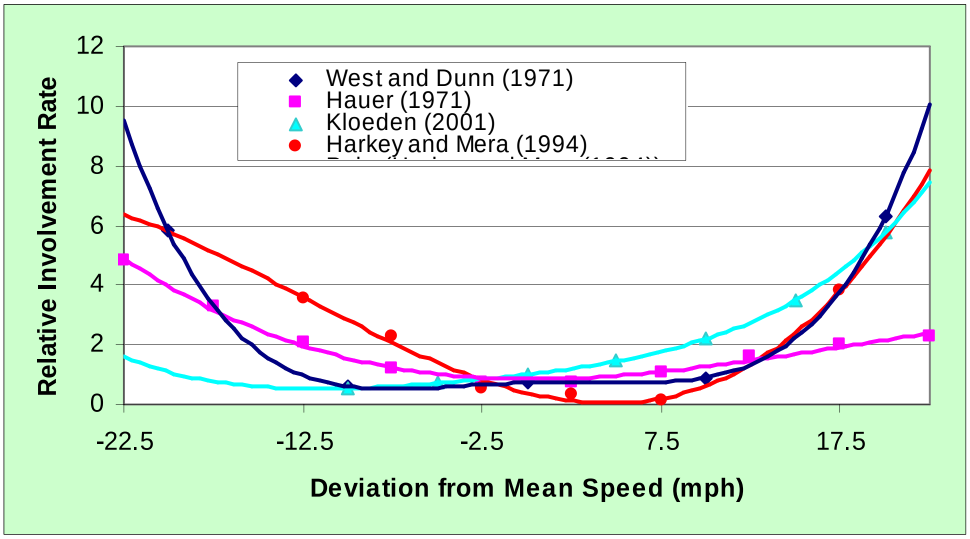

Figure 9. Accident Involvement Rate by Variation from Average Speed (Source: West and Dunn (1971), Hauer (1971), Harkey and Mera (1994) in Coffman, 1998 and Kloeden (2001))

A study by Munden (1967) conducted on the rural main roads in the United Kingdom investigated the connection between a driver's characteristic speed and accident rate. The speed and registration numbers of more than 31,000 automobiles were recorded at ten sites on rural highways. The speed ratio for each automobile was calculated by dividing the observed speed of the automobile by the mean speed of the four automobiles preceding and four automobiles following the observed automobile. Many of the automobiles were observed several times and the mean ratios were obtained for these vehicles. The accident rates of more than 13,000 of the observed automobiles were obtained from the local police. For drivers who were observed more than once, those traveling more than 1.8 standard deviations above or below the mean traffic speed had significantly higher crash rates while the average speed drivers had the lowest crash rates. However, drivers observed only once did not exhibit a U-shaped relationship.

Fildes and Lee (1993) studied the issues associated with speed and traffic safety in Australia and did not find the U-shaped relationship. They found a linear relationship between crash involvement and increases in speed. It was also observed that, as a vehicle deviates from the mean traffic speed, the probability of being involved in a crash increased much more significantly on urban roads, compared to the probability on rural roads, probably because of the higher traffic volumes on urban roads.

Another Australian study, conducted by Kloeden, studied the relationship between free traveling speed and the risk of involvement in a casualty crash on rural highways with posted speed limits of 80 kph or greater. A total of 83 crash cases were investigated. The representative speed (average control speed) was obtained by measuring the speeds of 830 control passenger vehicles that matched the 83 crash cases by location, direction of travel, time of day, and day of week. The risk of involvement in a casualty crash was found to increase more than exponentially with increasing speed above the mean traffic speed (see Figure 9). Unlike the results of the studies by Solomon and Cirillo, the traveling speeds below the mean traffic speed were associated with a lower risk of being involved in a casualty crash. The crash risk doubled with each 3 mph increase above the speed limit. One of the possible reasons for the different results obtained by Kloeden, compared to Solomon or Cirillo is that Kloeden studied the risk of involvement in casualty crashes; whereas Solomon and Cirillo studied the risk of involvement in any crash, irrespective of its severity. As the travel speed increases, the accident severity increases.

Garber and Ehrhart (2000) found that, as the mean speed increased, the crash rate decreased slightly until the mean speed reached the posted speed limit of 65 mph, and then the rate began to increase. The crash rate also increased as the mean speed increased beyond the speed limit. It was noted that the changes in crash rates were not necessarily caused by any one independent factor. The changes were a result of the combined effects of independent factors like speed, standard deviation, and traffic flow.

Hauer (1971) performed theoretical analysis of “overtaking.” The study demonstrated that the number of vehicle interactions, in terms of passing or being passed, is a U-shaped curve with a minimum at the median speed. The increased risk of crash involvement was a result of potential conflicts created when a faster vehicle passes a slower vehicle. The relative overtaking rates for a vehicle as a function of deviation from mean speed on a 100-kph road is shown in Figure 9.

Harkey, Robertson and Davis (1989) studied the relationship between speed and accidents on non-55 mph urban roads in Colorado and North Carolina and observed a U-shaped relationship similar to the one obtained by Cirillo. The police estimated the travel speeds of 532 vehicles involved in accidents over a 3-year period and compared them to the 24-hour speed data collected on the same road. To make the crash and speed data more comparable, the analysis was limited to non-intersectional, non-alcohol and weekday crashes. The minimum crash rate was observed near the 90th percentile travel speeds.

Coffman, Stuster and Warren (1998) conducted a literature review of all American and international research to analyze the relationship between speed and accidents. It was concluded that the crash risk is lowest near the average speed of traffic and increases for vehicles traveling much faster or slower than traffic. Finch, Kompter, Lockwood and Maycook (1994) collected international speed and accident data and performed a regression analysis to study the relationship between speed and accidents. Their results indicated that the probability of being involved in an accident was represented by a U-shaped curve as a function of speed.

2.3.5 Effects of Speed on Crash Severity

The research literature presents a clear relationship between vehicle speed and the severity of injury resulting from a crash, when a crash does occur. In a crash, the basic physics of motion explains this relationship. A vehicle occupant continues in motion at the pre-crash speed for a short time after impact, until collision with another surface within or outside the vehicle occurs and completely halts the motion of the person (Evans, 1991). Seat belts and airbags provide some protection; however, greater vehicular speed upon impact usually results in faster motion of an occupant into the vehicle surroundings and a higher chance of serious injury or death. The relationship between travel speed and the severity of injuries sustained in a crash was examined more than 40 years ago by Solomon (1964) who reported an increase in crash severity with increasing vehicle speeds on rural roads. After analyzing 10,000 crashes, Solomon observed that crash severity increased rapidly at speeds in excess of 60 mph, and that the probability of fatal injuries increased sharply above 70 mph.

The impact of vehicle speed on the severity of an accident has been significantly affected by the improvements in automobile and truck crash worthiness. Passive systems, such as seat belts and air bags, have decreased the severity of highway accidents. Increasingly, active safety systems, such as lane departure, collision avoidance, and vehicle stability systems are improving highway safety for both automobiles and heavy trucks. The improvements in crash worthiness over time have, to some extent, made the direct relationship between speed and crash severity more difficult to interpret.

2.3.6 International Studies of the Safety Impact of Speed Limits

There has been a significant amount of international research conducted on the issue of the impact of speed limits on accidents and fatalities. However, as demonstrated by the wide disparity in rural speed limits in different countries, there is currently no consensus on the relationship between speed limits and safety. Table 2 summarizes the maximum speed limit in different countries and the accident and fatality rates in those countries (Source: International Road Traffic and Accident Database, 2004).

Table 2. Maximum Speed Limit and Accident and Fatality Rates of Different Countries (Source: International Road Traffic and Accident Database, 2004)

	Fatalities per 100,000 pop.	Injury accidents		Fatalities per 100 million vehicle km			Probability of fatality	
Country	Total	per 100,000 pop.	per 100 million vehicle km	All roads	Motor-ways	Speed	Based on VMT	Based on pop.
Australia	8.8			0.9		110		
Austria	11.9	537	55	1.23	0.72	130	1.31	2.22
Belgium	14.5	462	52	1.63	0.62	120	1.19	3.14
Canada	8.9	496	50	0.9	0	113	0.00	1.79
Czech Rep.	14	260	62	3.31	1.22	110	1.97	5.38
Denmark	8.6	133	15	0.92	0.49	110	3.27	6.47
Finland	8	119	13	0.85	0.41	120	3.15	6.72
France	12.9	178	19	1.36	0.45	130	2.37	7.25
Germany	8.3	439	59	1.11	0.41	130	0.69	1.89
Greece	19.3	218	30	2.67	0	100	0.00	8.85
Hungary	14	193		0	1	120		7.25
Iceland	10.1	301	41	1.6	0	70	0.00	3.36
Ireland	9.6	169	18	1.09	0.74	89	4.11	5.68
Italy	11.1	366		0	0.99	130		3.03
Japan	7.5	735	120	1.27	0.46	100	0.38	1.02
Luxemburg	14	174		0	0	120		8.05
Netherlands	6.1	208	30	0.85	0.17	120	0.57	2.93
Newfoundland	10.3	258	21	1.24	0	100	0.00	3.99
Norway	6.9	192	25	0.83	0	90	0.00	3.59
Poland	15.3	140		0	0	110		10.93
Portugal	21	505		0	1.51	120		4.16
Korea	14.9	485	74	2.28	0	100	0.00	3.07
Slovak Rep.	11.3	146	59	4.69	0	130	0.00	7.74
Slovenia	13.7	523	83	2.17	0.99	130	1.19	2.62
Spain	13.2	244		0	0	120		5.41
Sweden	6	178	23	0.83	0.25	110	1.09	3.37
Switzerland	7.1	326	39	0.84	0.37	120	0.95	2.18
Turkey	5.6	80	105	7.3	5.01	90	4.77	7.00
UK	6.1	386	52	0.75	0.21	113	0.40	1.58
USA	14.9	682	46	0.94	0.52	113	1.13	2.18

Nilsson (1977) studied the impact of having different speed limits on different highways within the same highway category in Sweden between 1968 and 1972. The speed limits tested on motorways were 130 kph and 110 kph (80.78 mph and 68.35 mph). For two-lane rural highways, the speed limits tested were 110, 90 and 70 kph (68.35, 55.93 and 43.50 mph). Speed limits were observed to have negative correlation with highway safety. An increase in speed limit from 90 kph to 110 kph on two-lane rural roads increased the accident rate (number of accidents per million axle pair kilometer) by approximately 40%. The reduction in the speed limit from 130 kph to 110 kph decreased the accident rate by 31%.

Another study by Nilsson (1990) analyzed the impact of a reduction in speed limits from 110 kph to 90 kph (68.35, 55.93 mph) on motorways in the summer of 1989 in Sweden. Speed and accident data for 1988 and 1989 were compared. Nilsson observed that the 20-kph (12.43 mph) reduction in speed limit resulted in a significant improvement in safety on all roads. To assess the impact of a reduced speed limit, the reduction in accidents on previously marked 110 kph and 90 kph roads was compared with the reduction in the accidents on 70 kph (43.50 mph) roads. The number of people killed and injured in accidents on roads that decreased their speed limit from 110 kph to 90 kph decreased by 21% and the number of personal injury accidents was reduced by 27%. For the roads, with a 90 kph speed limit, the number of people killed and injured in accidents decreased by 11% and the number of personal injury accidents was reduced by 14%. However, the reduction in speed limits was also accompanied by other activities of the Road Safety Office (i.e., mass media for public awareness, police surveillance, etc.), which could have favorably influenced speed behavior and traffic safety.

Cameron, Newstead and Vulcan (1994) conducted a study in Victoria, Australia to study the reasons behind a reduction in road fatalities from 776 in 1989 to 396 in 1992. Although it was a factor, the authors concluded that the reduction in speed limit from 110 kph to 100 kph (68.35 to 62.14 mph) was not the main reason for the reduction in fatalities. There were other factors involved in the reduction, such as increased enforcement, increased public awareness, and improved road systems.

In 2003, Cameron performed a total cost benefit analysis of the impact of increasing or decreasing speed limits on the overall economic costs. The author concluded that if the speed limits were raised to 130 kph (80.78 mph) from the speed limit of 110 kph for automobiles and 100 kph for trucks, the vehicle operating costs would increase by 7.2% and the crash costs would increase by 89.4%. Whereas the time savings, due to higher speed limits, would decrease the time cost for the public by 16.9%. Overall, the total economic cost was estimated to increase by 2.2%, from $288.8 million to $295.25 million. It was also observed that having a uniform speed limit of 110 kph for automobiles and trucks could reduce the overall cost. However, the optimum speed differed substantially by vehicle type and it was estimated that a speed limit of

120 kph (74.57 mph) for automobiles and 95 kph (59.03 mph) for trucks would minimize the economic costs.

Fieldwick (1987) conducted a global study to estimate the effect of speed limits on road casualties using 1984 accident data. The data collected from 20 European countries and the USA included: road accident fatalities, road accidents, population, total vehicle population, and maximum urban and rural highway speed limits. Using regression cross-section analysis, it was estimated that the reduction in the urban speed limit from 60 kph to 50 kph (37.28 mph to 31.07 mph) reduced the fatality rate by 36.6%. For rural highways, the reduction in speed limit from 100 kph to 90 kph reduced the fatality rate by 7.1%. The author noted that other excluded variables could reduce the beneficial effects found in their analysis.

Elvik and Vaa (2004) analyzed the results of many studies conducted worldwide to assess the impact of changes in speed limits on the number of accidents and on the average traffic speed. Based on a meta-analysis, it was concluded that increases in the speed limits from levels less than or equal to 90 kph (55.93 mph) to levels above 90 kph were associated with increases in the number of accidents for all levels of severity. The fatal accidents increased by 21% while the injury and property damage accidents increased by 17% and 16%, respectively. The increase corresponded to an average increase of 17.4 kph (10.81 mph) above 90 kph, which resulted in an increase of the mean traffic speed of 4.9 kph (3.04 mph). The reduction in speed limits from the range of 115-110 kph (71.46-68.35 mph) to the range of 97-88 kph (60.28-54.68 mph) was associated with a 54% reduction in the number of fatal accidents and a 6% reduction of injury accidents.

Donald (1998) investigated the possible impact of increasing the speed limits on rural roads in Australia. The rural highways in Australia generally had a posted speed of 100 kph (62.14 mph), except for Western Australia where the speed limit was 110 kph (68.35 mph). The Northern Territory had no general rural speed limits. In Western Australia, the mean automobile speed was observed to be 106.1 kph (65.93 mph) and the 85th percentile speed of the automobiles was measured to be 121.1 kph,(75.25 mph), indicating that automobile drivers considered 120 kph (74.57 mph) to be a reasonable speed on the rural highways. The percentage of drivers exceeding the posted speed limit was found to be 42%. The mean speed for trucks was 93.8 kph (58.29 mph) and the 85th percentile speed was 106.7 kph (66.30 mph). The percentage of truck drivers exceeding the posted speed limit was found to be 35%. In general, the 85th percentile speed of automobiles on all rural Australian highways was observed to be approximately 120 kph. This was consistent with the fact that the design speed of most of the rural highways in this area was 120-130 kph. Many drivers appeared to consider speeds over 110 kph to be reasonable.

Sliogeris (1992) conducted a study to analyze the impact of imposition and removal of 110-kph speed limits in Victoria, Australia. In June 1987, the speed limits on rural highways and freeways in Victoria were raised from 100 kph to 110 kph (62.14 to 68.35 mph).In September 1989, the speed limits were reduced back to 100 kph. An analysis was conducted that included two and half years of "before 110", "during 110" and "after 110" casualty accident data. The analysis indicated a statistically significant 24.6% increase in the casualty accident rate per km traveled (0.107 to 0.135 casualty accidents per million km traveled) when the 110-kph speed limit was introduced. A significant 19.3% decrease in the casualty accident rate per km traveled (0.131 to 0.090 casualty accidents per million km traveled) was observed when the 100-kph speed limits were reintroduced in 1989. When only high severity accidents were considered, a significant 21.5% increase in accident rate per km traveled was observed when the 110 kph speed limits were introduced and a significant 18.2% decrease in accident rate per km traveled was observed when the 100-kph speed limits were reintroduced in 1989. The 10 kph (6.21 mph) increase in speed limit increased the average speed by only 2 to 4 kph (1.2 to 2.5 mph).

Many speed limit experiments were conducted from 1962 to 1978 in Finland. Salusjarvi (1988) studied the impact of increases and decreases in speed limits on highway safety. From 1960 to 1969, only temporary speed limits were used in Finland. Speed limits were enforced only during the holiday season. Most of the rural roads had no speed limits. In 1969, "recommended road section speeds" were introduced, but were never enforced. Finally in 1973, compulsory speed limits were introduced. The author concluded that when the posted speed limits reduced the average speed of the traffic, the number of accidents was also reduced.

Even though there are no mandatory speed limits on the Autobahn in Germany, other than an advisory speed limit of 130 kph (80.78 mph), the fatality rates are comparable to the fatality rates on interstates in the United States that have posted speed limits. Ganote (1999) reported that the fatality rates declined on Autobahn, from 1.8 fatalities per 100 million miles traveled in 1980 to 0.81 fatalities per 100 million miles traveled in 1997. This fatality rate was, in fact, lower than the 0.89 fatalities per 100 million miles traveled on interstates in the United States in 1997.

Johansson (1996) studied the reduction of speed limits from 110 kph to 90 kph (68.35 to 62.14 mph) on Swedish motorways and other major highways. Monthly automobile accident data of these affected highways were collected and a Poisson time series analysis was used to determine the effect of reduced speed limits on fatalities, injuries, and vehicle damage. Ninety months of "before" data and 30 months of "after" data were used in the analysis. The results indicated no statistically significant effect on fatal or injury crashes, although the minor injury and vehicle damage crashes were reduced significantly.

Coesel and Rietveld (1998) investigated the social costs and benefits of reducing the highway speed limits in the Netherlands. The reduction in speed limits from 120 kph to 90 kph (74.57 to 55.93 mph) on motorways was estimated to reduce the number of fatal accidents by up to 30%. However, the estimated travel time increased significantly. The societal cost-benefit analysis indicated that reducing and enforcing speed limits would lead to significant savings for society. However it was also understood that a decrease in the speed limit would not be accepted by most of the general public. After surveying the public, they determined that most of the drivers find exceeding the speed limits by 5 to 10 kph (3.1 to 6.2 mph) as acceptable. Almost all the drivers in the survey opposed the idea of reducing the speed limits from 120 kph to 100 kph.

2.3.7 Studies of Speed Limits Changes in the United States

With the establishment of the 55 mph National Maximum Speed Limit in 1974, the primary aim of the new rule was partially achieved by reducing the fuel consumption by approximately 2.9%. This is partially due to the reduced speeds and partially due to a reduction in distances traveled by motorists. Before the National Maximum Speed Limit, most of the states had a 70 mph or higher speed limits. Four states had a 60 mph speed limit, 5 states had a 65 mph speed limit, 30 states had a 70 mph speed limit, 9 states had a 75 mph speed limit, and 2 states (Montana and Nevada) had no mandated speed limits (see Appendix A for details). In 1987 congress enacted legislation allowing states to increase speed limits on rural interstate highways from 55 mph to 65 mph (P.L. 100-17; P.L. 100-202). By the end of that year, 38 states had raised their speed limits with and two additional states following in 1988 (see Appendix B for details). Of the forty states that raised their limits, ten set differential speed limits for automobiles and heavy trucks. The National Highway Designation Act of 1995 repealed the national maximum speed limit and returned authority to the states to set speed limits. Twenty-nine states increased their speed limit for automobiles to above 65 mph. As of 2004, there were 11 states that had differential speed limits between automobiles and trucks. Figure 10 and Figure 11 below indicate the maximum speed limits for automobiles and trucks, respectively. Figure 10 illustrates that most of the north eastern states have a 65 mph maximum posted speed limit for automobiles, while many of the states in the Midwest have posted speed limits of 75 mph.

Due to the changes in federal speed limit policies over the last 40 years, there has been an abundance data available for studies of the impact of increasing highway speed limits in the United States. In this subsection, the impact of the increases in speed limits will be summarized. The subsequent sections will discuss both the national and state based research studies in detail.

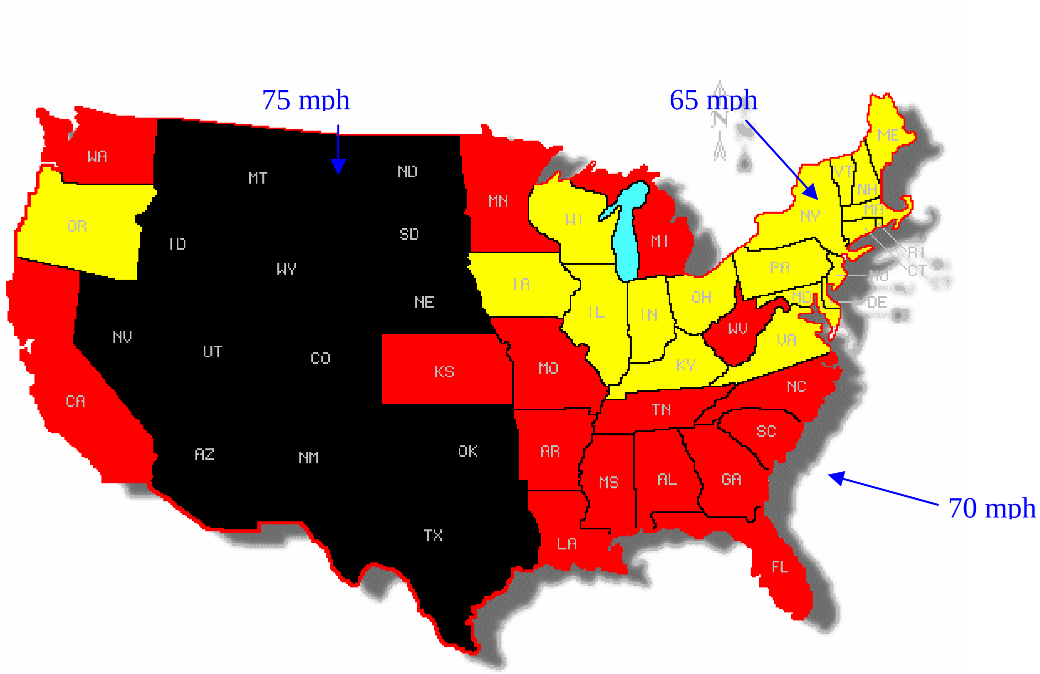

Figure 10. Maximum Interstate Speed Limit for Light Vehicles (Source: Monsere et al., 2004)

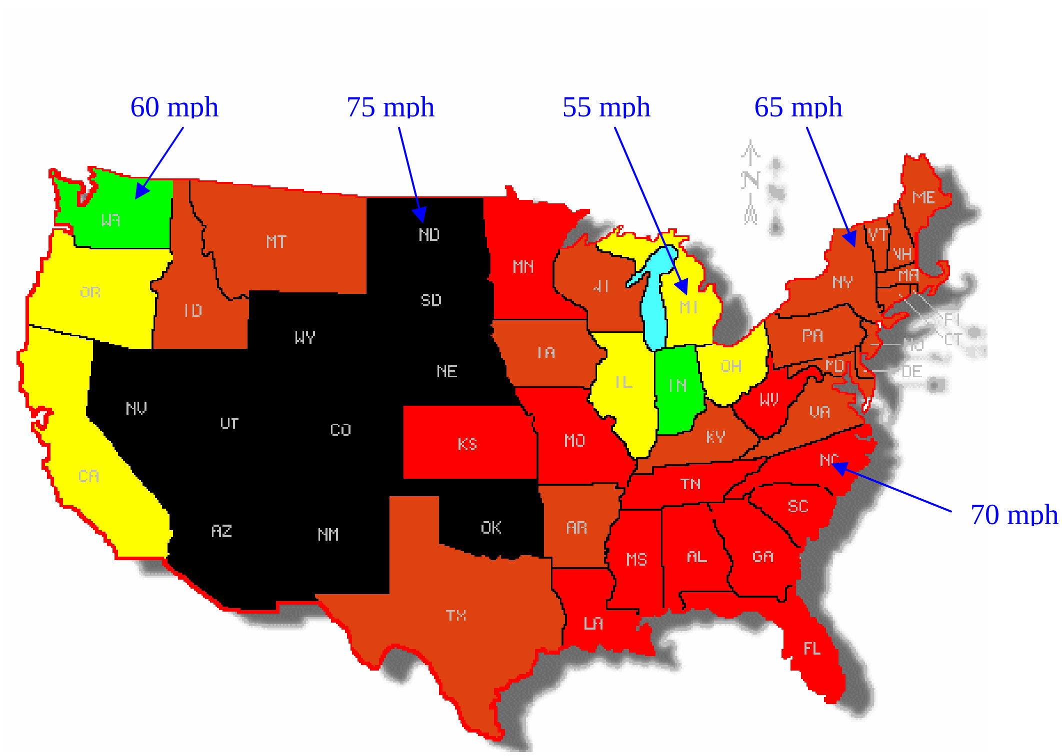

Figure 11. Maximum Interstate Speed Limit for Trucks (Source: Monsere et al., 2004)

Due to the changes in federal speed limit policies over the last 40 years, there has been an abundance of data available for studies of the impact of increasing highway speed limits in the United States. In this subsection, summarizes the impact of the increases in speed limits. The subsequent sections will discuss both the national and state based research studies in detail.

Most of the research literature that investigated the 1987 increases in speed limits concluded that the increased speed limit from 55 mph to 65 mph on rural interstates led to an increase in fatalities. However, the studies that found the largest effects frequently analyzed only the number of fatalities and did not consider the effect of vehicle miles traveled (i.e., fatality rate). Figure 12 summarizes some of the major studies that analyzed the impact of the 1987 interstate highway speed limit increase on the number of fatalities. These and others will be discussed in detail in later sections.

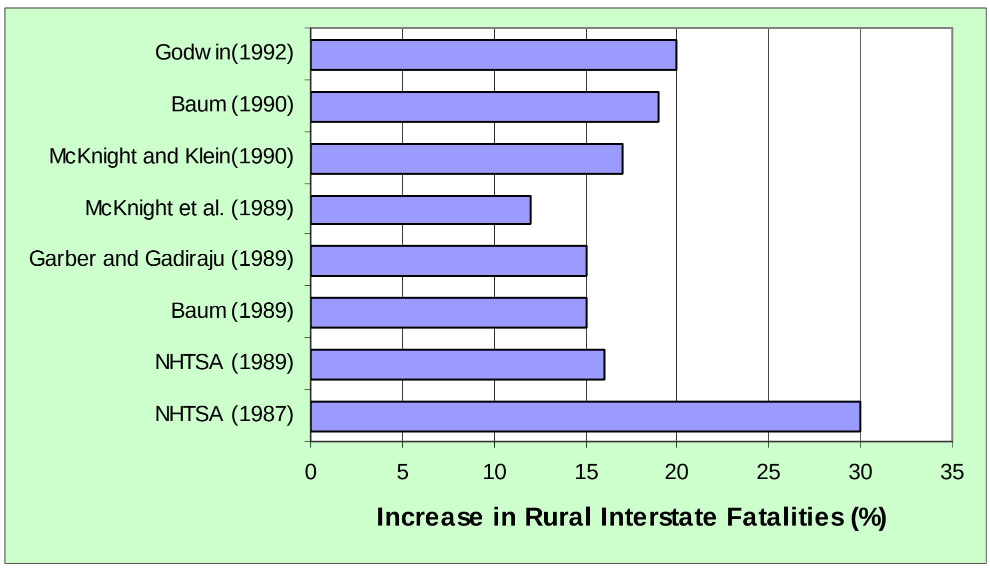

Figure 12. Summary of Multi-State Studies Dealing with the 1987 Increase in Speed Limit

Figure 13 summarizes the results obtained by studies that investigated the impact of the 1987 speed limit increase on safety at the individual state level. The label, “no effect,” indicates that the particular study concluded that the increase in rural interstate speed limits did not have a statistically significant impact on fatalities. Figures 14 and 15 summarize some of the major studies that analyzed the impact of the 1995 speed limit increase on safety at the national and state levels, respectively.

From the four graphs, is can be seen that the majority of the studies that found a difference observed a negative effect of increased speed limits on the affected highways. Among these studies, some concluded that increased interstate speed limits have positive effects on highway safety, when observed statewide. In addition, the many

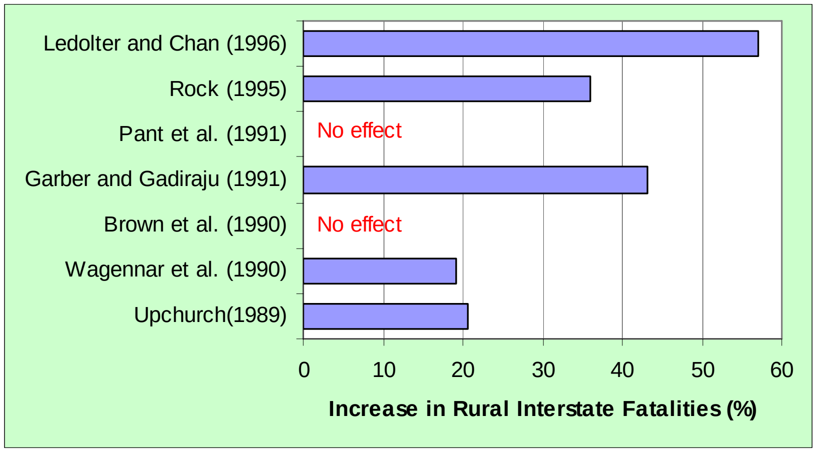

Figure 13. Summary of Single-State Studies Dealing with the 1987 Increase in Speed Limit

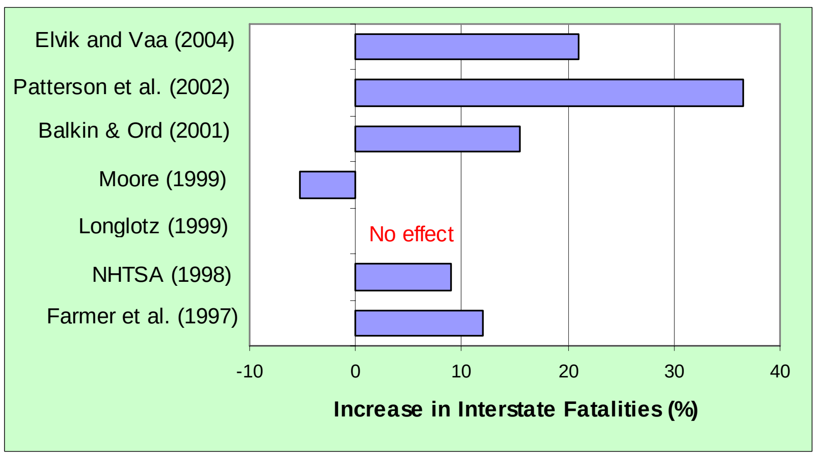

Figure 14. Summary of Multi-State Studies Dealing with the 1995 Increase in Speed Limit

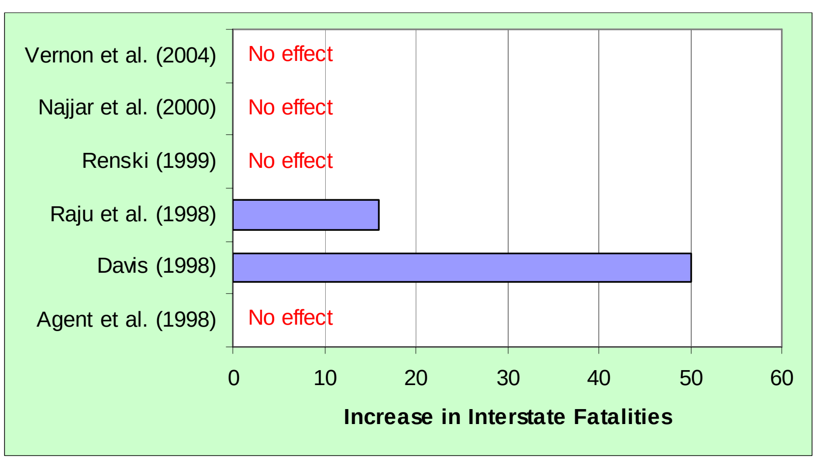

Figure 15. Summary of Single-State Studies Dealing with the 1995 Increase in Speed Limit

methodological issues that were previously mentioned make the interpretation of some of these results difficult. These issues will be discussed in detail in the following sections.

2.3.7.1 Studies Prior to 1987

When the National Maximum Speed Limit of 55 mph was established in 1974, the average vehicle speed dropped by 7.4 mph (65 mph to 57.6 mph); However, non-compliance with the new law was widespread (Meier and Morgan, 1981). Meier and Morgan analyzed the national fatality data from 1950 to 1980 and developed a regression equation that linked fatalities with average vehicle speed. According to the model, for every one mph increase in average speed, it was estimated that an additional 1,206 people would be killed in traffic accidents, all other things being equal. They disagreed with the opinion of other researchers that the reduction in vehicle miles traveled and safety improvements could have been the primary factors that led to the significant reduction in fatalities rather than the decrease in speed limits. After conducting a regression analysis of traffic fatalities including both vehicle miles traveled and the average vehicle speed, they concluded that vehicle miles traveled did have a statistically reliable effect on fatalities; although the average speed had a much more significant impact. However, the "significance level" of the statistic used in this study does not represent the relative impact of the two variables on the number of fatalities. The authors also argued that the standardized regression coefficients for miles traveled (0.57) was much lower than that of average speed (0.89). This comparison would only make sense if the basic units being compared were the same, which they were not.

Cerelli (1981) also analyzed the national fatality data and estimated that increasing the national speed limit from 55 to 60 mph would result in an increase of 3,500 fatalities per year. A study by the National Research Council (1984) found that lower speed limits had a significant positive effect on fatalities. It was reasoned that the reduction in vehicle miles traveled, improvement in vehicle safety, and improvement in roadway and medical services could not explain all of the reductions in fatalities, and claimed that lower and more uniform speeds were responsible for saving some 3,000 to 5,000 lives in 1974.

Godwin and Kulash (1988) indicated that highway travel declined by 1.5% between 1973 and 1974, and long-term improvements in the rate of fatalities per mile driven averaged approximately 3%. The sudden drop in the fatality rate in 1974, which was measured to be approximately 15%, was still more than three times the combined effect of the two factors: 1) decline in travel and 2) improvement in the fatality rate. Further, the greatest decline in fatality rates occured on those roads where the speed limit reduction was largest.

2.3.7.2 Impact of the 1987 Speed Limit Increase

The review of the studies conducted to estimate the safety implications of the speed limit increase in 1987 from 55 to 65 is divided into two major categories: (1) studies conducted using data from multiple states (mostly national level studies) and (2) studies conducted at the individual state level. These two categories will be reviewed separately. Within each category, the reviews will follow the pattern: the studies that found a negative effect of increased speed limits are discussed first and then the studies that found no effect or a positive effect are discussed.

The National Highway Traffic Safety Administration (1992) estimated that in 1990, the 38 states that had increased the speed limits to 65 mph in 1987 experienced a 30% increase in the number of fatalities on rural interstate highways than what would have been expected if the limits had not been raised. However, the study concluded that, even though the number of fatalities had increased on rural interstates with the implementation of the 65 mph speed limit, the interstates remained the safest component of the national highway system. The fatality rate on rural interstates was 1.3 fatalities per 100 million vehicle miles traveled in 1990 compared to 2.1 fatalities per 100 million vehicle miles traveled for the nation as a whole.

A study conducted by Advocates for Highway and Auto Safety (1995) agreed that the increase in speed limits in 1987 caused 30% more fatalities on rural interstates among states that increased their speed limits. This same study estimated that if the National Maximum Speed Limit was repealed, the highway fatalities would increase by 6,400 every year at a cost of an additional $19.3 billion every year. It is important to note that, after the repeal of National Maximum Speed Limit, the annual fatalities increased by only 248, from 41,817 deaths in 1995 to 42,065 in 1996, which was 96% below the projected values by Advocates for Highway and Auto Safety.

Balkin and Ord (2001) studied the national fatality data from 1975 to 1988 to estimate the effect of increasing speed limits. They found that 19 of the 40 states that increased their speed limit in 1987 experienced a significant increase in fatal crashes on their rural interstate highways; however, the exact impact of the speed limit increase on highway fatalities was not provided. The lack of an impact of increased speed limits on fatal crashes in 21 of 40 states weakens the argument made by the authors that the increased speed limits had a significant negative impact on highway safety.

The National Highway Traffic Safety Administration (1989) analyzed accident data from 1975 to 1987 and found that the 38 states that increased their speed limits in 1987 experienced 16% more rural interstate fatalities than expected. However, note that a large percentage (64%) of this increase resulted from only six states. The actual increase in the number of fatalities on rural interstates was 19% for the states that raised limits, and 7% for the states that retained lower speed limit.

