SAFETY AND OPERATIONAL IMPACTS OF DIFFERENTIAL SPEED LIMITS ON TWO-LANE RURAL HIGHWAYS IN MONTANA

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Final Report

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THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

July 2016

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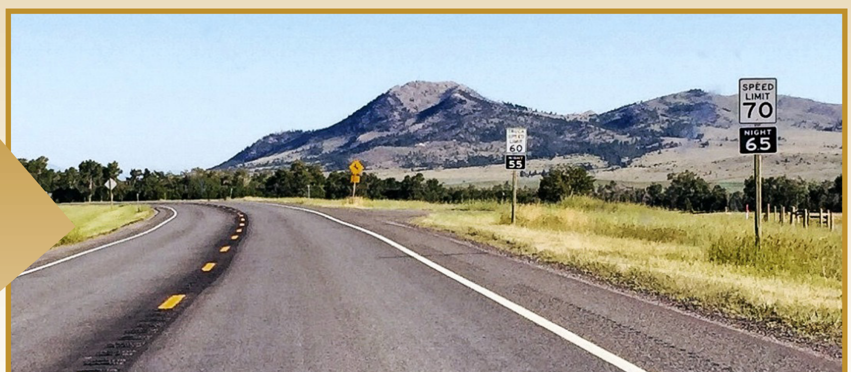

RESEARCH PROGRAMS

MDT

Safety and Operational Impacts of Differential Speed Limits on Two-Lane Rural Highways in Montana

FINAL REPORT

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16. Abstract

As of July 2016, Montana was the only state to maintain a differential speed limit on two-lane two-way rural highways, utilizing a daytime statutory speed limit of 70 mph for cars and light trucks and 60 mph for trucks exceeding a one-ton payload capacity. Although differential speed limits are common on freeways, the use of differential limits on two-lane roadways presents unique safety and operational issues due to passing limitations and subsequent queuing, and prior research on such issues is scarce. Consequently, research was performed to evaluate the safety and operational impacts associated with the aforementioned differential speed limit on rural two-lane highways in Montana, particularly when compared to a uniform 65 mph speed limit. A series of field studies were performed on two-lane rural highways in Montana, which predominately possessed the 70 mph/60 mph differential speed limit, and in neighboring states where uniform 65 mph speed limits prevailed. The locations with 65 mph speed limits generally displayed less variability in travel speeds, shorter platoon lengths, less high-risk passing behavior, and fewer crashes. Surveys were performed to determine the speed limit policy preferences among motorists and members of the trucking industry in Montana. Although motorist support for the uniform 65 mph speed limit was mixed, the trucking industry strongly supported the uniform 65 mph limit over the current differential limit. Overall, the collective findings support transitioning to a uniform 65 mph speed limit on two-lane rural highways in Montana. Selective implementation of this new speed limit is advised initially, and candidate highways should possess relatively high traffic volumes, relatively high truck percentages, and limited passing opportunities.

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CHAPTER 1:
INTRODUCTION AND BACKGROUND

Maximum speed limits are posted to inform drivers of the highest speed that is considered safe and reasonable for ideal traffic, road, and weather conditions. Speed limits also establish a basis for the enforcement of legislation for unreasonably high travel speeds. The 1995 repeal of the National Maximum Speed Limit (NMSL) returned all speed limit authority to the states. In the time since, a wide variety of speed limit policies have been enacted and modified, with nearly all states eventually choosing to raise maximum freeway speed limits beyond 55 mph. Recently, further speed limit policy modifications have resulted in a general upward trend in many states, particularly for rural freeways and in western states.

Speed limit policies can be broadly classified into two categories: uniform speed limits (USL) and differential speed limits (DSL). Uniform speed limit policies involve setting the same maximum limit for all vehicles, while differential speed limit policies set a lower limit for heavy trucks (buses are typically also included) in comparison to cars and light duty trucks. The principal philosophical arguments supporting USLs and DSLs are as follows:

- Support for DSL policies – Given their larger size, trucks require a greater time and distance to stop. This increased size also tends to result in more severe injuries when trucks are crash involved. Fuel economy also tends to degrade at higher speeds.
- Support for USL policies – Maintaining uniform speed limits for all vehicle types should provide lower speed variability, thereby reducing the potential for collisions. Higher truck speed limits will also reduce travel times, creating potential economic benefits.

The popularity of differential speed limits between passenger vehicles and heavy trucks has diminished over time, as only seven states, including Montana, maintained differential speed limits on limited access freeways as of June 2016. However, Montana is the only state which extends its differential speed limit policy to undivided rural highways, which may present unique safety and operational issues, particularly on two-lane highways, due to passing limitations and subsequent queuing. Table 1 displays the current maximum speed limit by highway type for the

State of Montana. Note that Montana's two-lane highway speed limit went into effect in May of 1999.

Table 1. Current Maximum Speed Limits in Montana (in miles per hour)

TYPE OF HIGHWAY	CARS AND LIGHT TRUCKS		HEAVY TRUCKS (OVER 1 TON CAPACITY)	
	Daytime	Nighttime	Daytime	Nighttime
Interstate	80	80	65	65
Interstate Within Urban Area (Billings, Great Falls, Missoula)	65	65	65	65
Two-lane	70	65	60	55

Note: Information current as of June 2016. Daytime speed limits are in effect one-half hour before sunrise to one-half hour after sunset. Nighttime speed limits are in effect at any other time.

In April 2013, speed limits were changed to a uniform 65 mph along 55 miles of MT-16 and MT-200 between Glendive and Fairview in eastern Montana. This change was made in response to observations of aggressive passing behavior by motorists queued behind trucks with little opportunity to pass. Consequently, it was necessary to assess the impacts associated with this speed limit change to determine if further application of the uniform 65 mph speed limit is warranted.

PROBLEM AND OBJECTIVES

Although a considerable amount of prior research has investigated the impacts of speed limits on traffic safety and operations, much of this research, and nearly all research related to differential speed limits, has been specific to limited access freeways. Thus, it was not possible to draw conclusions related to differential speed limits on two-lane highways through assessment of the research literature. To address this gap in knowledge, a comprehensive study investigating the safety and operational impacts of differential speed limits on rural two-lane highways was initiated by the Montana Department of Transportation (MDT) in mid-2014. The purpose of this research was to assist the MDT in determining conditions under which differential speed limits or, alternatively, uniform speed limits should be utilized on two-lane rural highways. The primary objectives of this study were as follows:

1. Determine the safety impacts associated with the use of differential speed limits rural two-lane roads, including the impacts on crash frequency and crash severity;

2. Determine the operational impacts associated with the use of differential speed limits on rural two-lane roads, including the impacts on speeds, queues, and passing maneuvers; and
3. Provide guidance towards the use or non-use of differential speed limits on two-lane rural highways in Montana.

REPORT ORGANIZATION

This report documents the methods, results, findings and conclusions associated with this study. The report is organized as follows:

- Chapter 1: Introduction and Background - provides introductory and background content, including problem statement, purpose, objectives, and a general overview of the report.
- Chapter 2: Literature Review - presents a review of the literature related to highway speed limits, including policy, safety, and operational aspects.
- Chapter 3: Speed Limit Policies and Practices in the United States - provides details regarding highway speed limit policies and practices in the United States.
- Chapter 4: Operational Data Analysis - describes the field data collection effort on two-lane highways in Montana and neighboring states, analysis of speed data and analysis of other operational data (including passing events and platooning), and Operation Safe Driver activities.
- Chapter 5: Crash Data Analysis – describes the collection and analysis of traffic crash data for two-lane roadways in Montana, including development of safety performance functions, and comparison of Montana safety performance with that of neighboring states.
- Chapter 6: Road User Survey – describes the results of a road user survey performed at rest areas and weigh stations throughout Montana to determine preferences towards various speed limit policy alternatives and potential impacts (behavioral, safety, etc.) associated with changes to speed limit policies.
- Chapter 7: Trucking Industry Survey– describes the results of an online survey of registered motor carriers in Montana to determine preferences towards various speed limit policy alternatives and potential impacts (behavioral, economic, safety, etc.) associated with changes to speed limit policies.

- Chapter 8: Conclusions and Recommendations – provides an overall summary of the research findings along with recommended guidelines for speed limit policies on two-lane highways in Montana.

CHAPTER 2:

LITERATURE REVIEW

RELATIONSHIP BETWEEN SPEED AND CRASH RISK

Some of the earliest work investigating the relationship between speed and safety was performed by Solomon in 1964 and followed later by Cirillo in 1968. Solomon compared the estimated speed obtained from police crash reports of 10,000 crash-involved vehicles with field-measured speeds from 29,000 control vehicles [Solomon, 1964]. Using these data, relative crash rates for 10-mph speed categories were estimated. The results, illustrated in Figure 1, present the crash involvement rate (per 100 million vehicle-miles of travel) with respect to travel speed (Figure 1 left) and with respect to variation from the average speed of traffic under similar conditions (Figure 1 right). Collectively, these figures suggest that crash risk (i.e. the possibility of being in a crash) is greatest at travel speeds that are well below or well above the average speed of the traffic stream. Vehicles traveling approximately 6 mph above the average speed exhibited the lowest crash rates.

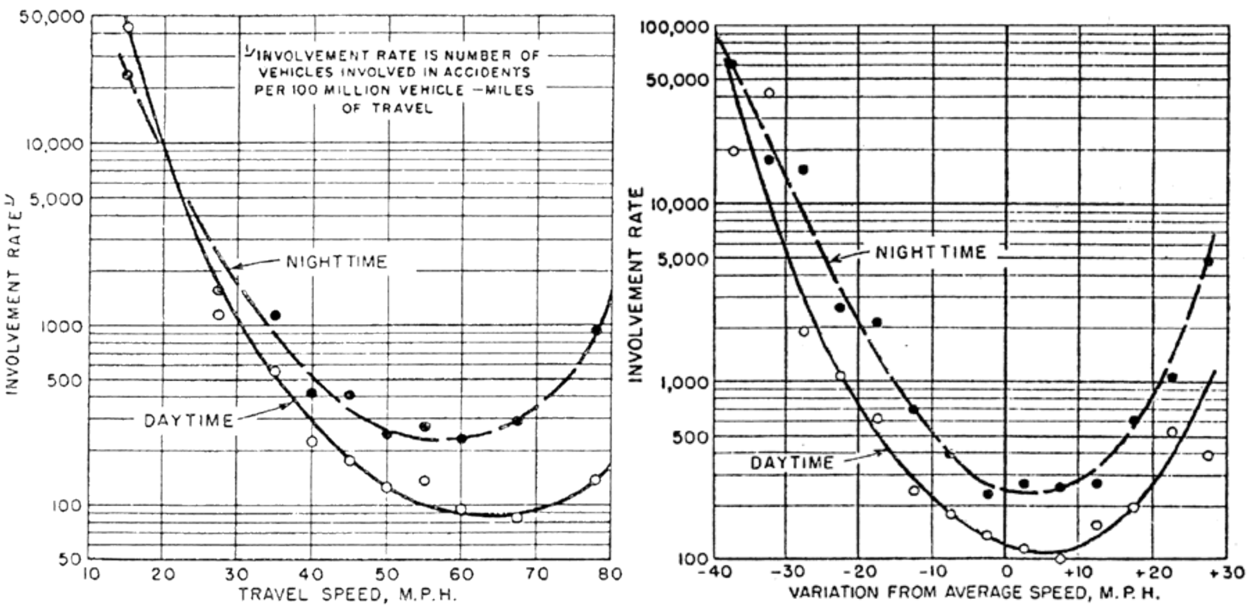


Figure 1. Crash Rates by Travel Speed and Variation from Average Speed [Solomon, 1964]

In 1968, Cirillo conducted a similar study on rural and urban interstates, which focused on two-vehicle, same-direction crashes [Cirillo, 1968]. The results generally reflected this same trend, though the lowest crash rate was about 12 mph above the average speed.

Subsequent research using speed data from traffic detectors in combination with pre-crash speeds based on crash reconstruction found similar trends [Research Triangle Institute, 1970]. However, 44 percent of these crashes involved low-speed maneuvers (e.g., turning into or out of traffic). A subsequent analysis excluding these low-speed maneuvers found that crash risks were much less pronounced at low speeds in comparison to the aforementioned evaluations by Solomon and Cirillo. Further confirmation of the low-speed impacts associated with turning vehicles was provided in subsequent work by West and Dunn, which found that removing turning vehicles substantially mitigates the crash risk at lower speeds [West and Dunn, 1971]. These results are shown in Figure 2.

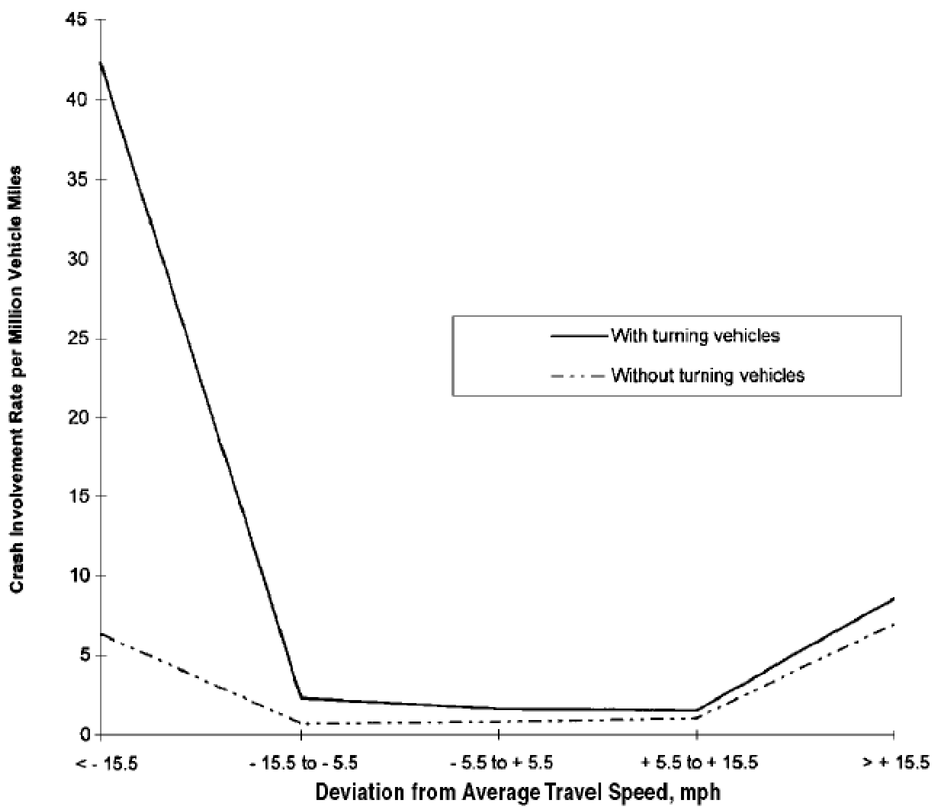


Figure 2. Crash Rates by Deviation from Average Speed [West and Dunn, 1971]

Finch et al. conducted a study in Switzerland, which showed fatal crashes to decrease by 12 percent when speed limits were lowered from 130 kph (81 mph) to 120 kph (75 mph) [Finch et al., 1994]. This research also showed crash rates to increase consistently with speed, as illustrated in Figure 3, when examining data from Denmark, Finland, Switzerland, and the United States.

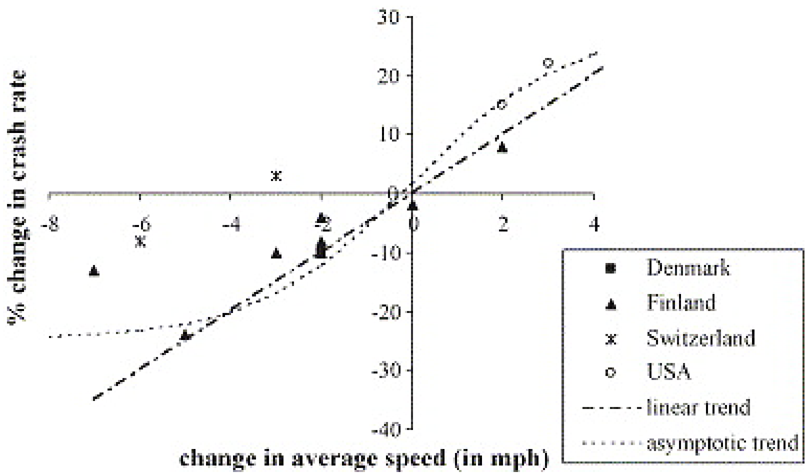


Figure 3. Change in Crash Rate with Respect to Average Speed [Finch et al., 1994]

Research in the United States by Garber and Gadiraju examined data more closely at the road segment level [Garber and Gadiraju, 1989]. This research focused on three types of roadways with 55 mph speed limits: interstates, arterials, and major collectors. It was found that roads with larger speed variance (i.e., greater speed differences between drivers) exhibited higher crash rates than roads with lower variance. Ultimately, it was determined that the relationship between speed limit and design speed was a key determinant of safety trends. Both crash rates and speed variance were lowest when speed limits were 5 to 10 mph below the road's design speed.

SAFETY TRENDS FOLLOWING SPEED LIMIT POLICY CHANGES

Implementation of the National Maximum Speed Limit

Following the introduction of the National Maximum Speed Limit in 1974, which mandated a maximum speed limit of 55 mph on all highways nationwide, Burritt [Burritt et al., 1976] found crash rates to decrease at all injury severity levels, which was attributed to reduced speeds and speed variance. Subsequent studies by Dart [Dart, 1977], Weckesser et al. [Weckesser et al., 1977], Tofany [Tofany, 1981], and Deen and Godwin [Dean and Godwin, 1985] found that lower speed limits resulted in safety benefits. For the five year period post-NMSL, Forester et al. estimated that fatalities decreased nationwide by nearly 7,500 annually as a result of the speed limit reduction [Forester et al., 1984]. Conversely, Labrum concluded that available data could not allow for the determination of speed limit impacts due to concurrent changes in other factors (e.g., fuel shortage, driver attitude, etc.), representing one of the few studies that did not find safety benefits associated with the NMSL [Labrum, 1976].

Relaxation of the National Maximum Speed Limit

In 1987, the NMSL law was relaxed, allowing states to raise their speed limits to 65 mph on rural interstate highways. Much additional research was conducted following this change, as many states increased the speed limits on their rural interstates. Hoskin [Hoskin, 1987], Gallaher et al. [Gallaher et al., 1989], and Upchurch [Upchurch, 1989] each found fatalities to increase in various states following these legislative changes. Baum et al. estimated a 15 percent increase in fatalities in states that increased speed limits as part of a 38-state study [Baum et al., 1989], a finding that corroborated with research by Garber and Graham [Garber and Graham, 1990]. These results varied significantly between states, likely reflecting the effects of other factors such as seasonal patterns, highway design improvements, the quality of emergency medical care, traffic volumes, mandatory belt-use laws, etc. Subsequent research, which expanded this analysis to 48 states [Baum et al., 1992], estimated fatalities to increase by 29 percent in states where the rural interstate limits were increased to 65 mph, while 12 percent fewer fatalities occurred in those states that retained the 55 mph limit. Greenstone found fatality rates to increase by 30 percent on rural interstates and fall by 17 percent on urban non-interstates nationwide from 1982 to 1990 [Greenstone, 2002]. McKnight and Klein found a 22 percent increase in fatal crashes after implantation of the 65 mph speed limit on rural interstates [McKnight and Klein, 1990]. Similar increases were also found in Iowa following the speed limit increase [Ledolter and Chan, 1996].

In many cases, researchers also found a relationship between increased speed limits, increased operating speeds, and increased crash occurrence. Lynn and Jernigan noted increases in fatal crashes and fatalities, in addition to increases in mean and 85th percentile speeds on rural interstates in Virginia following the speed limit increase from 55 to 65 mph [Lynn and Jernigan, 1992]. This was contrasted with no significant changes to crashes or speeds on urban interstates, which remained posted at 55 mph. Similarly, Ossiander and Cummings found a large increase in fatal crash rates on rural highways in Washington State while urban rates remained stable

[Ossiander and Cummings, 2002]. In addition to these safety impacts, mean and 85th percentile speeds on rural highways also increased by 5.5 and 6.4 mph, respectively. Interestingly, it was noted that increases in operating speeds did not occur immediately, but over time as drivers adapted to the new limits.

In certain cases, crashes were also observed to increase on other types of highways that did not experience increased speed limits. Wagenaar et al. reported increases of 19 percent in fatalities, 40 percent in serious injuries, and 25 percent in moderate injuries after increasing the speed limit from 55 to 65 mph on rural freeways in Michigan, along with a 38 percent increase in fatalities on other rural highways where the 55 mph limit was retained [Wagenaar et al., 1990]. The authors suggested that spillover speeding (i.e., speeding on roadways near the site of the speed limit increase, and potentially due to the increase) may have contributed to the increases on the 55 mph highways. Similarly, although Rock found crashes, injuries, and fatalities to increase on rural freeways in Illinois where the speed limit was increased to 65 mph, similar increases were also observed for each of these measures on 55 mph rural highways [Rock, 1995].

In contrast to the aforementioned research, which showed an increased safety risk associated with increased speed limits, certain studies [Pant et al., 1992; Chang and Paniati, 1990] have found no safety impacts associated with increasing the speed limit to 65 mph on rural freeways, while others [Lave and Elias, 1994; Lave and Elias, 1997; Houston, 1999] found positive safety benefits. Pant et al. compared monthly crash rates on rural interstates in Ohio and found no difference following the 1987 change in rural speed limits [Pant et al., 1992]. Similarly, Chang and Paniati assessed monthly fatality data, but could not reach a conclusion as to the impact of the 65 mph limit due to limited post-increase data [Chang and Paniati, 1990]. Lave and Elias estimated that fatal crash rates fell by 3.4 to 5.1 percent following the 1987 speed limit increase [Lave and Elias, 1994; Lave and Elias, 1997]. The authors suggested that the decrease in fatalities may have resulted from a shift in police resources from speed enforcement on the interstates to other activities and other highways, in addition to changes in driver route choice toward safer interstates.

Repeal of the National Maximum Speed Limit

The safety impacts of speed limit policies were revisited after the repeal of the NMSL in 1995. This repeal gave states full authority to determine speed limits on all roadways, regardless of functional classification. In the years since the NMSL repeal, states have subsequently increased speed limits well-beyond the previous limits, both on freeways (rural and urban) and non-freeway highways. In 1996, Taylor and Maleck examined the impacts of increasing the speed limit on 500 miles of rural freeway in Michigan from 65 to 70 mph [Taylor and Maleck, 1996]. Results showed that, after the speed limit was raised, the 50th and 85th percentile speeds increased by 2 mph in some locations and less than 1 mph at most locations. In a follow up study [Taylor, 2000], total crashes were found to increase by 10.5 percent, severe crashes increased by 4.5 percent, and fatal crashes decreased by 9.3 percent. Friedman et al. conducted a 10-year study on fatal crashes in the United States subsequent to the 1995 repeal of the NMSL, concluding that the increase in speed limits accounted for approximately 12,545 fatalities during that period [Friedman et al., 2009]. Several additional studies found increases in fatality rates, including Farmer et al. [Farmer et al., 1999], Patterson et al. [Patterson et al., 2002], and Haselton et al. [Haselton et al., 2002]. However, a study conducted in Kansas did not find significant changes in interstate crash rates or fatality rates after repeal of the NMSL [Najjar et al., 2002].

Kockelman conducted one of the more recent comprehensive studies aimed at estimating the impacts of raising speed limits on high-speed roads (both limited and non-limited access) through a disaggregate-level analysis of the relationships between speed limits, speed choice, crash frequency, and crash severity [Kockelman, 2006]. Based on the results of this cross-sectional study, it was estimated that a 10-mph increase from 55 to 65 mph would result in an increase of approximately 3 percent in total crashes and 28 percent in fatal crashes, assuming that expected increases in operating speeds also occur. This effect was predicted to diminish at higher speeds, as speed limit increases from 65 to 75 mph were projected to increase total and fatal crashes by 0.6 percent and 13 percent, respectively. In addition to speed limit impacts, other roadway features also affected crash rates. Specifically, segments with horizontal curves and/or vertical curves were found to have higher crash rates, assuming all other factors were held constant.

The most recent comprehensive evaluation of the safety effects associated with freeway speed limits was completed for the Michigan DOT in 2014 [Savolainen et al., 2014]. Nationwide fatal crash data from 1999 through 2011 were obtained and examined to assess the fatal crash impacts of interstate freeway speed limits. Maximum freeway speed limit policies were also obtained for each state for each year during this period and paired with the fatal crash data and other relevant data for each state. It was determined that fatal crash rates were significantly lower in states with 60- or 65-mph speed limits compared to states with 70 mph speed limits, especially when the limits were 75 mph or above. These fatal crash rate trends are displayed in Figure 4. The trends were similar for truck and bus involved fatal crash rates.

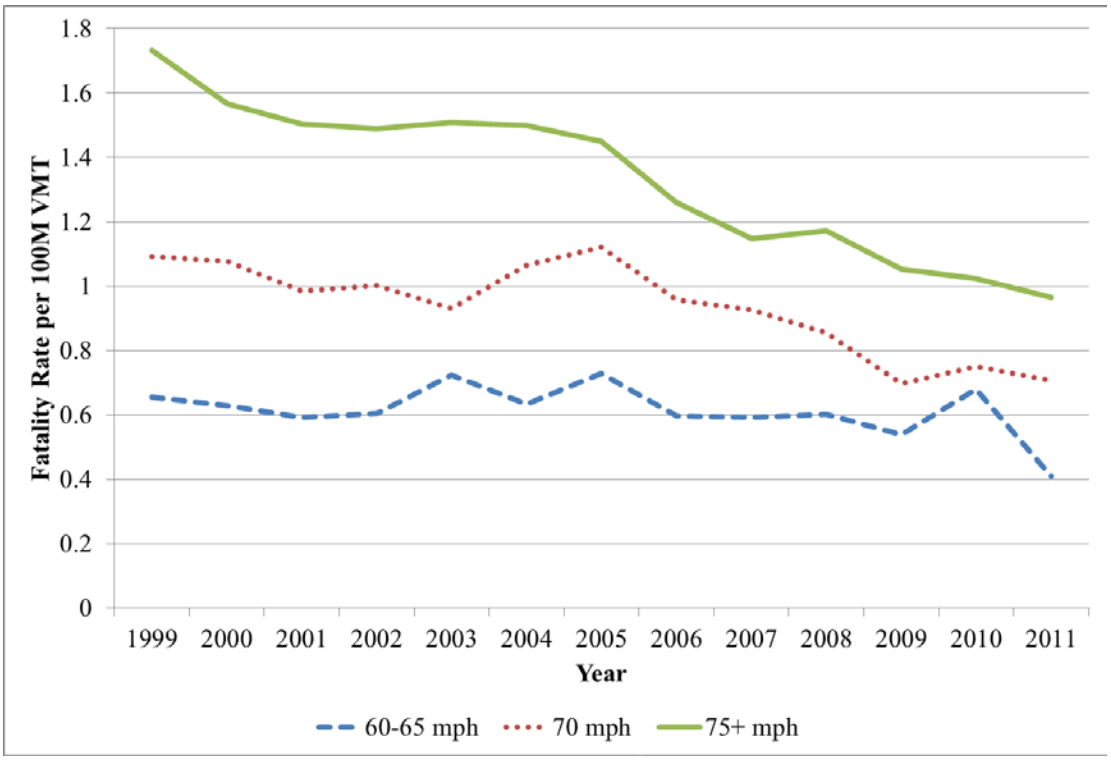


Figure 4. Annual Rural Interstate Fatality Rates by Maximum Speed Limit [Savolainen et al., 2014]

In contrast to the United States, where most studies have evaluated the speed and safety effects of raising speed limits on limited access highways, several international studies have examined the effects of reductions in speed limits with similar results. Research examining the effects of speed limit reductions in Finland [Salusjarvi, 1981], Denmark [Egsmose and Egsmose, 1985], Sweden [Nilsson, 1990; Johansson, 1996], the Netherlands [Borsje, 1994], and Australia [Sliogeris, 1992] all reported the lower speed limits to result in lower average speeds, with these reductions typically being less than the associated reduction in the speed limit. Lower speed limits were also associated with reduced crash incidence and, in some cases, reduced crash severity. Aarts and Van Schagen conducted a meta-analysis that focused on the relationship between speed and crash frequency and severity [Aarts and Van Schagen, 2006]. The examined studies generally found that average speed, either along select road segments or with respect to individual vehicles, significantly increased crash rates, especially on minor roadways. Other factors that were found to influence crash rates were lane width, access point density, and traffic volumes. Vehicles moving much faster than the surrounding traffic had a higher crash rate, though results regarding slower moving vehicles were mixed [Aarts and Van Schagen, 2006].

RELATIONSHIP BETWEEN SPEED LIMITS AND OPERATING SPEEDS

An area of substantive debate is how posted speed limits influence the actual speed selection behavior of drivers. According to the American Association of State Highway and Transportation Officials (AASHTO), driving speeds are affected by the physical characteristics of the road, weather, other vehicles, and the speed limit [AASHTO, 2011]. Among these, geometric factors have a particularly pronounced impact on driving speeds, although numerous other factors also affect speed selection [Emmerson, 1969; McLean, 1981; Glennon et al., 1985; Lamm and Choueiri, 1987; Kanellaidis, 1990; Islam and Seneviratne, 1994; Krammes et al., 1993; Voigt, 1996; Polus et al., 2000; Al-Masaeid et al., 1999; Andjus and Maletin, 1998; Abdelwahab et al., 1998; Schurr et al., 2002; Fitzpatrick et al., 2003]. Research has generally shown that speed limit changes result in changes in mean and 85th percentile speeds that are less pronounced than the actual speed limit change. This has been true for cases where speed limits were decreased [Dart, 1977; Forester et al., 1984] or increased [Upchurch, 1989; Lynn and Jernigan, 1992; Ossiander and Cummings, 2002; Freedman and Esterlitz, 1990; Brown et al., 1991].