Baum, Lund and Wells (1989) analyzed the fatality data from 1982 to 1987 for the 38 states that increased their speed limits in 1987, and found that the rural interstate fatalities in 1987 were 15% (confidence interval of 65 to 24%) more than expected; whereas, the rural interstate fatalities for states that did not increase their speed limits decreased by 6% (confidence interval of -23 to -13%) in the same period. Baum, Lund and Wells (1990) conducted a second study, this time including the data from 1988. They found that, for the 38 states that increased their speed limits to 65 mph in 1987, the fatal crashes increased by 26% to 29% (i.e., approximately 500 more fatalities), while no significant increase in crashes was observed for states that did not increase their speed limits. After adjusting the fatality risk on rural interstates for the increase in vehicle miles traveled on those roads, Baum, Wells and Lund (1991) estimated the increase in fatality risk to be 19%. They suggested that two-thirds of the estimated increase in fatalities on rural interstates in 1989 (almost 400 of the approximately 600 extra deaths) could be directly attributed to increased speed limits.

Garber and Gadiraju (1989) collected fatality data from 1976 to 1988 and performed separate time series analyses for each of the 40 states that enacted a 65 mph speed limit. The authors concluded that the fatalities increased by a median value of 15% on rural interstates and 5% on non-rural interstates. However, it should be noted that the increase in fatalities wase not uniform across all the states. Out of the 40 states, 28 experienced an increase in the number of fatalities and 12 experienced a decrease in fatalities. One of the differences between the Baum, et al. study and the Garber and Gadiraju study is that the latter study used a longer period of time. As previously discussed, the time frame can have a large effect on the results observed.

According to McCarthy (1994a) there are three main highway safety consequences from an increase in rural interstate speed limits: (a) direct effect, (b) traffic diversion affect, and (c) spillover effect. Since the direct and the traffic diversion effects are likely to operate in the opposite direction of the spillover effects, the overall impact on highway safety remains ambiguous, with a possible bias towards improved highway safety. This bias reflects the induced shift of traffic away from the most dangerous, rural non-interstate, roads toward rural interstate highways that have traditionally been safer. McCarthy studied these effects using California data during the period from 1981 to 1989. The dependent variables were: total accidents, fatal accidents, injury accidents, and property damage accidents. The following observations were made: (1) citations had a negative and statistically significant effect, (2) the speed law effects were negative, thus showing that the spill-over effects were absent and providing evidence of improved highway safety, and (3) the combination of speed law and interstate roadway produced a strong positive, statistically significant effect that showed the presence of a direct traffic diversion effect.

McKnight and Klein (1990) studied the nationwide impact of increasing the speed limits to 65 mph on rural interstate highways. Speed and accident data were collected from 1982 to 1988 for all 50 states. In the states that raised their speed limits to 65 mph, the number of fatal accidents on rural interstates increased by 22% over projections based on previous trends. There was no change in the number of fatal accidents on non-rural interstates. In states that maintained the 55 mph limit on rural interstates, there were significant 10% and 13% increases in fatal accidents on rural interstates and non-rural interstates, respectively. States that increased their speed limit to 65 mph did not experience an increase in fatal accidents on non-rural interstates.

McKnight, Klein and Tippetts (1989) collected nationwide data from 1983 to 1988 and found that, in states that raised their speed limits to 65 mph, the fatal accidents on rural interstates increased by 22% over projections based on the previous trends. There was no significant increase in fatal accidents in the same states for non-interstate highways that did not experience an increase in speed limit. The states that did not increase their speed limit observed only a 10% increase in fatal accidents (i.e., approximately 20 more fatal accidents). The non-rural interstate highways from these 55 mph states observed a significant 12.7% increase in fatal accidents (i.e., an increase of 295 fatal accidents) indicating a “traffic diversion” effect.

Godwin (1992) analyzed national data from 1986 to 1988 and found that the fatalities on highways on which the speed limit was increased to 65 mph were 15 - 25% higher than expected in 1988. Furthermore, the fatality rates for rural interstate highways increased by 18% (1.4 to 1.7 per million vehicle miles traveled) for 65 mph states, while the fatality rates for non-rural interstate highways in the same states were 7% lower (2.7 to 2.5 per million vehicle miles traveled). The fatality rates for rural interstates and non-rural interstates for the 55 mph states remained the same. The traffic diversion phenomenon was noted in that, in that the fatalities and fatality rates went up on rural interstates for the 65 mph speed limit states, the fatality rates went down for non-rural interstates in the 65 mph speed limit states.

Some researchers have found that an increase or decrease of the speed limit makes only an initial negative impact on safety which later decays. Chang, Carter and Chen (1993) concluded that the increased speed limit had a significant “initial” impact on highway fatalities at the nationwide level; however, the impact decayed after approximately a year of “transition” period.

Wilmot and Khanal (1999) surveyed the literature and came to the conclusion that speed affects the severity of accidents but not the probability of accidents on rural interstates. The statewide fatalities can be reduced by having higher speed limits on rural interstate (which are the safest roads in the system, having the highest design speeds) while maintaining lower speed limits on other more dangerous highways that have lower design speeds.

Lave and Elias (1994) found that during the period of 1986 to 1988, the statewide fatality rates in states that increased their limits to 65 mph, decreased more than the states that retained the limit of 55 mph. The actual reduction in fatality rates observed in the 65 mph states was 6.15%; whereas, the 55 mph speed limit states had a reduction of 2.62%. The authors suggested that the three main reasons for this decrease were (1) state highway patrols were allowed to shift resources from speed enforcement on the interstates to other safety activities and other highways, (2) higher speed limits attracted faster drivers away from other, more dangerous roads (non-interstates), and (3) speed variance among vehicles might have declined. Lave and Elias also observed a significant increase in vehicle miles traveled in states that had increased their speed limits.

The following studies were conducted at the state level to investigate the effect of the 1987 speed limit increases. Bamfield (1989) studied California accident data for the years 1982 through 1988. The study concluded that during that period, there was no significant increase in injuries or fatalities due to the increase to a 65 mph speed limit. Smith (1990) analyzed California accident data for the years 1982 through 1989. No changes in fatality rates, fatal accidents rates or injury accident rates were found to be statistically significant. Although the number, of fatal accidents increased by 13%, the traffic flow increased by 11%. The severity of accidents was observed to decrease with increased speed limits; however, the decrease was not statistically significant.

McCarthy (1994b) also analyzed accident data from California from 1981 through 1989. There was a small decrease in the number of fatalities and accidents on roads on which the speed limit was not increased. This decrease was accompanied by a small increase in accidents and fatalities on roads with an increased speed limit to 65 mph. Thus, it author concluded that, overall, there was no significant effect of increased speed limits on statewide safety.

Wagenaar, Streff, and Schultz (1990) collected data from 1978 through 1988 to evaluate the effect of the 1987 speed limit increase in Michigan. They report a significant increase in the accidents on rural interstate highways: a 19.2% increase in fatalities (although this increase was not significant at the 0.05 significance level), a 39.8% increase in serious injuries, and a 25.4% increase in moderate injuries. A strong indication of a spillover effect was observed, as fatalities on other 55 mph freeways increased by 38.4%. No significant effect was observed in the serious injury accidents and other accidents on 55 mph interstates. This report took into consideration only 13 months of after data, which is not a sufficient time period to assess the impact of new speed limits. Table 3 shows the total fatalities in Michigan from 1984 through 1990. The speed limit change occurred in December 1987.

Table 3. Total Fatalities in Michigan (Source: NHTSA)

Year	Fatalities
1984	1,531
1985	1,545
1986	1,605
1987	1,602
1988	1,708
1989	1,639
1990	1,571

Table 3 shows that the number of fatalities increased by 106 from 1987 to 1988; however, in the next year, which this study did not consider, the fatalities decreased and, by 1990, the number of fatalities was below the level of the pre-increase years. This confirms what Chang, Carter and Chen (1993) suggested that highway fatalities increase in the initial "transition" period, but after the drivers "adapt" to the higher speeds, the number of fatalities decreases.

Ledolter and Chan (1996) studied the impact of the 1987 speed limit increase from 55 mph to 65 mph in Iowa. The accident data from 1981 through 1991 was analyzed and they concluded that there was a 20% increase in the number of statewide fatal accidents. On rural interstates, the fatal accidents increased by 57%. However, there was no significant increase in the number of major-injury accidents. The data obtained from NHTSA gives slightly different results for fatality rate data. From Table 4 it can be seen that the fatality rate increased in 1987, but is subsequently decreased, exhibiting the "transition" and "adaptation" theory.

Table 4. Fatality Rates in Iowa (Source: NHTSA)

Year	Fatality Rate
1986	2.16
1987	2.36
1988	2.54
1989	2.28
1990	2.02

Brackett and Ball (1990) studied a speed limit increase from 55 mph to 65 mph in Texas and observed a 24.5% increase (from 208 per month to 259 per month) in the number of serious accidents and a 15% increase in accident rate (23.8 to 27.4 accidents per 100 million vehicle miles traveled) on rural interstates. However, after the first year "transition" period, the number of accidents and the accident rates decreased in the second year. When the statewide effect was considered, no statistically significant increase in the number of serious injury accidents was observed, thus indicating a strong traffic diversion effect.

Pant, Adhami and Niehaus (1991) studied the impact of the 1987 speed limit increase from 55 mph to 65 mph in Ohio. Accident data from 1984 to 1990 was analyzed and it was reported that the higher speed limit had significantly increased injury accidents by 16% (3536 to 4097) and non-injury accidents by 10% (11,058 to 12,156) on rural interstates. However, there was no significant increase in fatalities on these roads. For non-rural interstate highways that were still posted at 55 mph, all accidents and fatalities decreased significantly, perhaps due to the traffic diversion effect.

Brown, Maghsoodloo and McArdle (1990) studied the effect of the speed limit increase in Alabama and found that accident severity appeared not to increase from the before (1986-1987) to the after time period (1987-1988). The frequency of accidents on rural interstates increased significantly, by 18.8% (2336 to 2757). The number of property damage accidents and the injury accidents increased significantly; whereas, the frequency of fatal accidents remained the same. The significant increase in accidents on the rural interstates was accompanied by a non-significant decrease of 456 accidents statewide. According to NHTSA data (Table 5), the statewide fatality rate actually decreased, thus indicating that the statewide safety had improved after the speed limit increase.

Table 5. Fatalities and Fatality Rates in Alabama (Source: NHTSA)

Year	Fatalities	Fatality Rate
1986	1,081	3.18
1987	1,111	2.97
1988	1,024	2.58
1989	1,029	2.52

Rock (1995) studied the effect of the 1987 speed limit increase (from 55 to 65 mph) in Illinois and observed a statistically significant increase in fatalities on rural interstates (from 384 per month to 521 per month, a 36% increase) and non-rural interstate highways (from 3794 per month to 4229 per month, a 12% increase). The vehicle miles traveled also increased by up to 9.37% on rural interstates, whereas the vehicle miles traveled remained almost the same on the non-rural interstate highways, thus showing a traffic diversion effect. Similar conclusions were obtained by Sidhu (1990), who also studied the speed limit increase in Illinois and observed that there was a significant increase in fatalities on rural interstates and non-rural interstates. It was noted that there was also a significant increase in fatalities due to drunken driving, pedestrians etc. Therefore, the data did not illustrate a clear increase in fatalities that could be associated with the increase in speed limits alone.

A Virginia study was conducted by Jernigan, Lynn and Garber (1988) to investigate the issues related to increasing speed limits on rural interstates to 65 mph. They estimated that the increased speed limits would increase the traffic speed from 60 mph to 63 mph resulting in an annual increase of 6 to 18 fatalities and 171 to 405 injuries. However, increased speeds would reduced travel time by up to 1.3 million hours. The authors concluded that the economic benefits of raising speed limit to 65 mph might outweigh the cost by a minimum of $3.8 million.

This study was followed by another Virginia study by Garber and Gadiraju (1991). This study found that the average speed and the 85th percentile speed increased by 3.6 mph and 5 mph, respectively. Fatalities increased by 43.2%, from 44 fatalities in 1987 to 63 fatalities in 1989. The authors concluded that other factors, such as weather conditions, change in traffic volume, trip type, or vehicle mix, could account for some of the increase in fatalities.

Agent, Pigman and Webber (1998) conducted a study to evaluate the speed limits in Kentucky and to recommend appropriate speed limits for various types of roadways. Accident data were collected between 1992 and 1995 in Kentucky. No increase in fatality or injury rates were found for rural interstates where the posted speed limit was increased to 65 mph compared to those for interstates that retained the 55 mph posted speed limit.

Khan and Sinha (2000) studied the impact of increasing speed limits in Indiana from a uniform 55 mph speed limit to a differential limit of 65 mph for automobiles and 60 mph for trucks. The increased speed limits did not have a significant effect on the number of crashes, fatalities, crash rate and fatality rates. The higher speed limits were found to have a positive effect on the trucking industry's productivity.

Upchurch (1989) in Arizona found that the increase in speed limit from 55 to 65 mph increased the average speed by 3 mph. After analyzing the crash data from 1983 through 1988, it was concluded that the speed limit increase in 1987 increased the rural interstate fatalities by 20.6% (97 to 117). The total number of injury accidents increased by 21% (2813 to 3408). However, the NHTSA data in Table 6 illustrates that the total number of statewide fatalities and fatality rate generally increased until 1986 (the year before the speed limit increase). After the speed limit increase in 1987 the statewide fatalities and fatality rates began to decrease. The result indicates the potential of a traffic diversion effect after the 1987 speed limit increase, that resulted in increased fatalities on rural interstate highways, but decreased statewide fatalities and fatality rates.

Table 6. Fatalities and Fatality Rates in Arizona (Source: NHTSA)

Year	Fatalities	Fatality Rate
1983	675	3.28
1984	869	4.15
1985	893	4.14
1986	1,007	4.44
1987	939	2.96
1988	944	2.76
1989	879	2.52

McCarthy (1988) studied the effects of increased speed limits in Indiana and found that the higher, 65 mph, speed limit caused a non-significant increase in rural interstate highway accidents and had no effect on statewide accidents. The study concluded that, enforcement had a more significant effect on accidents compared to speed, in that highways with stricter enforcement had a fewer accidents.

2.3.7.3 Impact of the 1995 Speed Limit Increase

Following December 1995 repeal of the National Maximum Speed Limit, many states raised the maximum interstate speed limit to 70 or 75 mph. Twenty-nine states increased their speed limit for automobiles to speeds above 65 mph (See Appendix C for details). There have been a number of studies that have estimated the impact of these increased speeds on the number of crashes and fatalities. As in the previous section, the following review will be divided into two major categories: (1) studies conducted using data from multiple states (mostly national level studies), and (2) studies conducted at the individual state level. Within each of the two categories, the review of studies will first present the studies that found a negative effect of increased speed limits, followed by the studies that found no effect or a positive effect.

Balkin and Ord (2001) studied the national fatality data from 1975 to 1998 to estimate the effect of higher speed limits. Ten of the 36 states that increased their rural interstate speed limits in 1995 experienced a significant increase in fatal crashes on those highways. However, data pertaining to the exact impact of the speed limit increase on highway fatalities was not provided. The lack of an impact resulting from increased speed limits on fatal crashes in 21 of 40 states, weakens the argument made by the authors that the increased speed limits have a negative impact on highway safety.

Farmer, Richard, and Lund, (1997) collected fatality rates and data on the number of fatal crashes from 1990 through 1997 for 12 states that increased their speed limits above 65 mph (study group) and 18 states that retained their 65 mph maximum speed limit (comparison group). It was estimated that there was a 12% increase in fatalities and a 17% increase in fatality rates on interstate highways and freeways for the 12 states that increased their speed limits. There was also a significant increase (p=.06) in fatalities and fatality rates on other roads associated with speed limit increases, indicating the potential of a spillover effect. Considering only the rural interstates, there was an 11% increase in fatalities due to higher speed limits. One of the limitations of this research is that it was limited to data from only 1995 and 1996. The year, 1996, was a transition year for most states that had increased their speed limits.

Moore (1999) observed that the results obtained by Farmer, Richard, and Lund would not be consistent with an analyses that used the data for the following year because 8 out of the 12 states from the test group (states that increased their speed limit after 1995) experienced a drop in fatality rates in 1997. Many states that either increased or maintained their speed limits were omitted from the study. Another fact that is problematic for the interpretation of the results of this study was that the fatality rate increased more than the fatality count for the test group. This would only be possible if the vehicle miles traveled had decreased, which was not the case.

The National Highway Traffic Safety Administration (1998) examined the effects of increased speed limits above 65 mph. Based on the fatality data from 1991 to 1995, NHTSA predicted the number of fatalities in 1996. When the predicted number of fatalities was compared to the actual numbers, it was observed that the group of states that increased their speed limit above 65 mph experienced a 9% increase (350 more fatalities) in fatalities on rural interstate highways in 1996 than were predicted by the model. This study did not appear to account for changes in traffic volume.

A national level study conducted by Patterson, Frith, Povey and Keall (2002) modeled changes in rural interstate fatalities considering the changes in speed limit along with fatality count data and vehicle miles traveled from 1992 to 1999. Compared to the states that did not raise their limits, it was estimated that there was an increase of 35% in rural interstate fatalities (confidence interval of 6% to 72%) for the states that raised their speed limits to 70 mph. There was a 38% increase in rural interstate fatalities (confidence interval of 8% to 78%) for the states that raised their speed limits to 75 mph. Again, these estimates were based on prediction models and,even though there was no significant increase in statewide fatality rates in states that increased their speed limits, there was a significant decrease in statewide fatality rates (19% decrease) in states that retained the 65 mph speed limit.

Srinivasan (2002) reviewed the literature on the research work done on examining the impact of increased speed limits and concluded that the increased speed limits in 1995 had increased the probability of fatal accidents, although the impact of speed on total accidents and speed dispersion was unclear.

Langlotz (1999) compared the changes in overall fatality rates following the 1995 speed limit increase between two groups: states that raised speed limits and a control group that did not. Langlotz compared the fatality rates of 1995 with the fatality rates of 1997. The fatality rates were studied in addition to fatality counts to account for the increase in miles traveled on highways. The state-wide effect was taken into consideration as well as the effect on interstates in order to address the potential traffic diversion from local roads to faster interstate highways. The fatality rates in states that raised their limit decreased by 5.00%; whereas, while the states that did not increase their limits experienced a fatality rate decrease of 5.38%. The difference between groups of 0.38% was statistically insignificant. Of the 33 states that raised limits, 10 experienced an increase in fatality rate, and 23 experienced a decrease in fatality rate. Of the 15 states in the control group, five experienced an increase in fatality rate and 10 experienced a decrease. No significant change in statewide fatalities was observed for either the test group or the control group.

Lave (1997) found that, after the 1995 increase in speed limits, fatalities did not increase nationally by the 10% to 14%, as expected by the opponents of higher speed limits. Instead, it decreased by 0.7% during a time when the vehicle miles traveled increased by 1.8%. However, the data available from NHTSA indicates that national fatalities had increased by 0.6% (from 41,817 to 42,065) between 1995 and 1996, and not decreased by 0.7%, as claimed by Lave. Although Congress gave permission to raise speed limits in November 1995, it took some states a period of time to adopt the new legislation. Only half of those that implemented the changes had done so by May 1996. To understand the effect of the 1995 speed limit increase, it is more meaningful to analyze changes in fatality data between 1996 and 1997, rather than comparing 1995 and 1996. From the NHTSA database, fatalities between 1996 and 1997 decreased by 0.12% (from 42,065 to 42,013).

After analyzing the fatality and accident data from all of the states, Moore (1999) came to the same conclusion as Langlotz (1999): that the increase in speed limits did not cause an increase in fatalities and accidents. Moore compared the fatality counts and fatality rates of states that increased their speed limit in 1995 and 1996 to states that did not increase their speed limits. It was pointed out that in 1997 there were 66,000 fewer road injuries than in 1995 (based on miles traveled). Moore noted that the states that had maximum speed limits below 70 mph experienced no change in fatality rates between 1995 and 1997; whereas, the states that had speed limits at or above 70 mph experienced a significant 5.3% decrease in fatality rates. Opponents of higher speed limits had earlier speculated that higher speed limits would increase accidents and the severity of accidents, thus increasing insurance premiums. However, in 1997 and 1998, insurance premiums dramatically declined, collision claims were down by 3.1% in 1997, and bodily injury claims fell by a huge 4.7%.

A number of studies were conducted to examine the safety implications of increased speed limits for individual states. Those studies will be discussed next.

Banasiak (1997) observed that the interstate traffic speeds increased after the 1996 speed limit increase from 65 mph to 75 mph. However, the number of fatalities decreased during the seven month period following the speed limit increase. Fatalities in those seven months decreased from 44 to 40 fatalities, compared to the same seven months in 1995.

Najjar, Stokes, Russell, Ali and Zhang (2000) studied the results of the 1996 change in the maximum speed limit from 65 mph to 70 mph on rural interstates in Kansas. A before-after comparison was done using two years of after data. The increase in speed limits had no significant impact on the fatality counts and fatality rates on these highways. However, there was a state-wide positive effect of higher limits, as crashes reduced on non-rural interstate highways. These results indicated the presence of a traffic diversion effect, which resulted in improving statewide safety with the increase in posted speed limits on interstates.

Davis (1998) studied the impact of an increase in the maximum speed limit from 65 mph to 75 mph on I-40 and I-25 in New Mexico. The accident frequency data of the 1996-97 ("after" period) was compared with the average accident frequency for 1994 and 1995 ("before" period). The travel speeds increased significantly with the increase in speed limit. The annual tow-away crashes increased significantly by 29% (1058 in the "before" period to 1366 in the "after" period). In addition, injuries increased by 31% (982 to 1288), incapacitating injuries increased by 44% (308 to 442), and fatalities increased by 50% (66 to 99). On highway I-10, where there was no significant increase in travel speed, the accident data did not change significantly after the increase in speed limits, suggesting that the increase in crash severity was due to the increased speed limit.

Vernon, Cook, Peterson, and Dean (2004) studied the results of change in maximum speed limit from 65 to 70 and 75 mph in Utah in 1996. No significant difference was observed between the predicted and experienced crash rate for the rural interstates and urban interstates.

A North Carolina study by Renski, Khattak and Council (1999) studied the impact of the increase in the maximum speed limit from 65 mph to 70 mph in 1995. They studied 2,729 single-vehicle crashes on highway sections where the speed limit had changed. Single vehicle crashes were studied because they are usually more severe, and as other research has shown, more likely to be speed-related. Increasing speed limits from 55 to 60 or 65 mph on the non-interstate system was found to be related to a significant increase in the probability of increased crash severity; however, the increase from 65 to 70 mph on interstates did not result in a significant change in probability of crash severity.

Dornsife (2001) studied the impact of changes in speed limits on accidents in Montana. In 1996, the speed limits were changed from 65 mph to a "reasonable and prudent" policy that had been in place before 1974. Reasonable and prudent speed limits were not based on numerical maximum speed, but rather, they required motorists to drive at speeds that are safe for the prevailing conditions. In June 1998, the maximum posted speed limit of 75 mph was introduced. Although the number of fatalities was expected to decrease after the introduction of this rule, the annual fatalities on interstate highways actually increased by 111%, from 27 to 56 fatal accidents after the speed limits were imposed. The vehicle miles traveled were also observed to decrease with the introduction of 75 mph speed limit. The possible reason for low fatalities during the "no speed limit" period was that the drivers were more courteous and the left lane was reserved for passing.

The Iowa Highway Safety Management System Task Force (2002) studied the impact of increased speed limits from 55 mph to 65 mph on rural expressways and freeways in Iowa in May 1996. Data were collected from mid-1993 through 2000. The fatality rate on rural expressways and freeways went up by 587% (0.3 fatalities per hundred million miles during the "before" period to 2.06 fatalities per hundred million miles during the "after" period). The injury crash rate and total crash rate went up by 28% and 26%, respectively. The annual average number of fatalities on rural interstates, where the 65 mph maximum speed limit was retained during these periods decreased from 32 to 31. Whereas, the surrounding states (Minnesota, Missouri, Nebraska and South Dakota), that increased their rural interstate speed limits to 70 mph and above, experienced an 8 to 58% increase in annual fatalities on rural interstates. When the change in total traffic fatalities from 1991-1995 to 1996-2000 was observed, it was found that the states that did not increase their maximum speed limits beyond 65 mph (Iowa, Illinois, Wisconsin), on average, experienced a 1.3% decrease (11 fatalities fewer per state, per year) while states that increased their maximum speed limits beyond 65 mph (Kansas, Minnesota, Missouri, Nebraska, South Dakota) experienced a 10.2% increase (55 fatalities more per state per year).

Raju, Souleyrette and Maze (1998) studied the accident data from 1980 to 1996 in Iowa to estimate the safety effect of an increase in rural interstates speed limit from 55 to 65 mph. Increased speed limits were found to be increasing the annual fatal accidents on rural interstates by approximately 60% on rural highways (16 fatal accidents more per year).

Bartle, Baldwin, Johnston and King (2003) examined the increase in the number of fatalities on Alabama interstates following the increase in speed limit from 65 mph to 70 mph in 1996. Data were collected from 1984-1999 and the researchers concluded that the increased speed limits significantly increased the fatalities on interstates while there was significant positive impact on fatalities for other roads. The "after period" data collected in this study was not enough to understand the long-term effects of speed on safety and the speed adaptation phenomenon. There was a small decline in fatalities in 1988, showing signs of speed adaptation.

Some studies investigated the relationship between 85^{th} percentile speed, design speed and highway safety. Parker (1992) collected speed and accident data from 22 states at 100 sites (non-limited access rural and urban highways) before and after the speed limits were altered. “Before” and “after” data were also collected at comparison sites where speed limits were not changed to control for the time effects. It was found that the average posted speed limits were set at the 45th percentile speed or below the average speed of traffic. Average speed average limits were posted between 5 and 16 mph below the 85th percentile speed. Raising the speed limits in the region of the 85^{th} percentile speed had a beneficial effect on drivers complying with the posted speed limit. This results in a more uniform traffic flow, thus reducing speed variance and improving highway safety. At the 58 experimental sites where speed limits were lowered, accidents increased by 5.4%, although this was not statistically significant. Accidents at the 41 experimental sites where speed limits were raised decreased by a non-significant value of 6.7%. This could be explained by the fact that after increasing the speed limit, the new posted speed would have become closer to the design speed of the highway, and also closer to the 85^{th} percentile speed of the traffic, thus decreasing the accidents on these highways.

Baxter (1999) expressed the opinion that considering design speed is critical to evaluating the relationship between speed and safety. The assertion is that accidents increase only if speed increases beyond the design speed of the highway, and that if the posted speed remains within the design speed of the highway, there will not be a significant increase in accidents.

Most of the national level studies conducted after the 1987 speed limit increase to 65 mph observed an increase in the number of crash fatalities in the range of 10% to 20%. However, the results of the studies conducted to estimate the impact of the 1995 increase in speed limits (from 65 mph to 70 or 75 mph) on crash fatalities have varied from no effect to a 55% increase. After reviewing the studies, the reasons for the difference in results obtained could be broadly classified into two categories: (1) random fluctuation in the number of accidents, which depends on many factors, including driving behavior, traffic conditions, geographic conditions, weather, economic issues, enforcement etc. and (2) research methodological issues, including the selection of different time frames, etc. The increase in speed limits has been observed to result in very different effects in individual states. The increase in speed limits appeared to increase highway fatalities in some states, reduced them in others, and had no detectable effect in the remainder. The global median effect was approximately a 10% to 15% increase in fatalities. However, increases in speed limits were also observed to be associated with increases in the vehicle miles traveled. Many of the studies did not take into consideration vehicle miles traveled. When the increase in the miles traveled was considered, the effects were much less pronounced or did not occur. Many of the studies illustrated that increases in speed limits on rural interstates result in traffic diversion, resulting in fewer fatalities on “less safe” highways, which compensates for the increase in fatalities on interstates.

2.3.8 Effects of Differential Speed Limits on Safety

The issue of setting uniform or differential speed limits for automobiles and trucks has also been controversial, particularly in recent years. The proponents of differential speed limits contend that trucks have significantly different operating characteristics than automobiles in terms of performance, maneuverability, and braking and should, therefore, operate at lower speeds. The opponents of differential speed limits on rural interstates contest the idea that lower speeds for trucks improves safety because the amount of variation in vehicle speed increases the probability of accidents.

The difference in operational characteristics of automobiles and trucks will be reviewed in detail in the next section. In this section, the impact of differential speed limits on highway safety will be discussed. There have been many studies conducted on this topic; however, the studies have been unable to provide consistent information as to how differential speed limits affect safety. During the period when the 55 mph National Maximum Speed Limit was in effect (from 1973 to 1987), there was no difference in the posted limits for trucks and automobiles. Therefore, the studies on differential speed limits were either conducted before 1973 or after 1987. In 1987, the states were faced with the question of whether to set speed limits for all vehicles or to set differential speed limits for automobiles and heavy trucks. Out of the 40 states that increased their speed limits in 1987, ten states set differential speed limits for automobiles and larger vehicles. Seven states adopted a 65/55 mph differential speed limit, and three states had 65/60 mph differential speed limit for automobiles and trucks, respectively. As of June, 2005, 11 states had differential speed limit for automobiles and trucks (Figure 15). Arkansas and Indiana had a 5 mph speed differential. Washington, Texas, Oregon, Ohio, Montana, Illinois and Idaho had a 10 mph speed differential. California and Michigan have a 15 mph speed differential.

These speed differentials do not only apply to heavy trucks. Some states also include buses, towing vehicles, etc. There have been extensive discussions in many states pertaining to whether to initiate, retain or eliminate differential speed limits. For example, the legislature of Illinois passed a bill (Senate Bill 2374), which would allow the trucks to operate at the same speed as automobiles on four-lane interstate highways, but it was vetoed by the Governor. In Oregon, where there have been recent discussions of whether to increase the speed limits from 65/55 to 70/70 or 70/65, but no action was taken and the decision was postponed. In Connecticut, where there has been a uniform speed limit of 65 mph for both automobiles and trucks, a bill was offered that would limit large trucks to 55 mph on rural interstates (Land Line Magazine, 2005).

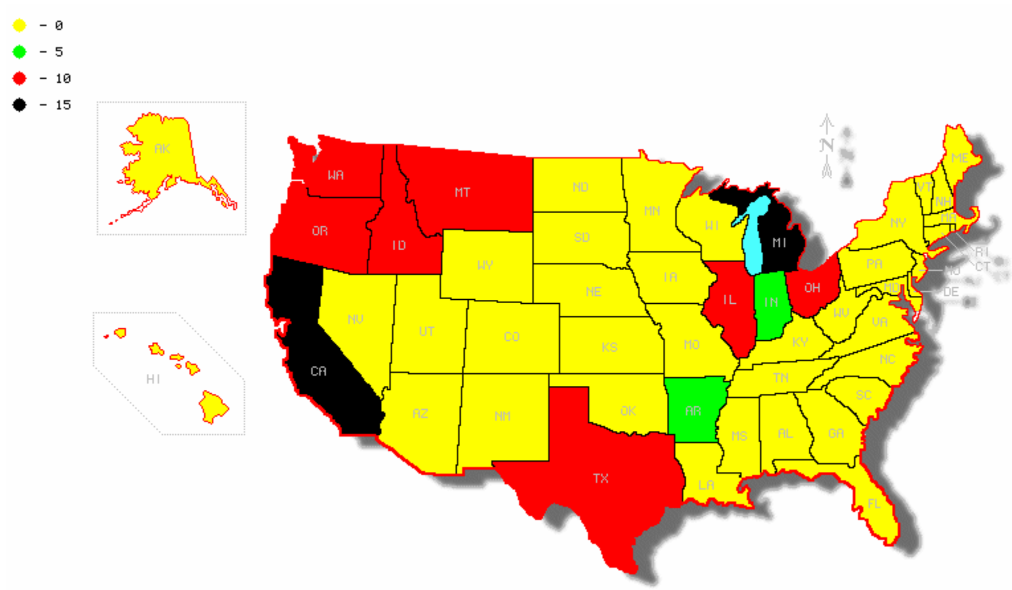

Figure 15. Difference between Maximum Interstate Speed Limits (Source: Monsere et al., 2004)

Efforts have been made on the international level to reduce the truck-involved accidents. The European Commission passed a regulation that required speed limiters on all trucks and buses. Speed governors with a maximum speed limit of 90 kph were made mandatory for all trucks and buses to reduce the severity and number of trucks involved in accidents.

The effect of differential speed limits on safety is a controversial issue. Lower speed limits for trucks help reduce truck-rear-ending-automobile accidents and the severity of such accidents. The Federal Motor Carrier Safety Administration's report of 2003 stakeholder forums indicated that the opinions of the participants were divided on the issue of speed differentials. Some participants viewed speed differential laws to be effective, while the industry representative and many enforcement personnel viewed them as less safe, stating that it forces trucks to become slower moving "obstacles" on the roads.

According to Cirillo (2003), a former assistant administrator and chief safety officer for the Federal Motor Carrier Safety Administration, traffic operating at or about the same speed, regardless of the speed limit, is the safest traffic environment. The author observed that the fatality rates and accident rates on interstate highways are 2 to 5 times less than the non-interstate highways. Adherence to differential speed limits creates an unsafe situation in which a significant percentage of traffic is operating much slower than general traffic. Lower truck speeds can also entice commercial traffic to use less safe non-interstate facilities.

Spencer (2003), executive vice president of the Owner-Operator Independent Drivers Association, stated that having a 10 mph speed differential between automobiles and trucks increases safety concerns on highways because it forces vehicles to be constantly in conflict with each other. Spencer's concerns include the problem that lane changing and passing are constantly required to avoid crashes, which increases probability of accidents. Differential a speed limit increases the number of bottleneck and leapfrog situations on highways.

Yuan and Garber (2002) studied the impact of differential speed limits by comparing the accident data of states having uniform speed limits (USL) with those having differential speed limits (DSL). Speed and crash data during the 1990's were taken from four types of states. The four groups were: *(a)* states that retained uniform speed limits, (*b)* states that retained differential speed limits during 1990's, *(c)* states that changed their speed limits from uniform speed limits to differential speed limits during 1990's, and (*d)* states that changed their speed limits from differential speed limits to uniform speed limits during 1990's. The states that retained uniform speed limits experienced increases in total crash rates and rear-end crash rates. All of the groups experienced increases in the total number of truck-involved crash rates. No significant increase was observed in truck-involved rear end crash rate for the third group (uniform to differential limits). States that changed from differential to uniform limits experienced an increase in total crash rate.

A study by Harkey and Mera (1994) examined the impact of differential speed limit on safety, based on data from nine states. The states were divided into four groups based on their speed limits: 65/65 (Iowa, Idaho and North Carolina), 65/60 (Indiana and Washington), 65/55 (Illinois, Oregon and Virginia), and 55/55 (Pennsylvania). The study investigated three collision types (rear-end crashes, sideswipe crashes, and all other crashes) for each of the four groups. The analysis also separated the data for passenger automobiles and trucks. Table 7 indicates that a higher proportion of automobile-into-truck and truck-into-automobile crashes occurred in uniform speed limit states. The exception was the rear-end crashes, where more automobile-into-truck collisions occurred in the differential limit group. These results were expected in that, in differential limit states, trucks travel at significantly lower speeds compared to automobiles. The truck-into-automobile sideswipe accidents in differential limit states were much lower compared to those in uniform limit states.

Table 7. Accident Proportions by Speed Limit, Collision Type and Vehicle Involvement (Source: Harkey and Mera, 1994)

Speed Limit	Rear End		Sideswipe		Other	
	Auto-into-truck	Truck-into-auto	Auto-into-truck	Truck-into-auto	Auto-into-truck	Truck-into-auto
USL: 65/65 mph and 55/55 mph	10.91	10.78	22.12	21.07	2.57	2.01
DSL: 65/55 mph and 65/60 mph	13.7	6.86	21.52	14.96	2.07	0.99

A study was conducted by Garber, Miller, Yuan and Sun (2003) to compare the safety impacts of differential and uniform speed limits on rural interstate highways, using crash data from six states for the period of 1991 to 1999. These states were divided into three groups based on the type of speed limit employed: states that maintained uniform limits (Arizona, Missouri and North Carolina), states that changed from uniform to differential limits (Arkansas and Idaho) and one state that changed from differential to a uniform limits (Virginia). Six types of crash rates were evaluated: total crashes, fatal crashes, rear-end crashes, total truck-involved crashes, truck-involved fatal crashes, and truck-involved rear end crashes. Using a before-and-after comparison, it was observed that the crash rates increased over the ten-year period, regardless of whether uniform or differential limits were employed. There was no consistent trend in crash rates matching the changes in speed limits. The authors concluded that measurable variation within crash rates by year and by state might have confounded the statistical tests employed.

A simulation study was performed by Garber and Gadiraju (1990) to analyze the safety impact of differential speed limits and the restriction of trucks in the right lane. It was concluded that the implementation of differential speed limits, in addition to lane restriction of trucks, increased the interactions between automobiles and trucks and, therefore, the potential for accidents. The authors recommended that, to reduce interactions, the best speed strategy was a uniform 65/65 mph posted speed limit.

The simulation study was followed by an empirical study, also by Graber and Gadiraju (1991). In this study, three differential limit states (California, Michigan and Virginia) were compared to two uniform limit states (Maryland and West Virginia). The data covered the time durations before and after 1987. There was no significant difference in automobile-truck accident rates or two vehicle accident rates for states that introduced differential limits compared with those with uniform limits. There was a significant increase in the two-vehicle accident rates in states having differential limits. Comparisons of crash rates in the adjacent states of Virginia (differential limits) and

West Virginia (uniform limit)) showed an increase in rear-end crashes and sideswipe crashes in Virginia, suggesting that differential limits might have a negative impact on safety. One possible explanation of this difference could have been that the increase in speed limits from 55/55 to 65/55 mph in Virginia increased the overall speed variance among vehicles; whereas West Virginia, where speed limits were increased from 55/55 to 65/65 mph, had lower speed variance. These results confirm the results obtained from the previous study by Garber and Gadiraju (1990) that used simulation to investigate the effects of differential speed limit strategies.

Hall and Dickinson (1974) obtained similar results when they analyzed accident data from 83 sites in Maryland. It was concluded here that a speed differential between automobiles and trucks contributed to accidents, primarily rear-end and lane-changing accidents. The study also suggested that lower rates of truck accidents could be expected with higher speed limits, and hence recommended an increase of truck speed limits from 55 to 60 or 65 mph on highways carrying high percentage of trucks.

Pfeffer, Stenzel and Lee (1991) conducted a time series analysis to examine the safety impact of differential speed limits in Illinois where the speed limits were raised from 55/55 to 65/55 mph in April 1987. Monthly crash and miles traveled data were collected between January 1983 and July 1988. For automobiles, a statistically significant increase of 14.2% was observed in the frequency of accidents on the 65 mph rural interstate sites; however, there was no increase in the accident rates. There was a significant 27.3% decrease in the automobile-truck accident rate for fatal and injury accidents; however, when all accidents were considered, there was no change observed in the automobile-truck accident rates. These findings suggest that the severity of accidents involving trucks is reduced significantly by setting lower speed limits (55 mph) for trucks. These results were in contrast to those from the Graber and Gadiraju's (1991) study and Hall and Dickinson's (1974) study, which did not observe any beneficial effect of DSL in reducing automobile-truck accidents.

Monsere, Newgard, Dill, Rufolo, Wemple, Bertini and Miliken, C. (2004) examined the differential speed limits in Oregon and concluded that except for travel time savings and some economic development benefits, all other issues (like crashes, enforcement, health, environment etc.) to be negatively impacted by the proposed reduction of speed differentials fom 65/55 to 70/65 mph.

2.3.9 Cause and Impact of Truck Accidents

Even though the number of fatalities associated with truck accidents has been fluctuating in the last few years (Figure 16), the fatality rates have been steadily declining for the past decade (Figure 17). In fact, the figure illustrates that the decline in the fatality rate has been much higher in trucks compared to the decline in automobiles.

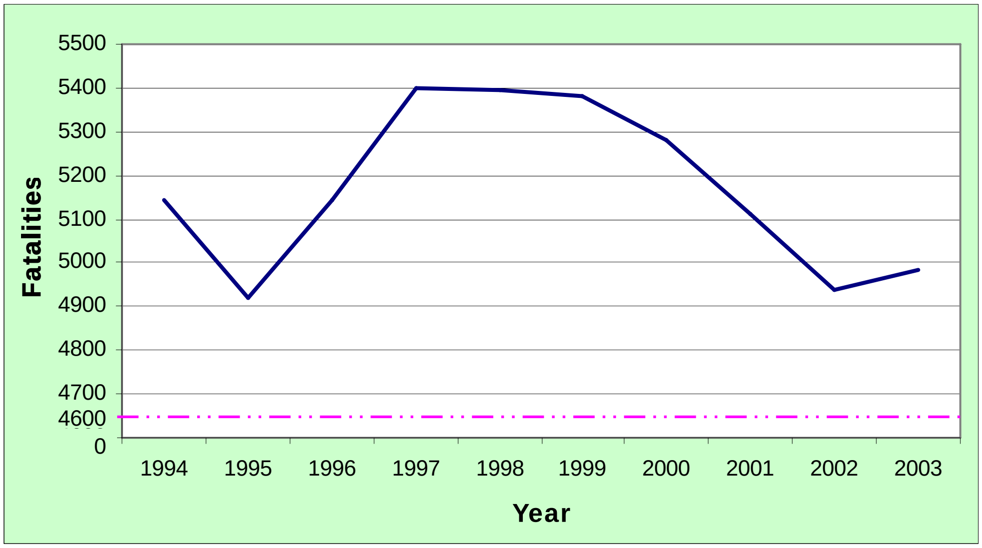

Figure 16. Fatalities Caused by Truck Accidents
(Source: Federal Highway Administration)

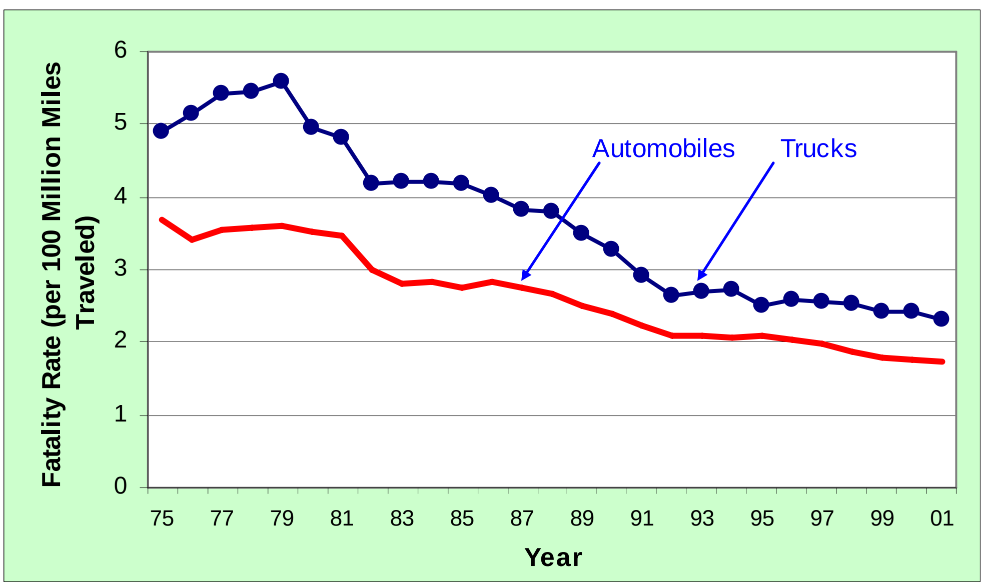

Figure 17. Fatality Rates (Automobiles vs. Trucks)
(Source: Federal Highway Administration)

Wislocki (2003) reported that the truck related fatalities fell in 2002 for the fifth year in a row, dropping by 4.2% (5,111 fatalities in 2001 to 4,897 fatalities in 2002); whereas, the overall number of traffic fatalities increased from 42,196 in 2001 to 42,815 in 2002.

From Figure 16, shows that there was a 9.6% increase in truck accidents from 1995 to 1997. These were the two subsequent years after the 1995 speed limit increase from 65 mph (National Highway Designation Act). There could four possible reasons that could account for this increase: (1) normal fluctuation in accident frequency, (2) greater number of vehicle miles traveled, (3) higher truck speed, and (4) higher speed increase of automobiles relative to trucks. Since most of the commercial fleets had speed limiters on their trucks that were set at or below 65 mph, the increase in posted speed limit beyond 65 mph would not have had a significant impact on the average truck speed. As a result, the speed of trucks became significantly lower than the average speed of automobiles, thus increasing the speed variance between the two. As discussed in a previous section, speed variance has been associated with an increase in accidents. From the data available from the Federal Highway Administration's website, the increase in vehicle miles traveled by trucks, from 1995 to 1996 was just 1%. Therefore the increase in miles does not completely account for the increased number of truck accidents. In addition, the reduction of approximately 10% accidents, from 1997 to 2002 during which speed limits did not change indicates that the increased speed variance between automobiles and trucks in the initial period could have contributed to the increase in truck accidents between 1995 and 1997.

Truck accidents are a major concern for safety authorities because of the higher probability of involving fatalities. According to Council, Harkey, Nabors, Khattak and and Mohamedshah (2003), in 1998, large trucks accounted for 7% of total miles traveled but were involved in 13% of all traffic fatalities (5,374 out of 41,471). In these truck crashes, the automobile's occupants were much more likely to be killed (78% of the fatalities) or injured (76% of the injuries) than the truck driver. It was found that an automobile driver's behavior was three times as likely to contribute to a fatal crash as the truck driver's behavior. Automobile drivers were solely responsible for 70% of fatal crashes, compared to 16% for the truck drivers. A similar study conducted by Carroll (2004) analyzed the interaction-critical incidents (incidents during vehicle interactions which could possibly lead to accidents), and concluded that 82.4% of these incidents were initiated by automobile drivers, while 17.6% were initiated by truck drivers. Kostyniuk, Streff and Zakrajsek (2002) conducted a study for the AAA Foundation for Traffic Safety of fatal, large truck-passenger vehicle accidents between 1995 and 1998. The study found that, when improper following or improper lane changes were a contributing factor in an automobile-truck accident, the automobile driver was in error 75% of the time and the large truck driver was in error 25% of the time.

Another reason provided for having lower speed limits for trucks is to avoid accidents that are caused by a loss of vehicle control at higher speeds. However, the research indicates that most of the accidents are the result of human error and very few are due to mechanical failure of vehicles. Treat (1977) performed a five-year study that examined the cause of 2258 automobile accidents. Only 2.4% accidents were caused solely due to mechanical fault and 4.7% were caused by environmental factors. It was observed that human error was the sole factor in 57% and a contributing factor in 92.6% of the accidents. Of those accidents, 90% involved perceptual error and only 10% response error.

Garber and Joshua (1989) studied the characteristics of large truck crashes in Virginia and found that driver related factors were responsible for 91% of large truck fatal crashes and 75% of all large truck crashes. Vehicle related factors were responsible for only 2.5% of large truck fatal crashes and approximately 8% of all large truck crashes. The driver related factors were identified as: driver error (50%), speeding (21%), drinking (15%) and driver handicap, which included fatigue and sleeping (14%). It should be noted that speeding in this context is defined as “driving faster than conditions” rather than simply being above the speed limit.

Blower and Campbell (2002) studied the actions by automobile and truck drivers that lead to fatal truck accidents. Truck driver fatigue was found to be responsible for 2.9% of the fatal crashes. Truck driver action was found to be responsible for 21.8% of the fatal crashes, while other vehicles were responsible for 59% of the fatal crashes. The loss of control of truck was responsible for 5.8% of all fatal crashes. Speed contributed to 2.4% of these crashes, road conditions to 1.7% and vehicle failure to 0.7%. The number of fatigue-related accidents reported in this study was much lower than was reported in the study by Garber and Joshua (1989). However, when only the crashes caused by truck drivers were considered, fatigue was found to be responsible for 13.3% of the fatal crashes.

The study by Kostyniuk, Streff and Zakrajsek (2002) documented the frequency of unsafe driver actions in fatal automobile-truck accident. They found that the top three factors for automobile drivers involved in automobile-truck accidents were: (1) failure to keep within the lane or running off the road (21%), (2) failure to yield right of way (16%), and (3) driving too fast for road conditions or exceeding the speed limit (12%). For truck drivers, the top three factors were: (1) failure to yield the right of way (14%), (2) failure to keep within the lane or running off the road (12%), and (3) driving too fast for the road conditions or exceeding the speed limit (11%).The top three “unsafe actions” of automobile drivers involved in automobile-automobile accidents were similar to the actions of automobile drivers involved in an automobile-truck accident. The data suggest that pre-crash driving actions of automobile drivers involved in fatal crashes were not significantly affected by whether the crash involved another automobile or a truck.

Thiriez, Radja and Toth (2002) found that more than 70% of accidents that occurred in traffic moving in the same direction were rear-end accidents. These were, followed by sideswipe and forward impact crashes, which constituted 20% and 10%, respectively.

Craft (2002) conducted an analysis of trucks involved in fatal accidents that focused on rear-end accidents. It was found that each year, approximately 400,000 trucks are involved in motor vehicle crashes. Eighteen percent of the accidents involving trucks are rear-ended crashes. Rear-end crashes can be further categorized into automobile rear-ending a truck and truck rear-ending an automobile. Since the operating characteristics (maneuverability and braking distance) and physical features (weight) of automobiles and trucks are different, the two crash types are quite different in their probability of occurrence and their severity. Craft found that 50% more trucks rear-end automobiles than do automobiles rear-end trucks (42,000 versus 28,000). However, there are 70% more fatal accidents in which the automobile rear-ends the truck. Of the 271 fatal accidents in which the truck hit the automobile, 58% took place on interstates, while 40.5% of the 461 fatal accidents where the automobile hit the truck occurred on interstates. The probability of a fatal accident, given that an accident has occurred is 183% more for automobiles rear-ending trucks than for trucks rear-ending automobiles.

Large trucks are much more likely to be involved in fatal multiple vehicle crashes than automobiles. According to Knipling, Waller, Peck, Pfefer, Neuman, Slack and Hardy (2004), 84% of all crashes involving large trucks were multiple vehicle crashes, compared to 61% for passenger vehicles. According to Craft (2002), 18% of all accidents where the truck rear-ended an automobile involved three or more vehicles; whereas, only 5% of the automobile rear-ending a truck accidents involved three or more vehicles. For fatal accidents only, Craft observed that 46% of all accidents in which a truck rear-ended an automobile involved three or more vehicles; whereas, only 16% of the accidents in which an automobile rear-ended a truck involved three or more vehicles.

Stuster (1999) performed an analysis of the causes of fatal accidents and listed the 25 most frequent acts committed by automobile drivers that can lead to accidents. The top 5 were: (1) driving inattentively, (2) merging improperly into traffic and causing a truck to maneuver or brake quickly, (3) failing to stop for a stop sign or light, (4) failing to slow down in a construction zone, and (5) following too closely.

Carroll (2004) studied the incidents that led to 142 automobile-truck accidents. The top two incidents attributable to automobile drivers were: (1) lane change without sufficient gap and (2) entering the roadway without sufficient clearance. The most frequent incident attributable to truck drivers was entering a roadway without sufficient clearance. Posted differential speed limits and truck speed limiters can increase the potential problems with drivers entering the roadway at traffic speed.

To examine the impact of differential speed limits on traffic fatalities involving trucks, Neeley and Richardson (2004) analyzed nationwide fatality data from 1994 to 2000. They found that truck speed limits and the drunken driving laws were the only laws that significantly reduced the fatalities in crashes involving large trucks. The authors concluded that the difference between automobile and truck speeds did not affect safety, and the enforcement also did not affect the number of traffic fatalities.

Another major factor that has been associated with truck accidents is speeding. Speeding is the act of exceeding the posted speed limit or driving too fast for existing conditions. The accident databases do not differentiate between these two scenarios. When the percentage of truck accidents caused by "speeding" trucks is reported, care must be taken to understand that most of the trucks were not traveling at a rate above the posted speed limits. Reviewers of the literature that discuss the frequency of "speeding" related accidents and drawing conclusions about the posted limits may be drawing invalid conclusions. It should also be noted that the definition of "traveling too fast for conditions" is not clearly defined. Therefore, studies that classify accidents using this category may report different results based on their definition. In some of the reported research, "speeding" is defined as the act of exceeding a certain speed (i.e., 65 or 70 or 75 mph) which may not be the posted speed limit.

Bowie and Marie (1994) analyzed the nationwide accident data and found that speeding was involved in 12% of all police-reported crashes and 33% of all fatal crashes. Speed was found to affect the single-vehicle accidents most, as up to 40% of single vehicle accidents were due to high speed. According to the National Highway Traffic Safety Administration (2004), speeding was a contributing factor in 31% of all fatal crashes in 2003. Speeding and driving while intoxicated (DWI) frequently occur together. In 2003, 28% of the drivers who were involved in fatal crashes when speeding were driving under the influence of alcohol. Advocates for Highway and Auto Safety (1995) reported that speeding was a factor in 33% of all fatal crashes, and it was also reported that 56% of the drivers in speed related fatal crashes were under the influence of alcohol.

According to Gruberg (1999), 22% of the accidents involving trucks in multi-vehicle fatal accidents involved speeding by at least one of the drivers. Truck drivers were found to be speeding in 6.7% of the occurrences compared to 14.9% for automobile drivers. Speeding related multi-vehicle crashes most frequently result in rear-end collision (34%), followed by head-on (27%), angle (25%) and run-off-road (9%). According to Garber and Joshua (1989), who studied the characteristics of large truck crashes (both single and multiple vehicle), 21% of the fatal crashes caused by truck driver-related factors were associated with speeding.

Although there are different opinions as to the effect of speed, as opposed to "speeding," there is a consensus as to the physics involved. Faster vehicles have less time to respond (in seconds and distance) and the severity of accidents that occur at higher speeds is greater.

2.4 Effect of Speed on Driver Fatigue

A significant amount of research literature has addressed the relationship between fatigue and accidents. Driver fatigue can be categorized in two main types: (1) physical and mental fatigue caused by physical and mental stress and, (2) inattention caused by boredom. Fatigue causes several problems for drivers, such as slower reactions and decisions, slower control movements, hallucinations; decreased tolerance for other road users, poor lane tracking and maintenance of headway speed, and loss of situational awareness. Symptoms vary among drivers, but may include: yawning, poor concentration, tired or sore eyes, restlessness, drowsiness, slow reactions, boredom, feeling irritable, making fewer and larger steering corrections, missing road signs, having difficulty in staying in the lane and micro sleeps. As fatigue can decrease the ability of a driver to maintain a steady speed, it increases the speed variation, which can increase the speed variance of the traffic flow (Roads and Traffic Authority, 2004).

A study conducted by Sagberg (1999) showed that 4% of incidences of micro sleeps can lead to a crash, most of which are running-off-the-road crashes (3.5%). The most common consequences of fatigue were incidents such as crossing the right edge line (42%), which occurred more frequently than crossing either the centre line (16%) or the left edge line (4.6%). Williamson, Feyer, Friswell and Sadural (2001) surveyed professional long distance heavy vehicle drivers in Australia and asked them about the influence of fatigue on their driving. Truck drivers' self-reports indicated that fatigue influences their driving performance, resulting in increased reaction time, gear shift errors, and reduced speed.

According to the National Highway Transportation Safety Administration (1994), truck driver fatigue is a contributing factor in as many as 30-40% of all heavy truck crashes. In 1995, the National Transportation Safety Board found that of 107 heavy truck crashes, fatigue was a prominent factor in 75% of the run-off-the-road crashes, with 68% of long-haul drivers and 49% of short haul drivers involved in fatigue-related crashes (Advocates for Highway and Auto Safety, 2001).

Data from Western Australia that used proxy measures (such as: "drifted off curve or straight", "wrong side of road with no overtaking maneuver", "where speed or alcohol was not a factor"), indicated that approximately 30% of the rural crashes could be attributed to fatigue (Office of Road Safety, Western Australia, 2004). This estimate is much higher than the estimated 14% fatigue related accidents reported by Garber and Joshua (1989) because the former study considered only the rural roads, whereas the later study considered all highways types. Most fatigue-related crashes occur on rural roads. One reason for this is that the average trip length is likely to be longer on these roads and inattention and drowsiness are brought on by the constant speeds and monotony. In 1998-2002, 79% of fatigue-related fatal crashes in New South Wales, Australia, occurred on country roads.

In another Australian study, Fell (1987) reported that commercial trucks have a higher involvement in fatigue-related accidents, compared to their involvement in other types of accidents. Heavy trucks in New South Wales, Australia involved in 3.7% of all fatigue-related accidents, but only 1.5% of all non-fatigue-related accidents. Ryan, Wright, Hinrichs and McLean (1988) conducted an in-depth study of automobile and truck crashes on rural roads near Adelaide, Australia. When automobile drivers were surveyed, 31.4% responded that they had felt slightly, moderately, or highly fatigued just prior to the accident. The percentage reporting fatigue was much higher for truck drivers (41.7%).

Limerick (2002) studied the main factors that often cause truck drivers to be fatigued while driving. These factors, listed in decreasing order of importance, were: automobile drivers, underpowered vehicles, peer road conditions, early morning driving, city traffic, lack of sleep during trips, highway traffic, loading/unloading, driving without breaks, bad weather, breaks too short, poor diet, lack of sleep before trips, etc. In a study conducted by the Federal Highway Administration, Carroll (2004) studied the factors that induce fatigue in short-haul commercial truck drivers. The factors responsible for inducing fatigue, in decreasing order of importance, were: (a) not enough sleep, (b) hard physical work day, (c) heat without an air conditioner, (d) waiting to unload, and (d) irregular meal times. The European Transport Safety Council (2001) also studied the factors that could increase the risk of fatigue related truck accidents, and the following three factors were observed to be the most crucial ones: inadequate sleep, length of the working day, and irregular working hours. Haworth (1998) examined the factors that contribute to the development of driver (both automobile and truck) fatigue in Australia. The five main factors that induced fatigue according to this report were (in no particular order): (a) intensity and length of manual and mental work, (b) psychic factors: responsibilities, worries and conflicts, (c) surroundings: illumination, climate and noise, (d) monotony, and (e) illness, pain, and eating habits.

Although there has been a significant amount of research conducted on the effect of driver fatigue on safety, there has been virtually no published research that addresses the effect of operating speed on driver fatigue. One study conducted by Jiao (2004) assessed the impact of operating speed on fatigue. Thirty drivers were chosen for observation and were randomly divided into three groups, driving at 40 kph (24.86 mph), 80 kph (49.71 mph) and 120 kph (74.57 mph), respectively. All of the three groups were asked to drive for 2 hours, without any break. After the completion of two hours, the heart rate variability was measured. The group that drove the fastest had the maximum change in heart rate variability and the slowest group had the least change. Based on this physiological measure, the author concluded that the higher speeds induce more fatigue on drivers compared to lower speeds. However, these results are based on the amount of fatigue per unit of time, not the amount of fatigue per mile. The fastest group drove for 240 km in 2 hours; whereas the slowest group drove only 80 km in the two hours. If all of the three groups of drivers had traveled for an equal number of kilometers, the results might have been different.

Oron-Gilad, Ronen, Cassuto and Shinar (2003) conducted a study to examine changes in driving performance, subjective feelings of the driver, and physiological measures while maintaining different travel speeds in a driving simulator. Drivers were divided randomly into two groups: one driving at the “legal” speed of 90 kph (56 mph) and other at the “low” speed of 60 kph (38 mph). Each driver was instructed to initially drive the simulator for 10 minutes without any speed limit settings (“fun” speed) and then instructed to drive at either ‘legal’ or ‘low’ speed for an additional 25 minutes. At the end of this driving cycle, the participant was again asked to complete a questionnaire.

The driving performance was measured using five variables: the average lane position, lane position variability, steering wheel variability, average speed and speed variability, and the rate of off-road incidents. The average speed during the “fun” speed driving section was measured to be 110 kph (68.35 mph). The between subject comparison of driving performance under the 90 kph and 60 kph showed that performance in 90 kph speed trial was significantly poorer than in the 60 kph speed trial. The physiological measures indicated that the driver was most relaxed and least stressful operating at 90 kph compared to operating at 60 kph or the even higher “fun” speed. Based on the survey results, motivation to continue driving was observed to be significantly lower in ‘low’ speed condition compared to “legal” speed condition. It was concluded that, although lowering the travel speed can yield better driving performance and lower rates of off-road incidents, it can also cause a significantly lower motivation to continue driving and a significantly higher level of stress.

Although fatigue has received a large amount of attention in the literature, particularly in the context of “hours of service,” none of the available research or applications literature addresses the relationship between vehicle speed and fatigue. To the extent that the speed is increased, the travel time, and possibly the amount of fatigue, is reduced. There is no empirical data indicating that increased speed, within the normal driving range, increases fatigue. To the extent that fatigue is related to driving time, rather than distance, higher speeds could reduce fatigue on a per mile basis. However, there is no published research or data to support or contest this hypothesis.

2.5 Effects of Speed and Weight on Braking Distance

Speed affects the handling, stopping and operating characteristics of vehicles. Due to the simple physics related to their large size and weight, vehicle speed has a significant effect on truck handling and dynamics. Among these, stopping distance has been the most frequent reason for setting lower speeds for trucks. Since rear-end accidents make up a high proportion of accidents involving trucks, some policy makers suggest that trucks should operate at slower speeds so that the stopping distance of trucks would be made more compatible to that of automobiles. Braking distance consists of two primary components: (1) the distance traveled by the driver from the time a hazard is perceived to when brakes are applied and (2) the distance traveled while brakes are applied. Generally the braking distance required to come to a complete halt increases as the speed increases. According to the North Carolina Department of Motor Vehicles (NCDMV) when the speed is doubled, the braking distance increases by four times and the vehicle will have four times the destructive power in a crash.

The effect of speed on a truck's operating characteristics is determined by its size and the configuration. Brake technology has been improving rapidly for heavy trucks. The Federal Motor Vehicle Safety Standards (FMVSS) have required anti-lock braking systems (ABS) on new trucks and trailers since 1997. According to Harwood (2003), roughly 43% of the trucking fleet is estimated to have anti-lock brakes. The wide spread use of anti-lock brakes on today's trucks helps avoid wheel lock and jackknife conditions, thus considerably improving stability during braking. Anti-lock brakes also help when stopping a truck in adverse weather conditions like ice, snow, and rain; however, the braking distance of the trucks remains longer than that of automobiles.

The stopping distances of automobiles and trucks are compared in Table 8 below. The Oregon Trucking Association web page provided estimates of the stopping distance for 80,000 lb., loaded tractor-trailers and mid-sized passenger automobiles traveling on a dry, level road.

The table illustrates that, for a completely loaded truck on a level roadway, up to 60% more distance is required to come to a complete halt at 65 mph compared to the distance required for 55 mph. With the improvements in truck braking systems (e.g., air disc brakes, electronic braking systems, etc.), the stopping distance for trucks has been significantly reduced. Currently, pneumatically braked truck tractors are required to stop from 60 mph in 355 ft. at gross vehicle weight rating; whereas the stopping distance requirement for passenger automobiles is 216 ft. The introduction of all-disc brakes and

Table 8. Stopping Distance of Automobile versus Truck (Source: National Safety Council's Defensive Driving Course for Professional Truck Drivers)

Speed	Reaction Distance Automobiles	Reaction Distance Trucks	Stopping Distance Automobiles	Stopping Distance Trucks
40 mph	44'	44'	124'	169'
55 mph	60'	60'	225'	335'
65 mph	71'	71'	316'	525'

“all S-cam” brakes, the new NHTSA law will potentially require reducing the stopping distance for trucks by 30 %, to 249 ft., making the stopping distance for automobiles and trucks more comparable. This will decrease the importance of one of the most frequently stated reasons for differential speed limits that require trucks to travel slower.

There is one advantage that a truck driver has over an automobile driver which is the eye height. Since the truck drivers’ an eye height is much higher than automobile drivers’ (8 feet as compared to 3.5 feet when seated, they can see farther down the road and over other vehicles. Therefore, the truck drivers have an advantage in response time to forward hazards. This also helps offset the effect of the longer stopping distances for trucks.

Many references, particularly in the popular literature, discuss the fact that truck speeds should be low because the weight of the truck significantly increases the stopping distance. This is not supported by data. The brakes, tires, springs, and shock absorbers on heavy vehicles are designed to work best when the vehicle is fully loaded. Empty trucks require greater stopping distances, because an empty vehicle has less traction. It can bounce and lock up its wheels, giving much poorer braking (Commercial Drivers License Study Guide). The data available from NHTSA also indicates that the difference in stopping distance between a lightly loaded truck (335 ft.) and heavy loaded truck (355 ft.) is just 20 ft. In near future, with the new NHTSA braking requirement law, the stopping distance for both the lightly loaded and heavily loaded truck will be reduced by 30 %, thus reducing the difference between them to only 16 ft.

2.6 Effects of Speed on Operational Costs

In addition to different posted speed limits on rural interstates, speed differentials between heavy trucks and other vehicles occur due to the fact that most large commercial trucking fleets use speed limiters to restrict truck speed. One of the primary reasons for the use of limiters is to reduce operating costs. This section will summarize the of speed on fuel economy, tire wear and other maintenance costs.

2.6.1 Effects of Speed on Fuel Costs

The National Minimum Speed Limit (NMSL) of 55 mph was introduced in 1973 for the primary purpose of saving fuel during an energy embargo. This rule was in effect until 1987, when it was modified and until 1995, when it was repealed. After the 1987 and 1995 legislation speed limits were raised in most of the states. However, many trucking companies preferred the lower speed to reduce operating speeds. Although there is the possibility of increasing their revenue with higher speeds, based on increased miles traveled by each truck, companies have chosen to operate at lower speeds because of the assumption that the increase in fuel costs would outweigh the benefit of increased revenue.

Within the trucking industry, there is a common “rule of thumb” that “each increase in vehicle speed of 1 mph reduces the fuel efficiency by 0.1 mpg.” This rule of thumb was developed by The Maintenance Council [now the Technology and Maintenance Council] of the American Trucking Association (1996) in their study that addressed the effects of truck speed on operational costs.

Fuel economy tests were conducted in 1987 and were re-published again in 1996. The actual tests were conducted in 1987. Two trucks operated simultaneously, one with a 55 mph maximum speed limit and other with a 65 mph maximum speed limit. The “55 mph” truck had an average speed of 50.1 mph over the complete trip; while the “65 mph” truck had an average speed of 57.1 mph. After testing, the average fuel consumption values were observed to be 5.46 mpg for the 65 mph condition and 6.44 mpg for the 55 mph condition. Therefore a loss of 0.98 mpg was observed, which was caused by a 10 mph increase in the maximum operating speed and a 7 mph increase in the average speed. It was concluded that for every 1 mph increase in average speed, there is a 0.14 mpg penalty on fuel economy. These results were once republished by the same committee in 1996, the reasoning being that most of the committee members thought that these results were still valid. Until today, the majority of the trucking industry uses these estimates when making speed limiter decisions. There were methodological issues involved with the 1987 study. The vehicles were underpowered, compared to most trucks today and, therefore, were not as suitable for operating at the higher speeds. During one of the test runs, the vehicle operating at 65 mph was not able to maintain its speed, which creates questions as to the validity of this study. It should be noted that the measurement of fuel efficiency is very complex and the Technology and Maintenance Committee of the American Trucking Association has recently formed a special group to study the test procedures for measuring the fuel efficiency of trucks.

Broderick studied the effect of speed on fuel consumption of heavy trucks (1975). The tests were conducted at 50, 55 and 60 mph operating speeds on the Massachusetts turnpike. The results indicated a fuel savings of up to 2% per mile per hour speed reduction between 60 mph and 55 mph. However, this test was conducted 30 years ago and both the internal (engines) and external (aerodynamics) characteristics of trucks are very different today. The applicability of these results is somewhat questionable with respect to modern vehicles.

Efficiency losses in heavy trucks include (a) aerodynamic drag, (b) grade resistance, (c) the rolling resistance, and (d) engine accessory/drivetrain losses. Aerodynamic drag has the largest effect at higher speeds (above 50 mph). There are a large number of aerodynamic forces acting on a vehicle that depend upon the speed, frontal area, and external shape of the vehicle. According to the U.S. Department of Energy, at 70 mph, aerodynamic drag accounts for approximately 65% of the total energy loss for a typical heavy truck (Ang-Olson and Schroeer (2003)). The authors state that, with no aerodynamic treatment, at 65 mph a total of 264 horsepower is needed to overcome all of the forces acting on the truck. Aerodynamic forces account for 145 hp (55%) of power demand, tire rolling resistance accounts for 87 hp (33%), and miscellaneous forces account for 32 hp (12%). At 65 mph, with full aerodynamic treatment, the horsepower required to overcome aerodynamic forces can be reduced to 113 hp (22% reduction).

The use of roof-top deflectors and fairings, cab-side extenders, gap seals, tapering rears of the trailer, along with underside and trailer sidewall improvements reduce aerodynamic drag (Cooper, 2003). Aerodynamic drag has been reduced by 40% in the last 30 years. Starting with aerodynamic drag coefficient value of 1 in the 1970's, today the value can be reduced to 0.7. Cab-over-engine designs further lower drag to 0.5. If the tractor and the trailer could be integrated then this value could be reduced to 0.4 (Muster, 2000).

A brochure published by Cummins, Inc. (2003) listed recommendations for improving the fuel economy of heavy trucks. The company brochure states that the "rule of thumb" is for each 1 mph increase in speed above 55 mph the fuel economy decreases by 0.1 mpg. It was also indicated that tires have the largest effect on fuel consumption below 50 mph, whereas aerodynamics is the most important factor above 50 mph. There were also other factors listed in the Cummins (2003) study that could improve the efficiency of trucks, summarized in Figure 18. The table illustrates that "driver variability" is almost twice the effect of vehicle speed.

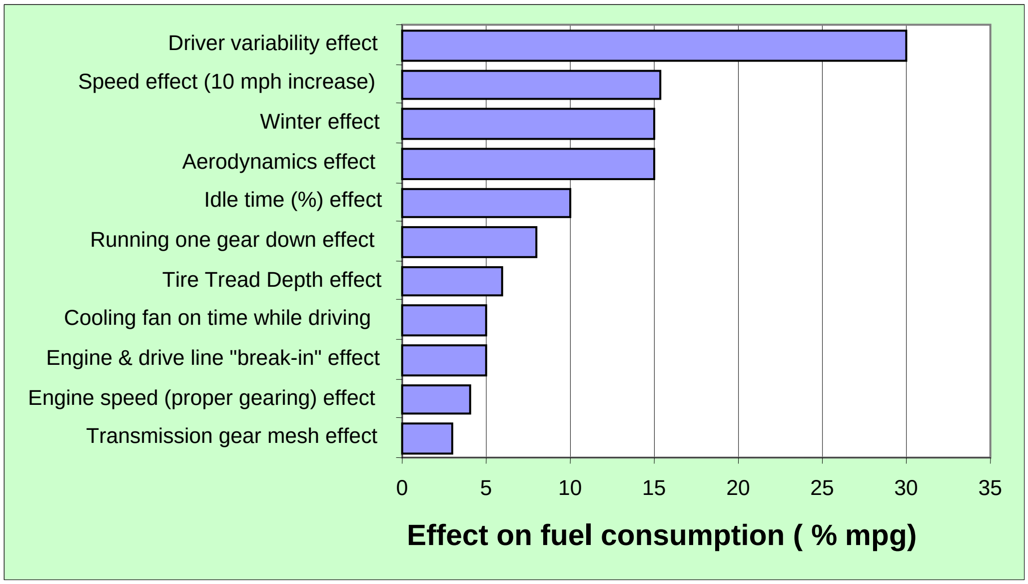

Figure 18. Factors Affecting Fuel Economy
(Source: Cummins, 2003)

According to Deierlein (2000), the most important fuel economy variable was the driver, who controls the idle time, vehicle speed, brake use, etc. The difference between a “good” and a “bad” driver can be up to a 35% in fuel efficiency. Another very important factor is the proper specification and setup of the engine. An electronically controlled engine can save up to 15% over a manual engine. Use of cruise control versus no cruise control can also improve fuel economy by up to 6%. These percentages are very dependent upon the skill level of the driver.

Considering the importance of fuel consumption by commercial carriers to the national economy, it is interesting that there is very little published research addressing the effect of truck speed on fuel consumption. To further address the issue of vehicle speed and fuel consumption the literature pertaining to automobiles will be addressed.

The power-to-weight ratio has been found to be an important factor in fuel consumption. For small power-to-weight automobiles, changing speed from 55 mph to 65 mph increased fuel consumption by approximately 13%; whereas for high power-to-weight automobiles the fuel consumption increases by only 9% (Bedard, 1996). This result has serious implications for the interpretation of the Maintenance Council’s results that have previously been discussed. Tests that are conducted with trucks that do not have sufficient power could give a distorted view of the impact of speed..