In one of the most extensive studies in this area, Parker conducted a large-scale study from 1985 to 1992 to determine the impact that raising or lowering posted speed limits on non-limited access highways had on driver behavior [Parker, 1997]. At the time of this study, the maximum speed limit on such roadways was 55 mph. Over the duration of the study, states and local authorities raised and lowered posted speed limits on short segments of roadways, typically less than two miles in length. Data on driver behavior and crashes were collected from 22 states.

These included 100 sites along non-limited access highways where the speed limits were either raised or lowered and 83 control sites where there were no changes made to speed limits. The range of speed limit changes consisted of lowering the speed limit by 5, 10, 15, or 20 mph, or increasing the speed limit by 5, 10, or 15 mph, with only one change made at each site. Interestingly, the difference in speed after these changes was less than 1.5 mph on average. The study results clearly demonstrated that drivers select their speeds on non-limited access highways primarily on the basis of roadway geometry and traffic characteristics rather than the posted speed limits [Parker, 1997].

In the recent NCHRP study, Kockelman found that raising the speed limit tends to increase average vehicle speeds by less than half of the amount of the actual speed limit increase [Kockelman, 2006]. Specifically, increasing the speed limit from 55 to 65 mph was expected to increase operating speeds by approximately 3 mph. Mean speeds and speed variance were influenced by highway design (particularly geometry) and lane use characteristics more so than posted speed limits.

The recent Michigan DOT speed study also included collection of spot speed data from 160 flat/straight freeway locations in Michigan, Indiana, and Ohio to provide a comparison between 55, 60, 65, and 70 mph freeway speed limits that collectively exist on freeways within these states [Savolainen et al., 2014]. These sites were split among urban and rural freeways and were selected from various regions to provide geographic diversity. A series of regression models were developed, which suggested a 2.3 to 2.6 mph increase in mean passenger vehicle speed for every 5 mph increase in freeway speed limit above 55 mph, with diminishing incremental increases at higher speed limits. These results were consistent both with those found by Kockelman [Kockelman, 2006] and results from Iowa, where mean speeds were observed to increase by approximately 2 mph after the speed limit was increased from 65 mph to 70 mph [Souleyrette et al., 2009]. The results also compared favorably to changes in mean speeds observed after freeway speed limit increases from 70 to 75 mph in Louisiana [Louisiana DOT, 2013] and from 75 to 80 mph Utah [Utah DOT, 2009], respectively, where operating speeds generally increased by 2 mph or less after raising the speed limit by 5 mph.

A second phase of the Michigan DOT study included comparison of spot speed data collected at a limited number of MDOT rural non-freeway highways with 65 mph speed limits versus similar nearby rural highways with the typical 55 mph statutory limits [Gates et al., 2015]. The results showed that mean speeds on the 65 mph segment were 3 to 4 mph greater than those on the 55 mph segments, which is consistent with observations from the aforementioned evaluations associated with raising speed limits on freeways.

The findings discussed above are largely reflective of driver opinions on speed limits as shown by recent surveys. Mannering conducted a 2007 freeway user survey studying their normal driving speed on interstate highways that have posted speed limits of 55 mph, 65 mph, and 70 mph [Mannering, 2007]. On average, drivers reported driving 11 mph over the speed limit on roads posted 55 mph, 9 mph over the speed limit on roads posted 65 mph and 8 mph over the speed limit on roads posted 70 mph. A national survey conducted by the United States Department of Transportation (USDOT) in 2003 showed that most drivers believe they can drive 7 to 8 miles per hour above the posted speed limit before being pulled over [Royal, 2003]. On average, drivers felt that the ideal speed limit for a highway would be approximately 67 mph. Approximately 40 percent of drivers stated they would drive over the speed limit on interstate highways even if the speed limits were increased by 10 mph. While 51 percent of drivers admitted to driving 10 mph over the posted speed limit, 68 percent felt that other drivers violating the speed limit were a danger to their own personal safety. Drivers reported that the most influential factors dictating their speed selection were weather, their perception of what speeds were "safe", the posted speed limit, traffic volume levels, and the amount of personal driving experience on a particular road [Royal, 2003].

DIFFERENTIAL SPEED LIMITS

Heavy commercial trucks and buses have long been a traffic safety concern given their large size, which results in restricted maneuverability, longer stopping distances, and higher impact forces in a collision. Given these concerns, following the relaxation of the NMSL, many states had initially implemented a differential speed limit, with trucks (and often buses) being held to a lower posted limit than passenger cars. While lower speed limits for larger vehicles helps to mitigate concerns with respect to high impact forces in truck-involved (the term truck-involved generally refers to trucks and buses) collisions, these differential limits potentially increase the variability in travel speeds and may increase the potential for truck-involved crashes. In light of this fact, numerous states have subsequently transitioned to a uniform speed limit, which establishes the same maximum speed limit for all vehicles. As displayed in Figure 5, seven states maintain DSLs on limited access freeways as of June 2016, with three states using a 15 mph differential, three using a 10 mph differential, and one using a 5 mph differential. It should be noted that Oregon maintains a 5 mph differential limit on select rural freeways where the maximum limit was increased to 70 mph. Recent changes were also enacted in Washington State, as the state legislature enacted policy in February 2016 allowing for maximum speed limits of up to 75 mph on highways, although trucks will remain limited to 60 mph, thereby increasing the maximum car/truck differential to 15 mph. It should also be noted that Illinois maintains a 5 mph differential speed limit (65mph/60mph) on select suburban tollways in the greater Chicago area, although uniform limits are utilized on all other freeways. Only Montana maintains systemwide use of differential limits on undivided highways. It should be noted that Oregon implemented a 5 mph differential limit on select undivided highways in March 2016, while Michigan maintains a 10 mph differential on two sections of non-limited access divided rural highways. In both Oregon and Michigan, the differential limits were introduced on highway segments where the maximum speed limit was increased to 65 mph.

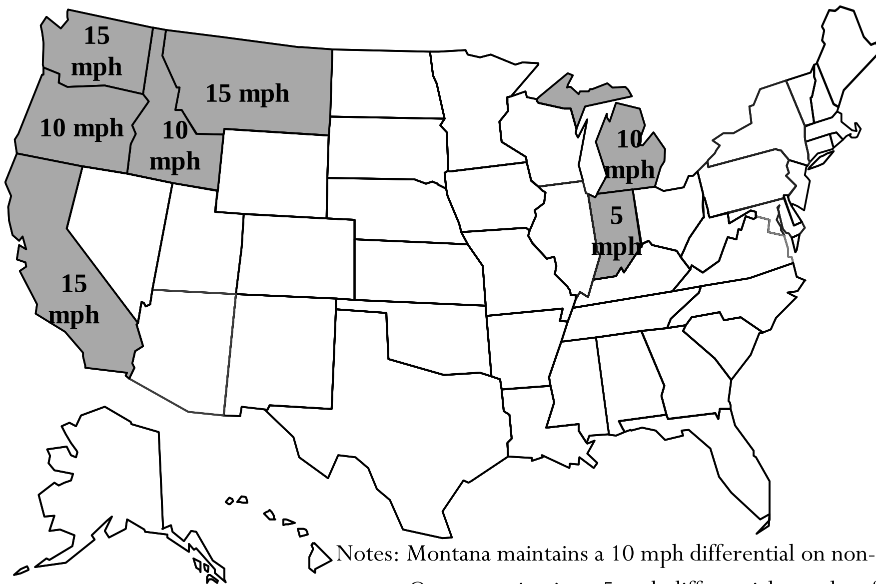


Figure 5. Use of Differential and Uniform Speed Limits by State (June 2016)

Limited Access Freeways

Research results are relatively mixed with respect to the operational and safety differences between USLs and DSLs on limited access freeways. Freedman and Williams analyzed data from eleven northeastern states to ascertain the effects of DSLs on mean and 85th percentile speeds [Freedman and Williams, 1992]. At the time of the study, six of the states maintained a uniform 55 mph limit, three states had uniform 65 mph limit, and two states implemented a 65-mph/55-mph differential limit. Neither passenger car nor heavy truck speeds differed significantly between the USL and DSL states. Compliance rates with the posted speed limits were also similar between the states. Similar results were obtained by both Johnson and Murray [Johnson and Murray, 2010] and Harkey and Mera [Harkey and Mera, 1994]. Conversely, Garber and Gadiraju found that there were differences in the mean speeds of trucks in states with DSLs and those with USLs [Garber and Gadiraju, 1989]. In addition, speed variances were found to be significantly greater in the DSL states.

One of the earliest studies of differential truck-car speed limits was conducted in 1966-67 by Ferguson in the state of Virginia [Ferguson, 1968]. Speed and crash data were collected at select locations on interstates and other routes, and surveys were conducted of the general public and state traffic engineers throughout the country. Based on the limited data, it was concluded that the 15 mph speed differential was unreasonably large, and the truck speed limit should be raised to be in line with the 85th percentile speed of trucks. As a result of the study, truck speed limits in Virginia were increased from 50 to 55 mph. Several years later when the car speed limit was raised to 70 mph, the truck speed limit was raised to 60 mph.

Joscelyn et al. conducted a 1970 study for the National Highway Safety Bureau, which involved a survey of jurisdictions to examine the rationale for separate maximum speed limits for trucks and other vehicles [Joscelyn et al., 1970]. Jurisdictions with the same limit for all vehicles noted that the same limit avoids impeding the flow of traffic. Jurisdictions with lower limits for trucks noted that their decision was based on the interest of safety.

In 1972, Hall and Dickinson examined speed and accident data on 55 sections of roadway in Maryland and found that the difference between car and truck speeds was typically less than 6 mph, which was less than the posted 10-mph differential [Hall and Dickinson, 1972]. This study also found that the separate limits were not significantly related to truck accidents.

A 1978 review of traffic speed limit laws in the United States noted that the National Committee on Uniform Traffic Laws and Ordinances has generally been opposed to imposing different speed limits for different vehicle types [English and Levin, 1978]. The Committee's position was based on the belief that safety was best served when all traffic moves at the same speed. They observed states that establish lower limits base their decision on the belief that larger vehicles need to operate more slowly to maintain control, have comparable stopping distances with cars, and to diminish the damage caused by the extra weight when these vehicles are involved in a collision.

Following enactment of the Surface Transportation and Uniform Relation Assistance Act (STURAA), 12 of the 40 states that raised the maximum speed limit retained lower limits for trucks than for cars. In an effort to examine the effects of the differential speed limits, the National Highway Traffic Safety Administration (NHTSA) conducted a study in 1988 that examined rural interstate fatalities [NHTSA, 1988]. This evaluation found few fatalities involving car and tractor-trailer crashes on rural interstates. Due to the limited sample of fatal crashes, the effect of the differential limits could not be determined.

A 1990 study by Baum et al. assessed speed data for rural interstates with uniform vs. differential speed limits for cars and trucks [Baum et al., 1991]. Average truck speeds were found to be 1.4 mph higher in states with uniform 65 mph limits than in states with a 55 mph speed limit for trucks. The primary statistics used were the 95^{th} percentile truck speed and the percentage of trucks exceeding 70 mph.

In 2005, Garber et al. compared crash, traffic volumes, vehicles speeds, and other data between the State of Virginia, which had transitioned from a DSL to a USL, and three groups of comparison states: (1) states transitioning from USL to DSL; (2) states maintaining USL; and (3) states maintaining DSL [Garber et al., 2005]. The results showed differences between passenger vehicle and truck operating speeds, but no consistent safety differences.

A 2008 study by Malyshkina and Mannering examined the effects of a 5 mph speed limit increase on crash severity after rural interstate speed limits in Indiana were raised from 65 to 70 mph [Malyshkina and Mannering, 2008]. The speed limit for trucks and buses was also raised from 60 to 65 mph as Indiana remained a DSL state. Using data from 2004 (the year before speed limits were raised) and 2006 (the year after speed limits were raised), statistical models of the severity of different crash types were estimated. The results showed that the speed limit increase did not have a significant effect on the severity of accidents on interstate highways.

A 2012 evaluation of differential speed limits was conducted in Idaho after a differential speed limit was introduced that reduced the truck limit from 75 to 65 mph [Dixon et al., 2013]. This research showed that truck mean speeds were reduced to 65.6 mph and that the speed variance and violation rate (in terms of vehicles traveling 5+ mph over the posted limit) were also reduced. The authors estimate that the DSL reduced crashes by 8.56 percent, though this result was not significant at a 95-percent confidence level.

The most recent investigation of the safety and operational effectiveness of differential speed limits on rural interstates was completed for the Michigan DOT in 2014 [Savolainen et al., 2014]. Nationwide fatal crash data from 1999 through 2011 were obtained and examined to assess the fatal crash impacts of uniform vs. differential limits on interstates. It was found total rural interstate fatalities were not significantly different between states with uniform and differential speed limits, which is reflected in Figure 6. However, truck- and bus-involved rural interstate fatalities were nearly 25 percent greater in states with uniform speed limits compared to states with differential limits.

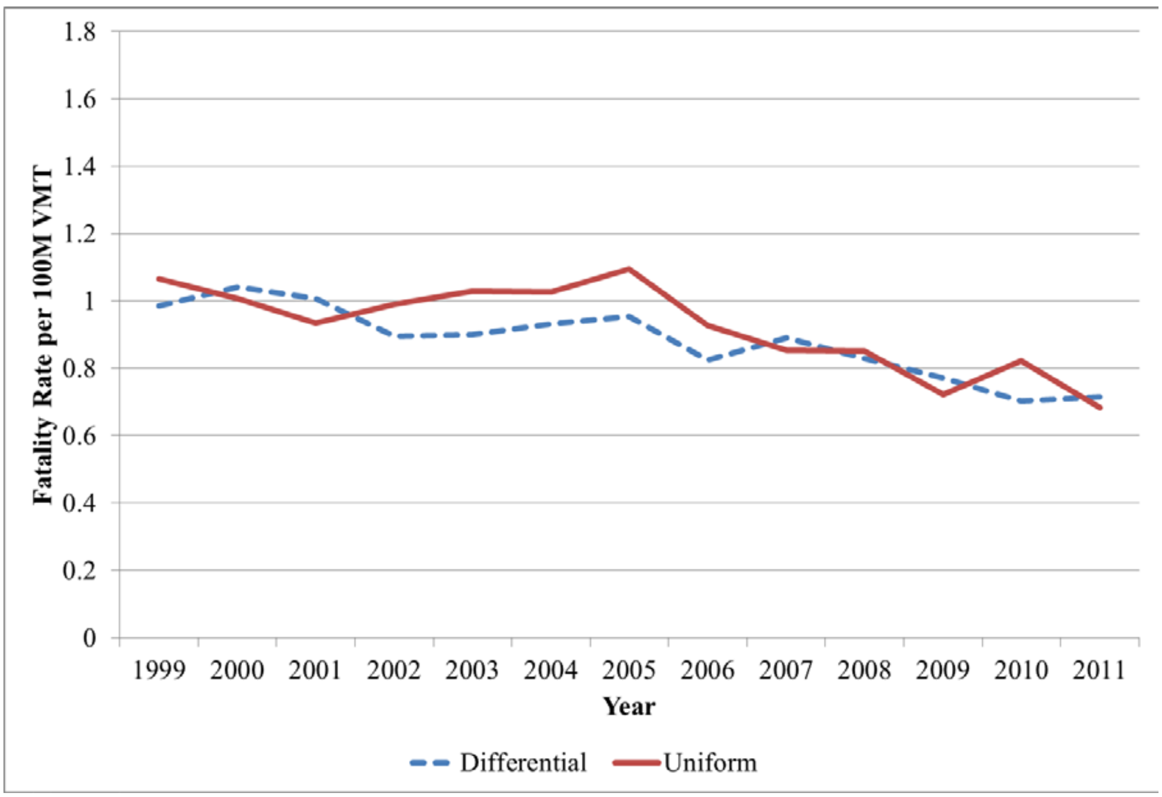


Figure 6. Annual Rural Interstate Fatality Rates by Truck Speed Limit Policy [Savolainen et al., 2014]

The recent Michigan DOT study also included spot speed studies conducted at 160 flat/straight freeway locations in Michigan, Indiana, and Ohio to provide a comparison between the 10-mph differential (Michigan), 5-mph differential (Indiana), and uniform speed limits (Ohio)

[Savolainen et al., 2014]. The maximum freeway speed limit within each state was 70 mph, while the differential truck limit was 60 mph in Michigan and 65 mph in Indiana. These states provided an additional advantage of possessing several freeways that pass between bordering states, thereby allowing for a controlled comparison of speed limit impacts. These sites were split among urban and rural freeways and were selected from various regions to provide geographic diversity.

Analyses of these speed data show that mean and 85th percentile travel speeds for passenger vehicles were consistent among the three states at locations with a common limit of 55 mph (urban) or 70 mph (rural). As expected, truck and bus speeds were more variable, which is likely due to the existing differential limits in Indiana (5 mph) and Michigan (10 mph). It is important to note that the increases in truck and bus speeds were less pronounced than the speed limit differences. For example, the increase from 55 mph to 60 mph resulted in increases of approximately 3-4 mph in mean and 85th percentile speeds. Increasing from 60 mph to 65 or 70 mph showed increases in the range of only 1-2 mph. These data suggest that transitioning from a differential to a uniform speed limit would result in moderate speed increases. While the mean and 85th percentile truck and bus speeds were above the posted limit of 60 mph in Michigan, compliance increased substantially in Indiana and Ohio [Savolainen et al., 2014].

The variability in travel speeds was also found to vary significantly based upon the posted speed limit. For all vehicles combined, the highest standard deviation in travel speeds was found on freeways posted at 70 mph for passenger vehicles and 60 mph for trucks and buses (7.0 mph on average), although this variability was not significantly different from uniform 55-mph locations in Michigan or locations with a 5-mph differential (70 mph/65 mph) in Indiana. In general, travel speeds were more consistent in Ohio, which was the only one of the three states with uniform speed limits on all freeways [Savolainen et al., 2014].

Non-Freeways

As noted previously, the vast majority of prior research related to differential speed limits focused on limited access freeways. Research investigating the effects of differential speed limits on non-limited access roadways is scarce, largely due to the lack of implementation of differential speed limits on such roadways nationwide. Ghods et al. compared the safety implications of three different speed control strategies on two-lane highways: uniform speed limit, differential speed limit, and differential speed limit with truck speed limiters (MSL) [Ghods et al., 2012]. The safety performance of each strategy was investigated using a calibrated microscopic traffic simulation model. Three overtaking indictors were used to evaluate safety performance: the number of vehicles overtaking (NOT), the percentage of time spent in the "desire to overtake mode" (PTOD), and the time-to-collision (TTC) when overtaking and a vehicle is coming in the opposing direction. The model was applied to a six-kilometer segment of a straight, two-lane highway of level and downgraded terrain. The traffic volumes implemented ranged from 100 to 1,500 vehicles per hour per direction with 15% trucks and a 50/50 directional split. Each simulation period was 70 minutes long and 10 runs were performed for each control strategy.

The results showed that as volume increased, the number of overtakes increased parabolically, reaching a maximum at directional volumes of approximately 900 vehicles per hour. The rate of overtaking was found to be slightly higher with the DSL and MSL compared to the USL. As expected, the number of car-truck overtakes shifted upwards with a DSL, increasing car-truck interactions and, potentially, the number of crashes. In contrast, the number of car-car overtakes dropped for DSL and MSL. The difference in TTC between the speed strategies was negligible but rapidly decreased for each of the three strategies when volume began to increase, with the greatest risk observed at directional volumes of 500 to 800 vehicles per hour. This indicator implies the highest head-on collision threat occurs at the mid-volume range. The difference in PTOD between the uniform and differential speed strategies was again negligible, but increased with volume [Ghods et al., 2012].

FACTORS AFFECTING SAFETY PERFORMANCE ON TWO-LANE HIGHWAYS

Several roadway characteristics have been shown to impact safety along rural non-freeway highways. Consideration of such factors may help to provide insight into determining the most effective speed limit policy for Montana's rural two-lane highways. Factors which have been found to impact safety along two-lane highway segments include:

- Traffic volumes and truck volumes;
- Design speed and posted speed limit;
- Horizontal and vertical alignment;
- Lane width, surface type, and associated pavement friction;

- Shoulder type and width;
- Access point density;
- Passing zones/passing relief lanes;
- Traffic control devices such as pavement markings and warning signs; and
- Rumble strips.

Detailed discussion of the relationship between the specific characteristics of two-lane roadways and traffic safety is provided in the following sections.

Traffic Volumes and Truck Percentage

The recent Michigan DOT non-freeway safety evaluation found that injury and fatal crashes on state-maintained undivided rural highways increased in a nearly elastic manner with respect to traffic volume [Gates et al., 2015]. Specifically, on average, a one-percent increase in traffic volume was associated with an approximate 0.99 percent increase in injury crashes and 0.95 percent increase in fatal crashes. It should be noted that total crashes tended to be less related to traffic volume, as a one-percent increase in traffic volume was associated with an approximate 0.64 percent increase in total crashes. The percentage of commercial trucks within the traffic stream was associated with an increase in observed crashes across all severity levels. This effect was more pronounced as the level of crash severity increases [Gates et al., 2015].

Posted Speed Limit

In general, speed limits are typically established based on consideration of several factors, including the roadway design speed. In rural areas, the roadway design speed is often based on the most restrictive geometric element, usually a horizontal or vertical curve. Vehicular operating speeds along tangent sections of two-lane highways have been shown to be impacted by the posted speed limit, with vehicular speeds tending to increase as the posted speed limit increases [Kockelman, 2006; Polus et al., 2000]. However, the magnitude of the increase in operating speed is typically only a fraction of the amount of the actual speed limit increase. For undivided roadways, mean speeds generally increase by 3 to 5 mph for every 10 mph increase in speed limit above 55 mph, with diminishing effects at higher speed limits [Kockelman, 2006, Gates et al., 2015].

Using data from Washington State, Kockelman estimated that increasing the non-freeway speed limit from 55 to 65 mph on high speed roadways (including limited and non-limited access) would increase the total crash rate by 3.3 percent, and the probability of a fatality (assuming a crash had occurred) would increase by 24 percent [Kockelman, 2006]. Injury crash probabilities were also expected to increase, while non-injury crash probabilities were expected to decrease. These effects were predicted to diminish at higher speeds, as speed limit increases from 65 to 75 mph were projected to increase total and fatal crashes by 0.6 percent and 13 percent, respectively, although these estimates are less applicable to two-lane roadways, as the higher speed analysis largely utilized data from limited access freeways. Kockelman's estimates were similar to those found after relaxation of the national maximum speed limit, as the fatality risk was estimated to increase between 15 and 19 percent on rural interstates after increasing the speed limit from 55 to 65 mph [Garber and Graham, 1990; Baum et al., 1992].

Horizontal Alignment

Several studies have generally demonstrated that horizontal alignment is a primary factor in the vehicular operating speeds along two-lane highways, as drivers tend to reduce speeds based on the degree of curvature [Islam and Senevirante, 1994; Krammes et al., 1993, Gates et al., 2015; Dimaiuta et al., 2011; McFadden et al., 2001; McFadden and Elefteriadou, 2000; Fitzpatrick et al., 2000; Donnell et al., 2001; Voigt and Krammes, 1998; Misaghi and Hassan, 2005; Fitzpatrick, 2000]. Kockelman suggested that geometric alignment has a greater influence over vehicular operating speeds than posted speed limits [Kockelman, 2006]. Specifically, Fitzpatrick et al. found that operating speeds on horizontal curves with a radius greater than or equal to 2,600 feet were similar to those on long tangents, although for radii below 800 feet, a sharp decrease in vehicle operating speed is observed [Fitzpatrick et al., 2000].

Although the *Highway Capacity Manual* (HCM) [Transportation Research Board, 2010] states that the base free-flow speed of a facility is limited by horizontal and vertical alignment, no actual methodology is given to determine the effect horizontal curvature has on base free-flow speed. The FHWA's *Interactive Highway Safety Design Model* (IHSDM) includes a series of models to help predict the speed reduction likely to occur when travelling from a tangent segment to a horizontal curve [FHWA, 2015]. Models are provided for horizontal curves at various grades as well as horizontal curves combined with a vertical curve.

Wooldridge et al. reported that horizontal curves are the most critical geometric design elements related to the influence of driver behavior and crash risk [Wooldridge, 2003]. On two-lane rural highways, horizontal curves with a design speed less than a driver's desired speed create operating speed irregularities and increase driver work load, which induce higher crash potential [FHWA, 2015; Wooldridge, 2003], particularly if operating speeds through the curve are reduced by more than 3 mph from the adjacent tangent section [Wooldridge, 2003]. Kockelman found that highway segments with horizontal curvature possessed higher crash rates than tangent segments [Kockelman, 2006]. This finding was consistent with the recent Michigan study, which found that the presence of horizontal curvature tended to increase the rate of injury and fatal crashes on undivided segments, although property damage crashes were not impacted [Gates et al., 2015]. In situations where the radius of a horizontal curve is sharper than the design criteria, mitigation strategies such as enhanced signage and delineation devices should be applied to reduce the crash risk, unless or until the curve is realigned [Harwood et al., 2014].

The *Highway Safety Manual* (HSM) [AASHTO, 2010] provides an equation for computing the crash modification factor for horizontal curves on rural two-lane highways:

$$CMF = \frac{(1.55 \times L_C)(\frac{80.2}{R}) - (0.012 \times S)}{(1.55 \times L_C)}$$

Where:

Lc = Length of horizontal curve including length of spiral transitions, if present (mi)
R = Radius of curvature (ft)
S = 1 if spiral transition curve is present: 0 if spiral transition curve is not present

The CMF applies to total crashes and the base condition consists of a tangent segment with no curvature.

Vertical Curvature

The safety effects of both categories of vertical curves (sag and crest) are not detailed in the *Highway Safety Manual*, but any influence they do have are most likely related to limited stopping sight distance. Kockelman found that segments with vertical curvature exhibit higher crash rates than relatively flat segments, and that increased safety risks associated with increasing speed limits would be exacerbated on segments with vertical curvature [Kockelman, 2006]. Recent research in Michigan found that that rolling terrain generally increased crashes on undivided 55 mph highways [Gates et al., 2015].

A recent NCHRP study [Harwood et al., 2014] evaluated the effect of stopping sight distance on crash frequency and severity for two-lane rural highways. Specifically, Type 1 crest vertical curves (connecting an upgrade to a downgrade) with stopping sight distances less than and greater than the AASHTO recommended design criteria were evaluated. Several negative binomial regression models were developed based on the following factors: AADT; whether the SSD was at, above, or below AASHTO criteria; whether a horizontal curve, intersection, or driveway was present; and whether the horizontal curve, intersection, or driveway was hidden from the view of the approaching driver. The results suggested that a crest vertical curve with an SSD below AASHTO standards does not by itself increase crash frequency. However, when that curve is combined with a horizontal curve or access point, particularly if that feature is hidden, a significant increase in the crash rate was observed.

An FHWA report by Bauer and Harwood developed crash modification factors for various types of crashes and vertical curves [Bauer and Harwood, 2012]. A CMF for fatal and injury crashes and for property damage only crashes is detailed for two types of crest vertical curves and two types of sag vertical curves. With the exception of Type 1 sag curves (connects a downgrade to an upgrade), all vertical curve tangents have a CMF of 1.0. If a horizontal curve is present, the CMF based on the radius of the horizontal curve, the length of the vertical curve, and difference in grades. To help mitigate limited stopping sight distance, signing should be provided for crest vertical curves and lighting can be installed for sag vertical curves, intersections, and merge/diverge areas.

Grade

Grade impacts roadway operating speeds, and is the controlling geometric feature on roadway tangent segments [Fitzpatrick, 2000]. Prior research has demonstrated that steeper vertical grades are associated with higher crash rates [Kockelman, 2006; AASHTO, 2010], although crashes on steeper vertical upgrades tended to be less severe [Kockelman, 2006]. The *Highway Safety Manual* [AASHTO, 2010] provides crash modification factors for grade based on the steepness. For level grade (≤ 3%), the CMF is set at 1.00. The CMF increases to 1.10 for moderate terrain (3% < grade < 6%) and 1.16 for steep terrain (> 6%). Research by Harwood et al. developed a continuous function for the CMF as follows [Harwood et al., 2014]:

$$CMF = (1.0 + 0.016G)$$

Where: G = absolute value of the percent grade.

Lane Width

The width of travel lanes has been shown to be related to the safety performance of both two-lane and multilane non-freeways. Specifically, the HSM suggests an association between lane width and reductions in single-vehicle run-off-the-road, head-on, and sideswipe type crashes [AASHTO, 2010]. While the impact of lane width on traffic crashes varies with the associated traffic volume, the affect is most pronounced for roadways involving lane widths of nine feet or less. It should also be noted that the effect of lane width on safety performance is smaller for multilane highways as compared to two-lane highways. The safety performance impact for multilane undivided and divided highways is equal to approximately 75 percent and 50 percent, respectively, of that for two-lane highways [Zegeer et al., 1990].

Shoulder Width

For rural two-lane highways, the AASHTO *"Green Book"* recommends minimum usable shoulder widths ranging from four to eight feet depending on AADT [AASHTO, 2011]. The HSM suggests that the width of paved shoulder along non-freeways has a similar effect on crashes as travel lane widths [AASHTO, 2010], due to the increased recovery and vehicle storage space and increased separation from roadside hazards. While this effect is related to the associated traffic volume along such non-freeway highways, the frequency of traffic crashes tends to increase as paved shoulder widths are reduced below 6 feet. Further, this effect is more significant for roadways involving greater than 2000 vehicles per day as lane widths are reduced to two feet or less [AASHTO, 2010]. Increased shoulder widths have also been shown to increase operating speeds, likely due to the increased shy distance [Gates et al., 2015].

Access Point Density

Several prior studies have demonstrated that as the density of access points (or the number of intersections and/or driveways per mile of highway) increases, the frequency of traffic crashes also increases [AASHTO, 2010; Harwood et al., 2000; Gluck et al., 1999]. This is at least partially due to driving errors caused by intersections and/or driveways, which may result in rear-end and/or sideswipe type crashes [AASHTO, 2010]. Specifically, the *NCHRP Report 420* concluded that as access point density increased from 10 to 20 access points per mile, a 40 percent increase in crashes could be expected, while an increase to 40 access points per mile was associated with a potential doubling in the frequency of traffic crashes [Gluck et al., 1999]. A recent study in Michigan found that undivided 55 mph roadway segments with between 5 and 15 access points per mile possessed total crash rates that were 20 percent greater than segments with fewer than 5 access points [Gates et al., 2015]. Further, undivided segments with greater than 15 access points per mile showed total crash rates that were 24 percent greater than locations with fewer than 5 access points, and injury and fatal crash rates that were approximately 14 percent greater. Access point density was also found to have an inverse relationship with vehicular speeds, as mean speeds tend to decrease as the density of access points increases [Gates et al., 2015; Gong and Stamatiadis, 2008].

Passing Zones and Passing Relief Lanes

While the presence, length, and location of passing zones on two-lane highways likely has an effect on the safety performance of two-lane highways, this effect has not been well-documented in the previous literature. Recent research of 55 mph undivided roadways in Michigan found that as the proportion of no-passing zones increases along a roadway segment, the frequency of total and injury crashes also increases, possibly due to illegal passing activity [Gates et al., 2015]. Similarly, the presence of a passing relief lane along undivided roadway segments was associated with a decrease in the observed number of total and injury crashes [Gates et al., 2015]. Neither passing zones nor passing relief lanes were found to impact fatal crashes. Passing relief lanes were found to increase vehicular operating speeds downstream of the passing lane termination point [Gates et al., 2015]. The *Highway Safety Manual* [AASHTO, 2010] notes a general lack of evidence related to the safety impacts of the following passing zone characteristics on two-lane highways:

- Available passing sight distance;
- Presence of access points/driveways around no-passing zones;
- Length of no-passing zone;
- Frequency of passing zones; and
- Impacts of various weather, cross-section, and operational conditions.

Rumble Strips

Centerline rumble strips (CLRS) and shoulder rumble strips (SRS) are common countermeasures to reduce lane departure crashes on two-lane rural highways, including run-off-road and head-on collisions. A 2011 state-of-the-practice survey found that at least 36 states in the US had implemented CLRS, covering more than 11,000 roadway miles [Karkle et al., 2013]. Several research evaluations have assessed the safety performance of CLRS and SRS on high-speed rural non-freeway roadways. An early evaluation of CLRS installations along 210 miles of two-lane highways across seven states showed a 14-percent reduction in total injury crashes and a 25-percent reduction in head-on and opposite-direction sideswipe injury crashes [Persaud et al., 2003]. Similar results were observed in subsequent evaluations, including a study in British Columbia, Canada that found reductions in run-off-the-road-left and head-on collisions of 29.3 percent [Sayed et al., 2010], and a Kansas study that found a 29-percent reduction in correctable cross-centerline crashes [Karkle et al., 2013].

NCHRP Report 641 provided a comprehensive multi-state evaluation of the safety impacts of CLRS, including data from extensive CLRS implementations in Minnesota, Pennsylvania, and Washington [Torbic et al., 2009]. Head-on and opposite-direction sideswipe collisions were reduced by 37.0 percent and 44.5 percent, respectively, while total crashes and injury or fatal crashes were reduced by 4.1 percent and 9.4 percent, respectively. Crash reductions were particularly pronounced on horizontal curves. This finding is consistent with recent behavioral research, which has shown improvements in vehicular lateral position due to CLRS to be larger on curves as opposed to tangent sections [Gates et al., 2012]. CLRS have also been shown to elicit more centralized vehicular lane positioning – an effect that is even more pronounced when SRS are used in combination with CLRS [Gates et al., 2012].

A recent study in Michigan evaluated the effectiveness of the Michigan DOT's centerline rumble strip implementation program, which included installation of CLRS across more than 5,000 miles of MDOT-maintained rural, high-speed non-freeway facilities [Kay et al., 2015]. Shoulder rumble strips were installed in combination with the CLRS at locations with paved shoulders of at least 6 ft in width. This system-wide installation of rumble strips on non-freeways was the largest of its kind in the United States, allowing for a comprehensive investigation to address several important questions regarding the efficacy of CLRS in reducing target (i.e., cross-centerline) crashes. An empirical Bayes analysis was performed, which found CLRS to reduce target cross-centerline crashes by 27.3 percent where SRS were not present and by 32.8 percent when used in combination with SRS. Rumble strips were also effective in reducing crashes that occurred under adverse pavement conditions, involved passing maneuvers, or driver impairment [Kay et al., 2015].

OPERATIONAL CHARACTERISTICS OF TWO-LANE HIGHWAYS

One of the primary concerns related to the study of the Montana DSL policy for two-lane highways is the impact on traffic operations. Specifically, given that anecdotal evidence in Montana has shown that the differential speed limit may result in significant queueing, passing operations are expected to be a key consideration as a part of the DSL study. Two-lane highways, which involve one lane for each direction of traffic, are unique in that passing maneuvers take place in the opposing lane of traffic. Further, such passing maneuvers are limited by both the availability of gaps in the opposing traffic stream as well as insufficient sight distance [Transportation Research Board, 2010]. Given these constraints, an increase in traffic demand or available sight distance decreases passing opportunities, often leading to queues in the traffic stream (i.e., platoons).

Platooning

Percent time spent following (PTSF) is defined in the *Highway Capacity Manual* as "the average percentage of time that vehicles must travel in platoons behind slower vehicles due to the inability to pass" [Transportation Research Board, 2010]. Essentially, PTSF represents the freedom of vehicles to maneuver and the comfort and convenience of travel on two-lane highways. However, PTSF is not easily measured in field studies and considerable debate exists as to the definition of a platooned vehicle. While the current version of the HCM states that the proportion of vehicles traveling with headways of less than 3.0 seconds is an appropriate surrogate measure, prior versions of the HCM suggested that vehicles traveling at less than their desired speed and with headways of less than 5.0 seconds as the measure of vehicles in a platoon [Gattis et al., 2014].

Several prior studies have been performed to quantify the headway at which a vehicle can be considered as being delayed in a platoon or queue, with some researchers arguing for values more closely related to the previously used 5.0 seconds [Al-Kaisy and Karjala, 2010; Lobo et al., 2014; Vogel, 2002] and others for values more closely associated with the 3.0 second definition [Gattis et al., 2014; Guel and Virkler, 1998; 114]. Research in Montana performed by Al-Kaisy and Karjala investigated car-following interactions using empirical data from two-lane highways in Montana [Al-Kaisy and Karjala, 2010]. The results demonstrated that while car-following interactions generally cease beyond headways of 6.0 seconds, a significant proportion of drivers maintained relatively short headways, suggesting that many drivers find a low level of congestion or platooning to be tolerable. Researchers in Japan have also suggested that determining following or platooned vehicles on the basis of time headway alone has several drawbacks, noting that this assumes that all vehicles and drivers behave the same under different conditions [Catbagan and Nakamura, 2014]. The authors ultimately developed speed distributions for various conditions which can be used to identify a vehicle's following probability on the basis of its operating speed.

Passing Maneuvers

Passing maneuvers on two-lane rural roadways have been recognized as one of the most significant and complex driving tasks [Polus et al., 1999]. Further, given the relative complexity of such maneuvers, developing models to quantify the stages of passing events has been covered in the AASHTO *Green Book* as well as several prior research efforts [AASHTO, 2011; Polus et al., 1999; Harwood and Glennon, 1989; Glennon, 1988; Harwood and Glennon, 1976]. Specifically, the ability of vehicles to overtake slower moving vehicles along two-lane highways has been shown to be affected by several factors, including:

- Traffic volumes of through and opposing traffic;
- The speed differential between the passing and passed vehicles;
- Geometric characteristics of the highway;

- Available sight distance; and
- Human factors (driver reaction times, gap acceptance characteristics.

Individual stages of passing maneuvers have also been previously defined [Polus et al., 1999]. The beginning of a passing maneuver has been previously defined as “location of the passing vehicle when its front left wheel first crosses the broken line separating the lanes as it sets out on the pass”. The end of a passing maneuver has been defined as “location of the passing vehicle when its back-left wheel crosses the broken line separating the lanes as it returns to the right lane after making the pass”. There has also been categorization of various types of passing maneuvers in prior research [Polus et al., 1999]. Specifically, aborted passes have been defined as occurring “when the vehicle begins to enter the opposite lane in an attempt to pass, notices the appearance of a car in the opposite lane, and reverts to its original lane behind the would-be passed car”. Further, “flying passes” involve maneuvers where an overtaking vehicle executes the passing maneuver without being delayed or slowing down by the vehicle being overtaken. Finally, “accelerative passes” are cases where the overtaking vehicle has to first slow down before accelerating past the overtaken vehicle in the adjacent lane.

CHAPTER 3:
SPEED LIMIT POLICIES AND PRACTICES IN THE UNITED STATES

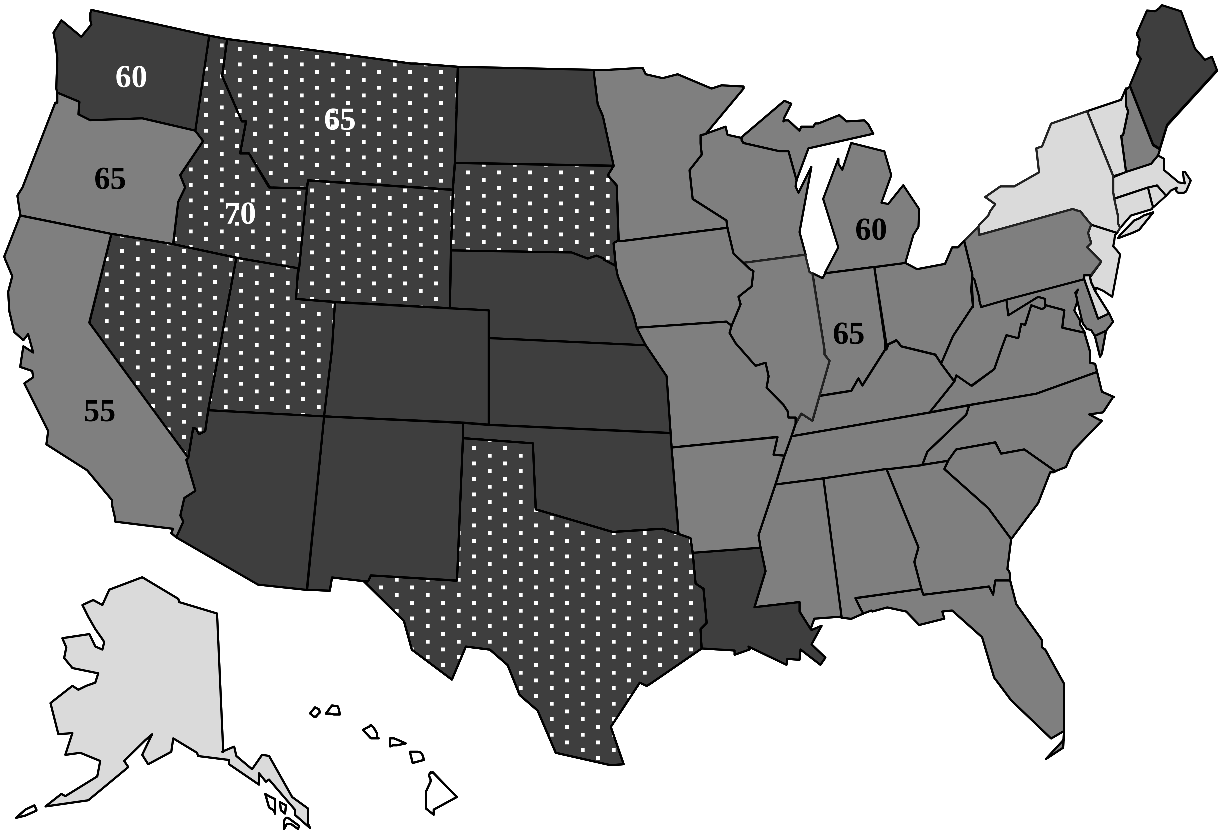
The preceding sections outline a wide range of important safety issues to be considered when establishing speed limits. While the extant research literature has generally shown that higher speed limits result in degraded safety performance, many states have recently increased or are considering increases to speed limit policies. This chapter provides a brief summary of such information, including current rural freeway and non-freeway (divided and undivided) speed limit policies nationwide, recently implemented speed limit increases, impacts associated with recent speed limit increases, and proposed speed limit policy changes.

CURRENT FREEWAY SPEED LIMIT POLICIES

Figure 7 displays the maximum freeway speed limits allowed for passenger vehicles and heavy trucks on rural interstate freeways within each state as of June 2016. In most cases, the displayed speed limits also apply to limited access freeways not designated as interstates. For states with differential limits between passenger vehicles and heavy trucks, the truck speed limit is displayed on the map.

CURRENT NON-FREEWAY SPEED LIMIT POLICIES

The maximum allowable speed limits for divided and undivided rural non-freeway highways vary throughout the United States. Currently, 30 states allow for higher posted speed limits for divided roadways than for undivided roadways while the remaining states utilize the same maximum speed limit across both roadway types. The maximum allowable posted speed limits for divided rural highways range from 45 mph in Hawaii up to 80 mph in Texas, while maximum speed limits on undivided rural highways range from 50 mph in Delaware and Rhode Island to 75 mph in Texas. While the majority of states utilize maximum non-freeway speed limits between 55 mph and 65 mph, speed limits of 70 mph or above are becoming increasingly popular, particularly for divided highways in western states. The current maximum allowable posted speed limits are presented in Figure 8 for divided rural highways and Figure 9 for undivided rural highways.



Legend:

- 80 mph
- 75 mph
- 70 mph
- 65 mph
- 60 mph

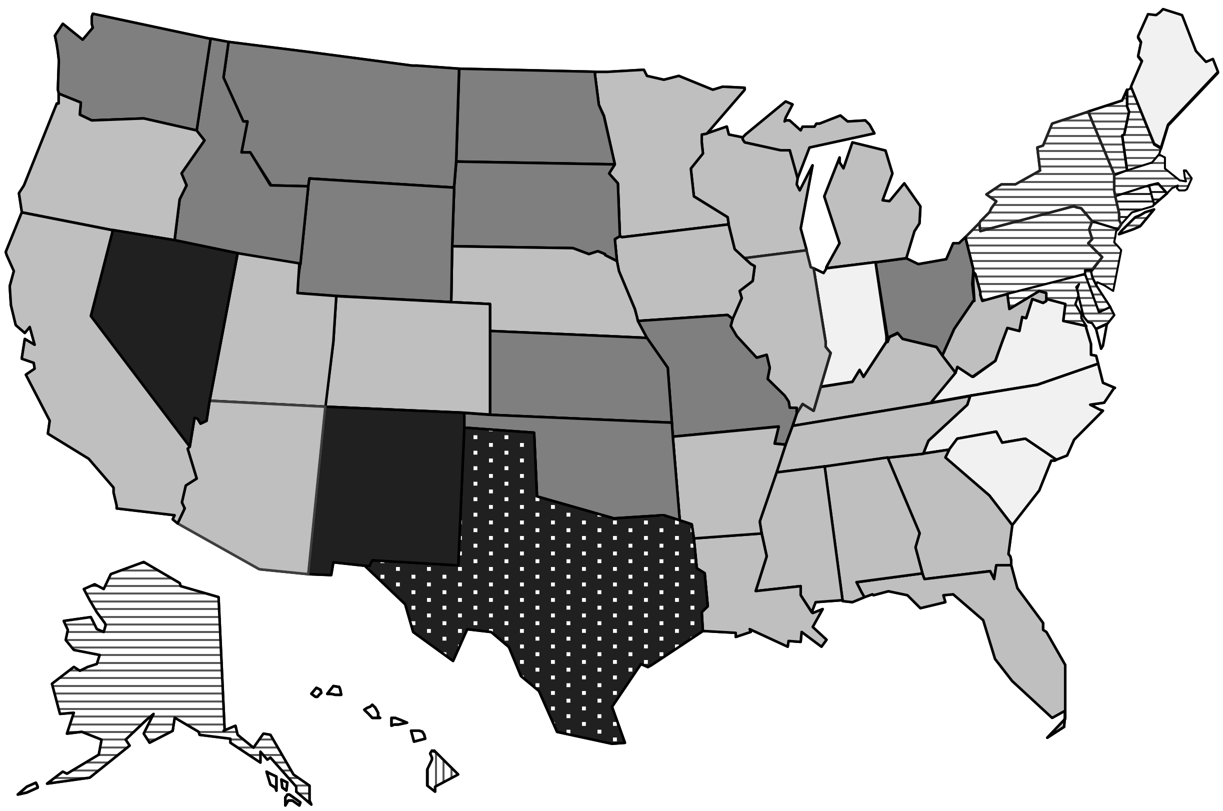
Notes: Maximum truck limits (mph) are displayed for states where differential limits are used

Oregon maintains 65/55 mph limits for cars/trucks on certain freeways

Texas maintains 85 mph speed limits on State Highway 130, a rural limited access freeway specifically designed for such travel speeds

Illinois maintains a differential limit for trucks on select suburban tollways

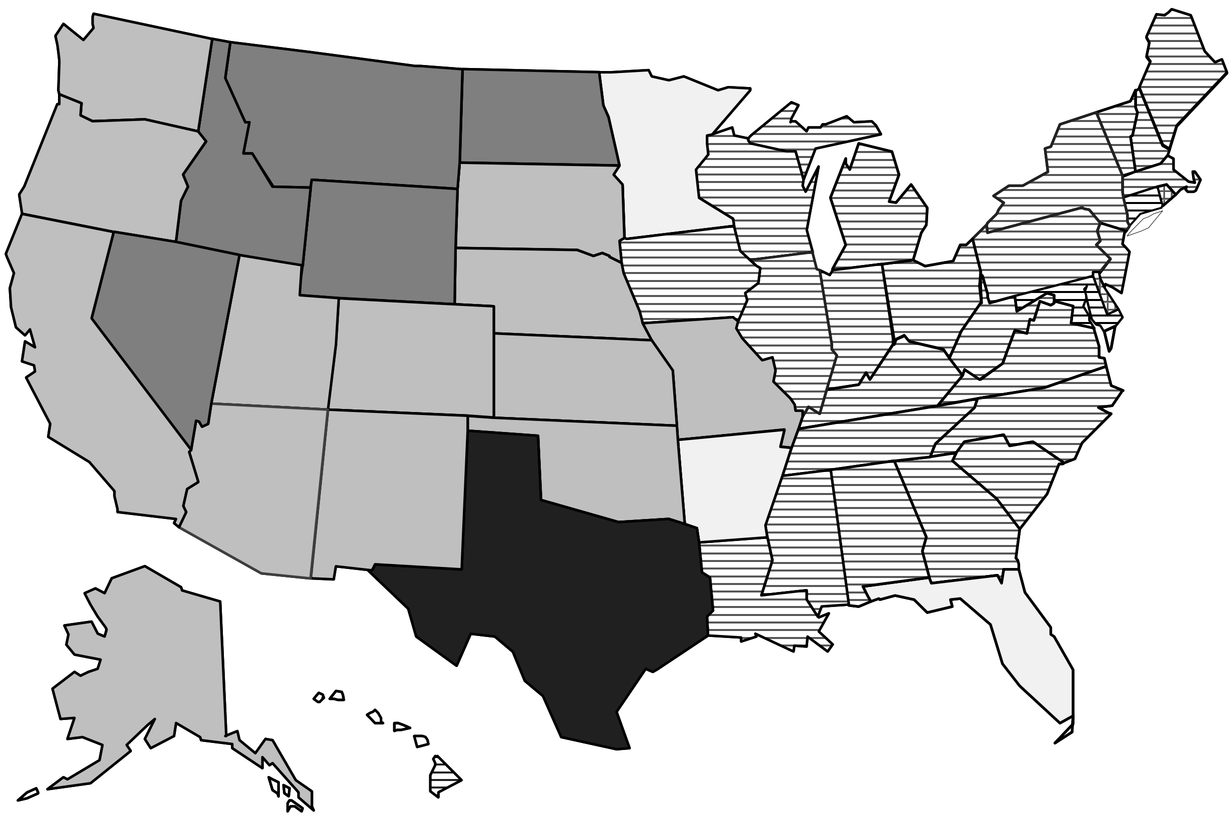
Figure 7. Maximum Speed Limits on Rural Interstates (June 2016)



Legend:

- 80 mph
- 75 mph
- 70 mph
- 65 mph
- 60 mph
- 55 mph
- 45 mph

Figure 8. Maximum Speed Limits on Divided Rural Highways (June 2016)



Legend:

- 75 mph
- 70 mph
- 65 mph
- 60 mph
- 55 mph
- 50 mph

Notes: Oregon maintains a 70 mph maximum limit (65 mph for trucks) on US-95, which is an undivided rural highway in the far southeastern portion of the state.

Montana maintains a 60 mph truck speed limit on the majority of two-lane rural highways statewide

Figure 9. Maximum Speed Limits on Undivided Rural Highways (June 2016)

RECENT SPEED LIMIT POLICY CHANGES

Since 2011, 25 states have increased speed limits on highways and/or limited access freeways. The majority of these increases were based on legislative action and most occurred along interstate highways. In general, these increases were performed selectively on eligible roadway segments based upon traffic engineering, speed, and safety studies conducted by the particular state DOT. This is an important distinction from prior speed limit policy changes, which typically affected all roadways within a particular classification. However, as speed limits have continued to increase, it has become less likely that all roadways within the affected roadway class are acceptable candidates for higher speed limits. In particular, roadway segments with extensive horizontal or vertical curvature, sight distance limitations, or other critical geometric features, may not be suitable for speed limit increases. Similarly, roadways may also be unsuitable candidates if the 85th percentile speed is in compliance with the existing limit or where high crash rates exist. Where available, specific details of the recent state speed limit policy changes are provided as follows (in alphabetical order), with a summary provided in Table 2 (in chronological order).

- **Idaho:** Speed limits were increased on three select rural interstates (I-15, I-84 and I-86) from 75 to 80 in August of 2014 [Anderson, 2014].
- **Illinois:** The speed limit for ninety percent of the interstate mileage was raised from 65 mph to 70 mph at the beginning of 2014. These roadways are made up of mostly rural highways, with the exception of five short sections of the Illinois Tollway, which were increased 15 mph to 70 mph. The Illinois DOT conducted traffic engineering studies and examined 85th percentile speeds in support of these recommendations [Gregory, 2013].
- **Kansas:** In July 2011, legislation was passed that raised the maximum speed limit on divided multilane highways to 75 mph. A committee comprised of staff from the Kansas DOT was given the authority of selecting candidate segments. Several criteria were used in selecting the locations for increased speed limits, including: area type, presence of at-grade intersections, natural barriers, commuter traffic, geometrics, surrounding state speed limits, district experience, traffic volumes, legal concerns, and crashes. The 75 mph speed limit was ultimately implemented on more than 800 miles of rural freeways in 2011.
- **Kentucky:** The state recently approved a speed limit increase on specific four-lane highway sections of KY-80 from 55 mph to 65 mph in an effort to reduce travel times and stimulate tourism in Western Kentucky [Canning, 2015]. This follows previous increases from 55 to 65 mph on select US highways in 2012.
- **Louisiana:** As a result of a 2010 bill, a 200-mile stretch of Louisiana's I-49 speed limit was increased from 70 mph to 75 mph. The increase was authorized by the state Department of Transportation and Development after engineering and traffic investigations [Associated Press, 2011].

- **Maine:** Beginning in May of 2014, Maine increased speed limits 5 mph on selected interstate freeways previously posted between 55-65 mph up to 60-70 mph following legislation which provided the state transportation commissioner with the authority to raise the speed limit on interstate freeways. Freeway segments were selected for the increased speed limit in order for the posted limits to be in general agreement with current travel speeds [Sambies, 2014].
- **Maryland:** Speed limits were increased from 65 to 70 mph along I-68 in September 2015, following legislation which increased the maximum speed limit in the state to 70 mph [Maryland Department of Transportation, 2015]. The Maryland Department of Transportation is also considering other 65 mph segments for similar speed limit increases.
- **Montana:** In October of 2015, Montana raised the posted speed limit on three interstate freeways (I-15, 90 and 94) from 75 mph to 80 mph following legislation which increased the maximum speed limit [Drake, 2015]. In April 2013, speed limits were modified along portions of two eastern Montana highways (MT-16 and MT-200) from the statutory 70/60 mph differential limit to a uniform 65 mph limit.
- **Nevada:** Following legislation, speed limits were increased along I-80 from 75 mph to 80 mph in October 2015 [Sain, 2015].
- **New Hampshire:** Speed limits were increased from 65 to 70 mph along a 30-mile stretch of I-93 in New Hampshire in 2013 [Associated Press: Concord, 2013].
- **North Carolina:** In September of 2013, the North Carolina DOT raised the speed limit of three major highways from 65 mph to 70 mph (I-540 between U.S. 70 and I-40; All of N.C. Highway 540; and N.C. Highway 147 between N.C. Highway 540 and I-40). These increases came as a result of traffic studies that included a review of the current travel speed, speed limits, crash data, and road characteristics such as lane and shoulder widths [WTVD:Raleigh, 2013].
- **Ohio:** In April 2011, speed limits were raised on the Ohio Turnpike from 65 to 70 mph. In 2013, state legislators voted to allow freeway speed limits in non-urban areas to be increased from 65 to 70 mph. The 70 mph speed limit was implemented on five rural freeway sections in 2013 [Armon, 2014].

- **Oregon:** State lawmakers voted to raise the posted speed limit of portions of I-84 and US-95 (two-lane undivided) from 65 mph to 70 mph (trucks 65 mph) as well as increasing the posted speed limit on sections of eight state highways from 55 mph to 65 mph (trucks 60 mph) beginning in March of 2016 [Oregon State House of Representatives, 2015]. However, in early June of 2016, the Oregon DOT announced that after completing a new engineering analyses and reviewing crash data, the new speed limits would be rolled back to the prior limits on four of the state highway segments. These changes are considered temporary until a permeant decision is made over the next year [The Oregonian, 2016].
- **Pennsylvania:** Speed limits were increased on select rural freeways in January 2014. The Pennsylvania DOT will conduct a study along these segments [Hartzell, 2013].
- **South Carolina:** Speed limits were increased along a section of SC-170, from 55 to 60 mph. The DOT examined this section of the route, which has no traffic signals and few exits, and determined it was safe to increase the speed limit [Murdock, 2014].
- **South Dakota:** Speed limits were increased from 75 mph to 80 mph on two select rural interstates (I-29 and I-90) in April of 2015 [Amundson, 2015].
- **Texas:** As a result of a 2012 bill passed by the state legislature, Texas became the first state in the U.S. to enact a speed limit of 85 mph. While the Texas DOT concluded that speeds this high could not be safely implemented on current highways, a new 41-mile toll road (SH 130) was designed to handle the higher speeds and was subsequently posted at 85 mph after a review of geometry and sight lines prior to opening [Little, 2011]. A 2011 law allows TxDOT to enact speed limits up to 75 mph (undivided) and 80 mph (divided) on all other state highways found to be reasonable and safe through an engineering study.
- **Utah:** Speed limits on select rural freeways were raised from 75 to 80 mph. Beginning in 2008, UDOT started conducting studies on portions of I-15 that were temporarily set to 80 mph. Results showed that crashes slightly decreased. Speed studies of highways posted at 75 mph, were also studied. UDOT concluded that most motorists preferred to drive between 82 and 83 mph regardless of the speed limit. As of September of 2013, 289 miles of highway in Utah were set to a speed limit of 80 mph [Hoschouer, 2013].
- **Wisconsin:** In June of 2015, Wisconsin raised the speed limit on rural interstates statewide from 65 to 70 mph [Renault, 2015], which was followed by a second phase of

161 miles of select non-interstate freeways also receiving a 5 mph increase from 65 to 70 mph [Harlow, 2015].

- **Wyoming:** In July 2014, Wyoming increased the posted speed limit from 75 mph to 80 mph on more than half of its interstate mileage including portions of I-25, I-80 and I-90 [Billings Gazette, 2015].
- **Washington:** The Washington State Legislature recently allowed for speed limits of 75 mph in sections deemed appropriate by an engineering study or where the design speed allows [Washington State Legislature, 2015].