The Transportation Energy Data Book: Edition 24, published by US Department of Energy, illustrated the relationship between speed and fuel efficiency for automobiles, as shown in Figure19 below. According to the 1997 test results, the increase in speed from 55 mph to 65 mph results in a 9.7 % loss in fuel economy; however, for the same

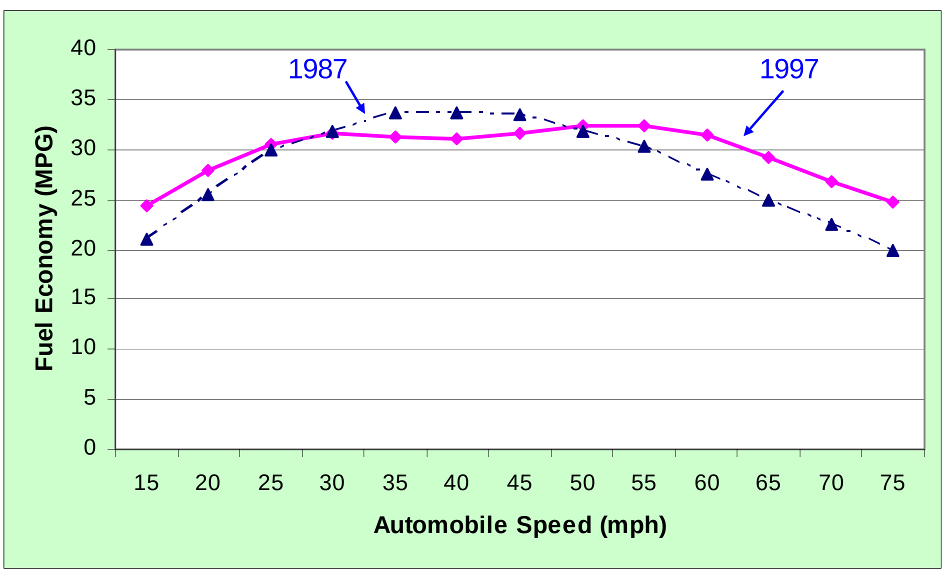

Figure 19. Effect of Speed on Fuel Consumption for Automobiles (Source: US Department of Energy, 2004)

increase in speed, the 1987 test results indicated a 17.8% loss in fuel economy. These results indicate that, with improvements in vehicles aerodynamics and engine components, traveling at a higher speed has a less negative impact on fuel consumption.

2.6.2 Effects of Speed on Tire Costs

After aerodynamic drag, the most significant factor that affects fuel consumption is tire rolling resistance. The energy (fuel) required to move the vehicle is directly proportional to the rolling resistance coefficient, which is influenced by the frictional properties of road and tires.

According to Muster (2000), there is a 1% truck fuel efficiency gain for every 2.6% reduction in the rolling resistance coefficient. A study by Hall and Moreland (2001), found a reduction in the rolling resistance of 10% can improve fuel efficiency by 0.5% to 1.5% for automobiles and 1.5 to 3% for trucks. They also found that 5 to 15% of the fuel is necessary to overcome rolling resistance for passenger automobiles and 15 to 30% for heavy trucks. There has been a significant effort to reduce the tire rolling resistance. Reductions in rolling resistance of 50% have been accomplished, relative to 1980 level. Muster (2000) reports that the rolling resistance coefficient has been reduced significantly by the introduction of radial tires (from 0.01 to 0.0054). It is predicted that in the future, super single tires will be able to decrease the rolling resistance coefficient to as low as low to 0.005.

Under-inflated tires increase the rolling resistance coefficient. According to Farkhan (1999), tires represent approximately 20% of the total maintenance costs. A 10 psi under inflation can result in a 1% increase in fuel consumption, and 20% faster tire wear. A properly inflated tire running at 65 mph will heat up to approximately 170 degrees and 5-psi under inflation can cause the tires to become up to 25 degrees hotter. Under inflation also results in more flexing, thus limiting the number of potential retreads from each casing.

A document published by Goodyear (2003) states that for every 1 mph increase in operating speed over 55 mph, there is a reduction of 1% in tread mileage. This means that operating at 75 mph instead of 55 mph would cost trucks 20% in terms of tread life. Similar data are presented in a document published by Bridgestone/Firestone Commercial Truck Tires (2004). This brochure states that higher speeds reduce tire life by 10-30%. At higher speeds, the tires are hotter, which can reduce casing life and retreadability. The maximum load capacity at 75 mph decreases by up to 12%, from the maximum load capacity at 65 mph. However, load-carrying capacity decreases by only 4% when operating at 70 mph rather than at 65 mph.

The effect of speed on rolling resistance was explained in detail by Hall and Moreland (2001). Different trends are observed as the speed increases. They found that the phase lag angle for the composite material of tires decreased with frequencies in the range of the rolling tire deformations. This results in a decrease in rolling resistance as speed increases. They also found that tire temperature increases with speed, which also reduces the rolling resistance. However, these two positive effects are more than offset by the increase in the tire deformation that occurs due to centrifugal force with increasing speed. In addition, the aerodynamic drag, which is a component of rolling resistance, also increases with the square of speed. Thus, the authors concluded that an increase in speed results in an increase in the rolling resistance.

2.6.3 Effects of Speed on Maintenance Costs

The Maintenance Council of the American Trucking Association analyzed the effects of speed on operation costs in a landmark study (1996). The operating speed was assumed to affect the component durability. No detailed data were presented in this study and most of the results obtained were based on the consensus among the committee members. According to the document, an increase in operating speed from 55 mph to 65 mph had the following effects:

(a) 10 to 15% decrease in miles-to-engine overhaul
(b) oil consumption increase of 15%
(c) shortened mileage between preventive maintenance intervals
(d) decrease in effective tire casing life
(e) reduction of up to 15% in brake lining life

With respect to comparing the potential increase in productivity (due to more miles traveled) to the estimated increase in cost, The Maintenance Council believed that it was nearly impossible to make a case for sufficient productivity gains to offset the increased costs associated with operating at speeds higher than 55 mph. No other published data related to maintenance costs, engine life, and operating speed were found by this study.

2.7 Effects of Speed on Pollution

The transportation sector is the dominant source of fuel consumption and emissions in the United States. The Environmental Protection Agency (EPA) (2001) uses a highway vehicle emission factor model, MOBILE, to predict how emissions will change with changes in various conditions such as average speed, temperature, fuel type, etc. The MOBILE model is based on emissions from vehicles tested under laboratory conditions. Because the data used in the recent model (MOBILE 6) were collected before the repeal of 65-mph National Maximum Speed Limit, the average vehicle speed for freeways was less than 65 mph. However, the report assumes that the emissions will increase beyond 65 mph. Compared to the previous models, MOBILE6 predicts a smaller increase in emissions at speeds above 55 mph for freeways, because the revised “speed correction factors” (SCFs) now differentiate between freeways and freeway on-ramps (where vehicles undergo hard acceleration). The factors estimated using MOBILE6 for light duty vehicles (model years 1996 and later) are shown in Figure 26. The Environmental Protection Agency (2001) only provides these estimates for speeds up to 65 mph. Monsere, Newgard, Dill, Rufolo, Wemple, Bertini and Miliken, C. (2004) used the extrapolation method to estimate the emission factors at 70 mph (Table 9 and Figure 26).

The Environmental Protection Agency has very little data on the emissions for heavy diesel trucks and does not differentiate among freeways, ramps, arterials, etc. Furthermore, the speed correction factors for trucks have only been developed using the older model (MOBILE5), thus they are questionable in that, as previously discussed, the factors may be overestimated by the older model. Table 10 provides the estimated changes in speed correction factors from 55 and 60 mph to 65 mph. Figure 27 illustrates the extrapolated estimates calculated by Monsere, Newgard, Dill, Rufolo, Wemple, Bertini and Miliken, C. (2004) using Environmental Protection Agency’s (2001) data.

The change in speed limit would impact only the “running emissions” that are produced when the engine is warm and the vehicle is in motion. But these are only a part of the total emissions produced. Therefore, the amount of increase in overall emissions due to increased highway speed is probably overestimated by these speed correction factors.

In addition to speed, the roadway geometry also has a large impact on the emission rates. Kean (2003) found that the carbon monoxide (CO) emissions for light duty vehicles increased more with speed while going uphill and varied little with speed while going downhill. Furthermore, vehicle acceleration and deceleration were found to have a significant impact on the emission rates.

In 1997, E.H. Pechan and Associates estimated the impact of the increased speed limit in 1995 on emissions using the MOBILE5 model. They found that the emission of volatile organic compounds on roadways with higher speed limits increased by 1 to 4%, while the NO_x and CO increased by much higher percentages (1-35% and 1-38%, respectively). According to den Tonkelaar (1994), for automobiles the increase in CO and NO_x emissions with speed is greater than those of hydrocarbons, especially for CO, which was observed to increase rapidly beyond 90 kph.

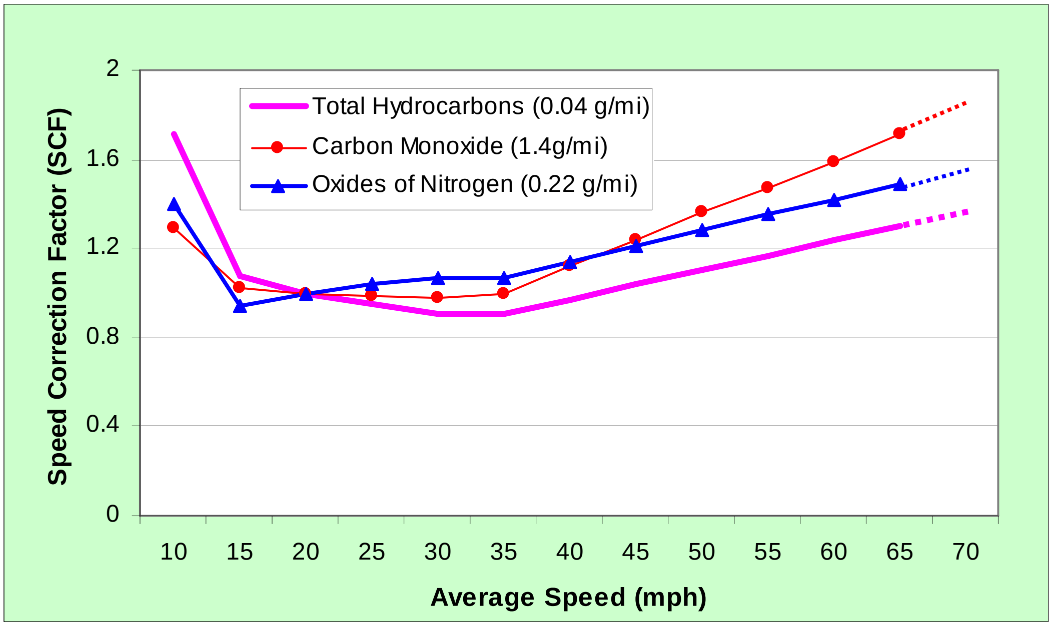

Figure 20. Freeway Speed Correction Factors for Light Duty Vehicles (Source: US Environmental Protection Agency, 2001; Monsere et al., 2004)

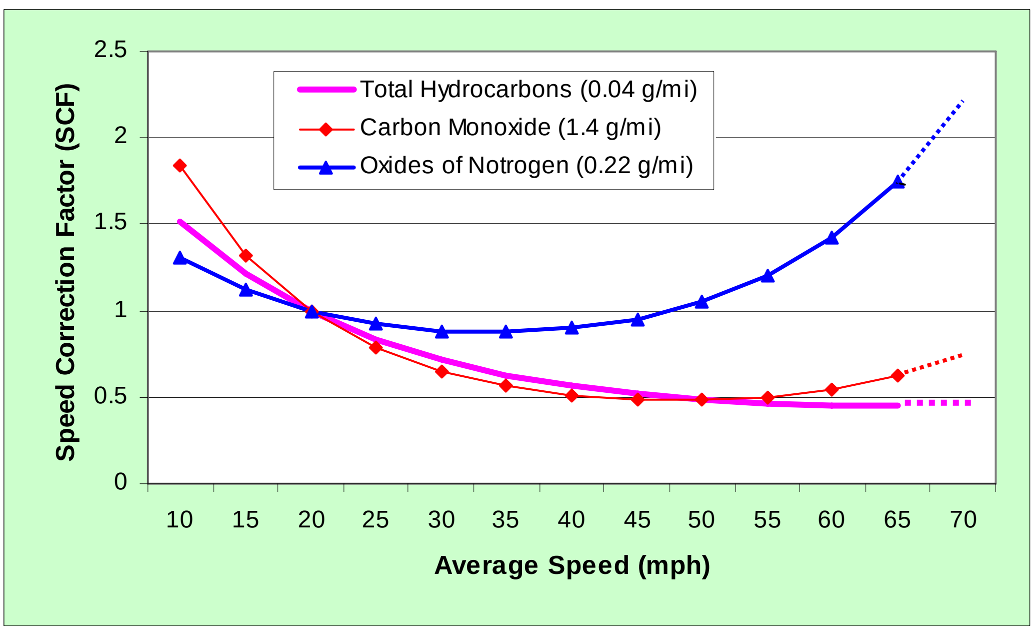

Figure 21. Freeway Speed Correction Factors for Heavy Diesel Trucks (Source: US Environmental Protection Agency, 2001; Monsere et al., 2004)

Table 9. Change in Freeway Speed Correction Factors (SCFs) for Light Duty Vehicles (Source: US EPA, 2001; Monsere et al., 2004)

	Total Hydrocarbons (THC)	Carbon Monoxide (CO)	Oxides of Nitrogen (NOx)
55 to 70 mph	16%	24%	16%
60 to 70 mph	10%	15%	10%
65 to 70 mph	5%	7%	5%

Table 10. Change in Freeway Speed Correction Factors (SCFs) for Heavy Diesel Trucks (Source: US EPA, 2001)

	Total Hydrocarbons (THC)	Carbon Monoxide (CO)	Oxides of Nitrogen (NOx)
55 to 65 mph	-2%	24%	45%
60 to 65 mph	0%	14%	23%

2.8 Effects of Speed and Speed Differentials on Roadway Wear

There is an issue of roadway wear as a function of highway speed limits. Chatti (1996) studied the impact of speed on pavement strains. The effect of vehicle speed on pavement strains was significant. Increasing vehicle speed from 2 mph to 40 mph caused a decrease of approximately 15 to 30% in transverse strains and 30 to 40% in longitudinal strains. However, one main issue with this study, relative to the current effort, was that the speed data did not exceed 40 mph.

Luskin (2001) studied the impact of truck operations on the highway infrastructure, and concluded that, for a truck moving over smooth pavement, the load transmitted to the pavement would be static. An increase in the operating speed of the truck would not affect the intensity of stress on the pavement, but it would reduce the duration for which the vehicle would be on pavement, thus reducing the amount of pavement damage. Akram, Scullion, and Smith (1993) studied the effect of operating speed on pavements using a multidepth deflectometer. Evaluation of vertical compressive strain data showed that sub grade strains at the bottom of the asphalt layer decreased substantially with an increase in vehicle speed. However, this study considered only speeds up to 55 mph.

While there have been very few scientific studies conducted to investigate the relationship between higher speeds (speeds above 55 mph) and road wear and maintenance, there seems to be a common consensus among researchers that the amount of wear and tear caused on the roadway is directly proportional to the time during which the roadway is exposed to the vehicle's tires. Therefore, as the speed limit increases, the amount of time that the tires will remain in contact with the unit area of the road decreases. Thus, wear caused by the tires on that particular unit area of road will decrease. Overall, as the traveling speed of the vehicles increases, the time for which the vehicles will be traveling on the road decreases, thus decreasing the roadway wear.

Although there have been no direct studies of the issue, there could be another important relationship between speed differentials and roadway wear. Generally, as the speed differential between automobiles and trucks, or among trucks, increases, the amount of maneuvering increases. These maneuvers include decelerating and accelerating and moving laterally across lanes. These activities could have a very large effect on roadway wear.

3. Research Methodology

This research effort used a number of approaches to assess the effects of speed differentials for heavy trucks and lighter vehicles. The approach included observations of both truck and automobile driver behaviors on highways with different speed limit configurations. In addition, opinion data were collected from over-the-road truck drivers, fleet safety and maintenance personnel, and engineers from the truck, engine, and tire manufacturers. Computer simulation of highway traffic was used to investigate the effect of speed differentials on the amount of interaction among vehicles. Finally, safety and operational data from participating fleets were used to address the effect of speed differentials on the trucking industry.

3.1 Measurement of Traffic Speeds on Highways with Different Limits

The research literature discussed in the previous section generally evaluates highway safety issues using the available accident and fatality databases (i.e., FARS). Some of the research discusses the distribution of vehicle speeds as a function of speed limit. However, very few studies discuss the distribution of speeds for heavy trucks versus lighter vehicles. In particular, the distribution of truck and automobile speeds on highways is important in order to understand the effect of speed differentials on traffic flow and vehicle interactions.

Different sites were investigated on rural interstate highways in Arkansas (I-40), Missouri (I-44), Oklahoma (Cherokee Turnpike) and Illinois (I-57). These sites had maximum speed limits that ranged from 65 mph to 75 mph for automobiles and from 55 mph to 75 mph for trucks. The sites included two that did not have truck-automobile speed differentials: Missouri (70 mph) and Oklahoma (75 mph). Arkansas has a 5 mph speed differential (70 mph for automobiles and 65 mph for trucks). Illinois was selected because of the 10 mph speed differential (65 mph for automobiles and 55 mph for trucks). These sites were also chosen to include the fastest speed limits for trucks (75 mph) and the slowest speed limit for trucks (55 mph).

All of the sites that were chosen were rural interstate highways that were flat and relatively straight for at least two miles prior to the site. The objective of the study was to address the highway geometry that is representative of the majority of rural interstate highway miles in the US. The data collected does not represent traffic behavior on highways that have lower design speeds due to highway geometry.

The data were collected between 11 am and 4 pm on weekdays to reduce the effect of commuter and weekend traffic. During the data collection period, the weather was clear and visibility was good. The speeds of both trucks and light vehicles were measured with a Prolaser II, Doppler lidar, manufactured by Kustom Signals, Inc.

When collecting traffic speed data, the relative levels of enforcement can obviously affect the results. Although it is difficult to characterize the enforcement levels at the various sites, there were no speeding citations observed at any site during any of the data collection periods.

3.2 Computer Simulation Evaluation of Speed Differentials on Vehicle Interactions

As indicated in the Literature Review, an important factor in traffic flow and highway safety is speed variance, which is a measure of the distribution of vehicle speeds on a roadway. Speed variance is often represented by the difference between the 85^{th} and 50^{th} percentile vehicle speed. The conclusion of a number of studies has been that higher speed variance increases the risk of two-vehicle accidents. This is simply the result of an increase in the number of interactions among vehicles (passing or being passed). Speed differentials, whether due to posted speed limits or company policies, increase the speed variance on highways. A computer simulation was developed to quantitatively investigate the relative number of vehicle interactions that result from traveling either faster or slower than the average traffic speed. The observed speed measurements from the sites in Missouri (70/70) and Illinois (65/55) were used to model the traffic flow. The simulation model calculated the number of vehicle interactions (passed and being passed) as a function of the vehicle's speed.

3.3 Assessment of Speed Limiters Use on Heavy Trucks

In addition to the limitations placed on heavy trucks by posted state-regulated posted speed limits, the speed of many trucks is also limited by electrical/mechanical devices that are used to restrict the maximum speed of the truck. These devices, which were originally mechanical (i.e., speed governors), now control the speed through the electronic control module (ECM) on truck engines. The primary reason for fleets using speed limiters is to improve fuel consumption. With the diesel fuel prices currently over $3.00 per gallon, fuel efficiency is an important issue for trucking companies, as well as for the shippers and consumers who eventually pay the additional costs of goods shipped by truck.

To determine the impact that company speed limitation policies have on traffic flow, surveys were conducted of over-the-road drivers, trucking company representatives, and truck sales organizations. The surveys of drivers were conducted at 11 truck stops in Illinois, Missouri, Arkansas, Oklahoma, New Mexico and Arizona from May 2004 through November 2004. It should be noted that this procedure resulted in an over-representation of long-haul drivers (multiple day trips) and an under-representation of private fleet vehicles (e.g. Wal-mart) and less-than-truckload (LTL) fleets that tend to make one-day trips. It was anticipated that this bias resulted in fewer trucks having speed limiting devices than are actually represented on rural highways. The drivers were categorized as being "company drivers" who worked for commercial carriers (Swift, Schneider, Yellow-Roadway, UPS, etc.), owner-operators that lease their truck to fleets, and independent owner-operators that operate on their own authority.

Representatives of commercial carriers were surveyed by telephone, visits to their headquarters, and through personal communications at professional/trade organization meetings (i.e., ATA Technology and Maintenance Council, SAE Truck and Bus Meeting, Great American Truck Show, etc.). Information as to company policies on speed limiting devices was also collected as part of a more general survey that is discussed in a later section of this report.

3.4 Survey of Truck Drivers' Opinions

Truck drivers are an important stakeholder in the context of speed differentials that result from both regulatory speed limits and company policies. Truck drivers were surveyed at the truck stops discussed above to obtain their opinions about truck speed in general and speed differentials, in particular. Out of the total of 205 drivers surveyed, 115 were "company drivers" who drive trucks owned by commercial fleets. Sixty eight (68) were owner-operators and the remaining 22 drivers did not indicate their status. Of the owner-operators, 20 were leasing their trucks to fleets and 48 operated under their own authority.

The drivers were surveyed as they filled their vehicles with fuel or in the restaurant or drivers' lounge at truck stops. The survey is provided in Appendix F. The majority of the drivers completed the entire survey; however, due to limited time available for some drivers, an abbreviated list of questions was used to obtain the most critical information for the study. These questions are indicated with asterisks on the survey shown in Appendix F. Prior to completing the survey, the drivers signed the Informed Consent (Appendix I) as per the requirements of the University of Arkansas Institutional Review Board. In addition to answering the questions on the survey, the drivers were interviewed in more detail to determine the basis of their opinions. Both the results of the survey and the comments of the drivers are discussed in the Results section.

3.5 Survey of Carrier Fleet Safety and Maintenance Personnel

As previously discussed, carrier fleets often restrict the speed of their trucks, which results in truck-automobile speed differentials, independent of the posted speed limits on rural interstates. The speed policies adopted by companies are primarily the result of two overriding factors: safety and economics. To address these considerations, safety and maintenance personnel from commercial fleets were surveyed. The opinions of these individuals were obtained by telephone survey, web survey, and personal interviews at company facilities or professional/trade association meetings. The survey instruments used for the safety and maintenance personnel are provided in Appendix F and G. The survey questions addressed both the effects of truck speed and speed differentials on both safety and operating costs.

As with the truck driver surveys, both the responses and the rationale behind the responses from the safety and maintenance personnel were obtained to determine the basis for the policies used by the companies. The results and conclusions drawn from those interviews are presented in the Results section of this report.

3.6 Survey of Equipment Manufacturers of Trucks, Engines and Tires

One of the primary reasons for speed limitations adopted by both fleets and owner-operators is related to the effects of speed on operational costs. As indicated in the Literature Review, there is very little information in the research literature relating to the effect of speed on operational costs. To the extent that the information was available in the public domain, it was generally provided in materials that are distributed by the manufacturers of the various components (engines, tires, etc.). To address the issue of truck speed on operational costs, the manufacturers of the equipment were surveyed. These surveys were primarily conducted by telephone and by personal communication at professional/trade association meetings (i.e., American Trucking Association's Technology and Maintenance Council meetings, Society of Automotive Engineer's Bus and Truck meetings, etc).

3.7 Comparison of Fleet Experience in States with Different Speed Limits

When companies adopt truck speed limit policies that are lower than the traffic speed, it effectively results in a speed differential for that fleet. As the posted automobile speed increases (i.e., 65, 70 or 75), the result is that the effective speed differential increases for the fleet. To analyze the impact of the "effective" speed differentials between trucks and light vehicles, participating companies were requested to provide their accident data from selected states for the past four years (2001 through 2004). Twenty-two states were selected based on their posted speed limits. Eleven states had differential speed limits and 11 states had uniform speed limits. The maximum speed limits in the selected states varied from 65 to 75 mph.

The accident type (lane change, passing, rear-ended, etc.), weather conditions during the accident, and the highway type on which the accident occurred were included in the data set. The monthly vehicle miles traveled by the companies' trucks in each of the states were also requested. Although the number of vehicle miles traveled on rural interstates was not available, this value was estimated as a proportion of the total state miles. The speed limits for the trucks in the participating companies were 62 and 65 mph. Therefore, the "effective" speed differentials were the difference between the

Speed Differential States			Uniform Speed Limits	
Texas	75	65	Arizona	75
Montana	75	65	Nevada	75
Idaho	75	65	New Mexico	75
Arkansas	70	65	North Dakota	75
Washington	70	60	Oklahoma	75
Michigan	70	55	Wyoming	75
California	70	55	Missouri	70
Indiana	65	60	Iowa	65
Illinois	65	55	Kentucky	65
Oregon	65	55	Pennsylvania	65
Ohio	65	55	Wisconsin	65

limited truck speeds and the posted speed limit for trucks and automobiles in a particular state. For example, although there is no regulated speed differential in Arizona (75 mph for both trucks and light vehicles), the "effective" speed differential for the 62 mph fleet is 13 mph. Whereas, the "effective" speed differential for the fleet in the state of Kentucky was 3 mph (uniform 65 mph limit).

The objective of this phase of the study was to compare the fleet accident experience across the states that have different speed limits that result in different "effective" speed differentials. The analyses of the fleets' experience with respect to different types of accidents are presented in the Results section.

3.8 Financial Cost-Benefit Analysis of Operating Speeds

As discussed earlier, one important reason that commercial trucking firms have lower operating speeds is to reduce the operating and maintenance costs. However, the reduction in operating costs by reducing speed is also accompanied by a reduction in company revenue, in that the truck assets potentially travel fewer miles per year. To evaluate the relative costs and benefits associated with lower operating speeds, operating and maintenance data were obtained from the participating companies. Estimates of the relative net revenues associated with different speed limit policies are presented in the Results section.

4. Analyses and Results

4.1 Traffic Speed Measurements under Different Speed Limits Configurations

This section of the report addresses the distribution of vehicle speeds on highways that have different speed limit configurations. The results illustrate how the posted speed limits affect the distribution of traffic speeds. In addition, the data are divided into heavy trucks and light vehicles (referred to in this report as automobiles). Four configurations were selected to represent the range of both absolute speeds and speed differential configurations.

State	Automobiles	Trucks	Differential
Oklahoma	75	75	0
Missouri	70	70	0
Arkansas	70	65	5
Illinois	65	55	10

For each configuration, the distribution of vehicle speeds is presented. In addition, the separate distributions for trucks and automobiles are presented. To illustrate the relative number of vehicles at various speeds, the combined truck and automobile distributions are documented as proportions. However, due to the fact that the volume of trucks and automobiles differs significantly within a site and from site to site, frequencies are used to compare the truck and automobile distributions. The statistics that are used to represent the traffic flow are the mean and standard deviation of the speeds. To represent the dispersion of speeds observed at the sites, the 85th percentile and median speeds are provided. There are two primary methods of calculating speed variance reported in the literature: (a) standard deviation of the individual vehicle speed and (b) the difference between the 85th percentile speed and the median speed (50th percentile). The present study defines speed variance as the difference between the 85th percentile and the median speed. The last statistic reported for each configuration is the compliance rate (proportion of vehicles traveling at or below the posted speed limit).

4.1.1 Arkansas Data (Automobiles 70 mph, Trucks 65 mph)

Speed data were collected at two sites on Interstate 1-40 near Ozark, AR. During the observation periods, the speeds of 361 vehicles were measured at the first site and 170 vehicles were measured at the second site for a total sample size of 531. The combined speed distribution for all vehicles is illustrated in Figure 22.

The general shape of the distribution shown in Figure 22 is similar to those found in the research literature for many different sites around the U.S. The mean speed for all vehicles was observed to be 71.35 mph and the standard deviation was 5.19 mph. The 85th percentile speed was 77 mph and the median speed was 72 mph. Speed variance, which is defined as the difference between the 85th percentile and the median, was 5 mph.

Figure 23 illustrates the speed distributions for automobiles and trucks separately. The speed of 362 automobile and 169 trucks were measured. The mean of the automobile speed distribution was 73.51 mph and the standard deviation was 4.32 mph. The 85th percentile was 78 mph, the median speed was 74 mph and the speed variance was 4 mph. The compliance rate for automobiles was 21.8%. The mean speed for trucks was 66.70 mph and the standard deviation was 3.69 mph. The 85th percentile speed was 70 mph, the median speed was 66 mph, and the speed variance was 4 mph. The compliance rate for trucks was 32.5%. The data illustrate that, although the posted speed differential was just 5 mph, the real speed differential between the automobiles and trucks was 6.8 mph.

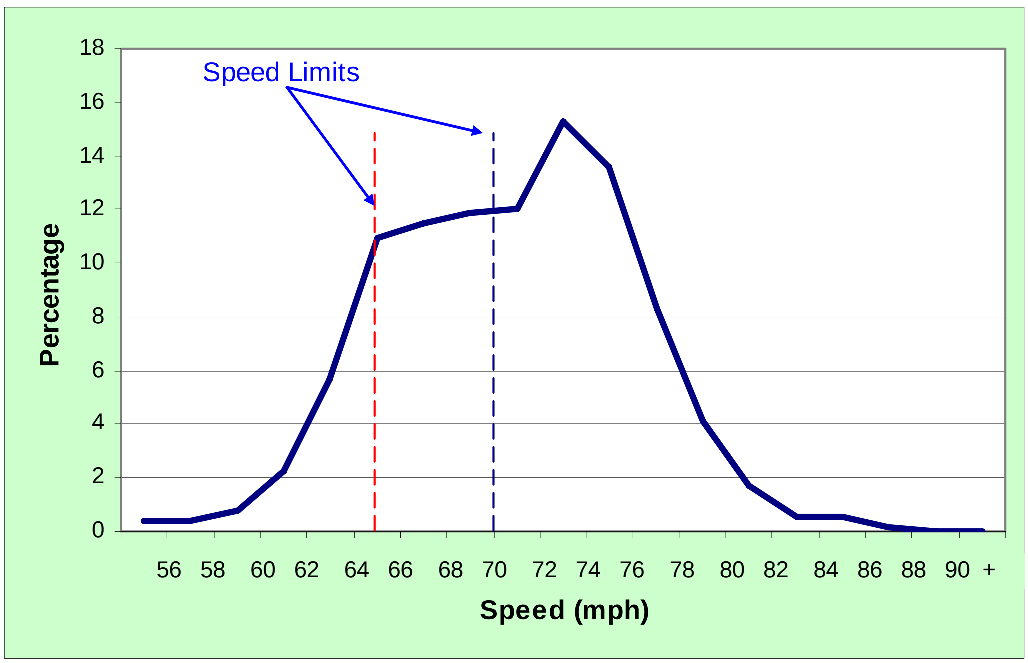

Figure 22. Speed Distribution for All Vehicles
(Speed Limit: Autos - 70 mph; Trucks - 65 mph)

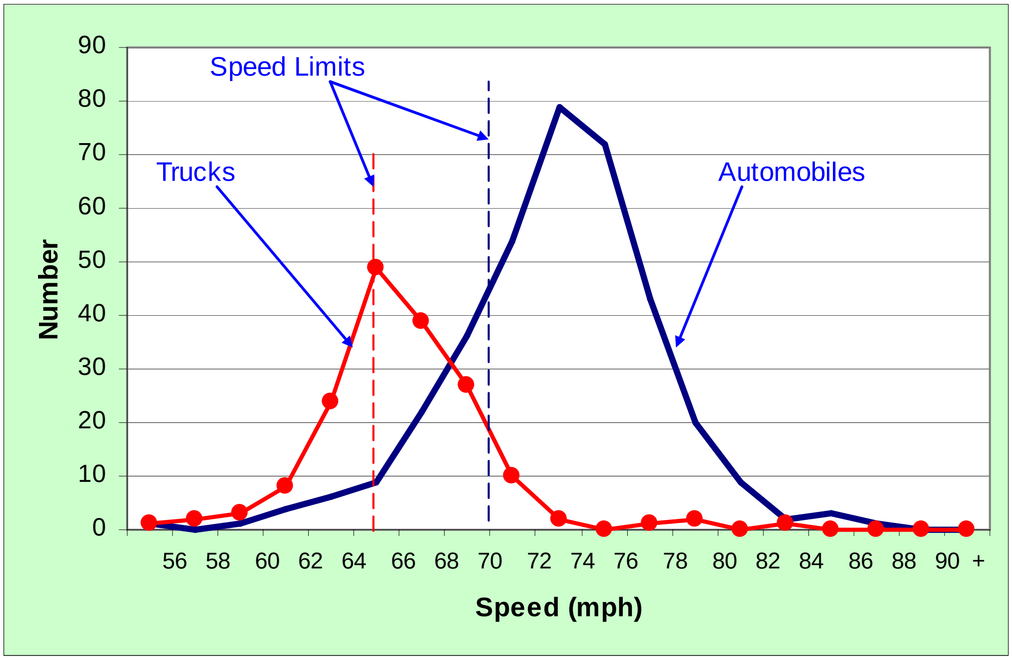

Figure 23. Speed Distribution for Automobiles and Trucks (Speed Limit: Autos - 70 mph; Trucks - 65 mph)

4.1.2 Illinois Data (Automobiles 65 mph, Trucks 55 mph)

Speed data were collected on Interstate I-57, near Effingham, IL. The posted speed limits were 65 mph for automobiles and 55 mph for trucks. During the observation periods, a total of 1140 vehicles were observed at three different sites. The combined speed distribution for all vehicles is illustrated in Figure 24. The mean speed for all vehicles was found to be 71.20 mph and the standard deviation was 6.54. The 85th percentile was 78 mph and median was 71 mph, resulting in a speed variance of 7 mph.

Figure 25 illustrates the speed distributions of automobiles and trucks, respectively, for the Illinois sites. A total of 878 automobile and 262 trucks were measured. Note that the proportion of trucks is lower at the Illinois sites (30%) compared to the Arkansas sites (47%).

The mean of the automobile speed distribution was 73.24 mph, which was 8.24 mph above the posted speed limit. The standard deviation was 5.67 mph, the 85th percentile speed was 79 mph, and the median was 73 mph. The speed variance for automobiles was 6 mph. The compliance rate for the automobiles was only 7.2%.

The mean speed for trucks at the Illinois sites was 64.24 mph, which was 9.24 mph above the posted speed limit. The observed standard deviation was 4.00 mph. The 85th percentile speed was 68 mph and the median was 64 mph resulting in a speed variation value of 4 mph. The compliance rate during the observation period was 0%. The truck drivers surveyed (see detail in a later section) indicated that, although the speed limit was not strictly enforced, penalties were high when they were considered by

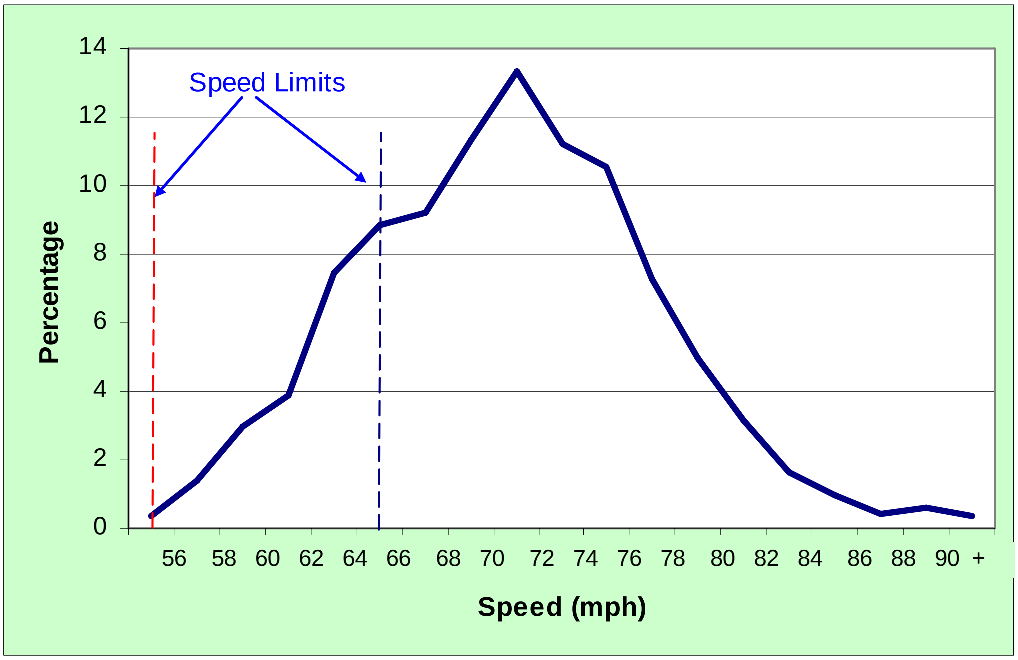

Figure 24 Speed Distribution for All Vehicles
(Speed Limit: Autos - 65 mph; Trucks - 55 mph)

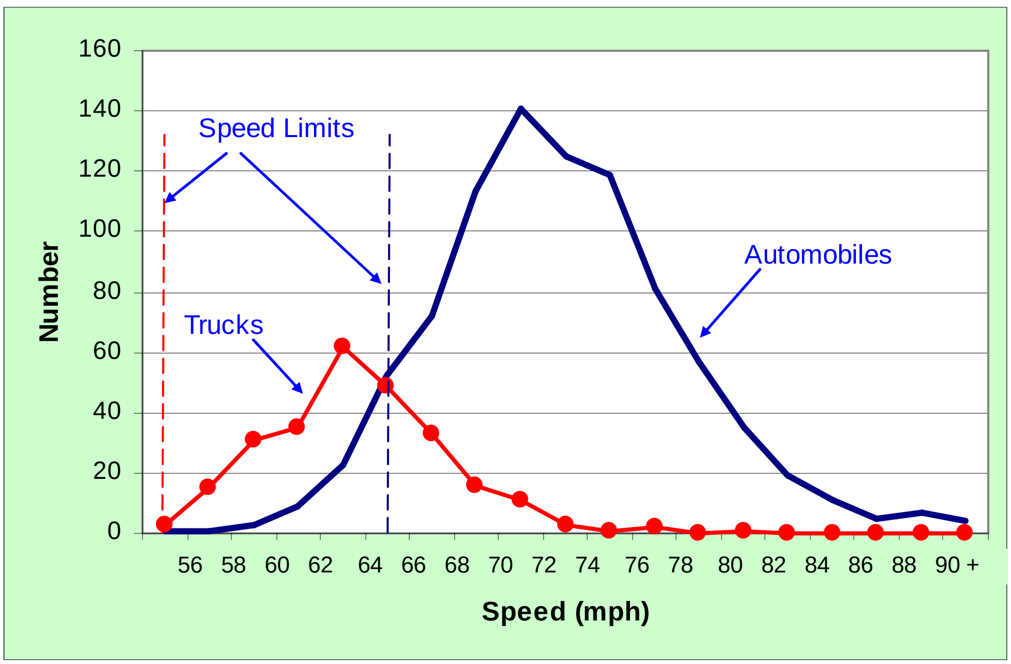

Figure 25. Speed Distribution for Automobiles and Trucks
(Speed Limits: Autos - 65 mph; Trucks - 55 mph)

the authorities as excessively speeding. The truck drivers expressed a perception that the speed limit enforcement for trucks was significantly stricter than for automobiles at the Illinois sites. This could help explain the combination of low compliance and low speed variance for trucks.

4.1.3 Missouri Data (Automobiles 70 mph, Trucks 70 mph)

Speed data in Missouri were collected at two sites on Interstate I-44, near Rolla and Joplin. The posted speed limit was 70 mph for both automobiles and trucks. During the observation period the speeds of 858 vehicles were measured. The combined speed distribution for all vehicles is illustrated in Figure 26. The mean speed for all vehicles was 71.46 mph and the standard deviation was 5.16 mph. The 85th percentile speed was 77 mph, median speed was 72 mph, resulting in a speed variance of 5 mph.

Figure 27 illustrates the separate speed distributions for 611 automobiles and 257 trucks from the Missouri sites. The mean speed for automobiles was 72.61 mph, which is only 2.61 mph above the posted speed limit. The standard deviation was 4.95 mph. The 85th percentile speed was 78 mph and the median was 74 mph, resulting in a speed variance of 4 mph. The compliance rate for the automobiles was 31.4%.

The mean speed of trucks was 68.61 mph, which is 1.39 mph below the posted speed limit. The standard deviation was 4.55. The 85th percentile was 70 mph, median speed was 66 mph, and the speed dispersion was 4 mph. The compliance rate for the trucks was 69.6%. Although the difference in the posted speed limit for trucks in Missouri and Illinois was 15 mph (70 mph versus 55 mph), the actual difference observed was only 4.4 mph (68.6 versus 64.2). In addition, although there was no difference in the posted speed limits for automobiles and trucks, there was actually a 4.0 mph differential. A partial explanation for this difference is the fact that many of the trucks have speed limiters that are below the posted limits.

4.1.4 Oklahoma Data (Automobiles 75 mph, Trucks 75 mph)

Speed data were collected on the Cherokee turnpike (US 412) in Oklahoma. The posted speed limit on this highway was a uniform 75 mph for both automobiles and trucks. The total sample size was 154. The speed distribution for all vehicles is illustrated in Figure 28. It should be noted that the sample size for this site was lower than the sites in the other states due to a much lower traffic volume. In addition, the proportion of trucks was lower (21%).

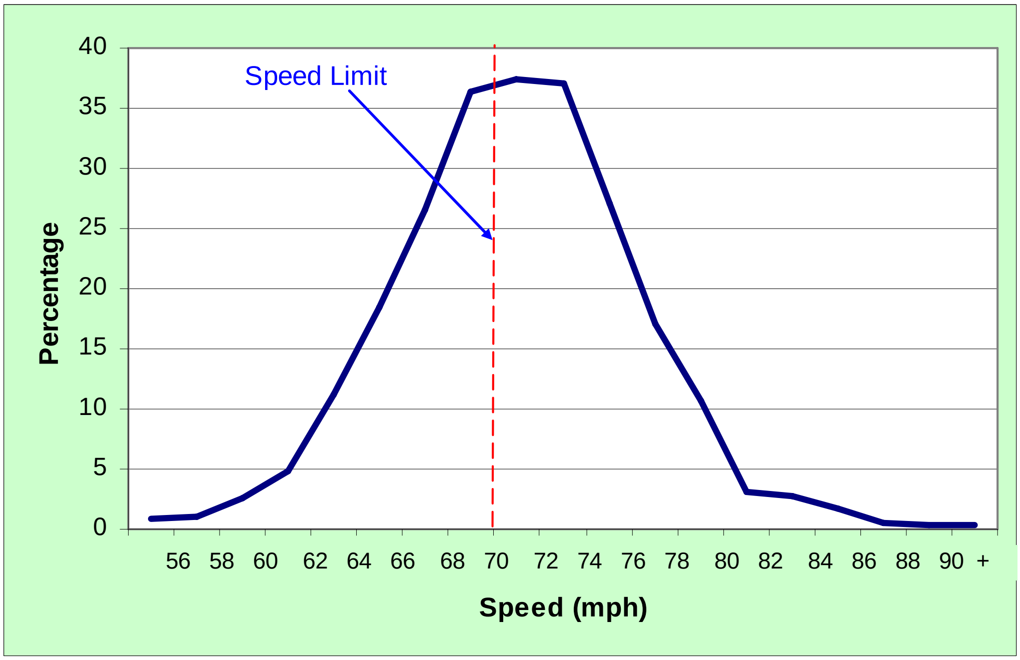

Figure 26. Speed Distribution for All Vehicles
(Speed Limit: Autos - 70 mph; Trucks - 70 mph)

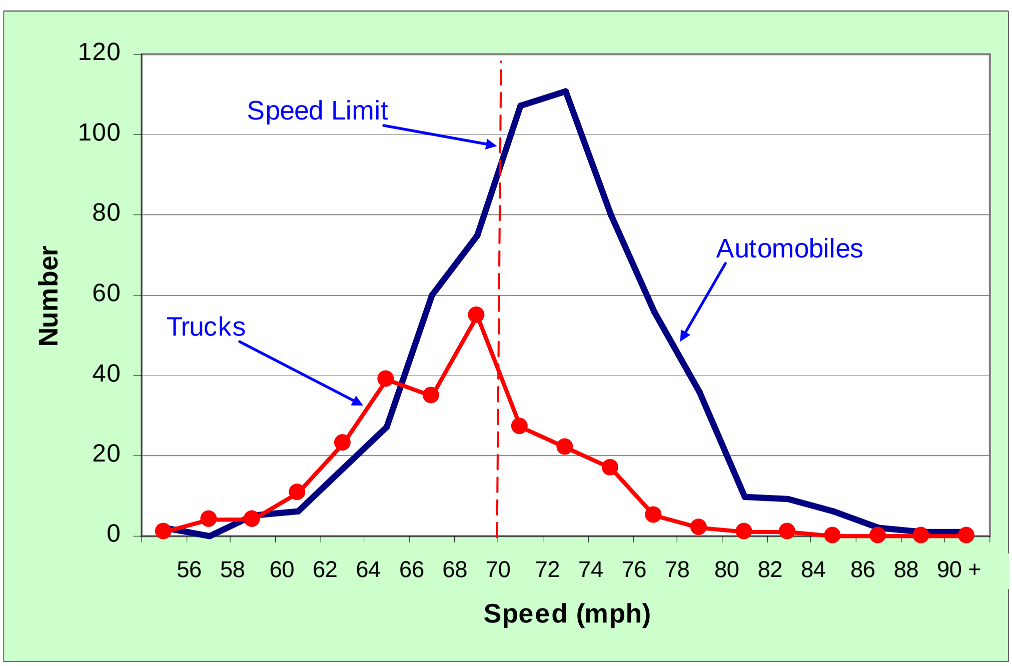

Figure 27. Speed Distribution for Automobiles and Trucks
(Speed Limit: Autos - 70 mph; Trucks - 70 mph)

The mean speed for all vehicles was 74.24 mph and the standard deviation was 4.93 mph. The 85th percentile speed was 79 mph, the median was 74 mph and the speed variance was 5 mph.

Figure 29 illustrates the speed distributions for automobiles and trucks at the Oklahoma sites. The speeds of 121 automobile and 33 trucks were measured. The mean automobile speed was 74.77 mph. This is 0.2 mph below the posted speed limit. The standard deviation was 4.61. The 85th percentile speed was 80 mph, the median was 75 mph and the speed variance was 5 mph. The compliance rate was 52.9%. For trucks, the mean speed 71.81 mph, 3.2 mph below the posted speed limit. The standard deviation was 4.95. The 85th percentile was 77 mph, the median was 72 mph and the speed variance was 4 mph. The compliance rate for trucks was 72.7%. Again, although the sample size for trucks was low, the confidence interval for the mean speed was still less than 1 mph.

4.1.5 Summary of Speed Data from Different Speed Configurations

Both the statistics and the shapes of the vehicle speed distributions are important in evaluating the effects of regulatory speed differentials on driver behavior and highway safety. In particular, the separate distributions for automobiles and trucks provide insight that is not provided by the combined data. A summary table that presents the statistics for each of the speed configurations is provided in Table 11.

The objectives of posted speed limits are to both reduce the negative effect of vehicles going at excessive speeds and to improve the flow of traffic. This is the reason that minimum speed limits (e.g., 45 mph) are imposed on highways. A significant amount of the research literature attributes the cause of accidents to "speeding." However, most accident reporting systems define speeding as "exceeding the posted limits or driving too fast for conditions." The result of this definition is that many, if not most, two-vehicle crashes that are characterized as being caused by speeding occur when the vehicle is actually traveling slower than the posted speed limits. The result is that the number of accidents attributed to exceeding the posted speed limit is often overestimated. From the data provided in this section, the amount of overestimate is possibly even more severe for heavy truck accidents. For the purposes of this report, speeding is defined only as the amount that the vehicle is exceeding the posted speed limit.

4.1.5.1 Speed Differentials and Compliance

One issue that is important from a regulatory perspective is the compliance rate for the different configurations. Table 12 illustrates the amount that the average speed exceeds the speed limits and the compliance rates for both automobiles and trucks.

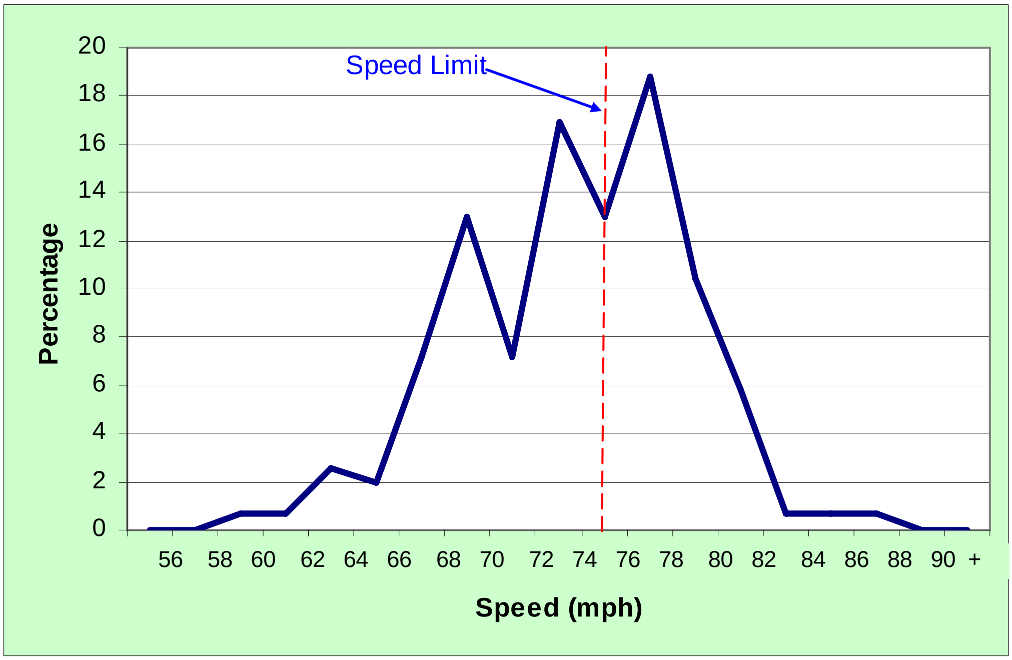

Figure 28. Speed Distribution for All Vehicles
(Speed Limit: Autos - 75 mph; Trucks - 75 mph)

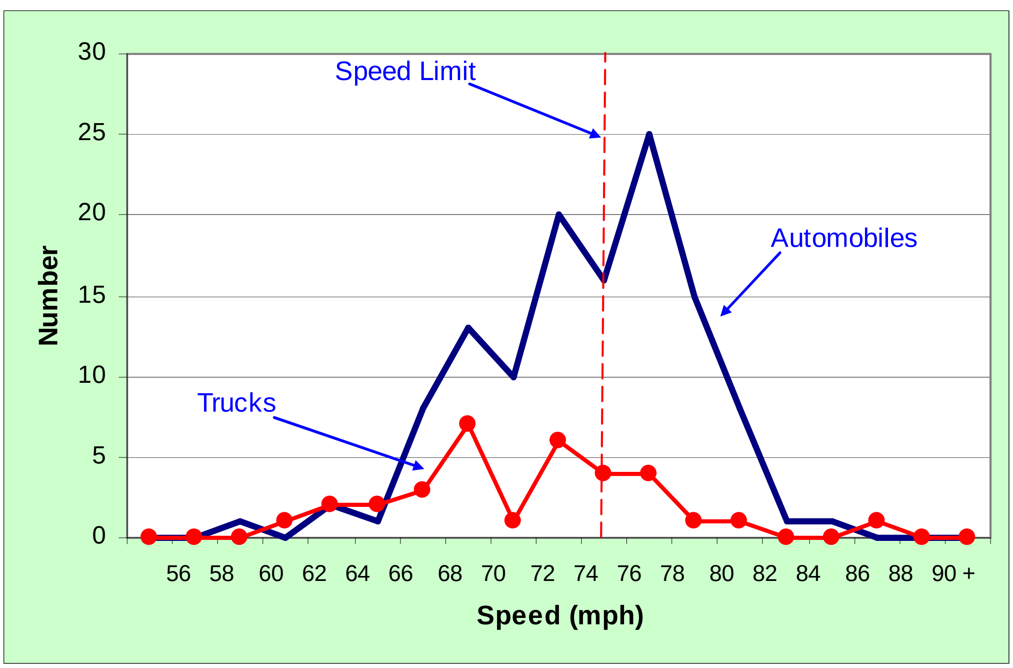

Figure 29.. Speed Distribution for Automobiles and Trucks
(Speed Limits: Autos - 75 mph; Trucks - 75 mph)

Table 11. Summary of Speed Data

State		Traffic	Automobile	Truck
Illinois **Autos: 65 mph** **Trucks: 55 mph** **(ADT = 19900)**	Average (mph)	71.2	73.2	64.2
	Standard Deviation	6.54	5.67	4.00
	Sample Size	1140	878	262
	Proportion of Trucks	0.23		
	Compliance (%)		7.17	0.0
	85th% (mph)	78	79	68
	50th% (mph)	71	73	64
	Speed Variance	7	6	4
Arkansas **Autos: 70 mph** **Trucks: 65 mph** **(ADT = 22000)**	Average (mph)	71.4	73.5	66.7
	Standard Deviation	5.19	4.32	3.69
	Sample Size	531	362	169
	Proportion of Trucks	0.32		
	Compliance (%)		21.82	32.54
	85th% (mph)	77	78	70
	50th% (mph)	72	74	66
	Speed Variance	5	4	4
Missouri **Autos: 70 mph** **Trucks: 70 mph** **(ADT = 34831)**	Average (mph)	71.5	72.6	68.6
	Standard Deviation	5.16	4.95	4.55
	Sample Size	858	611	247
	Proportion of Trucks	0.29		
	Compliance (%)		31.42	69.64
	85th% (mph)	77	77	73
	50th% (mph)	72	73	69
	Speed Variance	5	4	4
Oklahoma **Autos: 75 mph** **Trucks: 75 mph** **(ADT = 3500)**	Average (mph)	74.2	74.8	72.3
	Standard Deviation	4.93	4.61	5.63
	Sample Size	154	121	33
	Proportion of Trucks	0.21		
	Compliance (%)		52.89	72.72
	85th% (mph)	79	80	77
	50th% (mph)	74	75	72
	Speed Variance	5	5	5

Table 12. Effect of Posted Speed Limits on Compliance (%)

Automobile speed limit	Truck speed limit	Average automobile speed above posted limit (mph)	Compliance (%)	Average trucks speed above posted limit (mph)	Compliance (%)
65	55	+8.2	7.3%	+9.2	0.0%
70	65	+3.5	21.8%	+1.7	32.5%
70	70	+2.6	31.4%	-1.4	69.6%
75	75	-0.8	52.9%	-2.7	72.7%

Figure 30 illustrates the compliance rates for automobiles and trucks in different speed limit configurations. These compliance data are consistent with the results reported in the literature, in that when the posted speed is significantly below the design speed for a highway, the compliance rate can be very low. In these cases, the motorists ignore the posted limits and adopt a speed criterion based on the traffic speed. When the posted speed is closer to the design speed, motorists tend to comply more closely.

It can also be observed from the data in Table 12 that the compliance rate of trucks is often higher than that of automobiles. At the Missouri sites (70 mph for both automobiles and trucks), the compliance rate for automobiles and trucks was observed to be 31.4 and 69.6, respectively. The reason for this could be the fact that many of the trucks have speed limiters that do not allow them to travel at higher speeds; whereas, automobile drivers can choose their own operating speed, without restriction.

4.1.5.2 Posted Speed Limits and Mean Speeds and Differentials.

Table 13 illustrates that for the observed rural highways that had similar design speeds, the mean speeds for automobiles were very similar, even if the posted speeds were quite different. Although the speed limit in Illinois was 5 mph lower than the Arkansas and Missouri sites, the mean speeds were very similar (refer Figure 31). Although there is a 10 mph difference between the posted automobile limits at the Oklahoma and Illinois cites, the observed mean difference was only 3 mph.

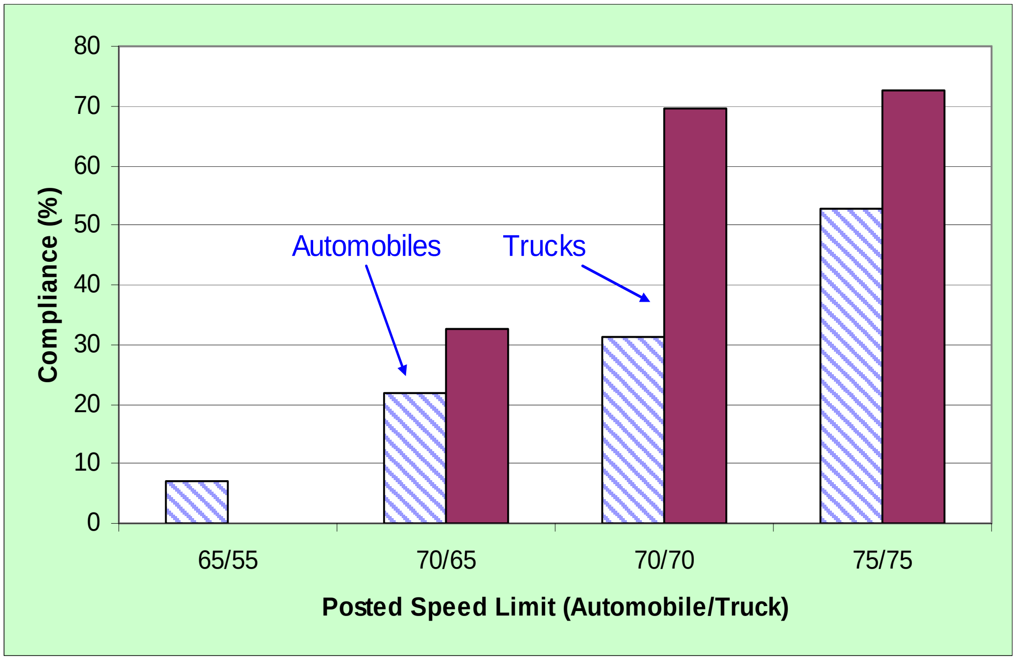

Figure 30. Compliance (%) for Different Speed Configurations

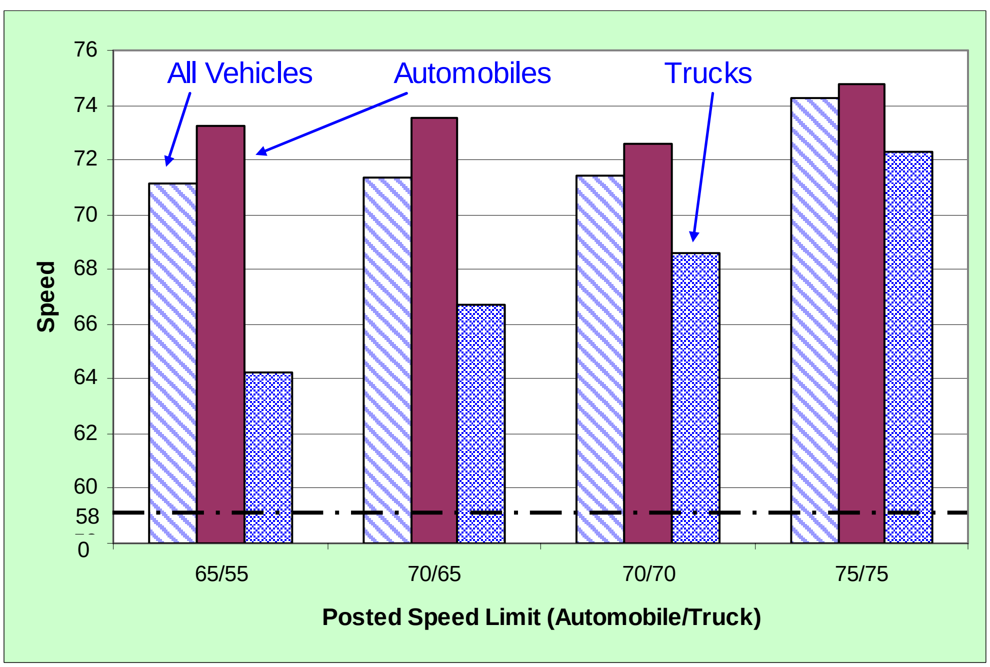

Figure 31. Mean Speed Limits for Different Speed Configurations

Table 13. Summary of Mean Speeds at Different Sites

Automobile Speed Limit	Truck Speed Limit	Mean Traffic Speed (mph)	Mean Automobile Speed (mph)	Mean Truck Speed (mph)	Posted Speed Differential (mph)	Observed Speed Differential (mph)
65	55	71.2	73.2	64.2	10	9.0
70	65	71.4	73.5	66.7	5	6.8
70	70	71.5	72.6	68.6	0	4.0
75	75	74.2	74.8	72.3	0	2.5

Again, it should be noted that the Oklahoma site was on a turnpike that required a toll payment. This potentially distorts the speed data for trucks in that only trucks that need to travel faster or are able to take advantage of the higher speeds (i.e., no speed limiter) might be willing to pay the toll. This site may not be representative of other interstate highways that have posted speed limits of 75 mph for both automobiles and trucks. Another reason for higher traffic speeds in Oklahoma could be the low traffic volumes on the site surveyed. From Table 11 it is evident that the annual average daily traffic (AADT) for Oklahoma is significantly lower than the AADT of the other three states considered. The AADT is a general unit of measure for traffic volume that represents the annual average traffic per day. It should be noted here that the AADT data in the table above are not representative of the statewide traffic, but are specific to the highway sites that were included in the study. Lower traffic volumes could lead to lower interactions among vehicles, thus resulting in higher traffic speeds.

The data also illustrate that there was an effective speed differential between automobiles and trucks, even if there was no posted speed differential. For example, the observed differential at the Arkansas sites (6.9 mph) was actually greater than the posted differential (5 mph). Again, this was due to many trucks having speed limiters that are set below the posted speed limits. The research literature that addresses speed differentials has not taken this "effective" differential into account. This is one reason why many of the studies have found very different results when they have studied states that have and do not have posted differentials between trucks and automobiles.

4.1.5.3 Posted Speed Limits and Speed Variance

As presented in the Literature Review, many studies have observed that the interaction among vehicles is an important factor in determining the potential risk for two-vehicle accidents on highways. The number of interactions is represented by the standard deviation and the speed variance. In this research, both measures are presented. Each measure has advantages and disadvantages. The speed data were measured during this study as integers (69, 70, 71, etc.). The result is that the speed variance statistic is also an integer value and is, therefore, a relatively insensitive measure of traffic speed dispersion. The standard deviations shown in Table 14 provide a more sensitive measure of the variation in traffic speeds.

Table 14. Summary of Standard Deviation Data at Different Sites

Automobile Speed Limit	Truck Speed Limit	Standard Deviation for Traffic Speed (mph)	Standard Deviation for Automobile Speed (mph)	Standard Deviation for Truck Speed (mph)
65	55	6.54	5.67	4.00
70	65	5.19	4.32	3.69
70	70	5.16	4.95	4.55
75	75	4.93	4.61	5.63

These data generally follow the trend cited in the literature that indicates that as the traffic speed increases, the standard deviation is reduced. For example, the variance is highest at the Illinois sites (5.67 mph) where the speed limit is lowest. Similarly, the variance is lowest (4.61 mph) at the Oklahoma sites, where the speed limit is highest. One reason that could account for this relationship is the finding in the literature that when the speed limits are perceived by motorists to be set at what is viewed to be arbitrarily low values, most of the motorists ignore the posted speed limit and choose their own safe operating speed. The person's individually chosen speed can be significantly different from other motorists' choices. In addition, there will continue to be some law abiding motorists who will operate at the posted speed limit even if the traffic speed is significantly higher. The differing behavior of these two groups increases the speed variation. In addition, the lower standard deviation at higher speeds can be explained by Lave's theory that as the speed limit increases, the speed variance decreases, as the law-abiding motorists catch up with the faster traffic (1985).

The variation among truck speeds appears to depart from the relationship where the amount of variation decreases as the speed increases. Figure 32 illustrates the standard deviation for all vehicles, automobiles and trucks, respectively. The standard deviation for speed is lower in states having slower speed limits for trucks (Arkansas and Illinois sites) compared to states having higher speed limits (Oklahoma and Missouri sites). One explanation for this is that when the posted truck speed is higher, there are two groups of traffic, one group of trucks travel at a slower speeds due to their speed limiters and other group of trucks (mostly owner-operators) is able to travel at a higher speed because they are not restricted by speed limiters.

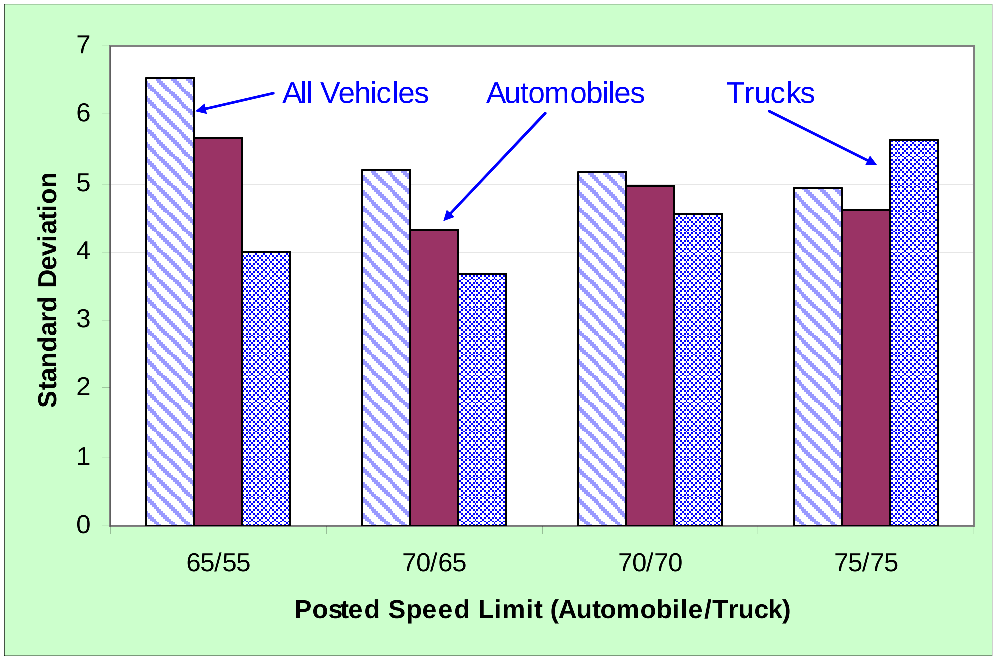

Figure 32. Standard Deviation for Different Speed Configurations

4.1.5.4 Speed Differentials and Clustered Congestion

As discussed earlier in the Literature Review section, imposition of differential speed limits could lead to traffic congestion. This argument was evident when the sequential traffic data observed at Effingham, Illinois (speed limit of 65/55 mph) was compared with the sequential traffic data of Joplin, Missouri (uniform speed limit of 70 mph). Figure 33 illustrates the sequential traffic data obtained from these two sites. The graph illustrates that on a highway with 65/55 mph posted speed limits, trucks have the tendency to cluster more than under the 70/70 mph posted speed limits. This phenomenon is also illustrated in the photograph shown in Figure 34.

With differential speed limits, automobiles tend to travel at speeds significantly higher than those trucks. This results in faster-moving automobiles traveling in the left lane, while the slower moving trucks get “stuck” in the right lane. An effect of truck speed limiters with different maximum speeds is that the trucks with higher limits or no limiters could move faster, but get “stuck” in the right lane behind the slower moving trucks, thus

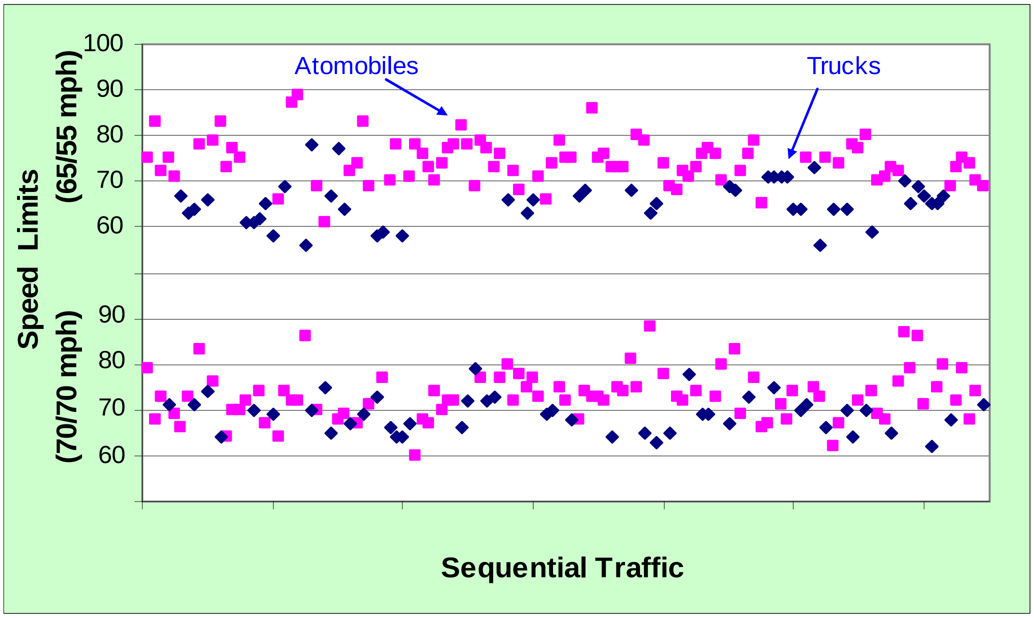

Figure 33. Sequential Traffic Arrival at Different Speed Configurations

Figure 34. Illustration of Localized Congestion

leading to a bottleneck situation. When a truck with a slightly higher limit (e.g., 2 mph) attempts to pass the slower truck, passing can take a significant amount of time. For example, if a truck with a 65 mph limit passes a truck with a 62 mph limit, in a 75 mph speed zone, traffic tends to experience “clustered” congestion (Figure 35).

Figure 35. Illustration of "Clustered" Congestion

4.2 Impact of Speed Differentials on the Number of Vehicle Interactions

In this section, the number of interactions an individual vehicle will have with other vehicles operating at different speeds in the traffic flow is modeled. The goal was to investigate the number of times a vehicle passes and is passed as a function of their individual speed relative to the traffic speed. It was assumed that the "reference vehicle" is operating at a uniform speed limit on a rural interstate highway. All the vehicles were assumed to be traveling at steady speeds in free-flowing traffic, and there was no speed fluctuation due to traffic congestion when one vehicle passed another vehicle.

For the purposes of the model, the distribution of automobile and truck speeds that were observed at the Rolla, Missouri site (uniform 70 mph) was used. The average traffic speed for this site was observed to be 71.8 mph, with the average automobile and truck speed being 73.2 mph and 68.7 mph, respectively. The simulation represents the number of vehicle interactions on a 1000 mile trip. Before allowing the "reference vehicle" to join the traffic stream, 3500 vehicles were allowed to start with the inter-vehicle interval being uniformly distributed between 1 and 11 seconds. The mean inter-vehicle interval of 6 seconds was based on the data collected at the site during the observation period. It was determined that allowing 3500 vehicles before the "reference vehicle" ensured that it would not pass the first vehicle, even if it were traveling at its highest speed and the first vehicle in the traffic stream was traveling at the slowest speed observed. After the "reference vehicle" departs, 3500 vehicles were allowed to join the traffic in the same manner. Each of the 7000 vehicles was designated as either an automobile or a truck based on the observed sequence from the Rolla, Missouri site.

The computer simulation calculated the total number of passing incidents involving the reference vehicle at different operating speeds. Each time a passing incident occurred, it was noted whether the passing or passed vehicle was a truck or an automobile. The total number of “passing” and “being passed” incidents were combined to determine the total number of interactions that would be encountered during the complete 1000 miles trip. This procedure was repeated for operating speeds from 60 to 80 mph. The results are illustrated in Figure 36. Figure 37 shows the results obtained after repeating the same procedure with the data collected from Effingham, Illinois (posted speed differential of 65 mph for automobiles and 55 mph for trucks). The mean traffic speed for this site was observed to be 71.3 mph, with the average automobile and truck speed, being 73.8 mph and 64.2 mph respectively.