Table 2. Recent Changes to State Speed Limit Policies

State	Type of Roadway	Prior Limit	New Limit	Effective Date
Ohio	Ohio Turnpike	65	70	April 2011
Louisiana	Select Rural Freeways	70	75	July 2011
Kansas	Rural Freeways	70	75	July 2011
Indiana	Tollway	55	70	February 2012
Arkansas	Select Rural Highway	55	60; 65	June 2012
Texas	Rural Freeways; Tollway	75; 80	80; 85	October 2012
Kentucky	Select US Highway	55	65	October 2012
Montana	Select Rural Highways	70c/60t	65c/65t	April 2013
Ohio	Select Rural Freeways	65	70	July 2013
North Carolina	Select Rural Freeways	65	70	September 2013
Utah	Select Rural Freeways	75	80	September 2013
Alaska	State Highways	55	65	November 2013
Georgia	Select Interstates	55	65	November 2013
Illinois	Tollway; Select Freeways	55; 65	70	January 2014
New Hampshire	Select Interstates	65	70	January 2014
South Carolina	Select State Highways	55	60	January 2014
Pennsylvania	Rural Freeways	65	70	January 2014
Maine	Select Interstates	55-65	60-70	May 2014
Wyoming	Select Interstates	75	80	July 2014
Idaho	Select Interstates	75	80	August 2014
South Dakota	Select Interstates	75	80	April 2015
Wisconsin	Rural Interstates, Select Fwys	65	70	June 2015
Maryland	Select Interstates	65	70	September 2015
Montana	Rural Interstates	75	80	October 2015
Nevada	Select Freeways	75	80	October 2015

Kentucky	Select Rural Highways	55	65	October 2015
Washington	Select Freeways	70c/60t	75c/60t	February 2016
Oregon	Select Rural Highways and Select Rural Freeways	55;65c/55t	65c/60t;70c/65t	March 2016

PROPOSED SPEED LIMIT POLICY CHANGES

In addition to the preceding speed limit policy changes, each of which has already been implemented or passed into law, five additional states have recently proposed speed limit increases, either by legislative action or other means. These proposed changes, summarized in Table 3, are as follows:

- **Florida:** State lawmakers proposed a bill that would allow the Florida DOT to selectively study and, if permitted, raise speed limits. Driver feedback and safety data would be used to prompt a speed study for candidate sections. The bill was focused on mostly rural stretches of highway, such as I-10 and I-4. These four-lane highways would see a 5-mph increase in the speed limit from 70 mph to 75 mph. Other four-lane highways with speed limits currently set at 60 mph or 65 mph could see similar 5-mph increases [Beaton, 2014]. However, this bill was subsequently vetoed by the governor, at the recommendation of law enforcement agencies.
- **Michigan:** In June of 2016, the Michigan House of Representatives passed House Bill 4423 that would increase the statutory maximum speed limit on at least 600 miles of rural freeways from 70 mph to 75 mph (65 mph for trucks) and at least 900 miles of state-maintained non-freeways from 55 mph to 60 or 65 mph [Detroit Free Press, 2016]. The candidate roadways would be selected by MDOT based on engineering studies that would include assessment of operating speeds and safety. The bill has been passed along to the state Senate for consideration. A previous version of the bill, which proposed a speed limit of 80 mph for rural freeways statewide, was defeated previously by the state legislature.
- **Missouri**: State lawmakers are considering allowing the speed limits along rural freeways, to be increased from 70 mph up to 75 mph [Pepitone, 2014].
- **New York:** Interstate highways, including the Thruway, could see a 10 mph boost from 65 mph to 75 mph, if permitted by the state transportation commissioner [Precious, 2013].

- **North Carolina:** State lawmakers are considering similar legislation to raise the maximum speed limit for some interstates and highways from 70 mph to 75 mph. If the bill is passed, NCDOT will then complete traffic studies and examine crash histories for specific roadways to determine if the increase is reasonable and safe [Siceloff, 2013].

Table 3. Proposed Changes to State Speed Limit Policies

State	Type of Roadway	Current Limit	Proposed Limit
Florida	Select Rural Freeways	70	75
	Four-Lane Highways	60	65
		65	70
Michigan	At least 600 miles of Rural Freeways	70c/60t	75c/65t
	At least 900 miles of State-Maintained Rural Highways	55	60 or 65
Missouri	Rural Freeways	70	75
New York	Interstates	65	75
North Carolina	Select Rural Freeways	70	75
	3 Major Highways	65	70

IMPACTS ASSOCIATED WITH RECENT SPEED LIMIT POLICY CHANGES

As a part of the recent MDOT speed research study, a follow-up survey was conducted of several DOTs from those states listed in Table 2 in order to obtain feedback on any preliminary findings associated with the recent speed limit increases [Savolainen et al., 2014]. The responses to these follow-up surveys are summarized as follows:

- Collectively, these states considered a range of factors in determining whether speed limit increases were appropriate at specific locations. This includes consideration of the existing 85th percentile speed, as well as whether there is a history of traffic crashes or fatalities on the associated segment. As one example, in Louisiana, the speed limit increases were conducted in accordance with the Louisiana DOT's *Engineering Directive and Standard Manual VIII Establishment of Speed Zones*.

- Preliminary data from these states show that both mean and 85^{th} percentile speeds generally increased by up to 2 mph for every 5 mph increase in speed limit. This finding is consistent with empirical research in this area [Souleyrette et al., 2009; Lousiana DOT, 2013; Utah DOT, 2014].
- Given how recently these increases were implemented, none of these states had been able to determine whether the speed limit changes had a measureable effect on traffic crashes.
- The only documented cost elements provided by any of the responding states was for the provision of new speed limit signage, which could include either sign replacement or the use of a new speed limit plaque that was overlaid on the existing sign.

In the absence of available cost data, an important component of the Michigan study was to estimate the tangible economic impacts associated with proposed speed limit policy increases for freeways and rural non-freeways, including systemwide estimation of the agency and user costs and benefits associated with the proposed increases. This included costs associated with necessary infrastructure modifications, increased fuel consumption, reduced travel times, and fatal crashes. Generally speaking, the infrastructure costs would initially involve upgrading low-cost features, such as speed limit signs, warning signs, and tapers. For non-freeways, modifications to passing zones, signal clearance intervals, and speed reduction zones would also typically be warranted. The benefit/cost ratios associated with raising speed limits on a systemwide basis were below 1.0, for freeways and non-freeways, suggesting unfavorable economic results. This was due in large part to the substantial infrastructure costs associated with geometric modifications along certain segments that will ultimately be necessary to achieve compliance with state and/or federal design speed requirements. Consequently, it was recommended that speed limit increases on high speed roadways should only be considered for select segments with high operating speeds, low crash occurrence, and where the increased speed limit remains compliant with design speed requirements to avoid costly geometric improvements [Savolainen et al., 2014, Gates et al., 2015].

CHAPTER 4:
OPERATIONAL DATA ANALYSIS

As of mid-2016, Montana was the only state in the United States that maintains a differential speed limit between passenger vehicles and heavy trucks on two-lane highways. Across most of the state-maintained rural two-lane highway system in Montana, the maximum daytime speed limit is 70 mph for cars and light duty trucks and 60 mph for trucks with greater than one-ton payload capacity. These speed limits have been in place since 1999. However, in April 2013, speed limits were changed to a uniform 65 mph along 55 miles of MT-16 and MT-200 between Glendive and Fairview in eastern Montana. This change was made in response to observations of aggressive passing behavior by motorists queued behind heavy commercial trucks with little opportunity to pass. Consequently, it was necessary to determine the operational and safety impacts associated with these speed limit changes and to determine if further application of the uniform 65 mph speed limit is warranted in Montana. To that end, the primary objectives of this operational analysis were as follows:

- Evaluate driver speed selection on rural two-lane highways as a function of posted speed (e.g., uniform 65 mph limit vs. differential limit of 70 mph for cars and 60 mph for trucks) and other site factors; and
- Evaluate traffic operational characteristics, including platoon length and passing behavior, on two-lane highways as a function of posted speed limit and other site factors.

To satisfy these objectives, data were collected at numerous two-lane highway locations from across Montana, which typically possessed 70/60 mph differential speed limits, although the select highway segments with uniform 65 mph speed limits were also included. Furthermore, to provide additional locations with 65 mph speed limits, data were also collected on rural two-lane highway segments in the near-border areas within Idaho, North Dakota, South Dakota, and Wyoming. Geometric and other site related factors were also collected at each study location for use in both the operational data analysis and the subsequent crash data analysis. Consequently, the study design allowed for an assessment of how travel speeds and other operational characteristics vary as a function of posted speed limit and other site factors, as well as how these characteristics vary between Montana and adjacent states on roadways with uniform 65 mph speed limits.

FIELD DATA COLLECTION

Field data were collected by members of the research team on two-lane state-maintained rural highways throughout Montana and within the neighboring states of Idaho, North Dakota, South Dakota, and Wyoming. The highway segments were selected in consultation with Montana DOT staff, such that a broad range of geometric, regional, traffic and other factors were represented in the data. The field studies were conducted during daylight hours and clear weather conditions on 10 weekdays in August of 2014. The traffic operational data were collected using a high-definition video camera that was mounted on top of a telescoping pole and temporarily attached to a roadside sign post (example shown in Figure 10). The videos were subsequently reviewed by the research team to extract a robust set of traffic operations and behavior data, which included traffic volumes, vehicle classification, speeds, headways, platoon lengths, passing events, and other information.

Figure 10. Example of Temporary Pole-Mounted Video Camera Installation

In addition to the video camera locations, spot speed data for free flowing vehicles were collected using handheld radar from covert roadside locations at numerous additional secondary locations, which tended to be lower volume roadways. The total directional volumes of passenger vehicles and trucks were also simultaneously collected during each radar speed data collection period, which were subsequently used to determine equivalent hourly volumes for each site. The two data collection methods were utilized in order to maximize the number of speed data collection locations given the limited data collection resources within the time frame for data collection. The data were collected separately for each traffic direction, regardless of the method used.

Upon completion of the field data collection activities, video data had been recorded at 124 field locations spread across 29 two-lane highways, providing a total of 744 hours of video, while radar speed data had been collected at an additional 80 secondary sites across 52 highways. Table 4 provides a summary of the field data collection activities.

Table 4. Field Data Collection Summary

	Video Observation Sites		Radar Speed Sites	
MDT District or State	**Site Count**	**Route Numbers**	**Site Count**	**Route Numbers**
MDT District 1	44	MT 135, MT 200, MT 83, US 12, US 2, US 93, US 93/MT 200	19	MT 1, MT 28, MT 37, MT 141, MT 212, MT 382, MT 486
MDT District 2	21	MT 55, US 12/US 287, US 287, US 89	13	MT 2, MT 41, MT 84, MT 85, MT 86, MT 284, MT 287, MT 359, US 20
MDT District 3	13	MT 200, US 87, US 87/US 89/MT 3/MT 200	7	MT 21, MT 80, MT 431, MT 434, US 89, US 287
MDT District 4	21	MT 16, MT 200, US 2, US 212	14	MT 7, MT 13, MT 23, MT 25, MT 39, MT 59, MT 200S, MT 201, MT 202
MDT District 5	11	US 212, US 310, US 212/US 310, US 87, US 87/MT 3/MT 200	8	MT 3, MT 78, MT 78/CR 289, MT 80, MT 81, US 12, US 12/MT 3
Idaho (eastern)	-	-	4	ID 87, US 2, US 20, US 95
Wyoming (northern)	5	US 212, US 310/WY 789	5	WY 59, WY 112/CR 2, US 14, US 20/US 16
North Dakota (western)	6	ND 200, ND 58, US 2	7	ND 16, ND 68, ND 1804, US 85
South Dakota (western)	3	US 212	3	SD 34, US 85
TOTALS	**124**		**80**	

After completion of the field data collection, a series of quality assurance checks were performed to ensure the locations were representative of typical field conditions. In some cases, it was necessary to exclude all or a portion of the video from further data extraction activities due to conditional abnormalities (e.g., atypical location, traffic incident, road maintenance, etc.) or issues with the recording. After these procedures were completed, a total of 160 data collection locations (84 video and 76 radar spot speed) were included in the final data set and subsequently prepared for analysis. The final sites are summarized in Table 5 by district and posted speed limit, and are displayed geographically in Figure 11. It should again be noted that data were collected independently by travel direction at each location, effectively doubling the number of sites available for use in the subsequent regression analysis.

Table 5. Study Sites by Data Collection Method, State/MDT District, and Speed Limit

District	Video Observation Sites: Uniform 65/65 mph	Video Observation Sites: Differential 70/60 mph	Spot Speed Sites: Uniform 65/65 mph	Spot Speed Sites: Differential 70/60 mph	TOTAL
MDT District 1	0	26	0	19	45
MDT District 2	0	11	0	13	24
MDT District 3	0	21	0	7	28
MDT District 4	5	7	0	12	24
MDT District 5	0	7	0	8	15
Idaho (eastern)	0	0	2	0	2
Wyoming (northern)	1	0	5	0	6
North Dakota (western)	5	0	6	1	12
South Dakota (western)	1	0	3	0	4
All Sites	**12**	**72**	**16**	**60**	**160**

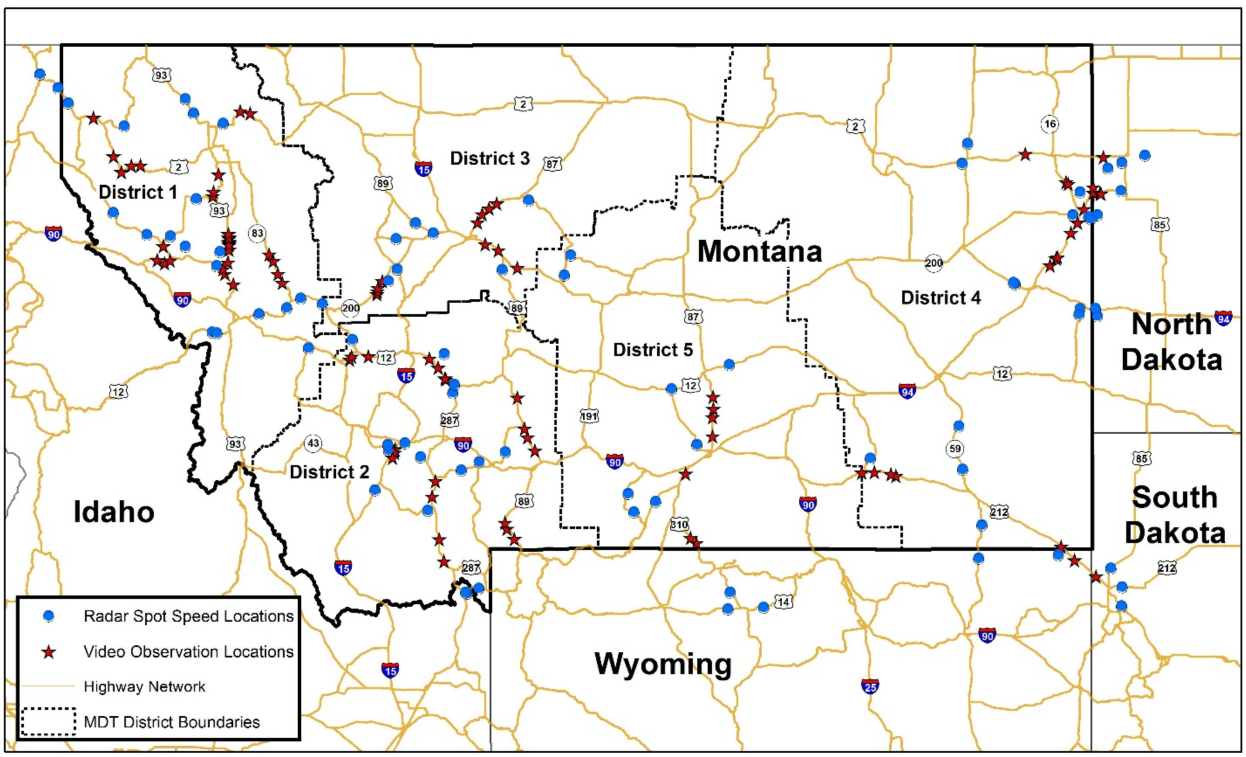


Figure 11. Map of Study Sites by Data Collection Method and MDT District/State

The videos were manually reviewed to extract relevant operational characteristics for each vehicle traveling through the site during the data collection period. An example video screenshot is shown in Figure 12. The operational characteristics included:

- Spot speed measurement (based on frame-by frame assessment of the time to traverse reference markers of a known distance);
- Vehicle classification (passenger vehicle, single unit truck, semi-truck, farm equipment);
- Headways and tailways (in seconds);
- Platoon length (number of queued vehicles per platoon); and
- Passing event data (including number of passing attempts and the estimated time gap between the passing vehicle and the nearest oncoming vehicle).

Figure 12. Example Video Screenshot

Additionally, relevant highway characteristics were collected either in the field or in the office at each data collection site for use in the subsequent analyses. Such characteristics included:

- Posted speed limit;
- Annual average daily traffic and commercial annual average daily traffic;
- Lane and shoulder widths;
- Presence of centerline or shoulder rumble strips;
- Percent no passing zones five miles upstream and downstream of the observation site; and
- Number of horizontal curves with radius less than 2,040 ft (i.e., 70 mph design speed at 6 pct. superelevation) five miles upstream and downstream of the observation site.

These site characteristics are summarized in Table 6 by MDT district or state for the 160 study locations. After the completion of video data extraction process, the operational data were aggregated into a single database and merged with the relevant site characteristics for analysis.

Table 6. Summary of Site Characteristics (Video and Radar) by District and State

District	No. of Sites	Avg. AADT	Avg. Comm. AADT	Avg. Comm. Pct.	Avg. Lane Width (ft)	Avg. Shoulder Width (ft)	Avg. Pct. No Passing Zones per 10 mi	Avg. Number of Curves per 10 mi
MDT District 1	45	2,708	255	9.4%	11.9	3.9	56.0%	1.8
MDT District 2	24	1,899	168	8.9%	11.8	3.3	43.7%	1.6
MDT District 3	28	2,229	249	11.2%	11.7	3.2	40.1%	1.1
MDT District 4	24	1,950	450	23.1%	12.0	4.4	30.6%	0.3
MDT District 5	15	1,952	212	10.8%	11.7	4.2	35.2%	0.9
Idaho	2	7,100	325	4.6%	12.0	3.5	44.2%	0.3
Wyoming	6	1,558	332	21.3%	11.8	4.5	20.1%	0.2
North Dakota	12	4,045	1,511	37.4%	11.8	3.9	28.2%	0.3
South Dakota	4	2,306	559	24.2%	12.0	5.6	10.4%	0.0
All Sites	**160**	**2,420**	**372**	**15.4%**	**11.8**	**3.9**	**40.9%**	**1.1**

EVALUATION OF FREE FLOW SPEEDS

The initial operational data assessment included an evaluation of speed selection by drivers, which was represented by the speeds of free flowing vehicles (defined as vehicles with a headway greater than 5 seconds). Free flow speed data were obtained from all 160 sites, including 136 sites in Montana, 12 sites in North Dakota, and 6 sites in Wyoming, 4 sites in South Dakota, and 2 sites in Idaho. Ultimately, speed data from 58,911 passenger vehicles and 15,895 heavy trucks (for a total of 74,806 vehicles) were analyzed. The free flow speed data were aggregated directionally by location and appropriate sample statistics (e.g., mean speed, 85^{th} percentile speed, and speed variance) were calculated. Table 6 summarizes the characteristics of the rural two-lane highway segments used in this evaluation. Raw summary statistics for the speed data are provided in Table 7 by MDT district, speed limit, and vehicle type.

Table 7. Free Flow Speed Summary Statistics by Vehicle Type, Speed Limit, and MDT District

District (Car/Truck Spd Lim)	No. Sites	PC Mean Speed (mph)	PC 85th Speed (mph)	PC Std. Dev. (mph)	SU Mean Speed (mph)	SU 85th Speed (mph)	SU Std. Dev. (mph)	TT Mean Speed (mph)	TT 85th Speed (mph)	TT Std. Dev. (mph)
MDT District 1 (70/60)	45	63.7	69.9	6.1	59.9	64.8	5.7	59.8	63.1	3.8
MDT District 2 (70/60)	24	65.1	71.9	6.5	60.1	64.9	6.1	60.4	65.0	4.7
MDT District 3 (70/60)	28	67.7	73.9	6.4	61.8	68.0	5.7	60.8	65.2	4.5
MDT District 4 (70/60)	19	67.8	74.4	6.7	63.0	67.8	5.3	61.3	64.8	4.0
MDT District 4 (65/65)	5	68.2	72.5	5.2	65.3	69.7	4.6	65.7	68.6	3.6
MDT District 5 (70/60)	15	66.8	72.5	5.8	63.2	69.0	7.2	61.7	65.1	4.0
Bordering State (65/65)	24	63.8	69.6	5.6	60.6	64.2	5.4	61.1	65.4	4.4
All Sites	**160**	**65.6**	**71.7**	**6.1**	**61.2**	**66.3**	**5.8**	**60.8**	**64.6**	**4.2**

Note: PC = Passenger Vehicles, SU = Single Unit Trucks, TT = Tractor-Trailer

Statistical Methods

As noted previously, it is important to recognize that speed limits may affect not only mean and 85th percentile free flow speeds, but also the standard deviation (and variance) of speeds, which may subsequently impact overall highway safety. Consequently, the focus of this operational evaluation was to determine the effects of speed limit policies on each of the three speed performance measures noted above. The free flow speed data were aggregated separately by direction for each of the 160 sites, thus creating 320 speed data points for use in the analysis. From there, separate ordinary least squares (OLS) regression models for mean speed, 85th percentile speed, and speed standard deviation were developed as follows:

$$ms_i = \beta_i X + \varepsilon_i \quad (1)$$

$$s85_i = \beta_i X + \varepsilon_i \quad (2)$$

$$sd_i = \beta_i X + \varepsilon_i \quad (3)$$

where: ms_i is the mean free flow speed (in mi/h) at location i;
$s85_i$ is the 85th percentile free flow speed at location i (in mi/h);
sd_i is the standard deviation of free flow speeds at location i (in mi/h);
X is a vector of speed limit, traffic, and roadway characteristics;
β's are vectors of estimable parameters; and
ε's are disturbance terms capturing unobserved characteristics.

Preliminary attempts were made to develop the models separately by vehicle type. Although the raw summary statistics showed mean and 85th percentile truck free flow speeds to be approximately 1.4 mph greater at the 65/65 mph locations compared to the 70/60 mph locations, the results for the truck-only regression models did not yield many significant or meaningful results. As a result, the models were ultimately developed using free flow speed data combined across all vehicle types. Several preliminary models were developed with consideration given to each of the site factors, although the final models only included variables that were statistically significant at a 95 percent confidence level. The following variables were included in the final models for mean and 85th percentile speed: speed limit indicator, shoulder width, percent no passing zones, horizontal curves per mile, 2-way hourly volumes, and the North Dakota indicator variable. The final speed standard deviation model included the speed limit indicator, 2-way hourly volumes, and the North Dakota indicator. Interestingly, the percentage of trucks in the traffic stream was not significant in any of the models. Table 8 provides raw summary statistics for variables included in the final regression models, along with free flow speeds by vehicle type.

Table 8. Summary Statistics for Free Flow Speed Analysis Variables

Site Characteristic	Number of Sites	Number of PV Obs.	Number of Truck Obs.	Total Obs.	Percent of Total Obs.	
Speed Limit (Car/Truck)						
Speed Limit 65/65	28	7,897	5,282	13,179	17.6%	
Speed Limit 70/60	132	51,014	10,613	61,627	82.4%	
Total	160	58,911	15,895	74,806	100.0%	
Observation State						
Idaho	2	100	8	108	0.1%	
Montana	136	54,778	12,373	67,151	89.8%	
North Dakota	12	3,050	2,840	5,890	7.9%	
South Dakota	4	446	280	726	1.0%	
Wyoming	6	537	394	931	1.2%	
Total	160	58,911	15,895	74,806	100.0%	
Site Characteristic	**Average**	**Std. Dev**	**Min**	**Max**		
Shoulder Width (ft)						
Speed Limit 65/65	4.95	2.83	0.00	9.00		
Speed Limit 70/60	3.63	2.92	0.00	11.00		
Percent No-Passing Zones						
Speed Limit 65/65	24.09%	17.40%	1.30%	77.88%		
Speed Limit 70/60	44.47%	25.12%	0.00%	100.00%		
Horizontal Curves per Mile						
Speed Limit 65/65	0.02	0.05	0.00	0.20		
Speed Limit 70/60	0.13	0.22	0.00	1.90		
	Passenger Vehicles		**Heavy Trucks**		**All Vehicles**	
Speed Characteristic	**Average**	**Std. Dev**	**Average**	**Std. Dev**	**Average**	**Std. Dev**
Mean Free Flow Speed (mph)						
Speed Limit 65/65	64.54	4.91	61.98	5.89	63.74	5.07
Speed Limit 70/60	65.79	4.14	60.56	4.59	64.93	3.92
85th Percentile Free Flow Speed (mph)						
Speed Limit 65/65	70.00	4.98	65.80	5.12	68.92	4.46
Speed Limit 70/60	72.07	4.15	64.38	4.67	71.60	4.06
Free Flow Speed Std. Deviation (mph)						
Speed Limit 65/65	5.53	1.29	4.17	1.77	5.45	1.23
Speed Limit 70/60	6.28	1.24	4.17	2.16	6.48	1.19

Results and Discussion

Table 9 provides the results of the final OLS models for free flow travel speeds. When interpreting the model results, the constant term corresponds to a uniform 65/65 speed limit. Thus, the parameter estimate (β) for the 70/60 mph speed limit indicator variable represents the difference in the response variable compared to the 65/65 mph limit. Among the state indicator variables in each of the models, only North Dakota was significantly different from the other states.

Table 9. OLS Regression Model Results for Free Flow Speed

Variable (X)	Estimate (β)	Std. Error	P-value
Mean Speed Model (R^2 = 0.274)			
Constant (S.L. 65/65)	65.271	0.741	<0.001
Speed Limit 70/60	1.558	0.677	0.022
Shoulder Width (ft)	0.426	0.088	<0.001
Percent No-Passing Zones	-3.172	0.952	0.001
Horizontal Curves per Mile	-3.989	1.046	<0.001
North Dakota Indicator	-3.182	0.933	0.001
Hourly Volume (2-way)	-0.008	0.002	<0.001
85th Percentile Speed Model (R^2 = 0.295)			
Variable (X)	**Estimate (β)**	**Std. Error**	**P-value**
Constant (S.L. 65/65)	70.728	0.745	<0.001
Speed Limit 70/60	3.237	0.681	<0.001
Shoulder Width (ft)	0.355	0.088	<0.001
Percent No-Passing Zones	-2.898	0.957	0.003
Horizontal Curves per Mile	-3.638	1.052	0.001
North Dakota Indicator	-2.170	0.938	0.021
Hourly Volume (2-way)	-0.010	0.002	<0.001
Standard Deviation Model (R^2 = 0.178)			
Variable (X)	**Estimate (β)**	**Std. Error**	**P-value**
Constant (S.L. 65/65)	5.504	0.205	<0.001
Speed Limit 70/60	1.352	0.203	<0.001
North Dakota Indicator	0.864	0.294	0.004
Hourly Volume (2-way)	-0.002	0.000	<0.001

Note: Speed limit variables represent: Passenger Vehicle Speed Limit/Truck Speed Limit

The results of the mean speed OLS model show that the mean speed of free flowing vehicles traveling on two-lane highways with a uniform 65/65 speed limit was 65.3 mph, while the mean speed of free flowing vehicles on two-lane highways with a differential 70/60 speed limit was 66.9 mph, a difference of 1.6 mph. This difference is less pronounced than differences observed on freeways in past studies [Russo et al., 2015], but is in agreement with non-freeway speed data collected elsewhere which suggested a 1.5 to 1.7 mph increase in mean speed per 5 mph increase in speed limit [Kockelman, 2006; Gates et al., 2015] Mean speeds tended to increase with increasing shoulder widths, an expected result as drivers may be more comfortable driving at higher speeds when they have greater clearance from roadside obstacles [Transportation Research Board, 2010]. Mean speeds tended to decrease with increasing percentages of no passing zones as well as increasing horizontal curves per mile, both intuitive results. These results are consistent with past studies which have generally shown that horizontal alignment is a primary factor in the observed operating speeds along two-lane highways, as drivers tend to reduce speeds when encountering horizontal curvature [Gates et al., 2015, Andjus and Maletin, 1998; Abdelwahab et al., 1998; Schurr et al., 2002]. Greater 2-way hourly volumes were associated with marginally lower mean speeds, an expected result as traffic would tend to travel slower at higher volumes and congested conditions, although it is again noted that speed data were only collected for vehicles with minimum 5-second headways.

Among the various state-specific indictors, sites in North Dakota tended to exhibit mean speeds that were 3.2 mph lower than the other states, and the other states were not statistically significantly different from each other for any of the speed measures. This finding may be due to differences in driving populations, but may also be due to varying enforcement practices and/or fine structures between the states. To further investigate the effect of speeding fines on operating speeds between Montana and the neighboring states, data for speeding related fines on two-lane rural highways were collected from each state's online legislative website and are presented in Table 10 [Montana Legislative Services, 2015; North Dakota Legislative Branch, 2015; State of South Dakota, 2013; Legislature of the State of Wyoming, 2015; State of Idaho, 2015]. It should be noted that the fines associated with speeding may vary based on the jurisdiction, type of highway, or other local traffic enforcement policies.