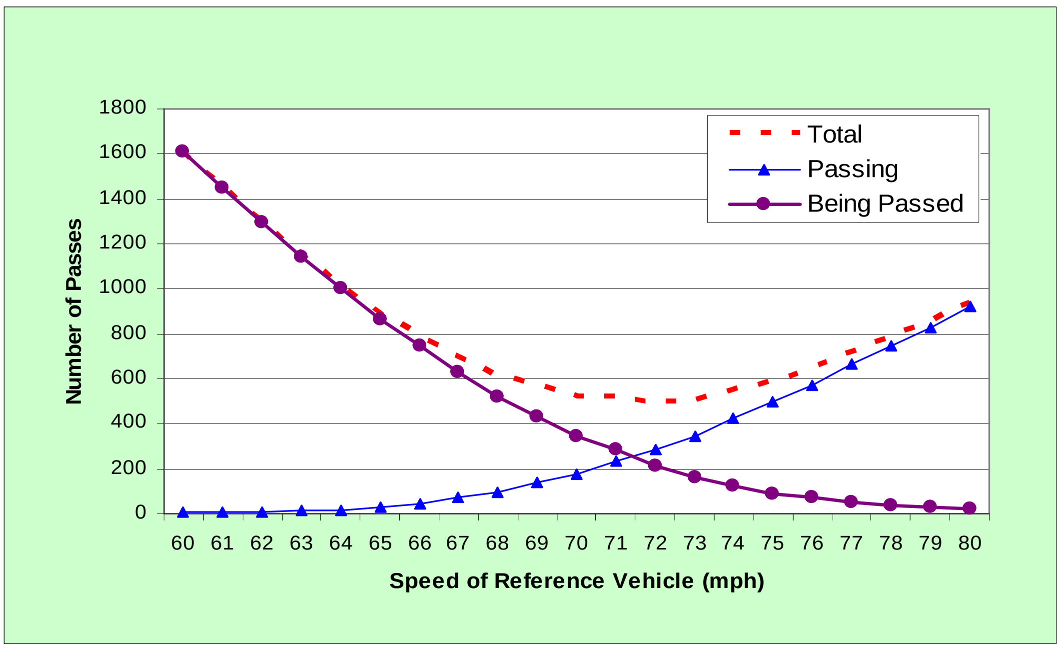

Figure 36. Number of "Passing" and "Being Passed" Incidents vs. Speed for a 70/70 Speed Limit State with Mean Speed=71.8 mph

Figures 36 and 37 illustrate that the number of interactions is minimized when the “reference vehicle” is traveling at the average traffic speed. Figures 38 and 39 illustrate the relative frequency of “passing” and “being passed” incidents by vehicle type (automobile versus truck). It can be seen that the relative frequency of a truck passing automobiles is very low, which is counter to publics’ perception that trucks frequently pass automobiles. It should be noted that the percentage of trucks was higher at the Missouri site (31%) compared to that at the Illinois site (26%). This is the reason that the number of “passing truck” and “being passed by truck” incidents are higher using the data from the Missouri site.

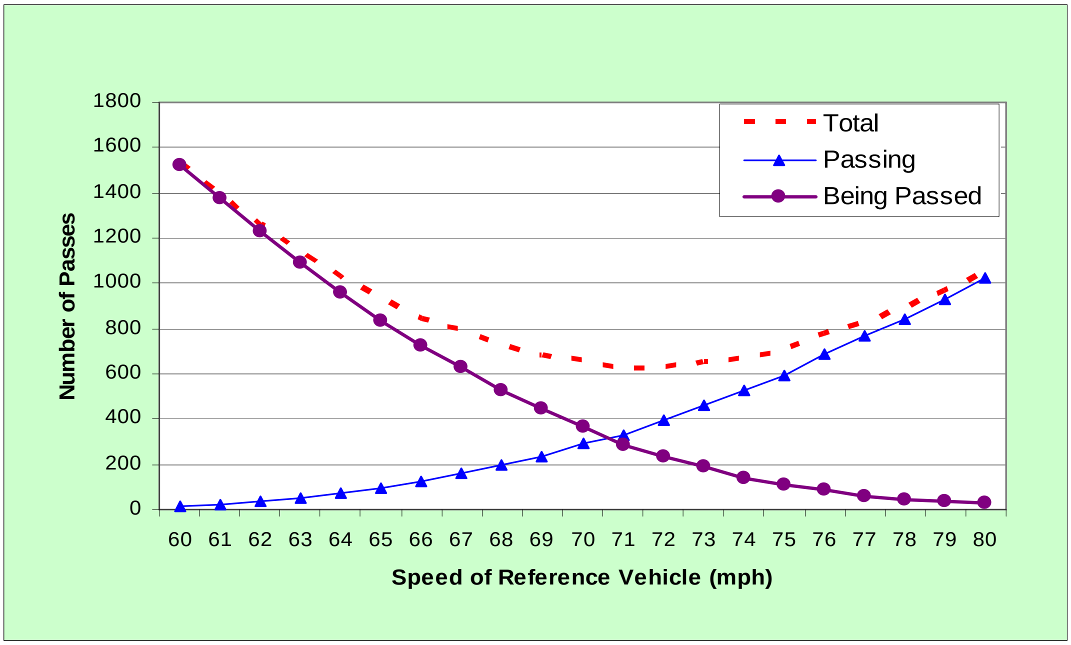

Figure 37. Number of "Passing" and "Being Passed" Incidents vs. Speed for a 65/55 Speed Limit (Mean Speed=71.3 mph)

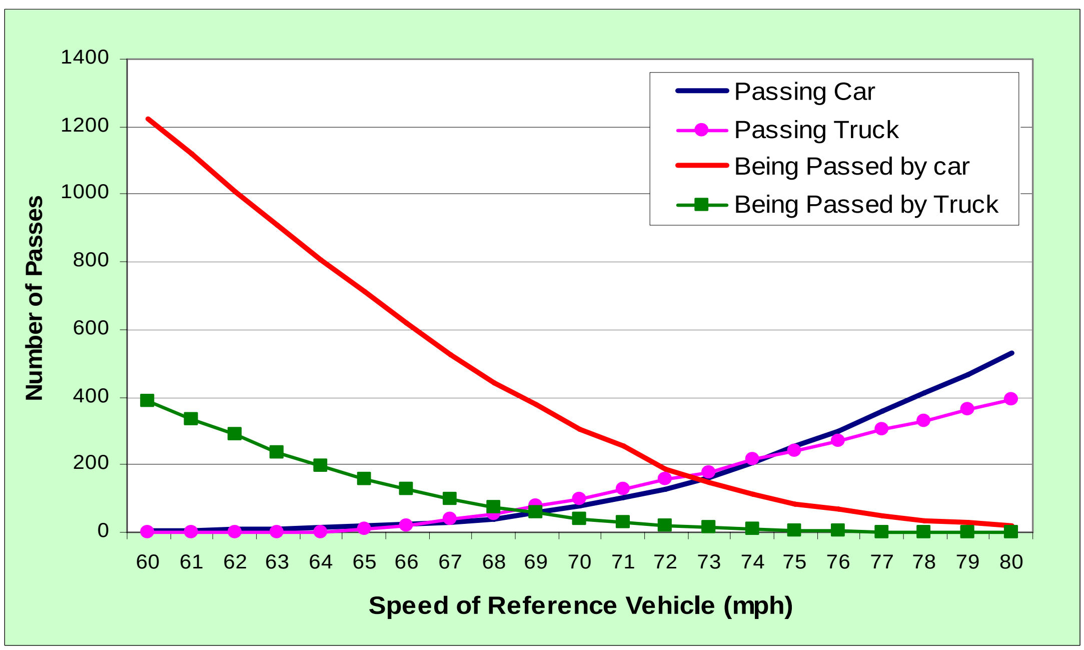

Figure 38. Number of Vehicle Interactions Based on Vehicle Type vs. Speed for a 70/70 Speed Limit (Mean Traffic Speed=71.8mph, Automobile Speed=73.2 and Truck Speed=68.7 mph)

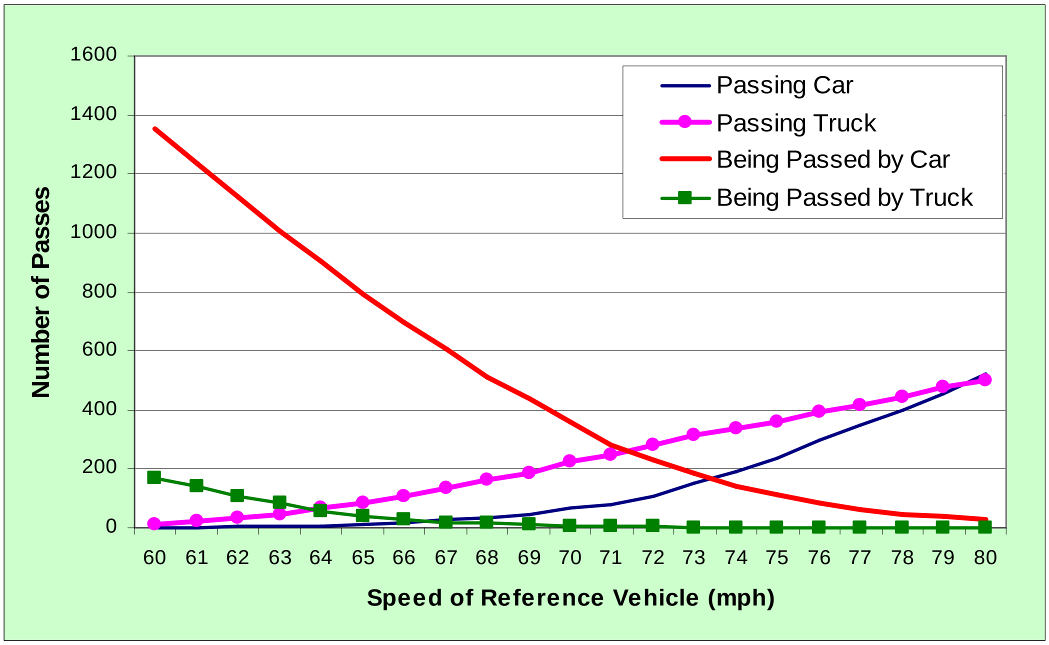

Figure 39. Number of Vehicle Interactions Based on Vehicle Type vs. Speed for a 65/55 Speed Limit (Mean Traffic Speed=71.3 mph, Automobile Speed=73.8 and Truck Speed=64.2 mph)

Figure 40 indicates that, as the speed of the individual vehicle deviates from the mean traffic speed, the number of interactions increases and the potential for being involved in a two-vehicle accident increases. The interactions with other vehicles were minimized at the average speed of traffic, which was 1.8 mph above the posted speed limit for Missouri and 6.3/16.3 mph for the Illinois site. On a highway with a posted uniform speed limit of 70 mph for both automobiles and trucks, the frequency of interactions with other vehicles by a vehicle traveling 10 mph below the posted speed limit (60 mph) is 227% higher than moving at traffic speed; whereas, the frequency of interactions with other vehicles for a vehicle traveling at 10 mph above the posted speed limit (80 mph), is just 90.67% higher.

Figure 41 illustrates the number of interactions for a posted speed differential of 65 mph for automobiles and 55 mph for trucks. The number of interactions for a vehicle moving at 60 mph is 149% higher than going at traffic speed; whereas, the number of interactions for a vehicle traveling at 80 mph, which is 15 mph above the posted speed limit, is only 70% higher when compared to the frequency of interactions at the average traffic speed. A truck traveling at the speed limit (55 mph) would have over four (4) times the number of interactions (407 % more) compared to a truck going at traffic speed.

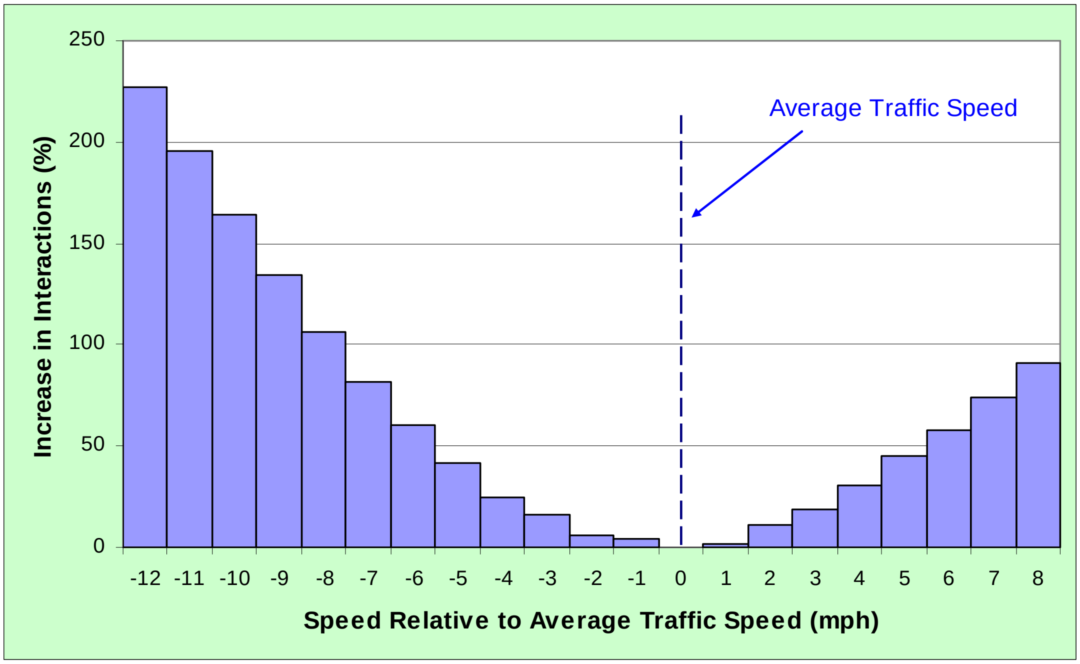

Figure 40. Increase in Probability of Interaction vs. Speed for a Traffic Flow with Mean Speed=71.8 mph

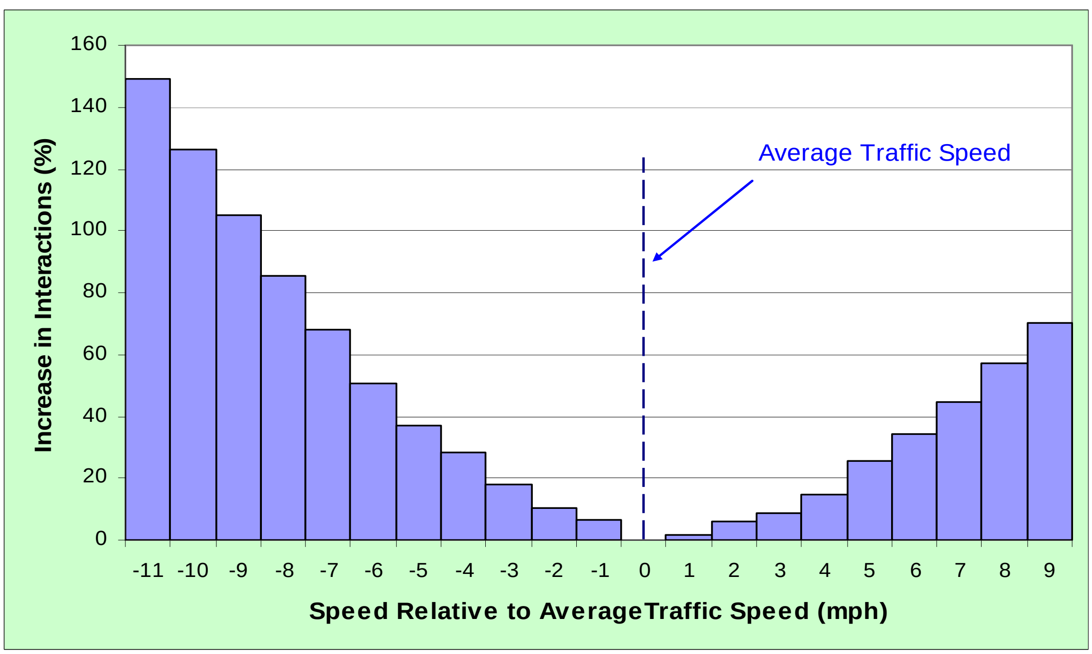

Figure 41. Increase in Probability of Interaction vs. Speed for a Traffic Flow with Mean Speed=71.3 mph

4.3 Use of Speed Limiter Use on Heavy Trucks

In this section, the results of a survey that was administered to obtain information from truck drivers on speed limiter settings are presented. The distribution of speed limiter settings based on the truck driver category and fleet characteristics are discussed in detail.

Table 15. Summary of Results Obtained from Truck Driver's Survey on Speed Limiter Use

Driver category	Drivers surveyed	Number of drivers with speed limiters	Percentage of drivers having speed limiters
Company Drivers	136	123	90.4
Lease Drivers	16	11	68.8
Owner-Operators (owning just the tractor)	38	15	39.5
Owner-Operators (owning both tractor and trailer)	24	6	25.0
Did not Identify Themselves	22	21	95.5
Total	**236**	**176**	**74.6**

4.3.1 Driver Category and Speed Limiter Settings

The classification of the 236 drivers surveyed is shown in Table 15. Speed limiters were on 74.6% of the trucks. Of the 176 with limiters, the breakdown by driver category and the proportion of each category that had limiters are shown in Table 15. In addition to the driver survey, thirty nine (39) trucking companies were surveyed. Of the 39, 34 used speed limiters on their trucks. The four that did not have limiters were companies that only hired contract drivers.

4.3.2 Distribution of Speed Limiter Setting

Figure 42 illustrates the distribution of the speed limiter settings on trucks from a combination of the surveys from drivers and company personnel. The "No Limiter" category indicates that the drivers who responded did not have a speed limiter or governor. Most of these drivers were owner-operators. To see the difference between the speed limiter distribution for company drivers and owner-operators, the data were divided into two categories as shown in Figures 43 and 44.

Figures 43 and 44 illustrate that most of the company drivers have a speed limiter set at or lower than 70 mph, whereas the majority of the owner-operators do not use a speed limiter or have their speed limiter settings in the high seventies. This illustrates a major difference in the approach of companies and owner-operators. The companies believe that they can maximize their profits by lowering speed to save fuel and maintenance costs. The owner-operators feel that they can maximize their profits by traveling at a higher speed, and, therefore, cover more distance in less time. In addition, the owner-operators do not want to be tied down by the speed limiter on open rural roads in states like Arizona and Nevada where high speed travel (e.g., 75 mph) is safe and legal. Figure 44 would not be representative of the distribution if Canadian truck drivers were included because the proportion of owner-operators is much lower in Canada than the United States. According to Transport Canada (2004), owner-operators constitute 20% of the long haul driver population; whereas in the United States, owner-operators constitute up to 70% of the long haul driver population (Truck Writers of North America, 1999).

The owner-operators can be further divided into two sub-categories: (1) lease drivers (Figure 45) and (2) independent drivers who operate under their own authority (Figure 48). The figures illustrate that a higher percentage of independent drivers do not have speed limiters, while more of the lease drivers have speed limiters set on their truck. Most of the owner-operators did not have speed limiters. The ones who had limiters indicated that they used them to reduce the potential of getting a "very expensive" speeding tickets.

4.3.3 Driver Experience and Speed Limiter Setting

The scatter plot of the relationship between driver experience and speed limiter setting is shown in Figure 47. There does not appear to be a systematic relationship between the factors. No statistically significant relationship was observed.

4.3.4 Fleet Size and Speed Limiter Setting

There was a strong relationship observed between the size of a carrier fleet and the speed limiter settings. Figure 48 indicates that many of the larger fleets tend to use lower speeds.

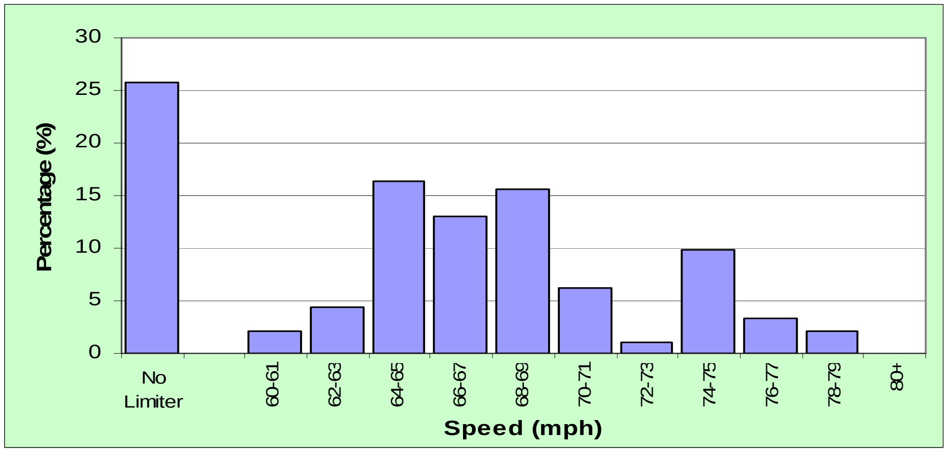

Figure 42. Distribution of Speed Limiter Settings

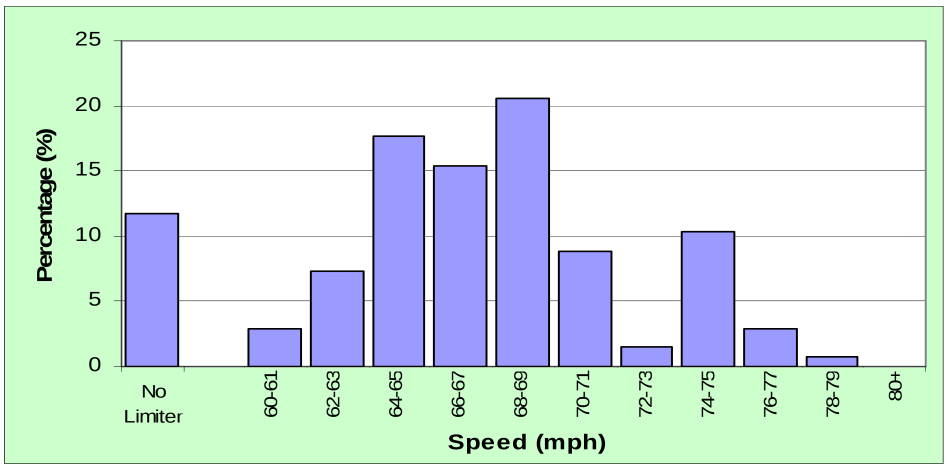

Figure 43. Speed Limiter Settings for Company Drivers

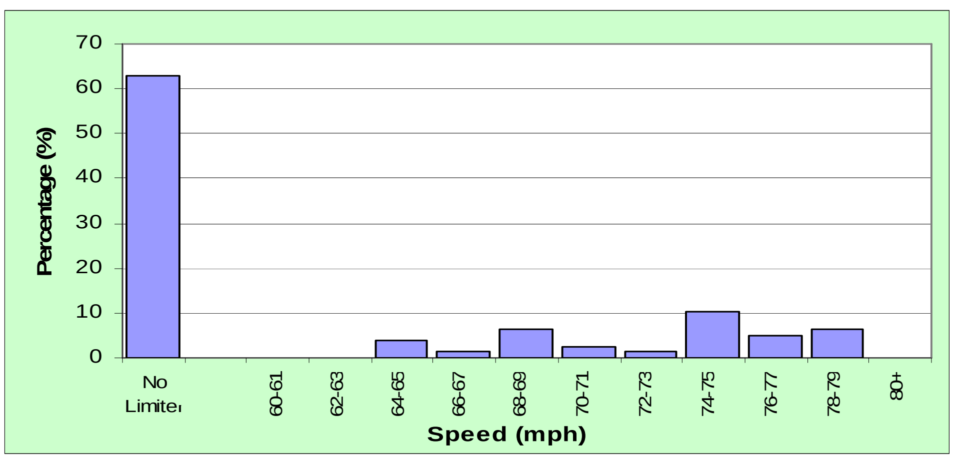

Figure 44. Speed Limiter Settings for Owner-operators

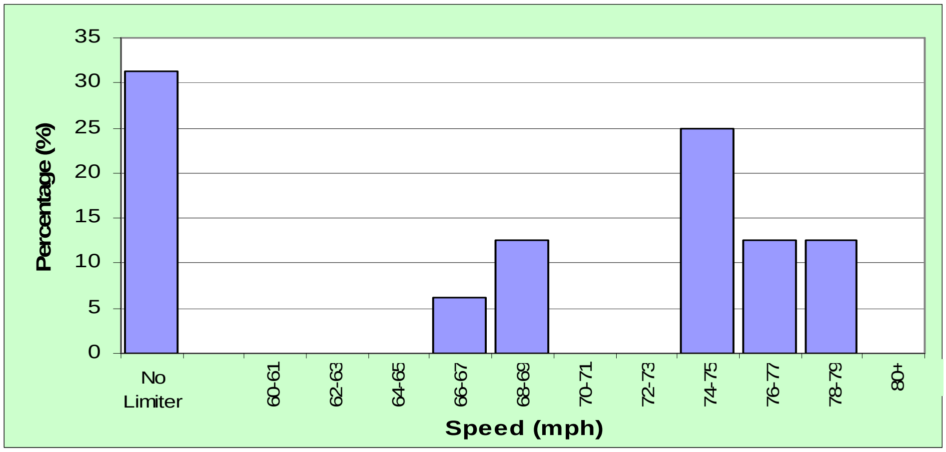

Figure 45. Speed Limiter Settings for Lease Drivers

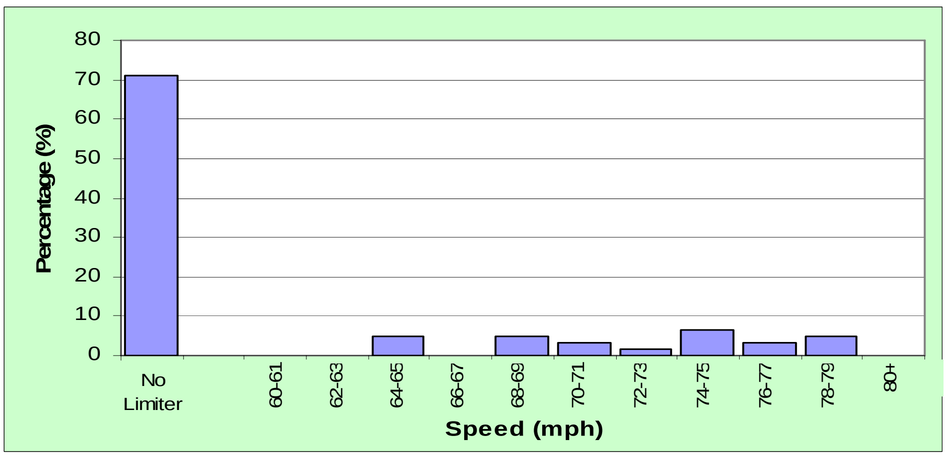

Figure 46. Speed Limiter Settings for Independent Drivers

4.4 Opinions of Truck Drivers

The results obtained from the truck drivers' surveys and the reasoning offered by the drivers is summarized below. It should be noted that the surveys are the opinions of the truck drivers, which may or may not be valid.

4.4.1 Characteristics of Vehicles and Routes

As previously discussed, a disproportionate number of drivers who stop at the truck stops are long haul drivers. Among the truck drivers surveyed, the trip lengths (home base to home base) of 55.19% of the drivers were more than 7 days, 40.09% of the drivers had trip length between 2 to 7 days, and only 4.72% of the drivers were out for a single day trip. When vehicles were classified on the basis of the type of cargo,

Figure 47. Speed Limiter Setting and Driver's Experience (n= 130)

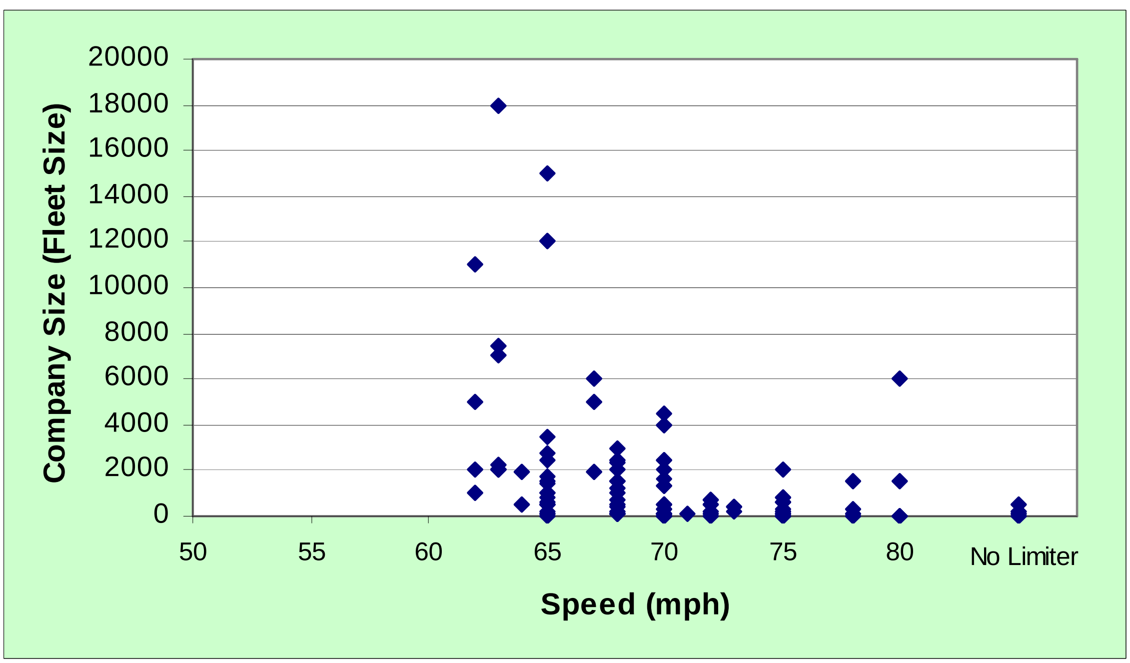

Figure 48. Fleet Size and Operating Speed (n= 122)

following proportions were observed: 55.62% dry vans, 26.04% reefers, 10.65% flat bed, 3.55% tankers and 4.14% miscellaneous tankers (doubles, triples etc). Of the total, 88.30% of the carriers were truck load, while only 11.70% were less than truck load (LTL).

Although there are many engine manufacturers worldwide, only three were observed to be widely used in our sample: Detroit Diesel (45.11%), Caterpillar (30.98%) and Cummins (17.39%). Other engine manufacturers, which included Volvo, Mercedes, Mack etc., contributed only 6.52% of the engines used. Among the drivers surveyed, 60.81% of the drivers had 10 speed gears on their trucks, while 27.03% of the drivers had 13 speed gears on their trucks, and 12.16% of the drivers had others..

4.4.2 Effects of Vehicle Interactions

The first set of questions related to the interactions among vehicles and the driver's perceptions of the relative risk of different activities. The interaction between a truck and another vehicle is a critical event during highway driving for both the truck driver and the other motorist. From a truck driver's point of view, there are three critical stages when a truck is passing an automobile: (1) beginning of pass, (2) traveling parallel and (3) pulling back into the lane. The relative importance of these three stages depends upon the traffic conditions, road conditions, driver's maneuvering technique, and driver's perception. The responses are divided into two scenarios: trucks passing automobiles and then automobiles passing trucks. The truck drivers were relatively evenly split on their perceptions of which causes more risk: a truck passing an automobile or an automobile passing a truck (47% and 53%, respectively).

For the maneuver where a truck passes an automobile, 13% of the truck drivers stated that the beginning of the maneuver was the most dangerous, 50% felt that driving parallel was most dangerous, and 37% considered re-entering the right lane the most dangerous.

Many of the truck drivers who considered the initial part of passing most dangerous addressed the perception issue that many automobile drivers dislike driving behind trucks. As a result, when the truck begins to pass, the automobile drivers often speed up so that they would not be passed. They subsequently slow down again until the truck attempts to pass. Furthermore, when the truck tries to shift from the left lane to the right lane in order to pass a slower-moving vehicle, other automobiles coming from behind in the left lane often speed up to restrict the truck's ability to enter the left lane. The truck drivers contended that these actions are often the cause of collisions or near-misses.

Half of the truck drivers responded that traveling parallel to another vehicle is the most dangerous period of a passing maneuver. The truck drivers perceive that some automobile drivers are frightened by the size of a passing truck (Figure 49). To increase separation, automobile drivers sometimes veer toward the shoulder of the road and can loose control of their vehicles. Another observation from the truck drivers was that the automobile drivers sometimes fixate on the wheels of the passing truck, and they tend to get “sucked into” the truck. This concentration on the wheels might be related to the fear of the tire tread separation. During inclement weather conditions (e.g., heavy rain or wind), both control and visibility of the automobile driver are compromised when being passed by a truck. Although these events occur both when the truck is passing the automobile and when the automobile is passing the truck, the perception is that the effects are exaggerated when the truck passes the automobile.

Figure 49. Impact of Truck Passing Automobile

For many of the truck drivers that contended that the time when the truck is pulling back into the right lane is the most dangerous part of the maneuver, the issue of the resistance of some automobile drivers to follow a truck was mentioned. It was contended that this concern sometimes results in the automobile driver speeding up when being passed by a truck, making it more difficult for the truck to re-enter the right lane. Visibility of automobiles in a potential “blind spot” was also cited as a cause of many accidents and near-misses when re-entering the right lane.

For the maneuver in which an automobile is passing a truck, 5% of the truck drivers stated that the beginning of the maneuver was the most dangerous, 53% felt that driving parallel was most dangerous, and 42% considered re-entering the right lane the most dangerous. One of the issues stated by the truck drivers pertaining to the initiation of the passing action was the misjudgment of the truck speed by the automobile drivers. When the truck is judged to be moving slower than it actually is, by trying to get around the truck quickly, the motorist sometimes end up at a very high speed and loses control of their vehicle. When the truck is judged by the motorist to be faster than it actually is, the result can be that the automobile rear-ends the truck. This impression of the truck drivers is supported by the accident data. Researchers have attributed the misjudgment of the truck speed and the rapid closure rate to the large image projected by the rear of the truck trailer.

The truck drivers, who responded that traveling parallel is the most dangerous part of the maneuver, also cited the same issues that occur when the automobile is passing the truck (fear of tire separation, veering away from the truck, etc.). The truck drivers stated that the motorists concern about the wind and reduced visibility effects that are associated with inclement weather also sometimes causes motorists to pass trucks at excessive speeds, which increases the risk of the motorist loosing control.

The 42% percent of truck drivers for which the period when automobiles are pulling back into the right lane is the most hazardous part of the maneuver frequently referred to being “cut-off” by the automobiles (Figure 52). This response of the motorist is also related to the fact that they often pass with higher than cruising speed, pull in front of the truck and then apply the brake to reduce their speed. Another scenario that relates to pulling back into the right lane occurs when an automobile passes a truck and then immediately needs to reduce speed in order to enter the exit ramp. Because the truck is unable to decelerate as fast as an automobile, these activities sometimes result in rear-end collisions. Similarly, the automobiles that are behind the truck do not anticipate the truck applying brakes and might hit the truck from the rear.

One of the outcomes of lower posted speed limits or speed limiting company policies for trucks is an increase in the number of vehicle interactions where automobiles pass trucks. The truck drivers stated the opinion that uniform speed limits significantly reduce the frequency and risk associated with vehicle interactions. Eighty-seven percent (87%) of the truck drivers responded that speed differentials, whether due to regulated speed limits or company policies, increase the risk of accidents. Ten percent (10%) of the truck drivers stated the opinion that there is no effect of speed differential limits on

Figure 50. Illustration of an Automobile “Cutting-off” a Truck

accidents. They contended that there are advantages and disadvantages that usually cancel out, with the result being that overall safety would not be affected. The remaining 3% of the truck drivers responded that they felt that having trucks move slower than automobiles improves safety due to operating and handling differences in the vehicles (braking distance, maneuverability, etc.).

With respect to the types of accidents, 43% of the truck drivers stated that speed differentials increase the probability of side collisions. Fifty-three percent indicated that side collisions would not be affected and 4% indicated that they would decrease.

There was a general consensus among truck drivers (76%) that the traffic speed enforcement in states having differential speed limits is much stricter than in states that have uniform speed. Ohio and California were frequently cited as the states with the strictest enforcement. They also felt that the authorities are more strict when enforcing speed limits for trucks than they are for automobiles..

4.4.3 Effects of Speed Differentials at On-Ramps and Off-Ramps

Another safety issue addressed by the truck drivers is related to the vehicle interaction at on-ramps. According to the truck drivers, restricted truck speed has a number of implications at on-ramps. First, slower trucks tend to get “trapped” in the right hand lane at on-ramps (Figure 51). The inability to move to the left lane to avoid merging traffic is frustrating to both truck drivers and the merging motorists. The interaction with merging traffic involves inherent risks that do not occur when driving in the flow of traffic. When motorists are merging onto the highway, they often assume that trucks are moving faster than they are. The result is that the motorist often reduces speed to merge behind the truck. Because the truck is going slower than other traffic, this causes congestion.

Figure 51. Truck Interacting with Merging Traffic

The truck drivers also indicated that another problem related to restricted truck speeds (speed limiters) is the inability of trucks to reach traffic speed when merging into traffic at on-ramps (Figure 52). This causes issues for both the truck and the flow of traffic and potentially increases the risk of accidents on-ramps.

Figure 52. Truck Merging into Traffic

4.4.4 Effects of Speed and Speed Differentials on Driver Fatigue

One of the topics of disagreement between many truck drivers and company management personnel is the impact of speed on fatigue. It is interesting to note that there does not appear to be any published literature on the effect of driving speed on fatigue for either automobiles or trucks. This is the case even though the effect of driving time has recently received an extensive amount of attention in the context of “hours of service” regulations. To investigate the truck drivers’ opinions on the relative effects of “driving time” and “vehicle speed,” they were asked which situation results in less fatigue: driving 60 mph for 7 hours or driving 70 mph for 6 hours. In both cases, 420 interstate highway miles would be covered. Eighty-seven percent (87%) of the truck drivers indicated that driving faster for a shorter period would result in less fatigue and drowsiness. This response was potentially confounded by the fact that drivers are usually paid on a per mile basis. Therefore, driving faster leads to more income per hour.