Table 10. Speeding Fines for Rural Two-Lane Highways by State

State	5 mph	10 mph	15 mph	20 mph	25 mph	Most Excessive Penalty
Montana	$20	$20	$70	$70	$120	$200 for 31+ mph over the limit
North Dakota	$25	$50	$75	$100	$125	$5 for each mph over the limit
South Dakota	$19	$39	$59	$79	$99	$154 for 26+ mph over the limit
Wyoming	$40	$55	$70	$85	$100	$25+$3 for each mph over the limit
Idaho	$90	$90	$90	$155	$155	$155 for 16+ mph over the limit.

Note: Fines may vary based on jurisdiction or local traffic enforcement policies.

Table 10 demonstrates that for speeding infractions of 5 mph, Montana's fines are similar to those of North Dakota and South Dakota, but substantially lower than Wyoming and Idaho, in particular. Infractions of 10 mph will result in considerably lower fines in Montana ($20) compared to each of the surrounding states, although, with the exception of Idaho, fines become more similar at infractions of 15 mph and above. Idaho maintains, by far, the highest fines across all levels of speeding infraction. Based on this speeding fine information, it is difficult to conclude what, if any, relationship speeding fines have on overall operating speeds. Ultimately, it remains unclear what factors may contribute to these state-to-state differences in operating speeds, although unobservable variations in driver behavior, terrain, and/or weather may play a role.

The results of the 85th percentile speed OLS model are generally similar to the mean speed model. The 85th percentile speed of vehicles traveling on two-lane highways with a uniform 65/65 speed limit was 70.7 mph, while the 85th percentile speed of vehicles on two-lane highways with a differential 70/60 speed limit was 73.9 mph, a difference of 3.2 mph (twice the difference of the mean speeds). The effects of percent no-passing zones, horizontal curves per mile, the North Dakota indictor, and 2-way hourly volumes on 85th percentile speed were all similar, yet slightly lower in magnitude compared to those for mean speeds.

The standard deviation OLS model showed the standard deviation of speeds on two-lane highways with a uniform 65/65 speed limit was 5.5 mph, while the standard deviation at locations with differential 70/60 speed limits was 6.8 mph, a difference 1.3 mph. This is an expected result as differential speed limits typically invoke greater speed variability between passenger vehicles and trucks. Higher 2-way hourly volumes also marginally reduced speed standard deviations.

EVALUATION OF PLATOON LENGTH AND PASSING BEHAVIOR

Beyond the analysis of driver speed selection, additional in-depth investigations were conducted on the operational data collected during this project. These evaluations focused solely on the 77 Montana sites from which video data were available, since the video recordings provided additional information on important operational characteristics such as platoon formation and passing behavior. Data were compiled separately for each travel direction, effectively doubling the number of study sites. The operational summary statistics for these 77 locations are provided in Table 11.

Table 11. Summary Statistics for Traffic Operations Data

Variable	Mean	Std. Dev.
Site Characteristics (n = 77 sites)		
Annual Average Daily Traffic (AADT), 2005-2014	2572.46	1628.83
Percent Commercial Vehicles, 2005-2014	13.15	5.30
Percent No-Passing Zones in Primary Direction	45.26	25.64
Percent No-Passing Zones in Opposing Direction	45.94	26.54
Lane Width (ft)	11.78	0.42
Shoulder Width (ft)	4.91	2.93
Grade (percent)	0.08	1.61
Site Operational Statistics		
Total Vehicles Observed	559.33	401.52
Vehicles Observed Under Free-Flow Conditions	372.89	197.31
Two-Way Equivalent Hourly Volume	225.64	138.74
Percent Trucks Observed	16.00	6.57
Mean Speed (All Vehicles)	65.03	4.31
85th Percentile Speed (All Vehicles)	71.32	4.26
Standard Deviation of Speeds (All Vehicles)	6.45	0.91
Proportion of Vehicles in Passing Position	0.02	0.02
Average Platoon Length (excluding lead vehicle)	1.61	0.37
Number of Passes Attempted	9.18	10.45
Proportion of Successful Passes (among passes attempted)	0.96	0.17
Number of High-Risk Passing Events	0.75	1.37

*Proportion of segment length with curve of specified radius range

Platoon Length

Platoon length is indicative of congestion and, as a consequence, may be reflective of locations that are subject to higher crash risk due to more frequent passing maneuvers by platooned vehicles and greater opportunity for crashes as a result. To analyze the effects of speed limit and other factors on platoon length, a multivariate linear regression model was developed using data from the 77 video data collection sites within Montana, with the results presented in Table 12. The response variable was average platoon length in terms of number of queued vehicles (exclusive of the lead vehicle), assuming a platoon was present.

Table 12. Results of Average Platoon Length Regression Model

Parameter	β	Std. Error	p-value
Constant	0.462	0.793	0.56
District 1 (Missoula)	0.285	0.088	0.001
District 2 (Butte)	0.200	0.966	0.038
LN (Two-Way Volume)	0.456	0.050	<0.001
Percent Trucks	0.017	0.006	0.008
Lane Width	-0.179	0.055	0.001
Centerline & Shoulder Rumble Strips Present	1.068	0.241	<0.001
Percent No-Passing Zones (Primary Direction)	0.008	<0.01	0.003
Percent No-Passing Zones (Opposite Direction)	-0.008	0.02	0.044
Radius < 2,640 ft*	0.297	0.134	0.027
Speed Limit of 70 mph/60 mph	1.163	0.260	<0.001
Mean Speed	-0.010	0.006	0.073

*Proportion of segment length with curve of specified radius range

These results shown that platoons tended to be longer in the more urban and mountainous portions of the state (e.g., Districts 1 and 2, respectively), as well as where traffic volumes and truck percentages were higher. The results are consistent with expectations and are largely reflective of higher levels of traffic congestion or terrain, subsequently resulting in less frequent passing opportunities. Interestingly, platoons tended to be longer at locations where centerline and shoulder rumble strips were present. This could be reflective of less aggressive passing behavior by motorists where centerline rumble strips have been installed, though this is in contrast to results of a Michigan study that showed rumble strips to have no significant impact on passing frequency. It may also be a reflection of the types of roadways where centerline rumble strips have been installed. Also consistent with expectations, platoons tended to be longer where passing opportunities were restricted, particularly along horizontal curves. Turning to the primary factor of interest, platoons were considerably longer (by 1.16 vehicles, on avg.) at sites with differential speed limits. This is an important point as speeds are likely to be more variable where differential limits are in place, an issue that is compounded as truck volumes increase. Platoons tended to be shorter where mean travel speeds were higher, which is indicative of lower congestion levels.

High-Risk Passing Behavior

In addition to examining platoon length, an additional negative binomial model (model framework described in Chapter 5) was estimated using data from the 77 Montana video sites to identify those conditions under which "high-risk" passing events tended to occur. For the purposes of this study, a passing maneuver was identified as being high-risk if it began with less than the design passing sight distance available as indicated by the AASHTO *Green Book* [AASHTO; 2011]. These types of events are a potential concern as they serve as surrogates for passing-related crashes, which tend to be more severe due to the increased likelihood of a head-on collision.

The results of this regression model are presented in Table 13, which shows the frequency of high-risk passing events to increase with traffic volumes and average platoon lengths. Both of these conditions tend to increase delay and may contribute to more aggressive passing behavior on the part of motorists. The results also show high-risk passes to occur more frequently in areas where curves with moderate radii (2640 ft. to 6600 ft.) are present, though this effect was not found where sharper curves were present. This is likely a function of two factors. First, horizontal curvature introduces sight distance issues, which may lead to drivers starting a passing maneuver before realizing there is an oncoming vehicle in the opposing direction. Secondly, curves of these radii may allow for passing whereas sharper curves tend to restrict passing opportunities through the implementation of no-passing zones. Neither speed limit nor average speed was found to have a significant effect on the frequency of high-risk passing events. However, the standard deviation of speed was found to have a large effect as a 1-mph increase in standard deviation resulted in a 54.3 percent increase in the number of these high-risk passing events. This finding suggests that locations with greater speed variability, including locations with high volumes of heavy trucks, farm equipment, or other slower moving vehicles, would experience a higher frequency of high-risk passing attempts.

Table 13. Results of High-Risk Passing Event Negative Binomial Model

Parameter	β	Std. Error	p-value	Change in High-Risk Pass Attempt Rate (pct)
Constant	-11.56	2.26	<0.001	N/A
Standard Deviation in Speeds	0.39	0.14	0.007	54.3%
LN (Directional Volume)	1.38	0.45	0.002	1.4%
2,640 ft ≤ Radius < 6,600 ft*	2.49	0.86	0.004	443.7%
Average Platoon Length	0.94	0.51	0.066	94.2%
Overdispersion Parameter	0.08	0.22	0.468	N/A

*Proportion of segment length with curve of specified radius range

CONCLUSIONS

A field study was performed to assess the differences in traffic operational characteristics between two-lane highways with 70/60 mph differential speed limits compared to those with uniform 65 mph limits. The data were collected at numerous two-lane highway locations across Montana, including numerous locations with the statutory 70/60 mph differential speed limit, in addition to the select eastern Montana roadway segments with uniform 65 mph speed limits. To provide an adequate sample of roadways with 65 mph speed limits, data were also collected on two-lane highways in the neighboring states of Idaho, North Dakota, South Dakota, and Wyoming. Consequently, the study design allowed for assessment of how travel speeds, platoon lengths, and passing behavior vary as a function of posted speed limit and other site factors, including geometry and cross-sectional features, as well as how these operational characteristics vary between states.

Ultimately, the free-flow speed model results showed that both the mean and 85th percentile travel speeds and the variability in travel speeds, as measured by the site-specific standard deviation, are generally lower at two-lane highway locations with uniform 65 mph speed limits compared to 70/60 mph differential limits. Overall, these results illustrate that statutory maximum limits play a meaningful role in affecting driver speed selection. Specifically, these results suggest that transitioning from a 70/60 mph differential speed limit to a uniform 65 mph speed limit on two-lane roadways in Montana would likely decrease the overall mean and 85^{th} percentile travel speeds, although truck speeds would be expected to increase. However, the resulting convergence of speed profiles for passenger vehicles and heavy trucks would consequently reduce the variability in travel speeds after transitioning to the uniform speed limit.

To provide further insight into the operational effects of speed limit policy, additional investigations were conducted using data for platoon length and passing behavior. The results showed that longer platoons and greater speed variability contributed to an increased occurrence of high-risk passing events. It follows that roadways with differential speed limits, particularly where high volumes of trucks or other slower moving vehicles are present, would likely experience greater platooning and subsequent high-risk passing attempts, thereby increasing the risk of passing-related crashes. Collectively, these findings provide evidence to support the anecdotal operational and safety concerns often associated with the prevailing 70/60 mph differential speed limit on rural two-lane highways in Montana.

CHAPTER 5:
CRASH DATA ANALYSIS

The purpose of this particular task was to assess the relationships between crash occurrence and various traffic and roadway factors (e.g., speed limit, geometry, cross-section) on rural two-lane highways in Montana. To accomplish this, a series of safety performance functions (SPFs) were developed based on historical data for the MDT's two-lane highway network. These SPFs were subsequently used to address the following study objectives:

- Compare the safety performance on two-lane highways in Montana with neighboring states, the *Highway Safety Manual*, and previously developed Montana models;
- Determine factors contributing to crash occurrence on Montana's two-lane highways; and
- Assess any short-term safety impacts related to changing from a 70/60 differential speed limit to a 65/65 uniform speed limit on 55 miles of select two-lane portions of MT16 and MT200 in eastern Montana.

DATA DESCRIPTION

Crash data were obtained from the MDT for all state-maintained rural two-lane highways for the period of 2005 - 2014. Additional roadway information, including traffic and cross-sectional data, were extracted from the Model Inventory of Roadway Elements (MIRE) database maintained by MDT. This included factors such as segment length, AADT, functional class, shoulder width, passing relief lanes, terrain, and MDT District. The posted speed limits and number of access points (driveways and minor roads) were collected by the researchers along each segment using aerial imagery. Horizontal curve radii and corresponding curve lengths were extracted by the research team from the Montana GIS roadway shapefile and merged with the other segment data.

The final dataset included 1,132 unique rural two-lane roadway segments totaling 4,788 centerline miles. Table 14 presents summary statistics for both the crash and volume data, as well as for the roadway characteristics. Crashes occurred at an average annual frequency of 0.52 crashes per mile, with approximately one-third of these crashes coded as animal-involved collisions. With respect to injury severity, approximately 2 percent of crashes resulted in a fatality and nearly 10 percent resulted in a severe injury.

The mean annual average daily traffic (AADT) along the study segments was 1,707 vehicles per day (veh/day), with volumes reaching a maximum of approximately 16,000 veh/day. Considering all segments in the sample, 9 percent included passing relief lanes and the density of access points (driveways and minor road intersections) averaged 3.4 per mile. Given the nature of the MIRE database, with an average segment length of more than 4 miles, many of the segments included multiple horizontal curves. Consequently, the proportion of each segment that included curves of various radii was calculated for use within the analyses.

STATISTICAL METHODOLOGY

To accomplish the study objectives, a series of safety performance functions were estimated using negative binomial (NB) regression modeling approach using the previously described crash dataset compiled for Montana's state-maintained rural two-lane highway system.

General Modeling Framework

The NB model specification estimates the probability $P(n_{it})$ of n_{it} crashes occurring on segment *i* during year *t* as [Washington et al., 2011]:

$$P\ (n_{it}) = (\frac{1/\alpha}{(1/\alpha)+\lambda_{it}})^{1/\alpha} \frac{\Gamma[(1/\alpha)+n_{it}]}{\Gamma(1/\alpha)n_{it}!} (\frac{\lambda_{it}}{(1/\alpha)+\lambda_{it}})^{nit} \quad (1)$$

The mean number of crashes on segment i in year t, λ_{it} , is a linear function of the covariates:

$$\lambda_{it} = EXP\ (\beta X_{it} + \varepsilon_{it}) \quad (2)$$

where β is the vector of estimated coefficients, X_{it} is the vector of variables associated with segment i during year t (e.g. AADT, segment length, shoulder width, etc.), and ε_{it} is the error term with the mean of one and variance of α, which is known as the overdispersion parameter. As the overdispersion parameter approaches zero, the NB distribution reduces to Poisson.

Table 14 Summary Statistics for Montana Rural Two-Lane Highway Segments included in Crash Analyses

Variable	Mean (or Proportion)	Standard Deviation
Annual Crashes	2.18	3.51
Annual Animal-Involved Crashes	0.71	1.46
Annual Non-Animal-Involved Crashes	1.46	2.62
Percent PDO Crashes*	64.61	35.89
Percent Non-Severe Injury Crashes*	23.72	31.83
Percent Severe Injury Crashes*	9.79	20.70
Percent Fatal Injury Crashes*	1.88	7.34
Segment Length (mi)	4.21	4.46
AADT	1707.30	1483.26
Percent Trucks	9.57	6.29
Major Arterial**	0.602	0.49
Minor Arterial**	0.395	0.49
Major Collector**	0.001	0.05
Access Point Density (per mile)	3.42	3.17
Passing Lane Section**	0.09	0.28
Flat Terrain**	0.33	0.47
Rolling Terrain**	0.59	0.49
Mountainous Terrain**	0.08	0.28
MDT District 1 (Missoula)**	0.20	0.40
MDT District 2 (Butte)**	0.15	0.36
MDT District 3 (Great Falls)**	0.19	0.39
MDT District 4 (Glendive)**	0.28	0.45
MDT District 5 (Billings)**	0.18	0.39
Curve Radius < 660 ft***	0.52	4.30
660 ft ≤ Curve Radius < 1,320 ft***	1.90	7.47
1,320 ft ≤ Curve Radius < 1,980 ft***	3.56	10.75
1,980 ft ≤ Curve Radius < 2,640 ft***	4.77	13.47
2,640 ft ≤ Curve Radius < 3,300 ft***	3.95	11.52
3,300 ft ≤ Curve Radius < 3,960 ft***	3.35	11.27
3,960 ft ≤ Curve Radius < 4,620 ft***	2.55	9.08
4,620 ft ≤ Curve Radius < 5,280 ft***	2.17	9.12
5,280 ft ≤ Curve Radius < 5,940 ft***	1.90	8.44
5,940 ft ≤ Curve Radius < 6,600 ft***	2.86	11.01

*For segments experiencing greater than zero crashes
**Proportion of total mileage
***Percent of segment length with curve of specified radius range

Volume-Only Models

Chapter 10 of the *Highway Safety Manual* presents a method for development of a simple NB SPF for estimation of the annual number of crashes for two-lane rural highway segments based solely on AADT and segment length [AASHTO, 2010]. This *HSM* SPF was developed using data from Minnesota and Washington and serves as the basis for the crash prediction model for two-lane highway segments in the Interactive Highway Safety Design Model (IHSDM). The base SPF for rural two-lane two-way roadways is shown in Equation 3.

$$N_{spf,i} = \mathrm{AADT}_i \times \mathrm{L}_i \times 365 \times 10^{-6} \times e^{-0.312}, \tag{3}$$

where:

- $N_{spf,i}$ = annual average crash frequency for segment *i*;
- $AADT_i$ = annual average daily traffic for segment *i*; and
- L_i = length of segment *i*.

One limitation with the base model from the *HSM* is that it is constrained such that increases in traffic volume and segment length result in increases in crashes that are directly proportional (i.e., doubling the AADT or length doubles the crash frequency). However, prior research has generally shown the effects of volume to be inelastic, with crash frequencies plateauing at higher AADT values. To account for the inelastic effects of traffic volumes, Equation 3 can be modified as shown in Equation 4, where β_1 is a parameter that reflects the average crash increase associated with a one-percent increase in volume and β_0 is a constant term, which captures the effects of unobserved factors affecting crash severity:

$$N_{spf,i} = e^{-\beta_0} \times AADT_i^{\beta_1} \times \mathrm{L}_i. \tag{4}$$

Several states have developed state-specific SPFs based on Equation 4. This includes the bordering states of Idaho and South Dakota. Thus, an initial step in the crash data analysis was to develop an SPF for Montana two-lane highways using Equation 4. Estimation of the SPF in this manner allowed for a comparison of the safety performance between Montana and other states for which SPFs have been developed based on *HSM* procedures.

Advanced Models

The AADT-only base SPF models provide a convenient basis for comparison of the general safety performance between states. However, such models do not account for additional roadway factors that have been shown to influence crash occurrence, such as horizontal curvature, lane width, shoulder width, grade, and speed limit, among other factors. The effects of such factors can be captured directly as a part of SPF development, assuming sufficient data are available. Thus, more advanced SPFs were developed using the Montana data to account for the effects of other factors in addition to AADT and segment length, including posted speed limit, functional class, shoulder width, passing relief lanes, driveway density, terrain, horizontal curve radii, and MDT District.

In addition to these measurable variables, concerns also arise with respect to temporal and spatial correlation that occurs due to unobserved factors. Since the data used for this study included crash counts over a 10-year period, there may be potential correlation between the crash frequencies on a particular segment over the study period. Moreover, additional unobserved heterogeneity is likely since there may be other factors affecting crash frequency that have not been captured in the dataset. To account for additional heterogeneity in the crash data, random effects negative binomial models were estimated. In the random effect models, the constant term is allowed to vary across years and takes the following form [Washington et al., 2011]:

$$\beta_i = \beta + \varphi_i \quad (5)$$

where φ_i is an additional term, which follows a normal distribution in the context of this study. The constant term varies across the road segments and is able to accommodate for differences in safety performance due to common, unobserved factors, including those described earlier. The random effects models developed for this study were shown to provide superior fit as compared to the standard negative binomial model with a fixed constant term, and were thus used for subsequent modeling to determine the specific factors affecting crash occurrence in Montana.

RESULTS AND DISCUSSION

Crash Occurrence in Montana Compared to Neighboring States and the HSM

Figure 13 presents the results of a simple AADT-only model for the Montana two-lane highway crash dataset. The constant term (β_o) was equal to -0.74 with a slope (β_1) of 0.95 for the AADT term. This implies a nearly elastic relationship between crashes and volume (consistent with the assumptions of the *HSM* base model). This model is illustrated graphically in Figure 13, along with the base *HSM* two-lane highway models (based on Washington and Minnesota data) and SPFs for two-lane highways in Idaho and South Dakota. While it appears as though these four models are quite distinct from one another, it is important to note that the average AADT in the study dataset was 1,707 veh/day. The Montana and Idaho SPFs are quite similar up to volumes of approximately 6,000 vehicles per day, which encompasses a majority of the two-lane highway network for both states. Both states tend to experience significantly more crashes than South

Dakota, which has significantly lower traffic volumes. The rates are also significantly higher than the *HSM* base model that was derived using data from Washington and Minnesota.

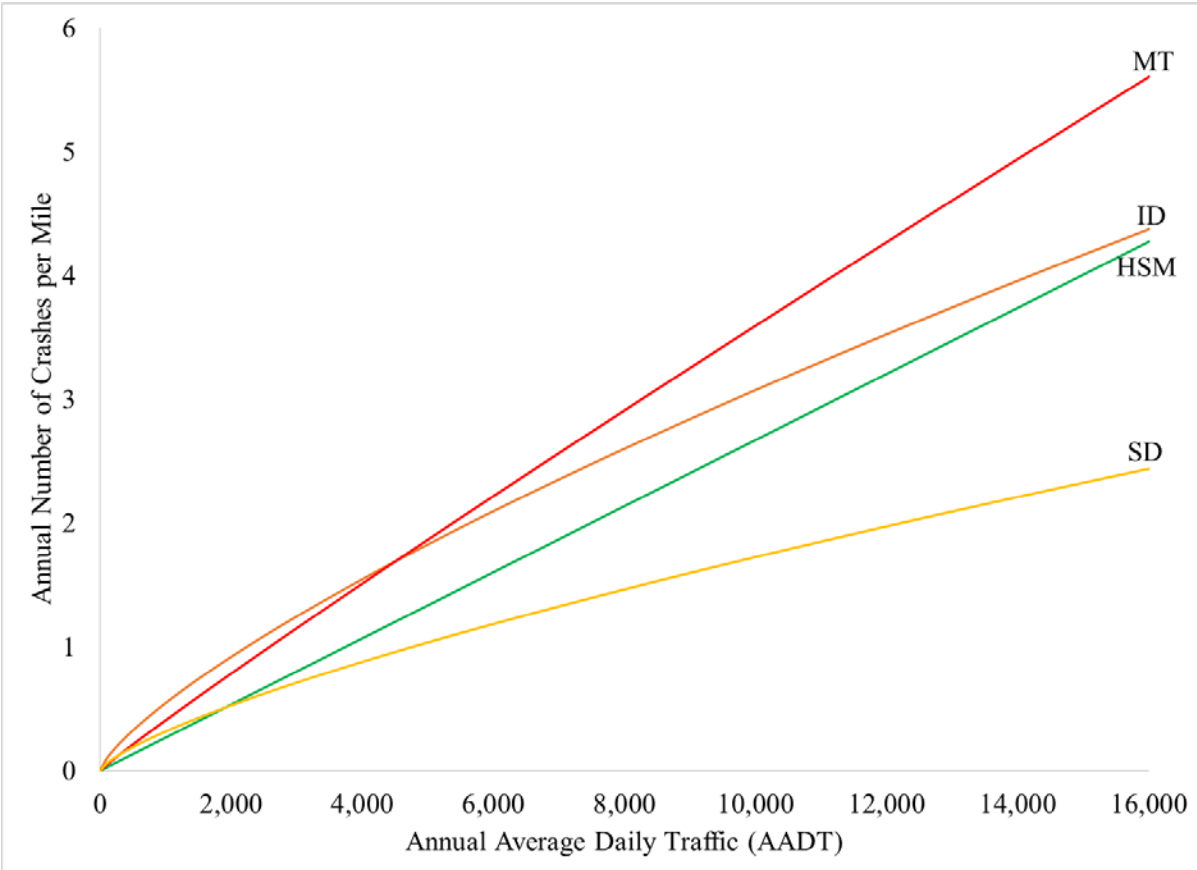


Figure 13. Comparison of Two-Lane SPFs from Montana, Idaho, South Dakota, and the HSM

Comparison to Previously Developed SPFs for Two-Lane Highways in Montana

Figure 14 provides a comparison of the Montana AADT-only SPF developed here with the Montana SPF for two-lane highways on flat or rolling terrain developed in a prior study based on crashes from 2008 - 2012 [Kononov and Allery, 2013]. The model results are quite similar, particularly for lower ranges of AADT. The average AADT in the sample used here was 1,707, and the models are nearly indistinguishable from one another within this range. Differences between the models emerge as AADT increases beyond 4,000, which is likely reflective of various factors such as slightly different samples of segments and different time periods. Nonetheless, this comparison suggests good correlation with respect to the statewide SPFs currently in use in Montana.

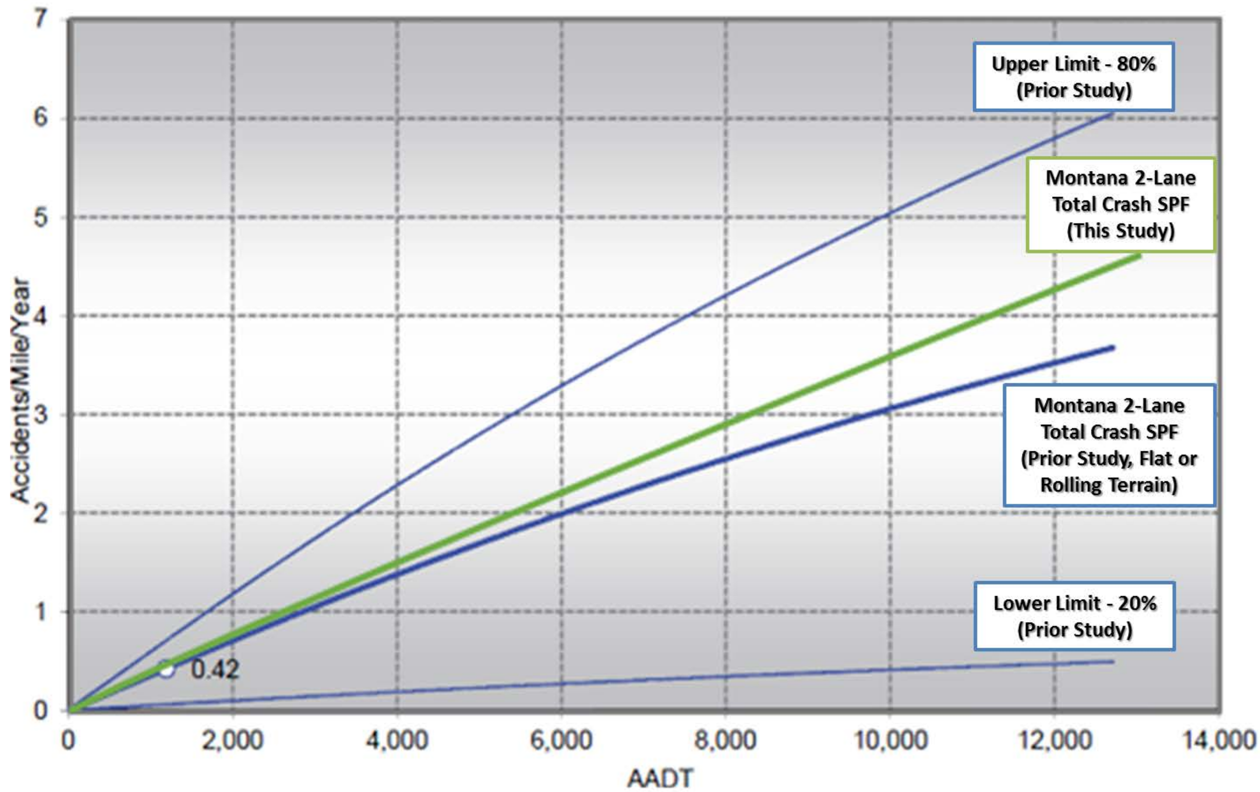


Figure 14. Comparison of Montana Two-Lane SPF with Previously Developed Montana SPF [adapted from Kononov and Allery, 2013]

Factors Affecting Crash Occurrence in Montana

The subsequent analyses of Montana-only data involved the estimation of more complex multivariate models. Since animal-involved crashes accounted for a significant proportion of the total crashes on the study segments (32.6% were animal crashes), two separate crash frequency models were developed: one for total crash frequency and one for non-animal-involved crashes. The results of the random effects negative binomial regression models are presented in Table 15, which includes the estimated coefficients, as well as the associated standard errors and p-values for each parameter. Statistically significant parameters were those with p-values less than 0.05. Goodness of fit parameters and diagnostic measures for each model are also included in Table 15.