Many of the drivers stated that the handling characteristics of the trucks have improved significantly over the past decade and that driving at higher speeds is not as tiring as it was previously. However, many of drivers indicated that driving above 75 mph increases stress and fatigue. Some drivers (13%) felt that driving 70 mph is too fast, takes more energy and increases fatigue. Most of the drivers stated that, irrespective of their individual speed, driving with the average traffic speed minimizes the fatigue. They contended that driving either above or below the traffic speed causes them more fatigue. Some drivers indicated that although driving significantly below traffic speed reduces the number of maneuvers (lane changes), it can increase the boredom and can make them “drowsy”, thus increasing the risk of running off of the road.

Some company managers contended that drivers who drive at higher speeds (e.g., 70 mph) take the same amount of time to cover a given distance as is taken by drivers driving at slower speeds because the drivers of faster vehicles stop more often for breaks and the breaks are longer. In response to this question, seventy-one percent (71%) of the drivers stated that their driving time between each stop is independent of the speed they travel. This response appears to be related to the fatigue issue previously discussed, which is based on time, not distance traveled.. Twenty-nine percent (29%) felt that they take more frequent breaks when they travel at higher speeds. Approximately half of these drivers indicated that by traveling at higher speeds, more distance is traveled in less time, and so they can “afford” to stop more frequently and still make their deliveries on time. This assumes that the routing schedule uses an artificially low vehicle speed.

4.4.5 Effects of Speed Limits on Driver Retention

Truck driver retention is one of the more serious problems currently being faced by the trucking industry. Operating speed of the company vehicles could be one of the factors that affect driver retention. Of the surveyed truck drivers, 68% said that the company’s speed limit policies affect driver retention. They stated that if companies set the speed limits of their trucks lower, it would indirectly affect the driver’s paycheck. Because the drivers are often paid per mile, lower vehicle speed would translate into fewer miles traveled and less income for the drivers. Lower speed limits also translate into lower pay per hour and less personal time per mile traveled. The literature has shown that, for many drivers, personal time can have a larger effect than monetary factors. However, 32% stated that, as long as they keep getting healthy paychecks, the company’s speed limit policy does not affect their decision to remain with the company.

4.4.6 Effects of Speed and Speed Differentials on Operating Costs

The literature indicates that fuel costs are considered to be the single most significant factor in the overall operating costs for trucks that are associated with vehicle speed. To better understand this opinion, the truck drivers were surveyed about the impact of vehicle speed on the fuel efficiency. Fifty-five percent (55%) stated that an increase in speed from 60 mph to 70 mph would decrease the fuel efficiency. Twelve percent (12%) indicated that truck engines can be tuned and the axle ratio can be set up in a way as to provide best fuel efficiency higher speeds. There were 11% who believed that, fuel efficiency would not be affected up to 65 or 70 mph, however, beyond that fuel efficiency would start decreasing. Twelve percent (12) contended that modern truck engines are manufactured to provide best fuel efficiency at speed in the range of 65 mph to 70 mph and that fuel efficiency would improve as speed is increased from 55 mph to 65 or 70 mph. However they indicated the opinion that, beyond 70 mph, the fuel efficiency would decrease for the current engine configurations. Ten percent of the drivers stated that fuel efficiency would improve with is operating speeds increased from 55 to 75 mph.

As indicated in the literature review, some trade reports indicate that higher operating speed increases some of the maintenance costs. The truck drivers were surveyed to obtain their opinion of the relationship between speed and maintenance costs. For reference purposes, the drivers were asked to compare the maintenance costs for 60 mph versus 70 mph. Most of the drivers (64%) stated that, assuming that the maintenance is done at regular intervals (by mileage), the maintenance costs are independent of the truck's speed. Some of the drivers (28%) felt that higher speeds would cause more wear on the engine and thus increase the maintenance costs. Only 8% of the drivers thought that operating at 70 mph would have lower maintenance costs compared to operating at 60 mph.

The effect of speed on tire wear was another factor that was included in the truck driver survey. Again, for reference purposes, the drivers were asked to compare the wear associated with driving 60 mph versus 70 mph. Fifty-one percent (51%) of the drivers responded that the tire wear would remain the same, while 45% indicated that the higher speed would increase tire wear. Only 4% suggested that higher operating speeds would decrease tire wear. The group of drivers, who felt that tire wear would remain the same, irrespective of the speed, believed that if the correct tires are chosen for the speed and the correct tire pressure is maintained, there would not be additional wear at higher speeds. The other group of drivers, who believed that increasing speed increase tire wear referred to increased tire heat at higher speeds. The smallest group of drivers, who thought increasing speed would decrease tire wear, believed that, for a given distance, reducing the exposure time for the tires would be beneficial.

4.4.7 Comparison of Owner-Operator and Company Driver Opinions

As previously discussed, there is a difference between both the use of speed limiters and the speed limit setting used by owner-operators and commercial fleets. Speed limiters are used very little by owner-operators and, when used, they are often set at higher speeds. The owner-operators have control of the settings, whereas company drivers do not. The drivers were asked the question, "If you were paid the same every month, irrespective of the miles traveled, what safe speed would you drive on rural interstate highways?" The most frequent choice was 70 mph (see Figure 53). This is probably lower than the general public assumes that truck drivers would choose.

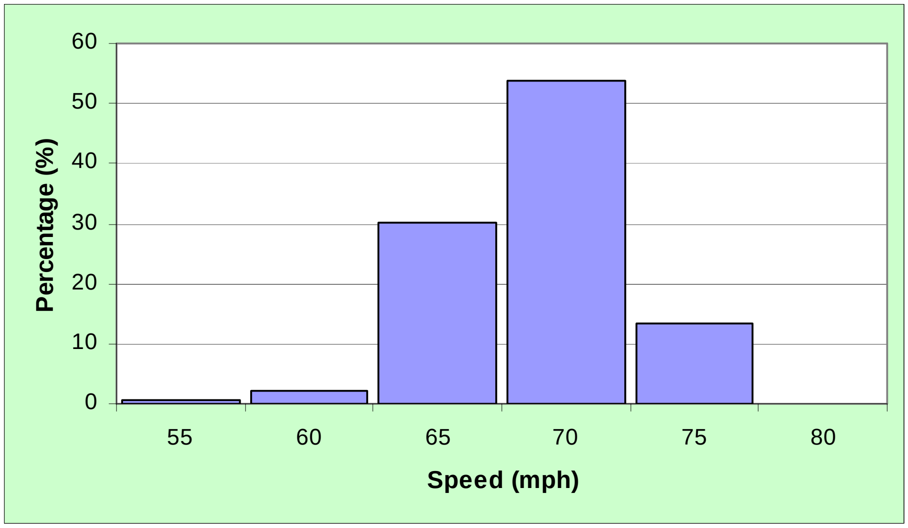

Figure 53. Preferred Speed of Travel by Truck Drivers

Figure 54 illustrates that fewer owner-operators indicated that they would prefer the higher speed of 75 mph than did company drivers. It is interesting that the individuals that have had the opportunity of driving faster tended to feel that the lower speed of 70 mph is preferable. One potential reason could be that the owner-operators have operated at the higher speeds and found that they are not as safe and efficient. However, the company drivers' opinions are based on less experience driving at the high speeds and not being responsible for the operating costs. It should be emphasized that this particular question did not address traffic speed or speed differentials between trucks and light vehicles.

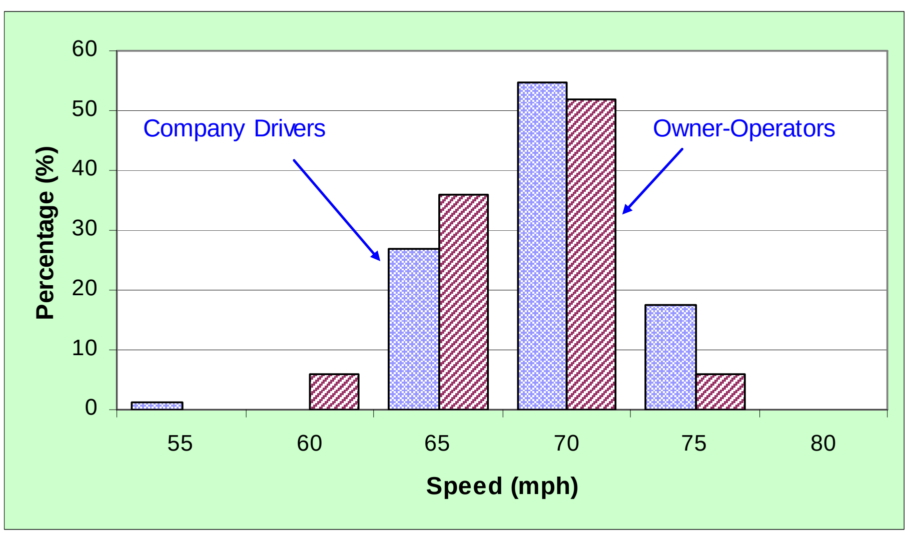

Figure 54. Speed Preferred by Company Drivers and Owner-Operators

There was also a difference between the company drivers and owner-operators as to the effect of speed on fuel consumption. Sixty-two percent (62%) of the owner-operators indicated that operating at higher speeds would reduce fuel efficiency. Only 50% of the company drivers responded that higher speeds reduced fuel efficiency. It is interesting that a relatively high proportion of both groups contended that higher speeds do not significantly reduce fuel efficiency and often prefaced their statement with the assumption that the truck engine and transmission are intended for the higher speeds. In particular, it is interesting that 38% of the owner-operators who paid for their own operating costs (fuel, tires, insurance, etc.) indicated that traveling at faster speeds was both safe and efficient. When the company drivers were asked why thy think companies limit their trucks to lower speeds, the majority responded that it is due to insurance costs rather than fuel, tire or maintenance costs.

When asked what maximum speed limit for automobiles and trucks should be used on flat interstate highways, 93% indicated that they would prefer a uniform speed limit, independent of the absolute limit. The highest percentage of drivers (62%) indicated that the appropriate truck speed should be 70 mph (refer to Figure 57). Of the remaining drivers, 19% indicated 65 mph and 18% indicated a preference for 75 mph, respectively. Again, the fact that 82% of the drivers actually prefered to have limits that are 70 mph or lower is probably not consistent with the driving public's assumption of truck drivers' preferences.

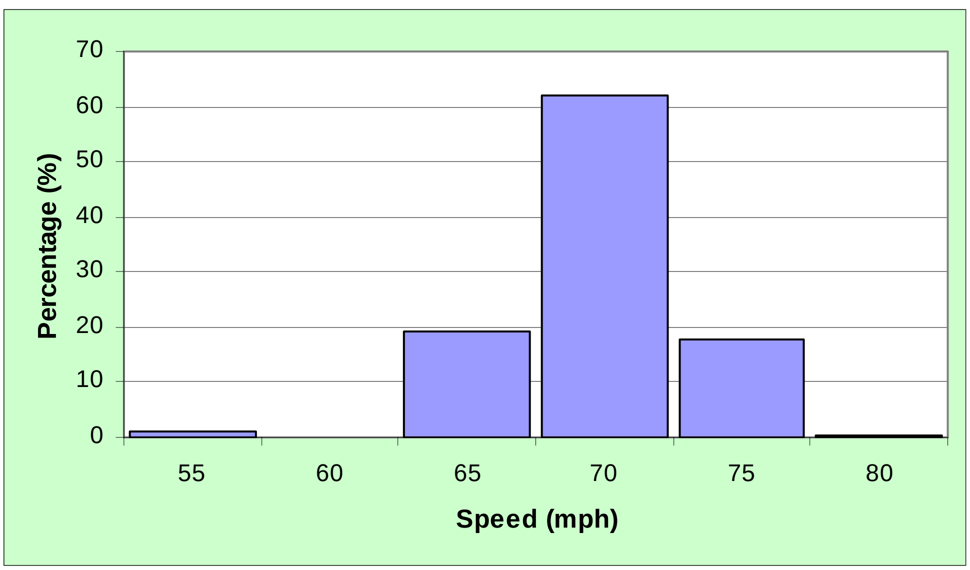

Figure 55. Speed Limits Preferred by Truck Drivers for Trucks

4.5 Opinions of Carrier Fleet Safety and Maintenance Management

Nearly all of the commercial fleets that were surveyed have speed limiters on their company vehicles. The only exceptions were fleets that only used contract drivers. Most of the fleets that had both company drivers and contract drivers require speed limiters only for the company drivers. Most of the companies operated between 62 and 70 mph. Flatbed, tanker and refrigerated trucks tend to operate at higher speed limits (70 to 75 mph).

Most of the safety managers indicated a firm opinion that higher speeds result in a higher frequency and, particularly, severity of accidents. They also indicated an opinion that higher speeds increase stress and driver fatigue, with the result that drivers take more frequent and longer breaks. The contention expressed by many fleet managers was that, over an extended trip, the total travel time would be the same for drivers having speed limiters set at 65 mph and 75 mph. When drivers were questioned about this opinion, they explained that the management's opinion might be accurate if the delivery schedules do not accommodate the higher truck speeds. If the schedule is based on an average speed that was established from historical data with a lower speed, there is no benefit for the driver to arrive before the delivery time. The drivers contend that the additional break frequency and duration is due to excess schedule time, rather than due to additional stress or fatigue related to the higher speeds.

Some companies indicated that they use the speed limiter setting as an incentive for improved safety and/or fuel efficiency. Drivers are allowed to travel at slightly higher speeds based on their safety and fuel consumption records. These companies have found that allowing an increased speed of one to five miles per hour can be an effective reward for many the drivers.

In some companies, new drivers are restricted to a lower speed limit than the experienced drivers. After a period of time, and sometimes based on their safety record, their operating speed is raised to the company's nominal limit. The purpose of this process is to reduce probability of accidents for less experienced drivers. However, the literature indicates that there might actually be a higher risk of accidents at speeds that are slower than the traffic speed due to the increased number of vehicle interactions.

The majority of the safety managers indicated that they believed that differential speed limits on highways cause more accidents and all of these managers stated that automobiles and trucks should operate at uniform speed. The most frequent speed that was indicated for a uniform limit was 65 mph, although some indicated that 70 mph would be acceptable. None of the safety managers suggested speed limits higher than 70 mph.

The consensus from the maintenance managers surveyed indicated that an increase in the operating speed of one mph decreases fuel efficiency by 0.08 mpg to 0.1

mpg. This value is much lower than the 0.14 mpg decrease published by The Maintenance Committee (TMC). One company reported that their fuel efficiency had actually gone down by only 0.1 mpg after increasing their operating speed by 3 mph. No conclusions were drawn from these preliminary results.

Regarding the tire wear, the consensus of the maintenance managers was that tire wear increases beyond a 65 mph operating speed; although there were no data available to support the view. One manager indicated that the company had observed no difference in tire cost between the trucks that operate in states that have a 55 mph speed limit and those that operate in other states where the company limit of 65 mph determines the maximum speed. Regarding preventive maintenance costs, the maintenance managers indicated that, if preventive maintenance is done at regular intervals on the basis of mileage, higher operating speeds would not cause more engine wear. None of the companies modified their maintenance schedules (i.e., oil changes, etc.) based on vehicle speed.

4.6 Opinions of Original Equipment Manufacturers

In addition to reviewing published literature and surveying commercial fleet managers, engineers from the companies that manufacture the trucks, engines, and tires were surveyed. These surveys consisted of discussions at professional and trade meetings such as the Technology and Maintenance Council meetings held by the American Trucking Association, Society of Automotive Engineers Bus and Truck Meeting, etc. In addition, a number of personal communications by telephone were used to solicit the opinions of the original equipment manufacturing company personnel.

4.6.1 Opinions of Engine Manufacturers

The primary issue being addressed with this group related to the effect of truck speed on rural interstates on the engine wear and life of the engine. The effect of changing driving speed from 60 mph to 70 mph was addressed. One engine manufacturer indicated that by increasing travel speed from 60 mph to 70 mph, the engine life would be reduced by 20%. This estimate was based on the opinion that the increased fuel consumption is directly related to engine life and that the 1987 Maintenance Council estimate of fuel consumption as a function of speed was still valid. Two other major engine manufactures both indicated that a change from 60 mph to 70 mph would not have a significant effect on the engine life, as long as maintenance was performed at the prescribed intervals. None of the manufactures, including the one that contended that higher speed reduces engine life, recommends more frequent maintenance (i.e., oil changes, engine rebuild, etc.) for trucks traveling at higher speeds. This is consistent with the fleet data that indicated that the maintenance intervals were not affected by the maximum speed allowed by the different fleets.

Another source of information that supported that the travel speed does not significantly affect engine life is that the fleets and owner-operators that purchase used trucks do not use the speed that the truck was driven in their purchasing decisions. The only issue considered was that the regular maintenance was performed at the appropriate times based on the miles traveled.

A critical issue addressed by all of the engine manufacturers was that the engine configuration (i.e., horsepower) and the transmission be based on the truck cruise speed. The size of truck engines being purchased have been increasing. This is supported by the data collected in the drivers' surveys that indicated that newer trucks generally had much larger engines than the older trucks.

4.6.2 Opinions of Tire Manufacturers

The opinions of the tire manufactures varied with respect to the effect of truck speed on tire wear and tire life. One of the manufacturers indicated that there is a significant increase in tire wear as speed increases. One basis for the opinion was the increase in tire temperature with increased speed. However, other tire manufacturers contended that, as long as the correct tire speed rating is used, the tire material can accommodate the higher speed. In addition, although the tires are somewhat hotter at higher speeds, they are hot for a shorter period because the time required to drive a given distance is shorter. These manufacturers stated that the effect of truck speeds, below 75 mph, is “in the noise” compared to other factors that affect tire wear and tire life. At higher speeds (i.e., 75 mph), tire irregularities become more of a problem than tire wear. At these speeds, the inertia (tire growth) can also become a problem.

One manufacturer cited that recent, unpublished data indicated that the increase in rolling resistance of newer commercial truck tires is between 2% to 3% for an increase in speed from 60 mph to 70 mph. This is significantly below the estimates in the range of 15% provided in other tire and engine manufacturer documents.

The one area where there was consensus among all groups, manufacturers, fleet management, and drivers, is the criticality of maintaining correct tire pressure for the weight and speed of the truck. There is a large amount of emphasis provided by these groups, as well as federal agencies, to increase the awareness of the importance of tire pressure.

4.7 Comparison of Fleet Experience in States with Different Speed Limits

The accident data were obtained from the participating companies for the previous three years (2001-2004). The maximum truck speeds were limited to 62 and 65 mph. By comparing the experience of the fleet in states that have different automobile speed limits, the “virtual” speed differential was investigated.

4.7.1 Selection of Accident Data

The accident data for the companies were obtained for the period of January 2001 through September 2004. The data were sorted based on the type of road on which the accident occurred. Although rural interstates are the focus of this report, the databases were not categorized in this manner. Therefore, the category of four-lane, divided highway was selected for the analysis.

The data were sorted to isolate the conditions where the maximum speed could be a determining factor. For example, sleet, snow, and fog conditions were not included. The data focused on both clear conditions and rain. Although rain does impair visibility, it is a condition in which drivers often maintain their maximum speed.

The data were also sorted based on the type of accidents. Only those accidents for which the speed of the vehicle could have been a cause of the accident were chosen. Accidents associated with other conditions (e.g., mechanical failure, hitting animals, etc.) were eliminated. Although the absolute speed of the vehicle has an affect on the risk and severity of these accidents, they are not directly associated with the issue of speed differential. Accidents that could not have occurred on the rural interstates (i.e., pedestrian, overhead obstacles, hit parked, etc.) were also eliminated. The primary types of accidents that were included for the purposes of this analysis included: hit by other, lane change left, lane change right, miscellaneous avoidable, passing, rear-end (truck hitting automobile), sideswipe-merge and turnover. Although it would have been beneficial to be able to differentiate accident types such as automobile rear-ending or automobile sideswiping the truck, all such accidents were categorized as “hit by other.”

4.7.2 Analyzing Accident Data by State Speed Limits

The states were grouped according to their posted speed limits. Some states had uniform limits (65, 70 and 75 mph) and other states had posted speed differentials (65/55, 65/60, 70/55, 70/60, 70/65, mph). The “virtual” speed differential for the fleet would be the difference between the company imposed limit of 62 mph or 65 mph and the posted speed for automobiles. Therefore, the “virtual” speed differentials for the fleet varied from 0 mph to 13 mph, depending upon the state.

The states were grouped on the basis of their maximum posted automobile speed limit. The first group consisted of states having a maximum automobile speed limit of 65 mph (IL, IN, KY, WI, PA, OR, OH and IA), the second group consisted of states having a maximum automobile speed limit of 70 mph (CA, AR, MI, WA and MO), and the third group consisted of states having a maximum automobile speed limit of 75 mph (MT, NM, NV, OK, TX, WY and AZ).

Unfortunately, the data from the participating companies were not separated by miles traveled on interstates. Therefore, valid accident rates (per million miles traveled) could not be calculated. To correct for the fact that different miles were traveled on rural interstates in various states, the data were normalized by using the proportion of occurrence for each accident type instead of comparing the absolute number of accidents. Table 16 illustrates the proportion of each type of accident within each group.

Table 16. Proportion of Occurrence of Each Accident Type in Each Group

Accident Type	Group I (65 mph)	Group II (70 mph)	Group III (75 mph)
Hit by Other	48.86	54.55	52.81
Lane Change Left	3.04	3.03	3.90
Lane Change Right	7.15	5.39	6.93
Misc. Avoidable	8.68	9.09	5.63
Passing	0.15	0.34	0.00
Rear-end A to B	10.65	8.42	9.52
Sideswipe - Merge	17.66	17.17	18.61
Turnover	3.81	2.02	2.60
Total Accidents	100	100	100

The only difference that was statistically significant ($p < 0.05$) was the "hit by other" category. The proportion of total accidents in the "hit by other" category was significantly higher in the 70 mph states than in the 65 mph states. This is potentially due to the increased number of interactions in which the other vehicle must maneuver around the truck. However, if this were the total explanation, it would be expected that the proportion for the 75 mph group would have been greater than the 70 mph group, which it was not.

4.8 Financial Cost-Benefit Analysis of Operating Speeds

The operating costs were estimated from a combination of the values from the literature, surveys of the drivers, and surveys of company maintenance personnel. Although the specific values would vary somewhat for different organizations, the basic concept of the cost-benefit analysis would be consistent for different fleets. From the maintenance data obtained from the participating companies, the fuel consumption was estimated to be 6.23 mpg at the speed of 62 mph. The estimate of the amount of fuel efficiency reduction due to increased vehicle speed was based on the literature review, interviews with fleet operations personnel, and preliminary data from a participating company. The participating company was evaluating the fuel consumption on a test fleet on which the speed limiters were set 2 mph above the rest of the fleet. The decrease in fuel efficiency estimates ranged from 0.1 mpg per mph (from the Technology and Maintenance Council), to 0.08 mpg/mph (from surveys of maintenance managers), down to 0.03 mpg/mph (from a participating company's preliminary results). The value for the reduced fuel efficiency for the first analysis was selected to be the high estimate of 0.1 mpg/mph. With respect to the impact of vehicle speed on tire wear, the estimates ranged from "no increase" (from some tire manufacturers and fleets that have vehicles in different speed zones) to a 1% decrease in tire life for each mph increase in speed (from the Technology and Maintenance Council and other tire manufacturers). The value of 0.5% for each mph increase was assumed for this analysis. Based on discussions with maintenance managers of trucking companies, it was assumed that increased speed would not have any significant impact on other maintenance costs on a per mile basis. The price of fuel was assumed to be $2.00 per gallon.

From a survey of the participating companies and other commercial fleets, the direct variable costs associated with vehicle speed were estimated. The context for the analysis is long-haul operations on rural interstates. It was determined that the direct costs, independent of the drivers' pay, was 29.3% of total revenue. The breakdown by category was as follows:

Cost Category	Percentage Revenue
Fuel	15.4 %
Tires	1.6 %
Maintenance Costs	4.3 %
Profit	8.0 %

The number of miles traveled per truck, per year was estimated to be 130,000 for the purposes of this analysis. This value is somewhat higher than some companies and is lower than the average annual miles traveled by many owner-operators, based on the surveys during this study. The breakdown of costs for the base speed of 65 and 70 mph are shown in Table 17.

For this scenario comparison, the increase in revenue per truck ($20,846) is less than the increase in incremental operating costs due to the higher speed. This would result in a net reduction in profit of $2,371 per truck. However, the driver's pay increased by $3,200 due to the increase in total miles. To the extent that the additional wages improve driver retention, the reduction in the costs required to replace drivers might offset the decrease in profit per truck. The cost of replacing a driver is approximately $5,000 to $8,000.

With more modern fleets that have electronically controlled engines, more effective aerodynamics and higher horsepower engines, the additional cost per mile in fuel is more likely to be .05 mph per mph. In this case, the annual reduction in profit per truck would be $328. If the lower estimate of .03 mpg/mph is used, based on the preliminary

Table 17. Per-Truck Cost Analysis for 0.1 mpg/mph Fuel Efficiency Loss

Speed (mph)	**65**	**70**	
Fuel cost ($/gallon)	2.00		
Fuel (mpg)	6.23	5.73	0.10 mpg/mph
Tires (% of total revenue)	1.60	1.64000	0.50% / mph
Maintenance (% of total revenue)	4.30	4.30	
Driver ($/mile)	$ 0.32	$ 0.32	
Annual Miles	130000	140000	
Total Revenue	$270,997	$291,843	
Gallons consumed	20867	24433	
Fuel cost	$41,734	$48,866	
Tire cost	$4,336	$4,786	
Maintenance cost	$11,653	$12,549	
Drivers Pay	$41,600	$44,800	
Other cost (70.7%)	$191,595	$206,333	
Operating Revenue	$249,317	$272,534	
Profit (8%)	$21,680	$19,309	**Reduction of $2,371**

Table18. Per-Truck Cost Analysis for 0.05 mph/mph Fuel Efficiency Loss

Speed (mph)	**65**	**70**	
Fuel cost ($/gallon)	2.00		
Fuel (mpg)	6.23	6.08	0.03 mpg/mph
Tires (% of total revenue)	1.60	1.64	0.50% / mpg
Maintenance (% of total revenue)	4.30	4.30	
Driver ($/mile)	$ 0.32	$ 0.32	
Annual Miles	130,000	140,000	
Total Revenue	$270,997	$291,843	
Gallons consumed	20,867	23,026	
Fuel cost	$41,734	$46,053	
Tire cost	$4,336	$4,786	
Maintenance cost	$11,653	$12,549	
Drivers Pay	$41,600	$44,800	
Other cost (70.7%)	$191,595	$206,333	
Operating Revenue	$249,317	$269,721	
Profit (8%)	$21,680	$22,122	**Increase of $442**

empirical fleet data, there would actually be an annual increase profit gain of $442 per truck by changing the company speed policy or the posted truck speed limit from 65 mph to 70 mph. The assumptions used in this analysis are obviously not representative of all trucking operations under all conditions. For example, the effective cost of fuel (accounting for surcharges) has a large effect on the costs associated with the reduced fuel efficiency. In addition, the assumption was that the trucks are long-haul operations that are always on interstate highways. However, for that portion of a fleet's operations that are spent on rural interstates, this type of analysis should apply.

5. Discussion

This study addressed the safety and financial costs and benefits of higher speed limits and of speed differentials between large trucks and other vehicles on rural interstate highways. This section of the report presents conclusions drawn from: (a) review and analysis of existing literature, (b) collection and analysis of speed, accident, and maintenance data, and (c) analysis of opinions of various stakeholders: truck drivers, safety and maintenance managers of companies, and original equipment manufacturers of trucks, tires, and engines.

5.1 Summary of Research on Truck Speed Effects on Traffic Flow and Safety

5.1.1 Impact of Speed Limits on Traffic Speed

Increases and decreases of the posted speed limits have been found to affect traffic speeds to various degrees by different studies. The concept of "design speed," often defined in terms of the 85^{th} percentile traffic speed, is frequently discussed in the context of setting speed limits. Although this concept has been shown to be useful for two-lane roadways with complex geometries, it does not appear to be applicable for four-lane rural interstate highways. The 85^{th} percentile speed of unrestricted traffic on rural interstates would be much higher than the limits that are generally considered to be acceptable. One of the reasons that studies have observed a large amount of variation in traffic speeds on highways with the same physical characteristics has been the level of enforcement. If speed limits are not strictly enforced, motorists choose their own "comfortable" operating speeds.

A factor that has affected the observed increase in the traffic speed when limits have been raised has been the time frame over which the data are collected. The change in traffic speed after a limit change is characterized by two stages, an initial transition phase and, subsequently, an adaptation phase. During the "transition" phase, only a few motorists increase their speeds immediately up to or above the new speed limits. The adaptation phase begins when the motorists become comfortable with the higher traffic speeds and increase their speed. If the magnitude of increase in the average speed is calculated soon after increasing the speed limit (during transition), the increase in the average speed is lower than if it is measured later, after the adaptation phase. Another important aspect of the transition phase is that the speed variance (distribution of vehicle speed in the traffic flow) is higher than it is after the adaptation phase. This speed variation has important safety implications which will be discussed later in this section.

An important issue that previous studies in the research literature have not addressed is the traffic mix of heavy trucks and light vehicles when investigating the relationship between speed limits and traffic speed. As illustrated in this report, the speeds of many (if not most) trucks are limited to below posted speeds by engine speed limiters. Since large trucks constitute a significant portion (15 to 45%) of rural interstate traffic, an increase in the posted limit of 10 mph does not produce the same amount of increase in the mean traffic speed. The level from which the speed limit was raised (from 55 to 65 mph or from 65 to 75 mph) was also been found to affect the amount of increase in the mean speed. An increase in the speed limit from 55 to 65 mph on rural interstate highways increases the mean traffic speed by 3 to 6 mph; whereas, an increase in the speed limit from 65 mph to 75 mph increases mean speed by only 2 to 4 mph. One reason for this is that most trucks can increase their speed from 55 to 65 mph; however, a significant portion of the trucks can not increase from 65 to 75 mph.

The speed data collected during this study illustrated that, although the posted speed limits for automobiles differed by 10 mph (65 versus 75 mph), the mean speeds differed by only 1.6 mph (73.2 to 74.8 mph). The posted speed limits for heavy trucks had a larger effect. The 15 mph difference in posted limits for trucks (55 versus 70 mph) resulted in mean truck speeds that differed by 4.4 mph (64.2 and 68.6, respectively). These data support the research literature that has frequently indicated that motorists tend to drive at a speed with which they are comfortable, regardless of the posted limits.

Even when the posted speed limits are the same for heavy trucks and automobiles (uniform limits), the average speed of trucks is 3 to 4 mph slower than the average speed of automobiles. This is primarily due to the fact that most trucks have speed limiters that restrict their speed. However, the truck drivers contend that it is also the result of different levels of enforcement for heavy trucks and automobiles. The compliance rates differed significantly for the four speed limit configurations studied during this effort. The compliance rate for the highest, uniform limits (75/75 mph) were 53% and 73% for automobiles and trucks, respectively. However the compliance rates for the lower differential in speed limits (65/55 mph) were 7% and 0%, for automobiles and trucks, respectively. This supports the contention in the literature that, if the limits are set at what is considered to be arbitrarily low values, motorists will not adhere to the limit.

5.1.2 Impact of Speed Limits on Rural Interstate Highway Safety

The fact that sections of interstate highways with virtually identical physical characteristics have very different speed limits in different states illustrates that there are many factors unrelated to the roadway and traffic that affect the setting of speed limits. For similar rural interstate highways, the speed limits range from 65 to 75 mph for automobiles and from 55 to 75 for heavy trucks. A good of a dramatic and immediate change in speed limit occurs when crossing the Nevada-California state line on

Interstate I-15. The speed limit for heavy trucks decreases by 20 mph (from 75 to 55 mph), although the roadway does not change at that point.

The large number of safety studies that were discussed in the Literature Review indicates that this issue has received a great amount of attention. Unfortunately, many of the studies involve more advocacy than science. One section of this report addresses the methodological issues associated with much of the research on the relationship between speed limits and highway safety. For example, the studies that analyzed the number of fatalities during the transition periods immediately after speed limits were increased often found very large increases in the number of fatalities. However, other studies that measured fatality rates or accident rates over a longer time frame often concluded that there was little or no negative impact of the speed limit increases. Similarly, many sources in the popular press refer to the statistics that indicate that more than one-third of the highway accidents are associated with "speeding." However, speeding is defined as "traveling faster than the posted limits" or "traveling too fast for conditions." Because there is no differentiation of these two categories in much of the literature, the effect of the posted speed limits on the number of accidents and fatalities is probably highly exaggerated in the popular literature.

5.1.3 Causes and Impact of Speed Variance

Although there is a large amount of controversy over the magnitude of the effect that increases in posted speed limits have on highway safety, there is a relatively strong consensus among both researchers and practitioners that a higher variance of vehicle speeds in the traffic flow increases the risk of accidents. This relates to the intuitive argument that the more interactions there are among vehicles, the higher the probability of a collision event occurring. Even when the traffic density is high, traveling on an interstate highway without passing or being passed would involve fewer opportunities for two-vehicle collisions than if the variation in vehicle speeds is high.

Various factors that affect traffic speed variance are enforcement, the design speed of the highway, and the percentage of trucks among traffic. High enforcement results in the reduction of the number of motorists traveling at excessively high speeds, which results in lower speed variance among vehicles. If the speed limit is set far below the effective design speed of the highway, some motorists will adhere to the limits, but most will choose a higher speed at which they feel comfortable. This will increase the speed variation among vehicles. From the traffic speed measurements taken during this study, it was observed that the rural interstate with a posted speed limit of 65 mph had much more "speeding" (i.e., low compliance) than was observed for the interstates with higher limits.

Another characteristic of speed limits that increases the speed variance is differential speed limits. If the posted limit for automobiles is higher than for heavy trucks, there will naturally be more variation in vehicle speeds. Company policies that restrict the maximum speed of their fleet with limiters on the engines also increase the amount of speed variance on interstate highways. As the proportion of trucks on a highway increases, the amount of speed variance increases.

Changes in posted speed limits also affect the speed variance. During the transition period, some drivers adapt slowly to the higher limits while others immediately travel at or above the new limit. This temporary behavioral difference of these two groups increases the amount of speed variance. This phenomenon has been cited as being a potential confounding factor when investigating the impact of increased speed limits on the number of accidents or fatalities. If the safety data for the transition period are used as the basis of comparison, the conclusion could be that there is a large negative impact of increased speed when, in fact, the increase in accidents could be due, at least in part, to the increased speed variance.

When the effect of increased speed limits on speed variance of automobiles and trucks were studied individually, different trends were observed for the two vehicle categories. Speed variance among automobiles decreased with increased speed limits. For trucks, increasing speed limits up to 65 mph resulted in reduced speed variance. However, increases in speed limits beyond 65 mph increased speed variance among trucks. Higher speed limits tend to divide truck traffic in two parts: one consisting mainly of owner-operators, who can travel at higher speeds, and the other consisting mainly of company drivers who can not travel at higher speeds due to the use of speed limiters. Results of the traffic speed measurements collected during this study support these conclusions. It was observed that the speed variance among automobiles on highways with 65, 70, and 75 mph speed limits decreased (5.67, 4.95, and 4.61 mph, respectively); whereas, the speed variance among trucks on the same 65, 70, and 75 mph speed limit highways increased (3.69, 4.55, and 5.63 mph, respectively).

With respect to speed variation, most of the studies that analyzed the effect of vehicle speed on the risk for an individual vehicle concluded that the probability of being involved in a crash follows a U-shape curve as a function. The risk increased for both vehicles going faster and slower than the traffic speed with the minimum value being at or slightly above the mean speed of traffic. A computer simulation used in this study indicated that, for the interstate with posted differential speed limits of 65/55 mph, the number of interactions for a truck traveling at the speed limit (55 mph) would be more than four times the number of interactions for a truck traveling at mean traffic speed.

One of the common misconceptions that motorists have is that they are often passed by trucks. However, results of the simulation study indicated that the frequency of automobiles being passed by trucks is very low. Using the traffic speed data from the uniform 70 mph sites, an automobile traveling at the mean traffic speed (71.5 mph) would be passed by only 30 trucks during a 1000 mile trip on a rural interstate.

5.1.4. Impact of Speed on Crash Severity

Most of the studies in the research literature have concluded that the severity of an accident increased with increased speed. Although the improvements in passive safety systems, such as seatbelts, airbags, and vehicle crash worthiness, have reduced the impact of speed on severity, basic physics indicates that a crash at higher vehicle velocities results in higher impact forces. This is particularly the case for heavily loaded trucks. The difference in braking distance between automobiles and heavy trucks is also affected by the speed of the vehicles. Although recent advances and projected future improvements in brake technology for trucks is reducing the brake distance differential, this is one of the most valid reasons for restricting truck speeds to lower than automobile speeds. One misconception that is often cited in the popular literature relates to the relationship between truck weight and braking distance. Due to the increased normal forces on the roadway surface, the braking distance for a fully loaded truck is not higher than for an empty truck.