Table15. Results of Random Effects NB Crash Frequency Models for Montana Two-Lane Rural Highways

	Total Crashes			Non-Animal Related Crashes		
Parameter	**β**	**Std. Error**	**p-value**	**β**	**Std. Error**	**p-value**
Constant	-5.292	0.106	<0.001	-6.350	0.128	<0.001
Standard Deviation	0.448	0.008	<0.001	0.426	0.009	<0.001
Ln Length	0.907	0.009	<0.001	0.891	0.011	<0.001
Ln AADT	0.664	0.013	<0.001	0.768	0.016	<0.001
Major Collector	-0.465	0.221	0.036	-0.665	0.264	0.012
Minor Arterial	-0.074	0.018	<0.001	-0.111	0.022	<0.001
Driveway Density	0.053	0.002	<0.001	0.040	0.003	<0.001
Shoulder Width	-0.034	0.004	<0.001	-0.077	0.004	<0.001
Passing Relief Lane	-0.035	0.040	0.384	-0.097	0.050	0.053
District 2 (Butte)	-0.236	0.022	<0.001	-0.160	0.027	<0.001
District 3 (Great Falls)	-0.240	0.024	<0.001	-0.189	0.030	<0.001
District 4 (Glendive)	-0.531	0.027	<0.001	-0.271	0.033	<0.001
District 5 (Billings)	-0.351	0.024	<0.001	-0.140	0.030	<0.001
Radius < 1,320 ft*	1.439	0.091	<0.001	2.087	0.105	<0.001
1,320 ft. ≤ Radius<2,640 ft.*	0.689	0.055	<0.001	0.956	0.068	<0.001
2,640 ft. ≤ Radius<6,600 ft.*	0.293	0.046	<0.001	0.308	0.055	<0.001
65 mph segment (before change)	0.452	0.046	<0.001	0.235	0.058	<0.001
65 mph segment (after change)	0.329	0.104	0.002	0.113	0.127	0.372
Overdispersion Parameter	0.056	0.005	<0.001	0.096	0.007	<0.001
Log Likelihood at Convergence	-16,400.16			-14,134.13		
Restricted Log Likelihood	-44,055.16			-29,444.00		
Chi Squared (p-value)	55,310.0 (<0.001)			30,619.7 (<0.001)		
McFadden Pseudo R-squared	0.628			0.520		

*Proportion of segment length with curve of specified radius range

As noted previously, the NB models were developed using a random effects framework to capture unobserved heterogeneity. The statistically significant standard deviation associated with the constant term is reflective of the existence of heterogeneity in the sample, which is due to inherent differences between the segments and indicates the presence of unobserved factors. In order to ascertain the magnitude of the effects of each variable included in the models, elasticities were calculated by taking the exponential of the estimated parameters in the NB models (except for length and AADT, which can be taken directly from the NB models because their natural logs were used during the modeling process). The elasticities are presented in Table

16 and represent the expected change in crash frequency if continuous variables are increased by 1 percent or if binary indicator variables are changed from 0 to 1.

Table 16. Percent Changes in Crash Frequency from Montana NB Models

Variable	Change in Total Crashes (percentage)	Change in Non Animal- Crashes (percentage)
Length	0.9%	0.9%
AADT	0.7%	0.8%
Major Collector	-37.2%	-48.6%
Minor Arterial	-7.1%	-10.5%
Driveway Density	5.4%	4.1%
Shoulder Width	-3.3%	-7.4%
Passing Relief Lane	-3.5%	-9.2%
District 2 (Butte)	-21.0%	-14.8%
District 3 (Great Falls)	-21.3%	-17.2%
District 4 (Glendive)	-41.2%	-23.7%
District 5 (Billings)	-29.6%	-13.1%
Radius < 1,320 ft*	321.6%	706.1%
1,320 ft. ≤ Radius < 2,640 ft.*	99.2%	160.1%
2,640 ft. ≤ Radius < 6,600 ft.*	34.0%	36.1%
65 mph segment (before change)	57.1%	26.5%
65 mph segment (after change)	39.0%	12.0%

*Proportion of segment length with curve of specified radius range

The results for the total crash model indicate that the exposure parameters (i.e. segment length and AADT) are significant determinants of crash frequency as expected. One-percent increases in segment length and AADT were associated with a 0.9-percent and 0.7-percent increase in total crashes, respectively. The coefficients for roadway classifications suggest that higher-class facilities (major arterials) tend to experience higher crash frequencies, most likely due to higher volumes and congestion on such facilities, in addition to differences in driver and vehicle characteristics between the various roadway classes. Higher driveway densities were also shown to be associated with higher crash frequencies, which is likely caused by the increase in conflict points for vehicles entering or exiting driveways. Additionally, the results show that wider shoulders would enhance the safety of two-lane highways, likely due to the greater recovery area afforded during lane departure events.

All of the MDT district variables were shown to have significant impacts on crash frequency. The reference category is District 1 (Missoula) meaning that all other districts are compared to District 1, which is the most populous district in Montana. Consequently, the negative coefficients for the district variables suggest that two-lane highway crash occurrence is highest in District 1, likely a consequent of greater traffic volumes and congestion levels experienced within this district. Additionally, District 4 (Glendive) in eastern Montana, which is the most rural and the least populated district, has the most negative coefficient, indicating two-lane highways in this district tend to experience the lowest crash frequencies. The effects associated with the district variables may also be reflective of particular driving behaviors or terrain characteristics associated with different regions of the state. The coefficients estimated for different proportions of curve radii indicate that horizontal alignment plays a significant role in roadway safety. Segments with higher proportions of sharper curves along the segment are associated with higher crash frequencies. This is likely due to sight distance restrictions on curves with smaller radii, as well as higher propensity for drivers to lose control while navigating sharp curves. The elasticities for the sharpest curve variable (percent of segment with curve radius less than 1,320 ft) are quite high, especially for non-animal-related crashes. However, it should be noted that the values in Table 16 represent the expected change if 100% of a segment consisted of curves with radii within the stated range. The actual percent change in crashes would be obtained by multiplying the values in Table 16 by the proportional length of the segment that contains curves of radii within the stated range.

The effects of the previously discussed variables were generally similar for non-animal- involved crashes as compared to total crashes. Most of these variables showed effects that were in the same direction (i.e. increasing or decreasing crash frequency), though the magnitude varied substantially in some cases. For example, the effects of geometric variables such as horizontal curvature and shoulder width were more pronounced (i.e., of a greater magnitude). This is likely reflective of animal-involved crashes being unavoidable in many circumstances whereas crashes due to driver error may be more frequent under adverse settings such as sharp curves and narrow shoulders.

While most of these effects were similar between the non-animal crashes and total crashes, two notable exceptions were observed. Passing relief lanes were not shown to have a significant effect for total crashes. However, when removing animal-involved crashes, passing relief lanes were shown to result in a 9.2 percent decrease in crashes on average. More importantly with respect to the primary objectives of this study, the effects of speed limit were found to vary significantly between the total and non-animal crash models. The results for the total crash model indicate that the segments where the speed limits were changed experienced higher crashes during both the pre-change (DSL) and post-change (USL) periods compared to the segments that maintained a consistent differential (70 mph/60 mph) limit. However, crash occurrence was reduced after implementation of the uniform speed limit on the study segments, although crash occurrence remained higher than the comparison sections. The results were more substantial after eliminating animal-involved crashes, as implementation of the USL reduced non-animal crashes to the point where crash occurrence was not significantly different between the segments with differential and uniform limits during the post-implementation period.

CONCLUSIONS

The purpose of this study was to examine the relationships between crash occurrence and various traffic and roadway factors (e.g., speed limit, geometry, cross-section) on rural two-lane highways in Montana. To accomplish this, a series of safety performance functions were developed using historical crash data from 2005 - 2014. Initial SPF s were developed for Montana's two-lane rural highway network using AADT as the sole independent variable, thereby allowing for comparison to the default model from the *HSM*, as well as similar models for Idaho and South Dakota. Within the typical range of traffic volumes, two-lane roadways in Montana were found to experience similar crash occurrence compared to Idaho. However, both states tend to experience significantly greater two-lane roadway crash occurrence than South Dakota, as well as in comparison to the base two-lane rural roadway model from the *HSM*. Montana was the only of these states with widespread use of both 70-mph maximum speed limits and differential limits on two-lane highways, which may have contributed to the comparatively higher crash occurrence rates. Furthermore, the AADT-only SPFs also compared favorably with those currently utilized by MDT for two-lane highways with level or rolling terrain [Kononov and Allery, 2013].

Subsequent analyses involved the estimation of multivariate models to assess factors that may contribute to the higher rates of crash occurrence. Random effects negative binomial models were estimated for both total and non-animal-involved crashes using the Montana crash data. The random effects models were shown to provide significantly improved fit, an indication of strong temporal correlation in crash counts on the same segments over time due to common, unobserved factors. Failure to account for such correlation tended to either over- or under-estimate the effects of several factors, including speed limits and passing relief lanes. Animal-involved crashes comprised almost one-third of all crashes and the effects of such crashes were particularly pronounced on several segments.

The random effects models also allowed for a preliminary assessment of the recent change from a differential speed limit (70 mph for passenger cars, 60 mph for trucks) to a uniform speed limit (65 mph for all vehicles) that occurred along 55 miles of MT-16 and MT-200 in eastern Montana in April 2013. When considering all crashes, these 55 miles tended to experience significantly more crashes than the other comparable segments prior to the speed limit change (i.e., when the 70/60 mph limit was in place). Although crash occurrence was reduced after the uniform 65 mph speed limit went into effect on these segments, crash occurrence remained greater than on the comparison sections on which differential limits were maintained. However, after eliminating animal-involved crashes, it was found that implementation of the 65 mph limit reduced non-animal crashes to the point where crash occurrence was not significantly different between the segments with differential and uniform limits during the post-implementation period. It should be noted that only 21 months of data were available after the uniform speed limit went into effect. Thus, these results should be considered preliminary and further analysis is necessary once additional crash data become available.

Beyond speed limits, a variety of additional factors were found to be associated with crash occurrence. Crashes tended to increase with driveway density, horizontal curvature, and on highways of higher functional class, as well as on segments located in District 1 (Missoula), which includes the most urbanized areas of the state. In contrast, fewer crashes were experienced on segments with wider shoulders or where passing relief lanes were in place.

The results of these crash analyses provide important insights into those factors that are associated with the safety of high-speed, rural two-lane highways. The evaluation also demonstrated several important methodological concerns associated with SPF development.

While data for the post-USL implementation period in Montana are limited, the findings of this study provide some indication that use of the 65 mph USL on two-lane highways may provide safety benefits over the 70/60 mph DSL, although additional evaluation is recommended once additional data are available.

CHAPTER 6:
ROAD USER SURVEY

Changes to Montana's two-lane highway speed limit policy would have a significant impact on road users. Consequently, a series of road user surveys were performed to assess the preferences and opinions regarding speed limit policies among motorists and truck drivers in Montana. The surveys were performed at a statewide sample of 10 Montana DOT rest areas and weigh stations. The interview-style survey was administered to drivers and adult passengers of passenger vehicles and heavy commercial trucks during a 10-day period in mid-August of 2014. The survey locations, displayed in Figure 15, were selected to provide statewide representation across Montana, while also ensuring an adequate number of responses. To capture responses from both motorists and truck drivers, the survey questionnaires were administered at the rest area and adjacent weigh station at five of the 10 locations, while three of the locations included only rest areas and the remaining two included only weigh stations. Seven of the locations were located on non-freeway highways while remaining three locations were located on interstate freeways.

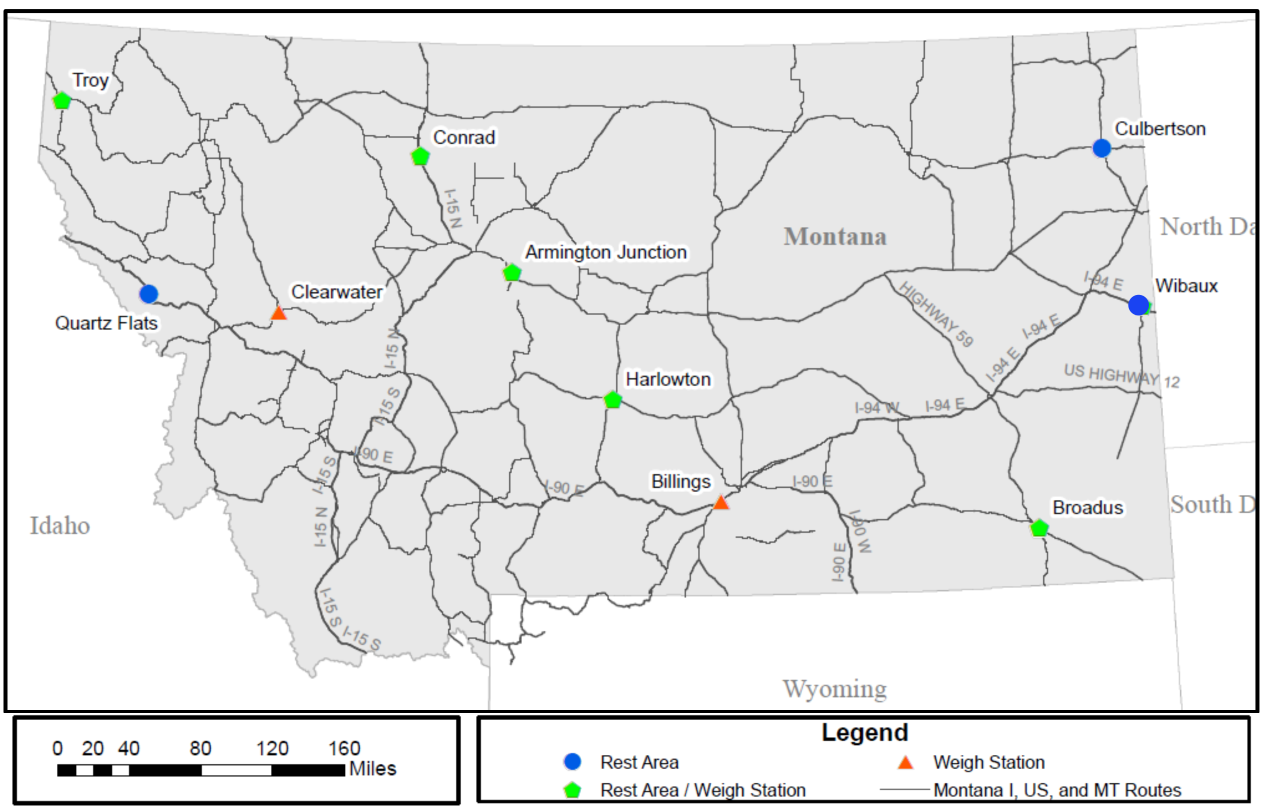


Figure 15. Road User Survey Locations

SURVEY OBJECTIVES AND QUESTIONNAIRE

The survey questionnaire sought information pertaining to the preferences of motorists regarding Montana speed limits, travel speeds, and general driving behavior. The survey included several demographic related questions, in addition to speed and travel related survey questions. The questions are paraphrased as follows, with the full questionnaire form provided in the Appendix.

- Demographic Information: age, gender, ethnicity, home zip code, primary mode of transportation, employment status, annual miles driven per year, and job-related driving;
- Frequency of driving on two-lane rural highways;
- Familiarity with Montana's differential speed limits and perceived safety effects of differential vs. uniform speed limits;
- Preference for the following speed limit alternatives (car/truck) on two-lane highways in Montana: 70/60 (current), 65/65, 70/65, 70/70, or other;
- Typical travel speeds and frequency of passing attempts on two-lane highways in Montana; and
- Questions for truck drivers only:
    - Would your travel speed increase if the truck speed limit is increased?
    - Use of speed limiters/governors.
    - Would the governed limit increase if the truck speed limit is increased?

A total of 586 road user surveys were obtained; 344 from passenger vehicle occupants and 242 from truck drivers. A summary of the survey data collection is provided in Table 17.

Table 17. Road User Survey Data Collection Summary

					Number of Completed Surveys		
Location	**MDT District**	**Location Type***	**Roadway Type**	**Day of Week**	**Passenger Vehicle Occupants**	**Truck Drivers**	**TOTAL**
Culbertson	4	RA	Non-Freeway	Mon	36	7	43
Wibaux	4	RA	Non-Freeway	Tues	42	11	53
Broadus	4	RA/WS	Non-Freeway	Wed	49	21	70
Billings	5	WS	Freeway	Thurs	1	32	33
Harlowton	5	RA/WS	Non-Freeway	Fri	20	38	58
Armington Jct.	3	RA/WS	Non-Freeway	Mon	66	7	73
Conrad	3	RA/WS	Freeway	Tues	30	48	78
Troy	1	RA/WS	Non-Freeway	Wed	13	26	39
Quartz Flats	1	RA	Freeway	Thurs	85	10	95
Clearwater	1	WS	Non-Freeway	Fri	2	42	44
ALL					**344**	**242**	**586**

*RA = Rest Area; WS = Weigh Station

RESULTS AND DISCUSSION

Demographic Characteristics

The survey respondents tended to be older, with the median age falling between 51 and 60, and one-third over age 60. Two-thirds of respondents resided outside of Montana, nearly three-quarters were male, and 88 percent were white. Nearly 60 percent indicated a passenger vehicle as primary daily mode of transportation, with the remainder indicating a heavy truck. Approximately 70 percent of respondents were employed, 25 percent were retired, and 5 percent were either a student or unemployed. Table 18 summarizes the demographic responses.

Table 18. Demographic Summary

Question	Category	Frequency	Percent
Home state	Montana	192	33%
	Elsewhere	394	67%
Question	**Category**	**Frequency**	**Percent**
Primary mode of transportation	Passenger Vehicle	344	59%
	Heavy Truck	242	41%
Question	**Category**	**Frequency**	**Percent**
Miles traveled per year	<16,000	288	49%
	>16,000	298	51%
Question	**Category**	**Frequency**	**Percent**
Age	<=30 years	73	13%
	31-60 years	316	54%
	>60 years	194	33%
Question	**Category**	**Frequency**	**Percent**
Gender	Male	432	75%
	Female	145	25%
Question	**Category**	**Frequency**	**Percent**
Ethnicity	White	510	87%
	Other	76	13%
Question	**Category**	**Frequency**	**Percent**
Job status	Employed	405	70%
	Retired/Other	176	30%

Speed Limit Policy Preference

Perhaps the most important objective of this survey was to identify the specific car/truck speed limit policy preferred by road users on two-lane highways in Montana. Respondents were asked to identify the preferred speed limit alternative (car/trucks) for Montana two-lane highways from the following list: 70/60 mph (current), 70/65 mph, 65/65 mph, 70/70 mph, or other. Nearly all of the 586 survey respondents provided a response to this question. Overall, there was a relatively even split between preference for uniform (65/65 or 70/70) and differential (70/60 or 70/65) speed limit policies. Uniform policies garnered 50.2 percent of the response, while differential policies comprised 44.5 percent. Further evaluation of speed limit preference by vehicle type, state of residence, age, gender and ethnicity showed several interesting findings, as shown in Table 19.

Table 19. Two-Lane Roadway Speed Limit Preference by Demographic Characteristic

Car/Truck Speed Limit →	Percent Indicating Preference				
Vehicle Type	**70/60 (current)**	**70/65**	**65/65**	**70/70**	**Other**
Passenger Vehicle Occupant	39.1%	17.7%	20.8%	15.6%	6.8%
Truck Driver	13.8%	14.2%	48.3%	20.4%	3.3%
State of Residency	**70/60 (current)**	**70/65**	**65/65**	**70/70**	**Other**
Montana	25.3%	18.9%	28.9%	22.1%	4.8%
Out of State	29.7%	14.9%	34.1%	15.6%	5.7%
Age	**70/60 (current)**	**70/65**	**65/65**	**70/70**	**Other**
<=30	32.9%	31.5%	9.6%	21.9%	4.1%
31-60	24.4%	16.0%	34.3%	19.2%	6.1%
>60	32.8%	10.9%	38.0%	13.5%	4.8%
Gender	**70/60 (current)**	**70/65**	**65/65**	**70/70**	**Other**
Female	38.7%	16.7%	24.7%	13.3%	6.6%
Male	24.7%	16.0%	35.1%	19.3%	4.9%
Ethnicity	**70/60 (current)**	**70/65**	**65/65**	**70/70**	**Other**
White	27.9%	13.7%	34.5%	18.4%	5.5%
Other	30.7%	33.3%	18.7%	13.3%	4.0%
OVERALL	28.3%	16.2%	32.4%	17.8%	5.3%

Table 19 displays several interesting findings. First, large differences in speed limit policy preference exist between passenger vehicle occupants and truck drivers. Preference for differential speed limit policies was much stronger among passenger vehicles occupants (56.8%), while truck drivers generally supported uniform speed limit policies (68.7%). This is consistent with the findings from a subsequent survey of registered motor carriers in Montana (see Chapter 7), which found 78.8 percent of respondents to favor a uniform speed limit alternative. Among passenger vehicle occupants, the most commonly preferred speed limit was 70/60 mph (39.1%), while the most commonly preferred speed limit among truck drivers was 65/65 mph (48.3%). Truck drivers showed little support for the current 70/60 mph limit. To examine the impacts of vehicle type in greater detail, the responses were further subdivided by state of residency as shown in Table 20 and Figure 16.

Table 20. Two-Lane Roadway Speed Limit Preference by Vehicle Type and Residency

		Percent Indicating Preference				
Vehicle Type	**Residency**	**70/60 (current)**	**70/65**	**65/65**	**70/70**	**Other**
Passenger Vehicle Occupant	Montana	35.8%	23.9%	11.9%	22.9%	5.5%
	Elsewhere	40.8%	14.7%	25.2%	11.9%	7.4%

Truck Driver	Montana	11.3%	12.5%	52.5%	20.0%	3.7%
	Elsewhere	15.0%	15.0%	46.3%	20.6%	3.1%

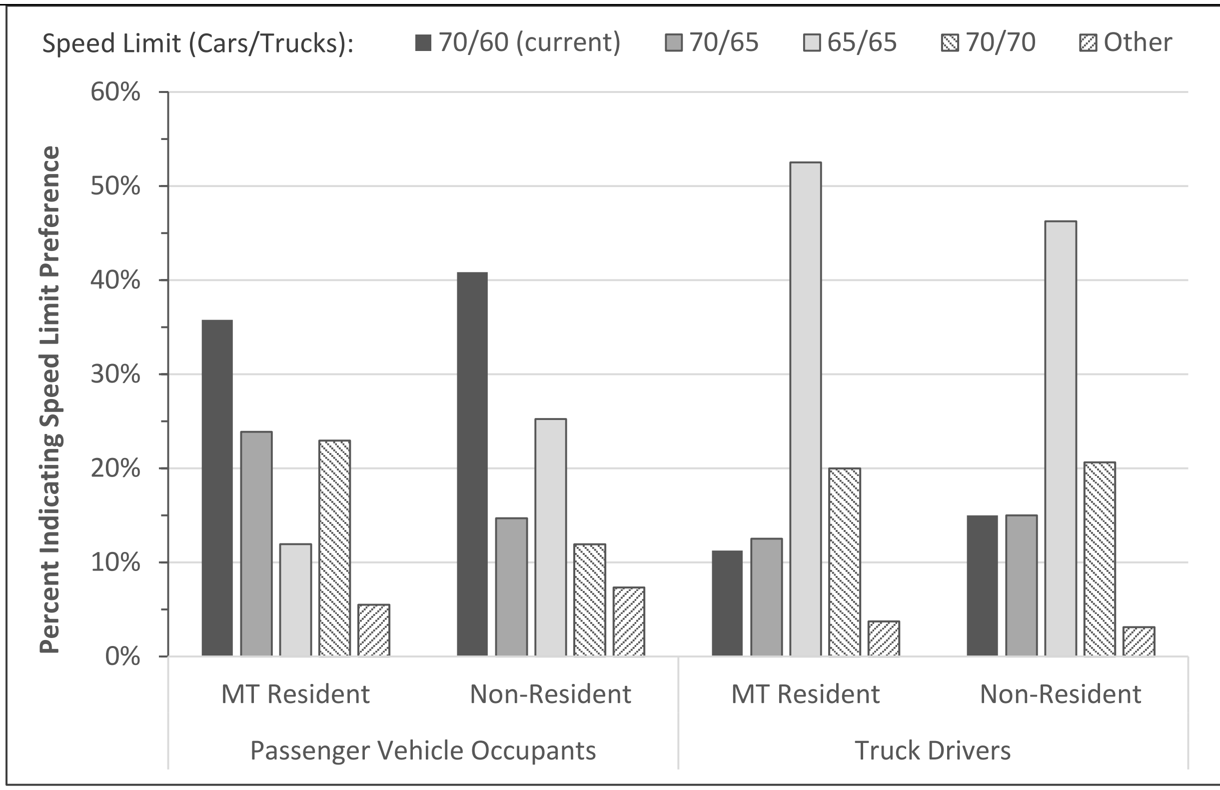


Figure 16. Two-Lane Roadway Speed Limit Preference by Vehicle Type and Residency

Surprisingly, in-state truck drivers were more likely to support 65/65 mph speed limits than truck drivers from out of state, where such speed limits are more common on two-lane highways. However, out of state motorists in passenger vehicles were much more likely to support 65/65 speed limits than their counterparts from Montana. Interestingly, out of state respondents were also more likely to support the current 70/60 mph limit than respondents from Montana regardless of vehicle type. Nearly all Montana residents surveyed were aware of the state's differential speed limit policy for two-lane roads, although only 77 percent of non-residents in passenger vehicles and 93 percent of non-resident truck drivers were aware of the differential speed limit policy.

Referring back to Table 19, age was also an important factor in speed limit preference. Support for the current 70/60 mph speed limit was relatively consistent among age groups. However, younger respondents showed very little support (9.6%) for 65/65 mph limits, instead favoring policy alternatives that included a 70 mph limit for passenger vehicles (86.3%). Respondents over the age of 30 were much more likely to support uniform speed limits than their younger counterparts, with 65/65 mph limits being the most popular choice, although support for the current limit was also strong. Respondents over age 60 were generally more likely to prefer lower limits.

Highway Safety Perceptions Associated with Speed Limit Policies

Responses to the question related to perceived safety benefits associated with differential or uniform speed limit policies are displayed in Table 21.

Table 21. Perceived Safety Benefits by Speed Limit Policy and Vehicle Type

		Percent Indicating Preference		
Vehicle Type	**Residency**	**Differential Safer**	**Uniform Safer**	**Unsure/No Response**
Passenger Vehicle Occupant	Montana	40.5%	36.9%	22.5%
	Elsewhere	47.9%	21.9%	30.1%
	All	45.5%	27.0%	27.6%
Truck Driver	Montana	16.5%	73.4%	10.1%
	Elsewhere	24.8%	62.1%	13.0%
	All	22.1%	65.8%	12.1%

Not surprisingly, when asked whether different speed limits for cars and trucks improved safety compared to uniform speed limits, responses were vastly different between passenger vehicle occupants and truck drivers. While 45.5 percent of passenger vehicle occupants felt that differential speed limits improved safety, 65.8 percent of truck drivers felt that uniform speed limits were safer. Interestingly, Montana residents were more likely to believe uniform limits improve safety. While these opinions do not necessarily relate to actual crash and injury data, they may be somewhat reflective of motorist behavior, which is described in the following subsection.

Potential Impacts of Speed Limit Policy on Passing Frequency

Responses related to the frequency of passing slower moving vehicles are provided in Table 22 as a function of the difference in travel speed and the type of vehicle being passed.

Table 22. Reported Passing Frequency by Speed Differential and Type of Vehicle Overtaken

Question	Category	Type of Vehicle being Passed: Passenger Vehicle	Truck
How frequently do you pass slower moving passenger vehicles or heavy trucks on two-lane highways when the vehicle is traveling **5 mph** less than you?	Frequently	31.7%	32.1%
	Occasionally	41.6%	34.4%
	Rarely	22.1%	24.8%
	Never	4.7%	8.7%
Question	**Category**	**Passenger Vehicle**	**Truck**
How frequently do you pass slower moving passenger vehicles or heavy trucks on two-lane highways when the vehicle is traveling **10 mph** less than you?	Frequently	58.8%	54.1%
	Occasionally	33.1%	29.1%
	Rarely	6.1%	12.6%
	Never	2.0%	4.2%

Respondents reported much less frequent overtaking of vehicles traveling 5 mph slower (31.9% of respondents reported frequent passing) compared to 10 mph slower (56.5% of respondents reported frequent passing). The responses were similar regardless of whether a passenger vehicle or heavy truck was the vehicle being overtaken. Thus, it appears that uniform speed limits may reduce passing frequency, assuming that variability in vehicle travel speeds is also reduced.

Potential Impacts of Speed Limit Policy on Truck Travel Speeds and Governed Limits

The final two questions on the survey questionnaire form were specifically related to the impacts associated with increasing the truck speed limit on two-lane roadways. Only truck drivers were asked to respond, with the answers summarized in Table 23.

Table 23. Potential Impact of Truck Speed Limit on Travel Speeds and Governed Limits

Question	Category	Montana Resident	Non-Resident
(Truck Drivers Only) Would you travel at a higher speed if the truck speed limit is increased from 60 to 70 mph on two-lane highways?	No	37.8%	40.3%
	Yes, 1-5 mph faster	36.5%	46.1%
	Yes, 6-10 mph faster	23.0%	13.6%
	Yes, >10 mph faster	2.7%	0.0%
Question	**Category**	**Montana Resident**	**Non-Resident**
(Truck Drivers Only) Will your vehicle's governed speed be increased if the speed limit is increased?	Yes	11.0%	10.9%
	No	27.4%	42.3%
	Not sure	21.9%	13.9%
	Governors not used	39.7%	32.8%

Greater than 60 percent of truck drivers noted that their travel speeds would increase if the speed limit was increased from 60 to 70 mph on two-lane rural highways. Truck drivers residing in Montana are more likely to increase travel speeds than out of state drivers, as 25.7 percent of resident drivers noted travel speed increases greater than 5 mph, compared to only 13.6 percent of non-residents. This response was not surprising, since resident truck drivers were also less likely to utilize speed governors, which were noted as being utilized by 60.3 percent and 67.2 percent of the resident and non-resident truck drivers, respectively. Non-resident truck drivers were also more likely to indicate that the governed limit will not be increased in response to an increase in the truck speed limit. This is likely a result of frequent travel outside of Montana where higher truck limits are common.

CHAPTER 7:
TRUCKING INDUSTRY SURVEY

Changes to Montana's differential speed limit policy on two-lane highways would likely have a significant impact on the trucking industry. Consequently, it was necessary to gain additional insight from members of the Montana trucking industry in order to assess how such changes would ultimately influence driver behavior, fleet operations, perceived economic benefits (or disbenefits), and safety. An online survey was developed and distributed via email link to more than 7,800 unique email addresses of motor carriers registered to operate in Montana in mid-March of 2015. These email addresses were obtained from the official motor carrier registration lists maintained by Montana Department of Transportation's Motor Carrier Services Division. To provide for a more robust analysis, the surveys were emailed and tracked separately based on the registration classification, which included the following (the number of unique registrations, number of emails sent, and number of responses are provided in parentheses):

- Montana Address – Intrastate Only (4,437 registrations, 1,716 emails sent, 67 responses);
- Montana Address – Interstate (5,185 registrations, 2,780 emails sent, 171 responses);
- Other State Address (3,064 registrations, 3,064 emails sent, 95 responses); and
- Canadian Address (317 registrations, 317 emails sent, 20 responses).

Responses were collected for a 12-day period, after which the survey data were downloaded and prepared for analysis. A total of 353 responses were received, representing 2.7 percent of all motor carrier registrations and 4.5 percent of all emails sent. Survey response rates across the various registration categories ranged from 3.1 percent of out-of-state registrations to 6.3 percent of Canada-based registrations. Due to the small sample (20) of responses received from Canadian agencies, these responses were merged with those from respondents in states other than Montana.

SURVEY OBJECTIVES AND QUESTIONNAIRE

The primary objectives of this survey were to assess preferences and opinions regarding current and alternative speed limit policies, including perceptions of safety and economic impacts, and how speed limit policy changes would ultimately influence fleet operations. Several fleet related demographic questions were included in the first portion of the survey, which were followed by the speed related survey questions. The questions included in the survey are paraphrased as follows, with the full survey questionnaire form provided in the Appendix.

- Fleet Information: company name; state/province of registration; contact information; number of trucks in fleet that operate in Montana, by vehicle class; industry(ies) that the fleet serves within Montana; region(s) within Montana where the fleet typically operates; annual miles traveled within Montana.
- Typical fleet travel speeds on two-lane highways in Montana posted at the current speed limit of 60 mph and assuming hypothetical increases to 65 mph or 70 mph.
- Percentage of fleet that is speed limited/governed, along with the governed limit when traveling on two-lane highways in Montana posted at the current limit of 60 mph and assuming hypothetical increases to 65 mph or 70 mph.
- Preference for uniform vs. differential limits on interstate freeways and two-lane highways.
- Order of preference for the following speed limit alternatives (car/truck) on two-lane highways in Montana: 70/60 (current), 65/60, 65/65, 70/65, and 70/70.
- Expected impacts (positive and negative) associated with increasing the truck speed limit on two-lane highways in Montana.
- Comparison of economic benefits vs. operating costs associated with increasing speed limits to 65 mph or 70 mph on two-lane highways in Montana.

RESULTS AND DISCUSSION

Table 24 summarizes the survey responses. It should be noted that all respondents indicated that their fleets travel on rural two-lane highways in Montana.

Fleet Characteristics

The majority (48 percent) of the survey responses were received from registered interstate haulers with Montana addresses. Registered interstate haulers with out-of-state addresses made up 33 percent of the responses, while intrastate operators made up 19 percent of the responses. Responses were relatively evenly split between regions, with 54 percent of respondents operating in eastern Montana (east of Billings), 53 percent in central Montana (between I-15 and Billings), and 46 in western Montana (west of I-15). Agriculture was the most represented industry serviced garnering responses from 38 percent of respondents, followed by freight haulers (31 percent), construction (29 percent), mining (19 percent), and manufacturing (16 percent). Note that many respondents indicated serving more than one industry.

Table 24. Summary of Trucking Industry Survey Responses

Question	Category	Frequency	Percent
Fleet registration status with Montana DOT	Montana Address - Intrastate Only	67	19%
	Montana Address – Interstate	171	48%
	Out-of-State Address	115	33%
Question	**Category**	**Frequency**	**Percent**
Region(s) of operation within Montana (multiple selections allowed)	Western Montana (west of I-15)	162	46%
	Central Montana (I-15 to Billings)	190	54%
	Eastern Montana (east of Billings)	188	53%
Question	**Category**	**Frequency**	**Percent**
Type of industry serviced (multiple selections allowed)	Agriculture	135	38%
	Mining	68	19%
	Construction	103	29%
	Manufacturing	58	16%
	Freight	108	31%
	Government	22	6%
	Timber	13	4%
Question	**Category**	**Frequency**	**Percent**
Approximate number of vehicles in fleet, by type	Medium Duty Pickup	423	10%
	Single Unit Truck (2-axle, 6 tire)	232	6%
	Single Unit Truck (3 or more-axles)	418	10%
	Number of Tractor-Trailers (single)	2311	57%
	Number of Tractor-Trailers (multi)	561	14%
Question	**10th %-tile**	**50th %-tile**	**90th %-tile**
Number of trucks in fleet	1	3	25
Question	**10th %-tile**	**50th %-tile**	**90th %-tile**
Annual fleet vehicle-miles of travel in Montana	3,000	25,000	350,000
Question	**Category**	**Median mph**	**85th %-tile mph**
At what speed does/would your fleet typically travel on 2--lane highways in Montana?	Speed Limit = 60 mph (Current)	60	65
	Speed Limit = 65 mph	65	67
	Speed Limit = 70 mph	68	70
Question			**Percent**
Percent of respondents using governors/limiters			49%
Question	**Category**	**Median mph**	**85th %-tile mph**
At what speed are/would trucks in your fleet be governed when traveling on 2-lane highways in Montana?	Speed Limit = 60 mph (Current)	60	70
	Speed Limit = 65 mph	65	70
	Speed Limit = 70 mph	69	72
Question	**Category**	**Frequency**	**Percent**
For INTERSTATE FREEWAYS, do you favor a uniform speed limit for cars and trucks or a differential (i.e., lower) limit for trucks compared to cars?	Uniform	197	72%
	Differential	46	17%
	No Preference/Unsure	30	11%
Question	**Category**	**Frequency**	**Percent**
For 2-LANE HIGHWAYS, do you favor a uniform speed limit for cars and trucks or a differential (i.e., lower) limit for trucks compared to cars?	Uniform	226	83%
	Differential	39	14%
	No Preference/Unsure	8	3%
Question	**Category**	**Frequency**	**Percent**
Considering 2-LANE HIGHWAYS in Montana, please indicate your most preferred speed limit policy alternative (car/truck):	Speed Limit = 65 / 65 mph	110	40%
	Speed Limit = 70 / 70 mph	105	39%
	Speed Limit = 70 / 65 mph	24	9%
	Speed Limit = 65 / 60 mph	15	5%
	Speed Limit = 70 / 60 mph (Current)	19	7%

Fleet sizes ranged from 1 truck (10th percentile) to 25 trucks (90th percentile), with a median of 3 trucks. Tractor-trailers made up the majority of the overall fleet (71 percent) with single unit trucks and medium duty trucks constituting 16 percent and 10 percent, respectively. Not surprisingly, registered interstate carriers were more likely to use tractor trailers in their fleets compared to intrastate-only carriers (79 percent vs. 58 percent). As expected, fleet size was dependent on registration, as larger fleets were more often reported by carriers with out-of-state addresses. Annual vehicle miles traveled (VMT) in Montana for each fleet ranged from 3,000 (10th percentile) to 350,000 (90th percentile), with a median of 25,000 annual miles of travel. Also as expected, carriers with Montana addresses generally hauled more miles within Montana than carriers with out-of-state addresses. These results are reflected in Table 25.

Table 25. Fleet Size and Annual VMT by Carrier Registration

Registration	Number of Responses	% with Tractor Trailers	Number of Trucks in Fleet			Annual VMT in Montana		
			10th%	50th%	90th%	10th%	50th%	90th%
Montana - Intrastate Only	67	58%	1	2	20	1,940	32,500	374,000
Montana - Interstate	171	78%	1	3	19	8,250	32,240	352,000
Out of State Address	115	80%	1	4	33	1,061	11,000	372,000

Fleet Travel Speeds and Governed Limits

The median and 85th percentile responses for travel speeds and governed limits on Montana's two-lane highways are displayed graphically in Figure 17 as a function of truck speed limit policy. The median and 85th percentile travel speeds for fleets operating on Montana's two-lane highways with posted limits of 60 mph were 60 mph and 65 mph, respectively. Not surprisingly, the posted speed limit had a greater impact on the median reported speeds than the 85th percentile reported speeds. When asked to report the expected fleet travel speed if the truck speed limit was increased to 65 mph or 70 mph, the median responses increased to 65 and 68 mph, respectively, while the 85th percentile responses increased to 67 and 70 mph, respectively.

Speed governors/limiters were noted as being used on the fleets of 49 percent of the responding carriers. Fleets registered in Montana (intra- and interstate) were less likely (46 percent of responses) to utilize speed governors than fleets registered out of state (56 percent of responses). The median and 85th percentile governed limits for fleets operating on Montana's two-lane highways with posted limits of 60 mph were 60 mph and 70 mph, respectively. While the median governed limit increased to 65 mph at speed limits of 65 mph, not surprisingly, the 85th percentile governed limit remained at 70 mph. For speed limits of 70 mph, the median governed limit increased to 69 mph, while the 85th percentile governed limit increased to 72 mph.

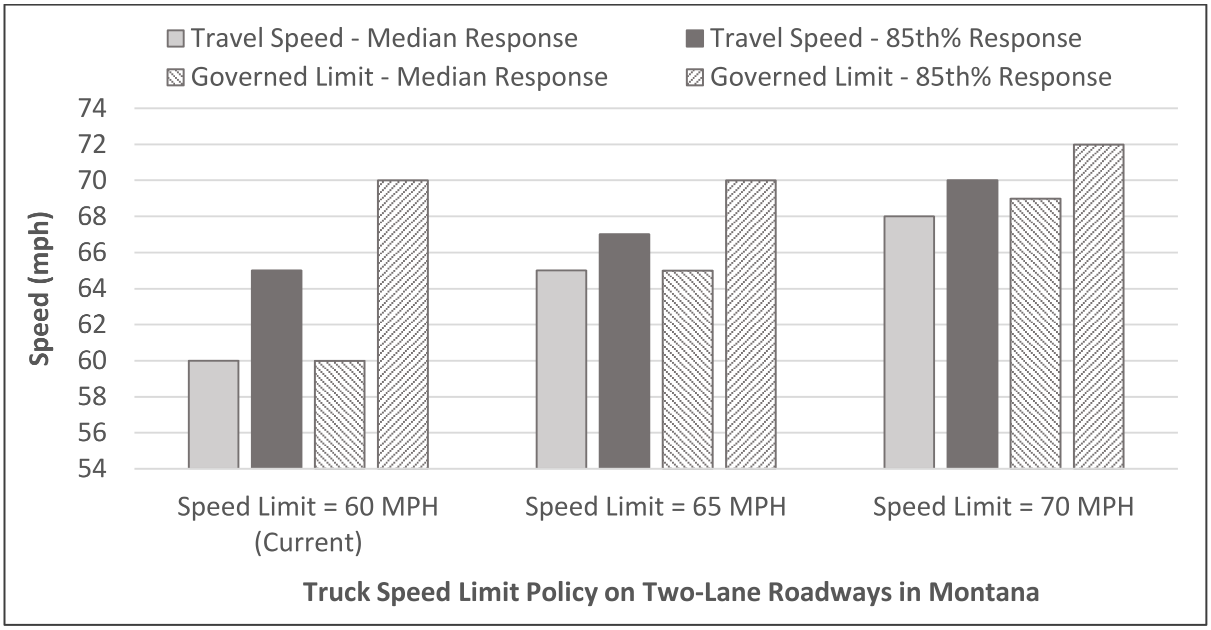


Figure 17. Reported Two-Lane Roadway Travel Speeds and Governed Limits by Speed Limit Policy

A subsequent assessment of the fleet related factors impacting travel speed selection was also performed, with the results displayed in Table 26. At truck speed limits of 60 mph, the median and 85th percentile reported fleet travel speeds were 60 mph and 65 mph, respectively, across all categories. Similarly, the median reported fleet travel speeds at speed limits of 65 mph and 85th percentile speeds at speed limits of 70 mph also showed no between-category differences. At speed limits of 65 mph, the 85th percentile reported speeds were higher (68 mph) for fleets without speed governors compared to fleets with governors (65 mph). This trend reversed at speed limits of 70 mph, where median reported speeds were higher for fleets with governors (68 mph) than without (65 mph). At speed limits of 65 mph, the 85th percentile reported travel speeds were also higher for fleets that included tractor trailers (67 mph) compared to those without (65 mph). A similar trend was observed at 70 mph speed limits, where the median reported speeds were 68 mph for fleets with tractor trailers compared to 65 mph for fleets without tractor trailers. Annual VMT had little impact on the reported travel speeds.

Table 26. Reported Two-Lane Roadway Fleet Travel Speeds by Fleet Characteristic and Speed Limit

	Speed Limit = 60 mph		65 mph		70 mph	
Registration	**Median**	**85th%**	**Median**	**85th%**	**Median**	**85th%**
Montana Intrastate Only	60	65	65	66	70	70
Montana Interstate	60	65	65	65	65	70
Out of State	60	65	65	67	68	70

	Speed Limit = 60 mph		65 mph		70 mph	
Speed Governor/Limiter Use	**Median**	**85th%**	**Median**	**85th%**	**Median**	**85th%**
Speed Governor/Limiters Used	60	65	65	65	68	70
Speed Governor/Limiters Not Used	60	65	65	68	65	70

	Speed Limit = 60 mph		65 mph		70 mph	
Fleet Size	**Median**	**85th%**	**Median**	**85th%**	**Median**	**85th%**
1 Truck	60	65	65	65	68	70
2 to 5 Trucks	60	65	65	68	68	70
6 to 10 Trucks	60	65	65	67	65	70
Greater than 10 Trucks	60	65	65	65	65	70

	Speed Limit = 60 mph		65 mph		70 mph	
Truck Type	**Median**	**85th%**	**Median**	**85th%**	**Median**	**85th%**
Tractor-Trailers in Fleet	60	65	65	67	68	70
No Tractor-Trailers in Fleet	60	65	65	65	65	70

	Speed Limit = 60 mph		65 mph		70 mph	
Annual VMT in Montana	**Median**	**85th%**	**Median**	**85th%**	**Median**	**85th%**
<15,000	60	65	65	66	68	70
15,000 – 50,000	60	65	65	66	67	70
>50,000	60	65	65	68	68	70

Uniform vs. Differential Policy Preference

A primary objective of the survey was to determine preference for uniform or differential speed limits on Montana highways. Although not a central focus of the survey, the survey included a question related to speed limit policy preference on interstate freeways in addition to 2-lane roadways. Overall, the overwhelming majority of respondents preferred uniform limits compared to differential limits for cars and trucks. Considering interstate freeways, 72 percent of respondents preferred uniform speed limits, while only 17 percent preferred differential limits and 11 percent had no preference or were undecided. Support for uniform limits was even stronger for two-lane roadways, as 83 percent preferred uniform limits compared to 14 percent who preferred differential limits and 3 percent had no preference or were undecided. Further evaluation of speed limit preferences by fleet characteristics are shown in Table 27.

Table 27. Speed Limit Policy Preference by Fleet Characteristic and Roadway Type

	2-Lane Highways			Interstate Freeways		
Registration	**Differential**	**Uniform**	**No Pref/ Unsure**	**Differential**	**Uniform**	**No Pref/ Unsure**
Montana Intrastate Only	18.4%	81.6%	0.0%	20.4%	65.3%	14.3%
Montana Interstate	15.8%	83.5%	0.8%	21.1%	70.7%	8.3%
Out of State	9.9%	82.4%	7.7%	8.8%	78.0%	13.2%
Speed Governor/Limiter Use	**Differential**	**Uniform**	**No Pref/ Unsure**	**Differential**	**Uniform**	**No Pref/ Unsure**
Governor/Limiter Used	13.0%	83.1%	3.9%	24.7%	63.6%	11.7%
Governor/Limiter Not Used	14.8%	82.7%	2.5%	13.8%	75.5%	9.7%
Fleet Size	**Differential**	**Uniform**	**No Pref/ Unsure**	**Differential**	**Uniform**	**No Pref/ Unsure**
1 Truck	9.0%	91.0%	0.0%	11.9%	77.6%	10.5%
2 to 5 Trucks	11.2%	85.4%	3.4%	7.9%	83.1%	9.0%
6 to 10 Trucks	15.9%	84.1%	0.0%	22.7%	61.4%	15.9%
Greater than 10 Trucks	21.1%	71.8%	7.0%	28.2%	60.6%	11.2%
Truck Type	**Differential**	**Uniform**	**No Pref/ Unsure**	**Differential**	**Uniform**	**No Pref/ Unsure**
Tractor-Trailers in Fleet	13.1%	84.0%	2.8%	16.4%	73.8%	9.9%
No Tractor-Trailers in Fleet	24.1%	72.4%	3.4%	20.7%	58.6%	20.7%
Annual VMT in Montana	**Differential**	**Uniform**	**No Pref/ Unsure**	**Differential**	**Uniform**	**No Pref/ Unsure**
<15,000	7.2%	88.0%	4.8%	7.2%	79.5%	13.2%
15,000 – 50,000	16.5%	81.0%	2.5%	17.7%	70.9%	11.4%
>50,000	18.8%	79.2%	2.0%	22.9%	67.7%	9.3%
OVERALL	14.3%	82.8%	2.9%	16.8%	72.2%	11.0%

Several interesting findings are displayed in Table 27. First and foremost, none of the fleet subcategories displayed in the table favored differential limits over uniform limits. In all cases, preference for uniform limits was stronger for two-lane roadways compared to interstate freeways. And while little difference in speed limit preference between registration classifications was observed for two-lane highways, out of state carriers had a stronger preference towards uniform speed limits on interstates than Montana carriers, which is displayed in Figure 18. This was not an unexpected result, as out of state carriers log a lower proportion of miles within Montana, contributing to a lessened familiarity with differential speed limits. The non-use of governors/limiters influenced a higher preference towards uniform limits on interstates, as well. Fleet size also tended to play a factor in speed limit policy preference, as smaller fleets generally showed stronger preference towards uniform speed limits than larger fleets. Further, fleets with tractor trailers also showed stronger preference towards uniform limits than those without. Finally, fleets with less travel in Montana also showed a greater preference towards uniform limits.

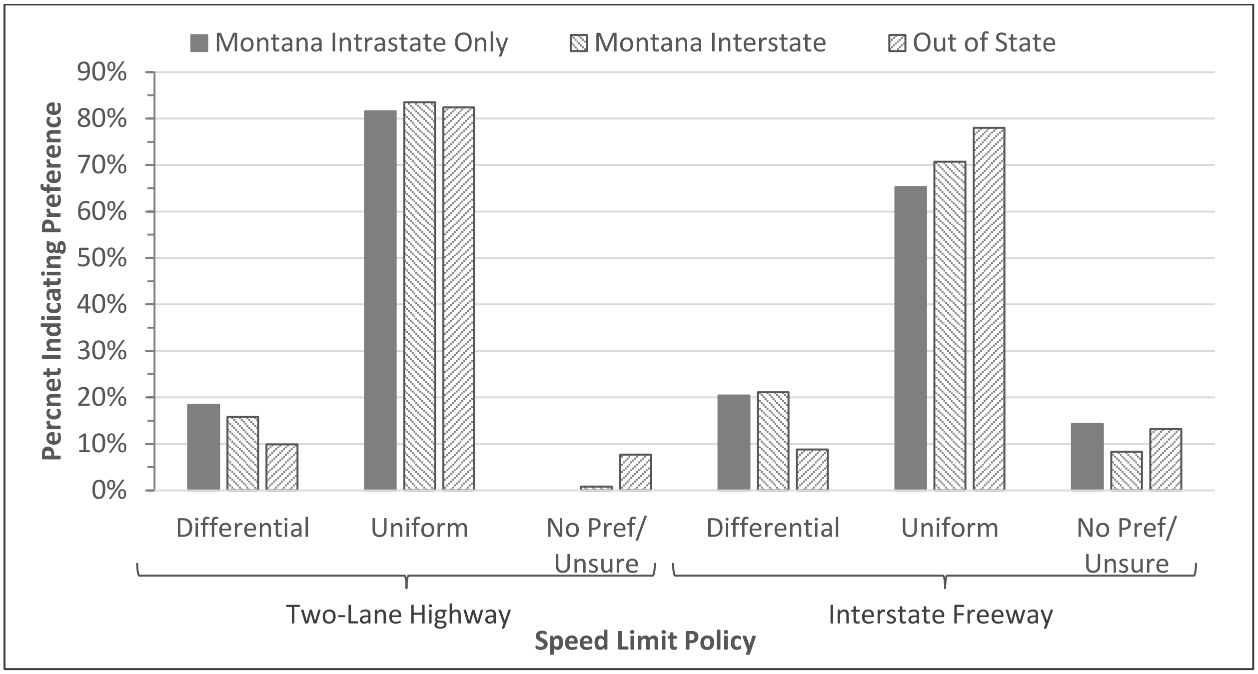


Figure 18. Speed Limit Policy Preference by Registration and Roadway Type

Speed Limit Preference

Perhaps the most important objective of this survey was to identify the specific car/truck speed limit policy preferred by registered motor carriers for use on rural two-lane highways in Montana. Respondents were asked to rank their preference (1 most preferred, 5 least preferred) for the following speed limit alternatives (car/trucks) on two-lane highways in Montana: 70/60 mph (current), 65/60 mph, 70/65 mph, 65/65 mph, and 70/70 mph.

The average preference rakings are displayed in Figure 19. Overall, the overwhelming majority of respondents gave highest preference to uniform limits of 65/65 mph (40.3% first preference; 2.14 average raking) or 70/70 mph (38.5% first preference, 2.54 average ranking) for two-lane roadways in Montana. Only 7.0 percent of respondents indicated the current differential speed limit as the most preferred alternative, and the alternative differential limits (65/60 and 70/65) fared no better, garnering only 5.5 and 8.8 percent of the respondents' top preferences, respectively. Further evaluation of speed limit preference by fleet characteristics showed several interesting findings, as shown in Table 28.

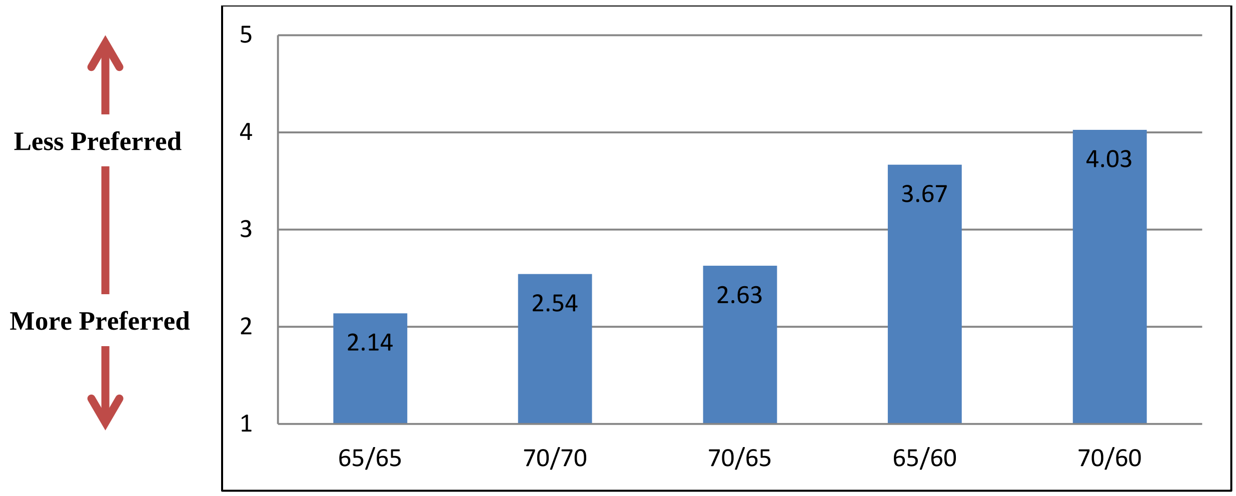


Figure 19. Average Preference Ranking for Two-Lane Roadway Speed Limits

Table 28. Two-Lane Roadway Speed Limit Preference by Fleet Characteristic

	Percent Indicating First Preference				
Registration / **Car/Truck Speed Limit →**	**70/60 (current)**	**65/60**	**70/65**	**65/65**	**70/70**
Montana Intrastate Only	8.2%	6.1%	8.2%	20.4%	57.1%
Montana Interstate	6.8%	6.0%	10.5%	39.8%	36.8%
Out of State	6.6%	4.4%	6.6%	51.6%	30.8%
Speed Governor/Limiters	**70/60 (current)**	**65/60**	**70/65**	**65/65**	**70/70**
Speed Governor/Limiters Used	8.5%	8.5%	10.9%	37.2%	34.9%
Speed Governor/Limiters Not Used	5.1%	2.9%	7.4%	44.9%	39.7%
Fleet Size	**70/60 (current)**	**65/60**	**70/65**	**65/65**	**70/70**
1 Truck	4.5%	3.0%	3.0%	52.2%	37.3%
2 to 5 Trucks	5.6%	5.6%	4.5%	36.0%	48.3%
6 to 10 Trucks	6.8%	6.8%	11.4%	45.5%	29.5%
Greater than 10 Trucks	9.9%	7.0%	16.9%	32.4%	33.8%
Truck Type	**70/60 (current)**	**65/60**	**70/65**	**65/65**	**70/70**
Tractor-Trailers in Fleet	6.1%	4.9%	9.4%	41.8%	37.7%
No Tractor-Trailers in Fleet	13.8%	10.3%	3.4%	27.6%	44.8%
Annual VMT in Montana	**70/60 (current)**	**65/60**	**70/65**	**65/65**	**70/70**
<15,000	3.6%	6.0%	3.6%	47.0%	39.8%
15,000 – 50,000	11.4%	3.8%	7.6%	35.4%	41.8%
>50,000	6.3%	5.2%	13.5%	38.5%	36.5%

As displayed in Table 28, all subcategories overwhelmingly supported the uniform speed limit options compared to the differential options, and major differences between subcategories were limited. Perhaps the most significant difference in speed limit preference was that between intrastate-only carriers and out of state carriers, which is reflected in Figure 20. Intrastate-only carriers overwhelmingly preferred (57.1 percent) 70/70 mph speed limits for two-lane roadways, while only 20.4 percent preferred 65/65 mph speed limits. This is in strong contrast to the out of state carriers, whose top preference (51.6 percent) was the 65/65 mph speed limit, while the 70/70 mph limit garnered top preference from only 30.8 percent of respondents. This result is not unexpected, as 65/65 mph speed limits are likely more familiar to carriers from out-of-state, where such limits are more common. The preferences of interstate carriers with Montana addresses were relatively evenly split between 65/65 mph (39.8%) and 70/70 mph limits (36.8%). Little difference was observed between the various registrant categories regarding support for the current 70/60 mph speed limit, which remained below 9 percent across the three registration categories.