The relationship between speed and crash severity is one of the reasons that research studies that use the number or rate of fatalities, rather than accidents indicate a much higher impact of higher speeds on highway safety. Even when the number of accidents does not increase, or even when the number decreases, the number of fatalities can increase because the accidents, when they do occur, are more severe.

5.1.5 Impact of Differential Speed Limits on Highway Safety

The fact that public policy makers have come to different conclusions about the efficacy of speed differentials is illustrated by the fact that states have adopted speed limits that range from a 15 mph differential to uniform limits for both automobiles and heavy trucks. Although there have been a number of studies that have investigated the safety implications of posted speed differentials between automobiles and heavy trucks, the results have been inconclusive. The studies have either compared data from states that have different configurations (Differential Speed Limits, DSL, or Uniform Speed Limits, USL) or data for states that changed from one configuration to the other. A representative conclusion is from the Federal Highway Administration’s Technical Report (FHWA-HRT-04-126, 2004) states that: “Overall, the study was not able to isolate or measure the effect of USL/DSL changes. The effect of the DSL, if any, is not enough to be detected in the aggregate speed data that were analyzed.”

One very important factor that has not been addressed by the research studies that have investigated posted speed differentials between automobiles and heavy trucks was the impact of speed limiters that are installed on most commercial trucks. To the extent that this resulted in an effective differential, even for states that had uniform speed limits, the studies were inherently flawed. This is one of the reasons that the various studies have found differing results.

Proponents of lower truck speed limits cite the fact that trucks require longer braking distances for any given speed and lower truck speeds help equalize the stopping distance. Truck drivers contend that their higher seat position allows a longer site distance (multiple vehicles forward), reducing the effect of the differences in braking distance. Opponents of lower truck speed limits have suggested that the differential speeds increase the speed variance and, therefore, has a negative impact on highway safety. It is likely that both of these arguments are correct. This would indicate that differential speed limits have two effects: (1) the positive effect that results from improved vehicle dynamics (braking and maneuvering) for trucks at lower speeds; and (2) the negative effect of increasing speed variation and the number of interactions among vehicles. These two effects of differential speed limits act in opposite directions and ultimately result in no observable effect on highway safety data.

When the truck drivers were asked for their opinions of speed differentials, most stated that differential speed limits increase interactions among vehicles and increase the probability of rear-end, side-swipe, and on-ramp accidents. Two scenarios that dominated the drivers' concerns were associated with on-ramps. The first safety issue related to trucks being "trapped" in the right lane and the increased risk of continually encountering merging traffic. The second issue involved trucks not being able to reach traffic speed when merging into traffic flow. They also indicated a concern that lower truck speeds result in congestion and clustering of traffic and bottleneck situations on highways. The majority of the truck drivers indicated that a uniform speed limit of 70 mph for both automobiles and trucks would be both the safest and the most efficient configuration for rural interstate highways. It was interesting to note that the drivers that generally have the ability to travel faster than 70 mph (owner-operators) also agreed that a 70 mph limit would be most appropriate.

Most of the company safety managers who were surveyed also expressed the opinion that differential speed limits increase the probability of accidents on rural interstate highways. However, many of the safety managers felt that a uniform limit of 65 mph would be the best alternative. Some managers indicated that new, less experienced drivers might benefit more from lower truck speeds, with more experienced drivers being able to handle the higher speeds. Other managers indicated that this policy would put less experienced drivers at additional risk due to the increase in the number of vehicle interactions that they would experience. The effect of company policies that restrict maximum speeds does not appear to affect the insurance premiums paid. From discussions with insurance carriers, it was determined that only the company's experience ratings were considered and that the company's speed policies were not included in the rate-setting process.

5.1.6 Effect of Speed on Driver Fatigue

Fatigue is a contributing factor in as many as 30-40% of all heavy truck crashes. Although research has been conducted to study the factors causing truck driver fatigue, there is no empirical data indicating that increased speed increases fatigue. However, there are studies that have found that operating time has significant impact on truck driver fatigue. The relationship among of driving time, fatigue, and accident risk has been extensively documented in the context of the recent changes in truck driver "hours-of-service" regulations. One of the methods of reducing driving time and fatigue without reducing transport efficiency or driver pay, would be to travel at a higher speed. From an hours-of-service perspective, an important issue is whether it would be safer to drive for 10 hours at 70 mph than it would be to drive for 11 hours at 64 mph.

When the truck drivers were surveyed about their opinions on fatigue, most of them stated that driving faster for a shorter duration of time would result in less fatigue and drowsiness. In addition, the consensus of drivers was that driving at the average traffic speed reduces fatigue.

Most of the company safety managers indicated the opinion that traveling at higher speeds results in more fatigue. A comment frequently expressed by managers was that, even when drivers are allowed to use higher speeds, they do not get to their destinations sooner because they stop more frequently and take longer breaks. However, most of the truck drivers stated that their driving time between each stop is independent of the speed they travel and that their stops are based on time rather than distance. The drivers did indicate that, if the scheduling of the delivery time is not adjusted for the higher speed, then there is no benefit in getting to the destination early. In this case, they would distribute their time rather than waiting at the destination. However, they indicated a preference for getting to the destination sooner if the delivery schedule was adjusted for the higher speeds.

5.2 Effect of Speed on Operational Costs

5.2.1 Effect of Speed on Fuel Efficiency

One of the primary reasons for commercial trucking firms limiting the maximum speed of their trucks is the reduction in fuel consumption which is the highest operational cost per truck. The rule of thumb provided by the trucking trade organization, The Maintenance Council (now the Maintenance and Technology Council), and some of the engine manufacturers is that each increase in one mph of speed above 55 mph will decrease the fuel efficiency by 0.1 mpg. However, this estimate is based on studies that were conducted nearly 20 years ago. The engines, electronic controls, aerodynamics, etc. are very different for trucks being purchased today. The survey of maintenance and operations managers indicated that a more accurate estimate for current fleets is probably 0.08 mph for each mile per hour increase in speed. Some recent, unpublished data, indicate that, for rural interstates, the cost of increased speed is 0.03 to 0.05 mpg per mile per hour increase.

In addition to the absolute vehicle speed, speed variance in the traffic flow also has an effect on fuel efficiency when both trucks and automobiles decelerate and accelerate to maneuver around slower traffic. As illustrated by the computer simulation in this study, speed differentials significantly increase the number of interactions among vehicles. The negative impact of traffic speed variation on fuel efficiency has not been addressed in the research literature or as a policy issue.

When speed policies are considered, it is important to consider that the driver effect is estimated to be double the effect of vehicle speed. It might be possible that by improving retention, the costs associated with higher speeds might, to some extent, be offset by the ability of more experienced drivers to conserve fuel.

The survey of the truck drivers indicated that they agreed that speeds beyond 65 mph decrease fuel efficiency. The drivers tended to focus on the impact of the appropriate truck configuration (engine, transmission, etc.) if higher speeds are used. It is interesting to note that the owner-operator drivers, who have direct knowledge of their individual operating costs, acknowledge the additional fuel cost associated with higher speeds; however, as a group, they preferred higher speeds due to the increased revenue, more flexible scheduling, and the benefits of increased personal time.

5.2.2 Effect of Speed on Roadway Wear

Although the literature search was extensive, no study that specifically addressed the impact of heavy truck speed on the required maintenance of limited-access highways was found. The basic laboratory research indicated that an increase in the operating speed of the truck would not increase roadway surface stress. The consensus of the researchers surveyed indicated that, to the extent that there was an effect, it would be that higher speeds reduce pavement wear based on the fact that the forces are exerted on individual segments of the roadway for a shorter period. Another widely held consensus was that, as speed variability increases, the increased level of vehicle maneuvering, braking, acceleration, and deceleration would increase the amount of wear on the roadway.

5.2.3 Effect of Speed on Tire Costs

There was no objective research data found in the public literature that related to the effect of speed on tire wear at the speeds appropriate for rural interstates. In the survey, some of the tire manufacturers indicated that a truck speed change from 65 to 75 mph reduced the tire life. This estimate was as high as a 1% reduction in tire life for each additional 1 mph. The primary reason for the reduction was reported to be the increased tire temperatures at higher speeds. The higher temperatures affect the number of times the casings can be retreaded. Other manufacturers stated that, as long as the correct tire rating was used and the pressure was appropriate for the load and speed, the amount of additional tire wear associated with the higher speed would be negligible. With respect to tire temperature, these manufacturers indicated that, although the tires were hotter, the materials were adequate to accommodate those temperatures and the exposure time during which they were hot was actually lower on a per-mile basis. However, there is no objectively verifiable data available to check the validity of either of these opinions, although one manufacturer had preliminary data that indicated that tire speed was relatively unimportant relative to the other factors (i.e., correct pressure).

The majority of the maintenance managers surveyed indicated that tire wear increases beyond a 65 mph operating speed. One of the participating companies indicated that they had observed no significant difference in tire cost between the trucks that operate in states that have a 55 mph speed limit and those that operate in other states where the company limit of 65 mph determines the maximum speed. Most of the truck drivers surveyed expressed that correct tire selection and tire pressure have a much more significant impact on tire wear than the operating speed.

5.2.4 Effect of Speed on Engine Life and Routine Maintenance Costs

With respect to the effect of higher truck speeds on engine life, the opinions of the manufacturers were again split. The estimates of the additional engine wear ranged from no effect to a 20 % reduction in engine life for a truck with a 70 mph operating speed compared to a 60 mph speed. As with estimates for other operating costs, the configuration of the truck (engine, transmission, etc.) is important. If the vehicle is not configured for higher speeds (i.e., low horsepower, wrong gear ratios, insufficient cooling system, etc.) engine wear can increase significantly at higher speeds.

None of the engine manufactures, including the one that contended that traveling at higher speeds reduces engine life, recommended more frequent maintenance intervals on a mileage basis for trucks traveling at higher speeds. This is consistent with the company and driver survey data that indicated that the maintenance intervals were not affected by the maximum speed allowed by different fleets. Another point to note is that fleets and owner-operators that purchase used trucks do not use the speed at which the truck traveled in their purchasing decisions; rather they are only concerned with the fact that maintenance was performed at the appropriate intervals based on the number of miles traveled.

5.3 Financial Cost-Benefit Analysis of Operating Speeds

The financial cost-benefit analysis illustrated how the results are very sensitive to estimates of the operational costs associated with increased truck speed. Unfortunately, although there is are many opinions, there is very little verifiable data that can be used to make these estimates. Therefore, the combination of the literature, survey results, and participating company data were used to derive estimates for the analysis. The analysis used estimates of the increased revenue that could result from higher speeds on rural interstates and estimates of the costs associated with those higher speeds. The results ranged from an annual decrease in net profit per truck of $2,371, for the higher estimates of speed-related operational costs to a net profit increase of $442 for the lower estimates. Even the costs derived using the higher estimates could be offset, to some extent, if the higher speeds and increased pay would improve driver retention. In addition, the number of trucks necessary for the same annual mileage would be reduced, lowering the truck inventory costs for commercial fleets.

5.4 Conclusions

The focus of the study was on absolute and differential speed limits for heavy trucks on rural interstate highways. Although there is an abundance of opinion on many of the issues, there is very little empirical, verifiable, and scientifically valid data available from either public or private sources. The current effort assessed the research and applications literature, measured traffic flow under different speed limit configurations, and surveyed the stakeholders that were affected by the policies. The object of the stakeholder surveys was to obtain their opinions and, more importantly, the basis for those opinions. It is evident that there is a need for additional research in many of the areas relevant to the maximum speed for heavy trucks. The data from the *Large Truck Crash Causation Study* should provide better detailed information that could assist in evaluating the safety implications of speed differentials between automobiles and heavy trucks. To satisfactorily address the issue, additional current and valid information is required about the operational costs of higher truck speeds that apply to both trucking operations and the general public.

The decisions pertaining to the state regulated absolute and/or differential speed limits for trucks will continue to be a political, as well as a technical issue. Similarly, the policy decisions of commercial trucking organizations related to maximum truck speeds involve many factors beyond those addressed in this study. The objective of this effort was to provide information that both regulatory agencies and trucking operations could use when making decisions related to maximum truck speeds, in general, and speed differentials between automobiles and heavy trucks, in particular.

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Appendices:

A. Speed Limits Before 55 mph NMSL in 1974: (Atkinson ,1996)

State	Speed Limit
Alabama	70
Alaska	70
Arizona	75
Arkansas	75
California	70
Colorado	70
Connecticut	60
Delaware	60
Florida	70
Georgia	70
Hawaii	70
Idaho	70
Illinois	70
Indiana	70
Iowa	75
Kansas	75
Kentucky	70
Louisiana	70
Maine	70
Maryland	70
Massachusetts	65
Michigan	70
Minnesota	65
Mississippi	70
Missouri	70
Montana	no speed limit
Nebraska	75
Nevada	no speed limit
New Hampshire	70
New Jersey	60
New Mexico	70
New York	65
North Carolina	70
North Dakota	70
Ohio	70
Oklahoma	70
Oregon	75
Pennsylvania	65
Rhode Island	60
South Carolina	70
South Dakota	75
Tennessee	75
Texas	70
Utah	70
Vermont	65
Virginia	70
Washington	70
West Virginia	70
Wisconsin	70
Wyoming	75

B. **1987 Speed Limit Increase: (**Baum, 1989; Advocates of Highway Safety, 1995)

State	Implementation Date for States which Increased Speed Limits in 1987	Implementation Date for States which Increased Speed Limits after 1987
Alabama	20-Jul-87	
Alaska	N/A	
Arizona	15-Apr-87	
Arkansas	20-Apr-87	
California	28-May-87	
Colorado	10-Apr-87	
Connecticut		
Delaware	N/A	
Dist of Columbia	N/A	
Florida	27-Apr-87	
Georgia		22-Feb-88
Hawaii		
Idaho	2-May-87	
Illinois	27-Apr-87	
Indiana	1-Jun-87	
Iowa	12-May-87	
Kansas	14-May-87	
Kentucky	8-Jun-87	
Louisiana	8-Apr-87	
Maine	17-Jun-87	
Maryland		1-Jul-95
Massachusetts		5-Jan-92
Michigan	29-Nov-87	
Minnesota	17-Jun-87	
Mississippi	14-Apr-87	
Missouri	1-May-87	
Montana	16-Apr-87	
Nebraska	27-Apr-87	
Nevada	13-Apr-87	
New Hampshire	16-Apr-87	
New Jersey		
New Mexico	2-Apr-87	
New York		1-Aug-95
North Carolina	10-Aug-87	
North Dakota	16-Apr-87	
Ohio	15-Jul-87	
Oklahoma	6-Apr-87	
Oregon	27-Sep-87	
Pennsylvania		13-Jul-95
Rhode Island		
South Carolina	15-Jul-87	
South Dakota	15-Apr-87	
Tennessee	8-May-87	
Texas	9-May-87	
Utah	21-May-87	
Vermont	21-Apr-87	
Virginia		1-Jul-88
Washington	20-Apr-87	
West Virginia	20-Apr-87	
Wisconsin	17-Jul-87	
Wyoming	19-May-87	

C. 1995 Speed Limit Increase. (NHTSA, 1998)

State	Implemented	Speed Limit Change
Alabama	9-May-96	To 70 mph on Interstates
Alaska		
Arizona	8-Dec-95	To 75 mph on Rural Interstates
Arkansas	17-Jul-96	To 70 mph on Rural four-lane divided highways
California	7-Jan-96	To 70 mph on Rural Freeways
Colorado	28-May-96	To 75 mph on Highway
Connecticut		
Delaware	26-Jan-96	To 65 mph on Interstate
Dist of Columbia		
Florida	8-Apr-96	To 70 mph for some Interstate segments
Georgia	1-Jul-96	To 70 mph on Interstate and look-alikes
Hawaii		
Idaho	1-May-96	To 75 mph on Interstates
Illinois	29-Nov-95	65 on Urban Interstate
Indiana		
Iowa	16-May-96	To 65 mph on selected four-lane divided
Kansas	22-Mar-96	To 70 mph on Interstates
Kentucky		
Louisiana		
Maine		
Maryland	18-Jul-96	To 60 or 65 mph on selected Urban Interstates
Massachusetts	29-Nov-95	To 65 mph on 13 Major Interstates and Highways
Michigan	18-Dec-96	To 70 mph on Interstates
Minnesota		
Mississippi	12-Mar-96	To 70 mph on Interstates
Missouri	13-Mar-96	To 70 mph on Interstates
Montana	8-Dec-95	Unlimited during day; to 65 mph at night
Nebraska	1-Jun-96	To 75 mph on Interstates
Nevada	8-Dec-95	To 75 mph on Interstates
New Hampshire		
New Jersey		
New Mexico	13-May-96	To 75 mph on Interstates
New York		
North Carolina	Aug-96	To 70 mph on Interstates
North Dakota		
Ohio	29-May-96	To 65 mph on Interstate
Oklahoma	Dec-95	To 70 mph on Interstates and four-lanes
Oregon		
Pennsylvania	Dec-95	On Turnpikes roads to 75 mph; Selected roads to 65 mph
Rhode Island	12-May-96	To 65 mph on some Interstates
South Carolina		
South Dakota	1-Apr-96	To 75 mph on Interstates
Tennessee	22-Apr-96	To 65 mph on some Urban Interstates
Texas	8-Dec-95	70 mph for Cars (65 mph at night) and 60 mph for Trucks (55 mph at night)
Utah	13-Mar-96	To 75 mph on Interstates
Vermont		
Virginia		
Washington	11-Mar-96	To 70 mph on Interstates
West Virginia		
Wisconsin		
Wyoming	24-Jan-96	To 75 mph on Rural Interstates

D. Rural Interstate Speed Limits. (Insurance Institute for Highway Safety)

State	State Abbreviation	Speed Limit
Alabama	AL	70
Alaska	AK	65
Arizona	AZ	75
Arkansas	AR	70 [trucks: 65]
California	CA	70 [trucks: 55]
Colorado	CO	75
Connecticut	CT	65
Delaware	DE	65
Dist of Columbia		N/A
Florida	FL	70
Georgia	GA	70
Hawaii	HI	60
Idaho	ID	75 [trucks: 65]
Illinois	IL	65 [trucks: 55]
Indiana	IN	65 [trucks: 60]
Iowa	IA	65
Kansas	KS	70
Kentucky	KY	65
Louisiana	LA	70
Maine	ME	65
Maryland	MD	65
Massachusetts	MA	65
Michigan	MI	70 [trucks: 55]
Minnesota	MN	70
Mississippi	MS	70
Missouri	MO	70
Montana	MT	75 [trucks: 65]
Nebraska	NE	75
Nevada	NV	75
New Hampshire	NH	65
New Jersey	NJ	65
New Mexico	NM	75
New York	NY	65
North Carolina	NC	70
North Dakota	ND	75
Ohio	OH	65 [trucks: 55; 65 on turnpike]
Oklahoma	OK	70 (75 on Turnpike)
Oregon	OR	65 [trucks: 55]
Pennsylvania	PA	65
Rhode Island	RI	65
South Carolina	SC	70
South Dakota	SD	75
Tennessee	TN	70
Texas	TX	day: 75 night: 65 [trucks: 65]
Utah	UT	75
Vermont	VT	65
Virginia	VA	65
Washington	WA	70 [trucks: 60]
West Virginia	WV	70
Wisconsin	WI	65
Wyoming	WY	75

E. Summary of Speed Data at Individual Sites

State		Traffic	Auto.	Truck
Effingham (IL) I-55 South (1) 65/55 mph	Average (mph)	71.3	73.8	64.2
	Standard Deviation	6.66	5.43	4.27
	Sample Size	353	260	93
	Compliance (%)		5.77	0
	85th % (mph)	78	79	68
	50th % (mph)	71	73	64
	Speed Variance	7	6	4
Effingham (IL) I-55 North 65/55 mph	Average (mph)	71.6	72.8	63.8
	Standard Deviation	6.26	5.69	3.44
	Sample Size	370	318	52
	Compliance (%)		5.66	0
	85th % (mph)	77	77	67
	50th % (mph)	71	72	64
	Speed Variance	6	5	3
Effingham (IL) I-55 South (2) 65/55 mph	Average (mph)	70.7	73.2	64.4
	Standard Deviation	6.68	5.84	4.02
	Sample Size	417	300	117
	Compliance (%)		10	0
	85th % (mph)	77	79	68
	50th % (mph)	71	73	64
	Speed Variance	6	6	4
Rolla (MO) I-40 East 70/70 mph	Average (mph)	71.8	73.2	68.7
	Standard Deviation	5.37	5.26	4.25
	Sample Size	284	196	88
	Compliance (%)		28.06	71.59
	85th % (mph)	77	78	73
	50th % (mph)	72	73	68
	Speed Variance	5	5	5
Rolla (MO) I-40 West 70/70 mph	Average (mph)	71.8	73.3	68.4
	Standard Deviation	5.33	4.88	4.73
	Sample Size	270	187	83
	Compliance (%)		24.6	72.29
	85th % (mph)	77	77	73
	50th % (mph)	72	73	69
	Speed Variance	5	4	4

		Traffic	Auto.	Truck
Joplin (MO) 70/70 mph	Average (mph)	70.8	71.5	68.7
	Standard Deviation	4.75	4.54	4.75
	Sample Size	304	228	76
	Compliance (%)		39.91	64.47
	85th % (mph)	76	76	73
	50th % (mph)	71	71	69
	Speed Variance	5	5	4
Ozark (AR) I-40 South 70/65 mph	Average (mph)	71.5	73.5	66.7
	Standard Deviation	5.35	4.50	4.05
	Sample Size	361	255	106
	Compliance (%)		21.96	31.13
	85th % (mph)	77	78	70
	50th % (mph)	72	74	67
	Speed Variance	5	4	3
Ozark (AR) I-40 North 70/65 mph	Average (mph)	71.0	73.5	66.7
	Standard Deviation	4.83	3.85	3.01
	Sample Size	170	107	63
	Compliance (%)		21.5	34.92
	85th % (mph)	76	77	70
	50th % (mph)	71	74	66
	Speed Variance	5	3	4
Tulsa (OK) 75/75 Cherokee Turnpike	Average (mph)	74.2	74.8	72.3
	Standard Deviation	4.93	4.61	5.63
	N	154	121	33
	Compliance (%)		52.89	72.72
	85th % (mph)	79	80	77
	50th % (mph)	74	75	72
	Speed Variance	5	5	5

F. Truck Driver's Survey:

1. Employment classification

   Company driver☐ Owner-operator (owns tractor only) ☐
   Owner-operator (leasing truck) ☐ Owner-operator (owns tractor & trailer) ☐
   Driving for Owner-operators☐

2. Working as a team? Yes☐ No☐

3. Classification of this trip: (home base to home base)
   Single day ☐ 2-7 days ☐ more than 7 days☐

4. Home base________________________,
   Previous load/unloading point (State) _____________, next load/unload point _______________.

5. Type of trailer you haul:
   Dry vans ☐ Flat beds ☐ Doubles, Triples ☐
   Reefers ☐ Tankers ☐ Others ☐___________

6. Kind of load you haul ? Truck Load (TL) ☐ Less than Truck Load (LTL) ☐

7. Speed limiter **maximum speed:** allowed by the limiter ________mph. Cruise speed (**if different**) __________mph

8. What should be speed limit **for cars and trucks** on flat rural interstate highways? Cars _____mph, Trucks _____mph

9. When you are **passing a car** on a **4 lane** rural highway, then what is the most dangerous part:
   ☐ When you are beginning to pass
   ☐ When you are traveling parallel to the other car
   ☐ When you are pulling back into the right lane

10. When you are **being passed by a car** on a **4 lane** rural highway, then what is the most dangerous part:
    ☐ When the car is beginning to pass
    ☐ When the car is traveling parallel to your truck
    ☐ When the car is pulling back into the right lane

11. In general, which of the following is **more dangerous**:
    ☐ When a car passes a truck
    ☐ When a truck passes a car

12. Do you think that the split speed limits (speed differential) for cars and trucks
    Increase accidents ☐ Decrease accidents ☐ No effect ☐

13. How does **split speed limits** for cars and trucks affect the likelihood of the following accidents effect:

	Increases	**Decreases**	**Does not change**
Side collision	☐	☐	☐
Car rear ending truck	☐	☐	☐
Truck rear ending car	☐	☐	☐

14. On **rural interstate highways**, your truck's **average fuel consumption** (**excluding idling**) is ___________mpg.

15. What is your estimate of your truck's fuel consumption (in mpg) for loaded trucks on rural highways for following speed limit?

	Posted Speed Limit (in mph)				
	55	**60**	**65**	**70**	**75**
Fuel Efficiency (in mpg)	___	___	___	___	___

16. Which causes more fatigue for the same distance? driving 70 mph for 6 hours ☐ driving 60 mph for 7 hours ☐

17. How often do you stop for a break? ______hours. How long does your break last? _____minutes.

18. Do drivers going at higher speeds (such as 70 mph) stop more frequently when compared to drivers going at lower speeds (such as 60 mph)? Yes ☐ No ☐

19. Do you think that the allowed truck speed **affects driver retention?** Yes ☐ No ☐

20. If you get paid exactly the same every month, **irrespective of miles you travel**, then at which one of the following speed would **you prefer** to travel (**in mph**): ☐ 55 ☐60 ☐65 ☐ 70 ☐75

21. In general, do states that have split speed limits for cars and trucks have:
less strict speed enforcement ☐ more strict speed enforcement ☐ same as other states ☐

22. How are you paid (**please write your answer in appropriate box)?**

    per mile $______ and per stop $_______
    per hour $______ and per stop $_______
    per load _____% and per stop $_______
    per load $______ and per stop $_______

23. Do you get any **safety bonus ___________** or fuel **efficiency bonus__________**?

24. By going at 70 mph instead of 60 mph, the **maintenance cost** will? increase ☐ decrease ☐ remain same ☐

25. By going at 70 mph instead of 60 mph, the **tire-wear** will? increase ☐ decrease ☐ remain same ☐

26. Approximately **how many trucks** does your company have? __________

27. Does your truck have an **overdrive**? Yes ☐ No ☐

28. How many **forward gears** do you have in your truck (**including overdrive**)? ________ gears

29. What is your truck **engine's** brand _____________, which year model______, Horse Power of your engine____ hp?

30. How many **years of experience** do you have in driving category 8 and above trucks? ___________years

31. List in chronological order the length of your past truck driving jobs.

Company	**Years**
Present company	____
Previous company	____

Company before that ____

G. Safety Manager's Survey:

1. Job title ______________________________, Company name________________________.

2. Region of operation in USA (select all regions that apply)
☐ Northwest ☐ North central ☐ Northeast
☐ Southwest ☐ South central ☐ Southeast

3. Fleet size: Trucks _____________ Trailers ____________.

4. In your company, what is the approximate percentage for the following driver categories :
Company driver, ________% Owner-operator (owns truck & trailer), ________%
Owner-operator (leasing truck), ______% Owner-operator (owns truck only), ________%

5. What is the approximate percentage for each of the following trip classifications (home base to home base):
Single day, ________% 2-7 days, ________% more than 1week, ________%

6. For your company, what is the approximate percentage of each of these trailer types:
Dry vans, ________% Flat beds, ________% Tandem trailers, ________%
Reefers, ________% Tankers, ________% Others, ________%

7. For your company, what is the approximate percentage of :
Truck Load (TL), ________% Less than Truck Load (LTL), ________%

8. Does your company limit the maximum truck speed (using ECM/governor)? ☐Yes ☐ No
If yes, what is the **maximum speed?** ____ mph. Maximum Cruise speed (**if different**)? ___ mph.

9. In your personal opinion, what should the **maximum** speed limits be **for trucks and cars** on rural interstate highways?
Maximum Speed Limit: Trucks ________mph & Cars ________mph.

10. In general, which of the following is **more dangerous**: ☐ When a car passes a truck
☐ When a truck passes a car

11. Which of the following causes **more** fatigue for the **same** distance traveled:
☐ Driving at 60 mph for 7 hours
☐ Driving at 70 mph for 6 hours

12. Do drivers going at higher speeds (such as 70 mph) stop more frequently when compared to drivers going at lower speeds (such as 60 mph)? ☐ Yes ☐ No

13. Do drivers going at higher speeds (such as 70 mph) take longer rest breaks when compared to drivers going at lower speeds (such as 60 mph)? ☐ Yes ☐ No

14. When a truck is **passing** a car on a 4-lane highway, the most dangerous time is:
☐ When the truck is beginning to pass
☐ When the truck is traveling parallel to the cars
☐ When the truck is pulling back into the right lane

15. When a truck is **being** passed by a car on a 4-lane highway, the most dangerous time is:
☐ When the car is beginning to pass
☐ When the car is traveling parallel to your truck

☐ When the car is pulling back into the right lane

16. What effect do you think that the split speed limits (speed differential) for cars and trucks has on the number of accidents:
☐ Increases accidents ☐ Decreases accidents ☐ No effect

17. How does **split speed limits** for cars and trucks affect the likelihood of the following accidents effect:

	Increases	**Decreases**	**Does not change**
Side collision	☐	☐	☐
Car rear ending truck	☐	☐	☐
Truck rear ending car	☐	☐	☐

18. In general, do states that have split speed limits for cars and trucks have:
☐ Less strict speed enforcement ☐ More strict speed enforcement ☐ Same as other states

19. Do you think that the allowed truck speed **affects driver retention**? ☐ Yes ☐ No

20. Does your company offer a **safety bonus** for drivers? ☐ Yes ☐ No

21. Does your company offer a **fuel efficiency bonus** for drivers**?** ☐ Yes ☐ No

H. Maintenance Manager's Survey:

1. Job title _______________________, Company's name ________________________________

2. Region of operation in USA (select all regions that apply)
   ☐ Northwest ☐ North central ☐ Northeast
   ☐ Southwest ☐ South central ☐ Southeast

3. Fleet size: Trucks _____________ Trailers ____________.

4. In your company, what is the approximate percentage for the following driver categories :
   Company driver, ________% Owner-operator (owns truck & trailer), ________%
   Owner-operator (leasing truck), ______% Owner-operator (owns truck only), ________%

5. What is the approximate percentage for each of the following trip classifications (home base to home base):
   Single day, ________% 2-7 days, ________% More than 1week, ________%

6. For your company, what is the approximate percentage of each of these trailer types:
   Dry vans, ________% Flat beds, ________% Tandem trailers, ________%
   Reefers, ________% Tankers, ________% Others, ________%

7. For your company, what is the approximate percentage of :
   Truck Load (TL), ________% Less than Truck Load (LTL), ________%

8. Does your company limit the maximum truck speed (using ECM/governor)? ☐Yes ☐ No

   If yes, what is the **maximum speed?** ____ mph. Maximum Cruise speed (**if different**)?____mph.

9. In your personal opinion, what should the **maximum** speed limits be **for trucks and cars** on rural interstate highways?
   Maximum Speed Limit: Trucks ________mph & Cars ________mph.

10. On **rural interstate highways**, what is the **average fuel consumption** for your company's newest trucks (**excluding idling**)? _________mpg.

11. Do you think that vehicles going at speeds slower than **your average truck speed**, on rural interstate highways, affect your trucks fuel efficiency? ☐ Yes ☐ No

12. What effect do you think that the split speed limits (speed differential) for cars and trucks has on the number of accidents:
    ☐ Increases accidents ☐ Decreases accidents ☐ No effect

13. What is your estimate of your truck's fuel consumption (in mpg) for loaded trucks on rural highways for following speed limit?

	Posted Speed Limit (in mph)				
	55	**60**	**65**	**70**	**75**
Fuel Efficiency (in mpg)	___	___	___	___	___

14. What truck speed would you recommend in order to minimize maintenance costs? ______ mph.

15. Does your company offer a **fuel efficiency bonus** for drivers**?** ☐ Yes ☐ No

16. What brand of engine is your newest truck______________________. Model ____________. horse power __________.

17. How often are the tires replaced in your company?
Every _______Months (or) ______Miles (or) ________Hours of service

18. By going at 70 mph instead of 60 mph, what happens to the following **cost components** (per mile traveled)**:**

	Increase	**Decrease**	**Remain same**
Maintenance cost	☐	☐	☐
Tire wear	☐	☐	☐
Engine life	☐	☐	☐
Oil consumption	☐	☐	☐

19. Which of the following two scenarios will cause more **tire-wear for new tires**?
    - ☐ Driving 60 mph for 7 hours
    - ☐ Driving 70 mph for 6 hours.

20. Which of the following two scenarios will cause more **tire-wear for retread tires**?
    - ☐ Driving 60 mph for 7 hours
    - ☐ Driving 70 mph for 6 hours.

21. Consider the two truck operations shown below:
- Truck A operates at 70 mph maximum speed and travels 15 thousand miles per month
- Truck B operates at 60 mph maximum speed and travels 13 thousand miles per month

Now comparing the **miles between Preventive Maintenance** for the above mentioned trucks, Truck A, when compared to truck B **should** have:
- ☐ **Less miles** between Preventive Maintenance
- ☐ **More miles** between Preventive Maintenance
- ☐ **Same** number of miles between Preventive Maintenance

I. Survey Statistics:

1. When passing a car, which is more dangerous: (n=173)
   - 13.3% Beginning of passing
   - 49.7% Traveling parallel
   - 37.0% Pulling back

2. When being passed by a car, which is more dangerous: (n=127)
   - 5.51% Beginning of passing
   - 52.76% Traveling parallel
   - 41.73% Pulling back

3. Which of the following is more dangerous: (n=151)
   - 52.98% Car passing a truck
   - 47.02% Truck passing a car

4. How does DSL affect the probability of side collisions: (n=136)
   - 2.94% Decrease
   - 42.65% Remain same
   - 54.41% Increase

5. How does DSL affect the probability of car rear ending truck: (n=143)
   - 2.80% Decrease
   - 4.90% Remain same
   - 92.31% Increase

6. How does DSL affect the probability of truck rear ending car: (n=138)
   - 30.43% Decrease
   - 48.55% Remain same
   - 21.01% Increase

7. Which of the following causes more fatigue for the same distance traveled: (n=198)
   - 13.13% Driving fast (70 mph for 6 hours)
   - 86.87% Driving slow (60 mph for 7 hours)

8. Do drivers going at higher speeds (such as 70 mph) stop more frequently when compared to drivers going at lower speeds (such as 60 mph)? (n=118)
   71.19% No
   28.81% Yes

9. Does company's speed limit policy affect driver retention? (n=148)
   31.76% No
   68.24% Yes

10. How does the split speed limits for cars and trucks affect accidents: (n=195)
   2.56% Decreases
   10.26% No effect
   87.18% Increases

11. Classification of the trip (home base to home base): (n=212)
   4.72% Single day
   40.09% 2 to 7 days
   55.19% More than 7 days

12. Type of trailer they were hauling: (n=169)
   4.14% Other
   3.55% Tanker
   10.65% Flat Bed
   26.04% Reefer
   55.62% Dry Van

13. What type of they load: (n=171)
   11.70% Less than Truck Load (LTL)
   88.30% Truck Load (TL)

14. Comparing enforcement in states with and without split speed limit: (n=155)
   5.81% Less Enforcement
   18.06% Same Enforcement
   76.13% More Enforcement

15. When asked if they received a Safety Bonus: (n=84)
   39.29% Company drivers said no
   60.71% Company drivers said yes

16. When asked if they received a Fuel Efficiency Bonus: (n=80)

55.00% Company drivers said no

45.00% Company drivers said yes

17. Drivers' opinion on impact of higher speed on fuel efficiency: (n=118)

55.08% Decreased

11.86% Remains Same

11.02% Remain same till 65 (or) 70 then decrease

10.17% Increase

11.86% Increase till 65 (or) 70 then decrease

18. How does 70 mph vs. 60 mph effect maintenance costs: (n=180)

7.78% Decrease

63.89% Remains Same

28.33% Increase

19. Company Drivers' opinion on impact of speed on maintenance cost: (n=109)

9.17% Decreased

61.47% Remains Same

29.36% Increased

20. Owner-operators' opinion on impact of speed on maintenance cost: (n=69)

5.80% Decreased

66.67% Remains Same

27.54% Increased

21. How does 70 mph vs. 60 mph effect tire wear: (n=133)

3.76% Decrease

51.13% Remains Same

45.11% Increase

22. Do you have overdrive: (n=138)

40.57% Yes

59.42% No

23. How many gears does your truck have: (n=148)

60.81% 10 Speed

27.03% 13 Speed

12.16% Other (5,9,12,15,18 speed)

24. Type of engine: (n=184)

30.98% Caterpillar

17.39% Cummins

45.11% Detroit

6.52% Other