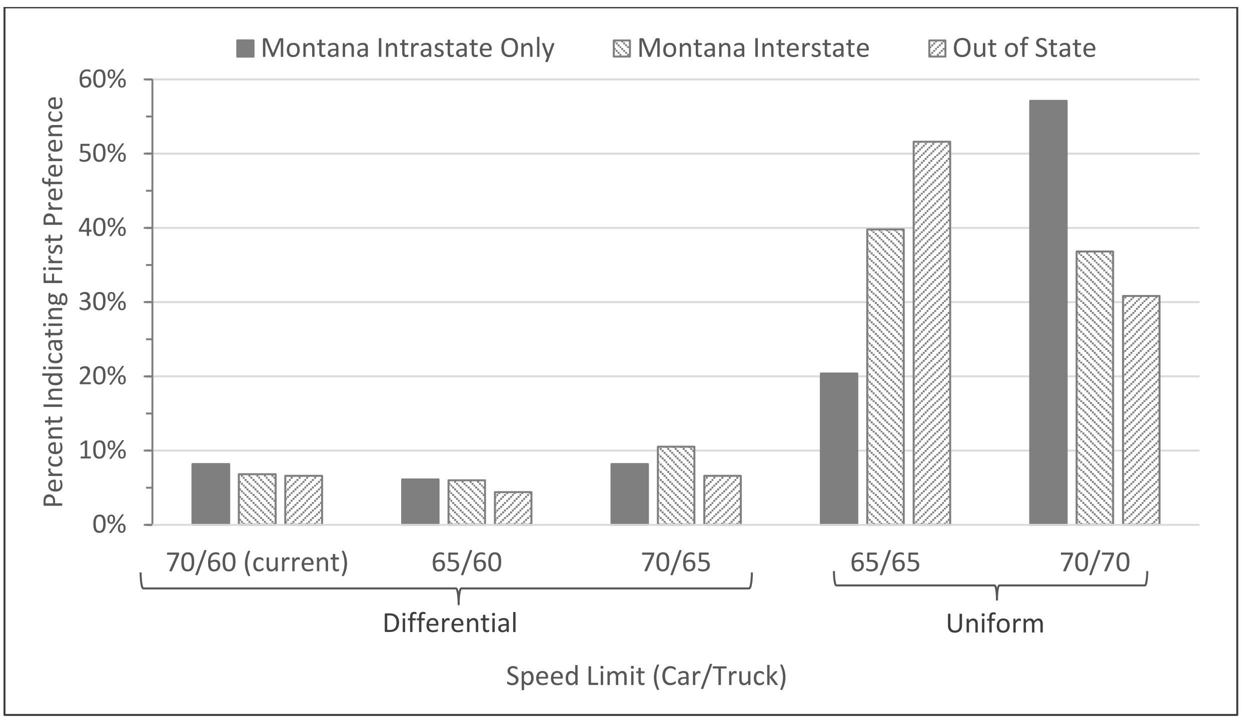


Figure 20. Two-Lane Roadway Speed Limit Preference by Registration Classification

Smaller fleets (five or fewer vehicles) generally seemed to be more supportive of 70 mph limits, although this is likely largely a reflection that smaller fleets are more common with local intrastate-only operators who were generally more supportive of 70 mph truck limits. Larger fleets tended to be more supportive of 65 mph limits, which are more common outside of

Montana. Similarly, carriers without tractor-trailers, which were more commonly local intrastate only operators, were also more likely to support 70 mph truck limits. Finally, neither VMT nor governor/limiter use was found to influence speed limit preference.

Expected Impacts Associated with Raising the Truck Speed Limit

Respondents were also asked to describe any expected positive or negative impacts associated with raising the truck speed limits on two-lane highways in Montana. These comments are summarized in Table 29.

Table 29. Expected Positive and Negative Impacts Associated with Increasing the Truck Speed Limit

Expected Positive Impacts of Increasing the Truck Speed Limit
- Travel times are likely decreased for trucks, resulting in more efficient use of drivers hours and faster haul times
- Smoother, more consistent flow of traffic due to less variance in speed
- Decreases likelihood for passenger cars to perform dangerous passing maneuvers therefore improving safety
- Decreases the amount of frustrated drivers queued behind trucks, therefore improving driver behavior and safety
- Modern trucks are much more capable of handling the increased travel speeds and therefore will decrease travel times without diminishing safety
- Ambulances and emergency vehicles would no longer have to deal with queues behind slow moving trucks
- Fewer passenger cars driving closely behind large trucks in their blind spots
- Fewer "run under" type crashes with tractor trailers
- Some smaller trucks perform better at speeds above 60 mph
- Some drivers increase speeds to 65 mph to climb hills, matching these speeds would be easier for the driver
- Increased fuel efficiency for some vehicles, noted between 65-67 mph
Expected Negative Impacts of Increasing the Truck Speed Limit
- Marginal decrease in travel time is far outweighed by negative safety impact
- Many trucks are already exceeding safe speeds and increasing the limit would exacerbate that problem
- Many two-lane highways in Montana are not designed to accommodate the higher speeds
- Fuel efficiency for several types of trucks would be negatively impacted
- Passenger vehicles often pull out in front of fast moving trucks (specifically to avoid getting stuck behind them), increases the likelihood for a conflict due to increased truck speeds which results in greater stopping distances
- Many truck drivers do not adjust for prevailing road conditions, increasing the speed would exacerbate this problem
- Large or very heavy trucks should not exceed 60 mph due to the relatively long stopping distances required
- Given the large animal population in Montana, would likely increase truck-animal crashes
- Presence of many blind driveways adjacent to two-lane highways in Montana, would likely increase crashes and conflicts related to drivers
- Passenger vehicles have a tendency not to use appropriate turn signals, increasing the stopping time required for trucks would result in more crashes related to vehicles failing to signal
- Reduced income for the State of Montana due to decrease in commercial speeding violations
- May create a conflict between unloaded trucks (which are typically driving faster) and loaded or oversize trucks (which are incapable of increasing speed)
- May create a conflict between trucks whose speeds are governed with trucks whose speeds are not governed, resulting in an increase of trucks passing trucks
- Increase in the truck speed limit without making it uniform with passenger cars will not improve safety
- Potentially more severe crashes, even if the frequency of crashes is decreased
- Road user cost of replacing speed limit signage and other traffic control devices
- Trucks will face a general decrease in reaction times to dangers in the roadway

Potential Economic Impacts Associated with Raising the Truck Speed Limit

Respondents were asked, considering their specific fleet, if they believed that the potential economic benefits (such as reduced delay) would outweigh the costs (such as increased fuel consumption) if the truck speed limit was increased from 60 mph to either 65 mph or 70 mph. The results are shown in Figure 21 for both alternative truck speed limit policies.

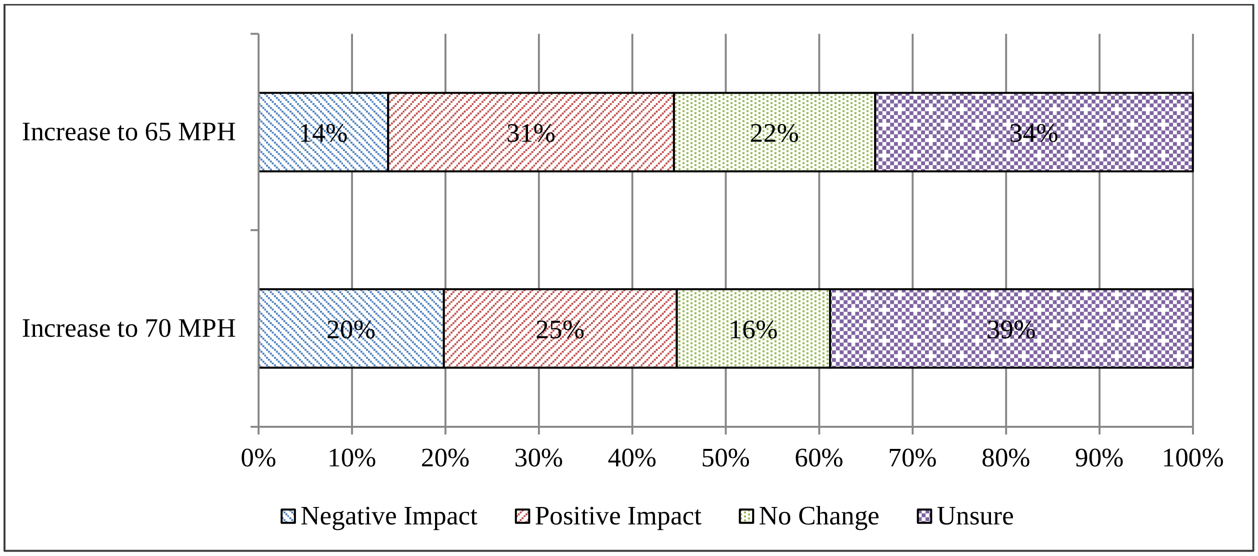


Figure 21. Expected Economic Impact Associated with Increasing the Truck Speed Limit

Respondents of the survey generally had similar beliefs regarding the potential economic impacts of increasing the truck speed limit for both the 65 mph and 70 mph alternatives with few slight differences of note. Specifically, respondents were slightly more positive about the economic impacts associated with increasing the truck speed limit to 65 mph (31 percent) than to 70 mph (25 percent). Similarly, fewer respondents felt increasing the truck speed limit would have negative economic impacts at 65 mph (14 percent) than at 70 mph (20 percent).

CHAPTER 8:
CONCLUSIONS AND RECOMMENDATIONS

Montana is currently the only state that maintains a differential speed limit policy on two-lane rural highways, with a current daytime statutory limit of 70 mph for cars and light duty trucks and 60 mph for trucks with greater than one-ton payload capacity. However, in April 2013, speed limits were changed to a uniform 65 mph along 55 miles of MT-16 and MT-200 between Glendive and Fairview in eastern Montana. This change was made in response to observations of aggressive passing behavior by motorists queued behind heavy trucks with little opportunity to pass. Consequently, it was necessary to assess the impacts associated with these speed limit changes to determine if further application of the uniform 65 mph speed limit is warranted.

Although a considerable amount of prior research has investigated the impacts of speed limits on traffic safety and operations, much of this research, and nearly all of the research related to differential speed limits, has been specific to limited access freeways. The unique safety and operational issues on highways without access control creates difficulty relating the conclusions from prior freeway-related speed limit research to non-freeway roadways. This is particularly true for two-lane highways due to passing limitations and subsequent queuing. To address this gap in knowledge, a comprehensive study related to the safety and operational impacts of differential speed limits on rural two-lane highways was performed for the Montana Department of Transportation. The primary objectives of this study were as follows:

1. Determine the safety impacts associated with the use of differential speed limits rural two-lane roads, including the impacts on crash frequency and crash severity;
2. Determine the operational impacts associated with the use of differential speed limits on rural two-lane roads, including the impacts on speeds, queues, and passing maneuvers; and
3. Provide guidance towards the use or non-use of differential speed limits on two-lane rural highways in Montana.

The salient findings from this research are summarized in the following sections along with overall conclusions. Recommended guidance towards continued implementation of uniform speed limits on rural two-lane highways in Montana is also provided.

PROJECT SUMMARY AND OVERALL CONCLUSIONS

Nationwide Speed Limit Policies

Since 2011, 25 states have increased speed limits on rural highways. The majority of these increases were based on legislative action and most occurred along interstate freeways. In general, these increases were done selectively on eligible roadway segments based upon traffic engineering, speed, and safety studies conducted by the particular state DOT. This is an important distinction from prior speed limit policy changes after repeal of the NMSL, which typically affected all roadways within a particular classification. In many cases, post-implementation data on the impacts of the speed limit changes within these states were not yet available.

As of June 2016, the maximum allowable posted speed limits for divided rural highways ranged from 45 mph in Hawaii to 80 mph in Texas, while maximum speed limits on undivided rural highways ranged from 50 mph in Delaware and Rhode Island to 75 mph in Texas. While the majority of states maintain maximum non-freeway speed limits that are between 55 mph and 65 mph, speed limits of 70 mph or above are becoming increasingly popular, particularly for divided highways and in western states.

The relaxation and ultimate repeal of the NMSL in the late 1980's and 1990's saw many states initially implement lower speed limits for trucks on limited access freeways. However, recently, numerous states have transitioned to a uniform speed limit for all vehicles. As of June 2016, only seven states continue to maintain DSLs on limited access freeways, with three states using a 15 mph differential, three using a 10 mph differential, and one using a 5 mph differential. Of these states, only Montana broadly uses differential limits on undivided highways.

Impact of Speed Limit Policy on Free Flow Speeds

Using data collected from 160 rural two-lane highway sites across Montana and the neighboring states of North Dakota, South Dakota, Wyoming, and Idaho, it was concluded that transitioning from the 70/60 mph speed limit to a uniform 65 mph limit on two-lane roadways would contribute to a moderate reduction in overall travel speeds, although truck speeds were expected to increase. This is based on the finding that locations with uniform 65 mph limits had overall mean and 85th percentile free flow speeds that were approximately 1.6 mph and 3.2 mph lower, respectively, compared to locations with 70/60 mph differential limits. However, when considering only trucks, the mean and 85th percentile free flow speeds were 1.4 mph higher at sites with uniform 65 mph limits compared to sites with 70/60 mph limits. Speed variability is expected to decrease when transitioning from a 70/60 to 65/65 speed limit, which would imply safety benefits, due in part to the convergence of the speeds profiles of passenger vehicles and heavy trucks.

Speed selection also appears to be influenced by local factors, as free flow speeds tended to be somewhat higher in Montana than in the neighboring states, particularly North Dakota. A follow-up assessment of speeding fines between the states did not prove any relationship between fines and operating speeds. Ultimately, it remains unclear what factors may contribute to these state-to-state differences in operating speeds, although variations in traffic law enforcement, driver behavior, terrain, and/or weather may play a role.

Safety Performance Evaluation

An assessment of the relationships between crash occurrence and various traffic and roadway factors (speed limits, geometry, cross-section) was performed through development of a series of safety performance functions using historical crash data for the MDT two-lane highway network.

Comparison of Montana SPFs with Neighboring States and the HSM

Initial SPFs were developed using the Montana crash data with AADT as the sole independent variable, thereby allowing for comparison to the default model from the *HSM*, as well as similar models for Idaho and South Dakota, where 65 mph limits prevail. Within the typical range of traffic volumes, two-lane roadways in Montana were found to experience similar crash frequencies compared to Idaho. However, both states tended to experience significantly greater two-lane roadway crash occurrence compared to South Dakota, as well as in comparison to the base model from the *HSM*. Montana was the only of these states with widespread use of both 70-mph maximum speed limits and differential limits on two-lane highways, which may have contributed to the comparatively higher rates of crash occurrence.

Factors Affecting Crash Occurrence in Montana

Subsequent analyses involved the estimation of multivariate models to assess factors that may contribute to higher rates of crash occurrence on Montana's two-lane highways. The use of random effects terms significantly improved model fit, which is an indication of strong temporal correlation in crash counts on the same segments over time due to common unobserved factors. Crashes on Montana’s two-lane rural highways tended to increase with driveway density, horizontal curvature, and on highways of higher functional class, as well as on segments located in District 1, which includes the most urbanized areas of the state. In contrast, fewer crashes were experienced on segments with wider shoulders or where passing relief lanes were in place.

Preliminary Safety Impacts of 65 mph Uniform Speed Limits

This study also allowed for a preliminary assessment of the recent change from a differential 70/60 mph limit to a uniform 65 mph speed limit that occurred along 55 miles of MT-16 and MT-200 in eastern Montana in April 2013. When considering all crashes, these 55 miles tended to experience significantly more crashes than the other comparable segments prior to the speed limit change (i.e., when the 70/60 mph limit was in place). Although crash occurrence was reduced after the uniform speed limit went into effect on these segments, crash occurrence remained greater than on the comparison sections on which differential limits were maintained. However, after eliminating animal-involved crashes, implementation of the 65 mph limit reduced crashes to the point where crash occurrence was not significantly different between the segments with differential and uniform limits during the post-implementation period.

It should be noted that only 21 months of data were available after the uniform speed limit went into effect. Thus, these results were considered preliminary, and further analysis should be performed once additional crash data become available. Nevertheless, while data for the post-implementation period of the uniform speed limit in Montana are limited, the findings of this evaluation provide some indication that use of the uniform 65 mph limit on two-lane highways may provide safety benefits over the 70/60 mph differential limit.

Impact of Speed Limit Policy on Platoon Length and High-Risk Passing Behavior

Given the relatively recent and selective nature of the transitions from differential to uniform speed limits in Montana and subsequent limited availability of crash data at these sites, it was deemed necessary to analyze additional surrogate safety measures to provide additional insights as to the prospective impacts of speed limit policies on safety. Thus, in addition to the speed-related analyses, additional operational measures, including average platoon length and frequency of high-risk passing events, were also assessed with respect to speed limit policy and other factors. For the purposes of this study, high-risk passing events were defined as cases where the passing attempt was initiated with less than the AASHTO design passing sight distance available. The evaluations of platoon length and high-risk passing behavior were conducted using data from the 77 Montana sites from which video data were obtained.

The rate of high-risk passing events was found to increase with increasing traffic volumes or average platoon lengths. This was not unexpected, since both of these conditions tend to increase delay and may contribute to more aggressive passing behavior. Although neither speed limit nor average travel speed was found to have a significant effect on high-risk passing, standard deviation of speed was found to have a large effect. This finding suggests that locations with greater speed variability, including locations with high volumes of heavy trucks or other slower moving vehicles, would experience a higher frequency of high-risk passing attempts.

Similar results were found related to platoon length as a function of speed limit policy. Not surprisingly, higher traffic volumes and truck percentages contributed to longer platoons. As expected, longer platoons were observed at locations where passing opportunities were restricted, including locations with a high proportion of no-passing zones, particularly along horizontal curves. Not surprisingly, platoons tended to be longer in the more urban and mountainous portions of the state, particularly Districts 1 and 2. Regarding speed limit policy, platoons tended to be significantly longer at locations with 70/60 mph differential limits compared to locations with uniform 65 mph limits. Since longer platoons were found to increase the likelihood of high-risk passing events, which serves as a potential surrogate for passing-related crashes, it was concluded that the use of uniform 65 mph limits may likely improve safety over 70/60 mph differential limits.

Collectively, these findings provide evidence to support the anecdotal operational and safety concerns often associated with the prevailing 70/60 mph differential speed limit on rural two-lane highways in Montana. The findings also support the results of the preliminary crash data analysis, providing further indication that use of the uniform 65 mph speed limit on two-lane highways may provide safety benefits over the prevailing 70/60 mph differential limit. As will be shown in the following subsection, these safety findings are further supported by the preferences and opinions of road users in Montana, particularly the trucking industry.

Motorist and Trucking Industry Preferences

Given that potential changes to Montana's two-lane highway speed limit policy would likely have a significant impact on road users, especially the trucking industry, a series of surveys were performed to assess preferences and opinions regarding speed limit policies among road users and registered motor carriers in Montana. The road user survey was administered in person to motorists at 10 Montana DOT rest areas and/or weight stations throughout the state in mid-August 2014, and a total of 586 surveys were completed. The trucking industry survey was administered online to both in-state and out-of-state motor carriers registered to operate in Montana, with a total of 353 surveys completed.

The road user survey found large differences in speed limit policy preference between passenger vehicle occupants and truck drivers. Preference for differential speed limit policies was much stronger among passenger vehicles occupants compared to truck drivers, who tended to support uniform limits. Among passenger vehicle occupants, the most commonly preferred speed limit was the current 70/60 mph differential limit. Motorists over the age of 30 were much more likely to support 65 mph limits than their younger counterparts, who overwhelmingly favored speed limit alternatives that included maximum limits of 70 mph.

Uniform speed limit policies garnered very strong support from the trucking industry, as nearly 80 percent of registered motor carriers favored a uniform speed limit policy. The most commonly preferred policy among the trucking industry (including drivers) was 65/65 mph, and the current 70/60 mph limit garnered little support. Support for uniform 65 mph limits was particularly strong for motor carriers from outside of Montana, where such limits are common on two-lane highways.

Not surprisingly, increasing the truck speed limit would likely increase truck travel speeds. Respondents to the trucking industry survey noted that increasing the truck speed limit from 60 to 65 mph would increase the median fleet travel speeds from 60 to 65 mph, while the 85th percentile fleet travel speed would increase from 65 to 67 mph. These findings further support the field speed analysis, which found the mean and 85th percentile free flow speeds for trucks to be 1.4 mph higher at sites with uniform 65 mph speed limits compared to those with 70/60 mph differential limits.

Regarding the potential safety implications associated with moving to uniform speed limits on two-lane roadways, motorists reported less frequent overtaking of vehicles traveling 5 mph slower compared to 10 mph slower. The responses were similar regardless of whether a passenger vehicle or heavy truck was the vehicle being overtaken and suggest that a uniform 65 mph speed limit may reduce passing activity, assuming that variability in vehicle travel speeds is reduced accordingly.

SPEED LIMIT POLICY RECOMMENDATIONS

Collectively, the findings from this study provide substantial evidence in support of uniform 65 mph speed limits on two-lane rural highways in Montana. Although implementation of a uniform 65 mph limit on two-lane rural highways will likely increase truck travel speeds compared to the current 70/60 mph differential limit, a reduction in travel speeds for passenger vehicles is also expected. The resulting convergence of the speed profiles for passenger vehicles and heavy trucks would consequently reduce the overall variability in travel speeds. As shown in the operational data analysis, a reduction in speed variability would likely reduce platoon lengths and dangerous passing behavior, thereby reducing the risk of passing-related crashes. Furthermore, although data from the post-implementation period of the uniform 65 mph speed limit along MT-16 and MT-200 are limited, the crash data analyses provided some indication that use of the 65 mph limit may provide safety benefits over the previous 70/60 mph differential limit. And while motorist support for uniform 65 mph speed limits was mixed, the trucking industry was strongly supportive.

Based on the collective findings, uniform 65 mph speed limits are recommended for further implementation on two-lane highways in Montana. Although the findings from this research support statewide implementation of 65 mph limits, it may be initially advisable to continue selective implementation on candidate segments that meet certain criteria. The critical objective of the uniform 65 mph limit is to reduce queuing and subsequent high-risk passing behavior by reducing the speed variability between cars and trucks. Thus, candidate roadways should possess greater traffic volumes (e.g., above 3,000 AADT), greater truck percentages (e.g., above

10 percent), and limited passing opportunities (e.g., above 40 percent no passing zones, particularly with frequent horizontal curvature and few passing relief lanes). As crashes and platoon lengths tended to be higher in District 1, roadways in this district that meet the criteria may serve as ideal initial candidates for further implementation of the uniform 65 mph speed limit. Furthermore, locations with low traffic volumes (e.g., below 1,000 AADT) or low truck percentages (e.g., below 5 percent) would not likely experience substantial operational or safety benefits after changing to a uniform 65 mph speed limit and should not be considered as initial candidates.

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APPENDIX

ROAD USER SURVEY FORM

Montana 2-Lane Highway Speed Limit Survey

This survey will provide valuable information to assist the Montana Department of Transportation in assessing public opinion towards speed limit policies. Your participation in this effort is greatly appreciated. If you have any questions or comments, please feel free to contact Dr. Timothy Gates at tjgates@wayne.edu

1) How often do you travel on 2-lane rural highways:

in Montana?
□ Daily □ Weekly □ Monthly □ Yearly □ Never

in other states or provinces?
□ Daily □ Weekly □ Monthly □ Yearly □ Never

2) Were you aware that the State of Montana uses different posted speed limits for cars and trucks on most rural 2-lane highways?
□ Yes □ No

3) Do different speed limits for cars and trucks make 2-lane highways more or less safe compared to highways with the same speed limit for all vehicles?
□ More safe □ Less safe □ Not sure

Why do you feel this way?______________________________
____

4) What should be the general speed limit for cars and trucks on rural 2-lane highways in Montana?
□ 70 cars / 60 trucks (current) □ 65 cars / 65 trucks
□ 70 cars / 65 trucks □ 70 cars / 70 trucks
□ Other: ________________

Why do you feel this way?______________________________
____

5) How fast do you generally drive on 2-lane highways in Montana?
□ Below 60 mph □ 60 to 65 mph □ 65 to 70 mph
□ 70 to 75 mph □ 75 to 80 mph □ Above 80 mph

6) Do you drive slower at night on 2-lane highways in Montana?
□ No, I do not drive slower at night □ Yes, 1 to 5 mph slower
□ Yes, 6 to 10 mph slower □ Yes, more than 10 mph slower

7) How frequently would you pass slower moving passenger vehicles on 2-lane highways when the vehicle is traveling:
5 mph less than you: □ Frequently □ Occasionally □ Rarely □ Never
10 mph less than you: □ Frequently □ Occasionally □ Rarely □ Never
More than 10 mph less than you: □ Frequently □ Occasionally □ Rarely □ Never

8) How frequently do you pass slower moving heavy trucks on 2-lane highways when the vehicle is traveling:
5 mph less than you: □ Frequently □ Occasionally □ Rarely □ Never
10 mph less than you: □ Frequently □ Occasionally □ Rarely □ Never
More than 10 mph less than you: □ Frequently □ Occasionally □ Rarely □ Never

9) What is your primary daily mode of transportation?
□ Automobile/Motorcycle □ Single Unit/Box Truck
□ Semi Truck □ Bus
□ Other____________ □ Do Not Drive

10) What is your employment status?
□ Employed □ Not Employed □ Student □ Retired

11) On average, how long is your commute to work?
□ 5 min or less □ 6-10 min □ 11-20 min □ 21-30 min
□ 31-40 min □ over 40 min □ N/A

12) Do you drive as a part of your job (not including your commute)?
□ Yes, daily □ Yes, occasionally □ No □ N/A

13) Approximately how many miles do you drive per year?
□ 4,000 or less □ 4,001 to 8,000 □ 8,001 to 12,000
□ 12,001–16,000 □ Over 16,000 □ Do Not Drive

14) Home Zip Code:________________

15) Age:
□ under 21 □ 21 to 30 □ 31 to 40
□ 41 to 50 □ 51 to 60 □ 61 to 70 □ Over 70

16) Gender: □ Male □Female

17) Ethnicity:
□ White □ Black □ Native American
□ Hispanic/Latino □ Asian □ Other

The next series of questions pertain to commercial vehicle operators only.

18) Would you travel at a higher speed if the truck speed limit is increased from 60 to 70 mph on 2-lane highways?
□ Yes, 1 to 5 mph faster □ Yes, 6 to 10 mph faster
□ Yes, more than 10 mph faster □ No

19) Is your vehicle speed limited or governed?
□ No
□ Yes, my vehicle's speed is capped at: __________ mph

→ **If yes, will your vehicle's maximum speed be increased if the speed limit is increased?**
□ Yes □ No □ Not sure

TRUCKING INDUSTRY SURVEY FORM

Fleet Details

2. Please indicate the approximate number of each type of vehicle in your fleet. If possible, consider only the portion of your fleet that operates in Montana.

Medium Duty Pickup (greater than 1-ton payload, Class 4 or greater)

Single Unit Truck (2-axle, 6 tire)

Single Unit Truck (3 or more-axles)

Tractor-Trailer (single trailer)

Tractor-Trailer (multi-trailer)

Other

3. If "Other" was indicated in the prior question, please describe these vehicle(s) in further detail.

4. What industry does your fleet that operates within/through Montana generally service? Please select all that apply.

- Agriculture
- Mining (including oil/natural gas exploration)
- Construction
- Manufacturing
- Freight
- Government

Other (please specify)

5. Where does your fleet typically operate within Montana? Please select all that apply.

- Eastern Montana (all areas east of Billings)
- Central Montana (all areas east of I-15 & west of Billings)
- Western Montana (all areas west of I-15)

6. Please estimate the number of miles traveled by your fleet in 2014 (or the most recent year for which data is available):

Within Montana

Elsewhere

Fleet Operations

***8. At what speed does your fleet typically travel on 2-lane highways in Montana? Similarly, what would be the typical fleet travel speed if the truck speed limit is increased to either 65 mph or 70 mph on these highways?**

Travel Speed @ Current Speed Limit (60 mph) =

Travel Speed @ 65 mph Speed Limit =

Travel Speed @ 70 mph Speed Limit =

***9. Do each of your answers to the previous question represent governed limits?**

- Yes
- No
- Speed Governors/Limiters are Not Utilized

Speed Governors/Limiters

***10. At what speed are trucks in your fleet currently limited or governed when traveling on 2-lane highways in Montana? What would be the governed limits if the truck speed limit is increased to 65 mph or 70 mph on these highways?**

Current Governed Limit (60 mph Speed Limit) =

Governed Limit if Speed Limit Increased to 65 mph =

Governed Limit if Speed Limit Increased to 70 mph =

Speed Limit Policy Preferences

***12. For INTERSTATE FREEWAYS, do you favor a uniform speed limit for cars and trucks or a differential (i.e., lower) limit for trucks compared to cars?**

- Uniform
- Differential
- No Preference
- Unsure

What is the basis for your selection?

***13. For 2-LANE HIGHWAYS, do you favor a uniform speed limit for cars and trucks or a differential (i.e., lower) limit for trucks compared to cars?**

- Uniform
- Differential
- No Preference
- Unsure

What is the basis for your selection?

***14. Considering 2-LANE HIGHWAYS in Montana, please rank the following speed limit policy alternatives (1 = highest preference; 5 = lowest preference).**

	1st Preference	2nd Preference	3rd Preference	4th Preference	5th Preference
Cars 70/Trucks 60 (Current)					
Cars 65/Trucks 60					
Cars 65/Trucks 65					
Cars 70/Trucks 65					
Cars 70/Trucks 70					

Speed Limit Policy Impacts

15. Please describe any expected POSITIVE impacts associated with increasing the truck speed limit on 2-lane highways in Montana:

16. Please describe any expected NEGATIVE impacts associated with increasing the truck speed limit on 2-lane highways in Montana:

17. Considering your truck fleet, do you believe that the potential economic benefits (such as reduced delay) will outweigh the costs (such as increased fuel consumption) if the truck speed limit on 2-lane highways in Montana is increased from 60 mph to:

	Yes	No	Unsure	No Economic Changes are Expected
65 mph	○	○	○	○
70 mph	○	○	○	○

METRIC-ENGLISH CONVERSIONS

ENGLISH TO METRIC			METRIC TO ENGLISH		
LENGTH (APPROXIMATE)			**LENGTH (APPROXIMATE)**		
1 inch (in)	=	2.5 centimeters (cm)	1 millimeter (mm)	=	0.04 inch (in)
1 foot (ft)	=	30 centimeters (cm)	1 centimeter (cm)	=	0.4 inch (in)
1 yard (yd)	=	0.9 meter (m)	1 meter (m)	=	3.3 feet (ft)
1 mile (mi)	=	1.6 kilometers (km)	1 meter (m)	=	1.1 yards (yd)
			1 kilometer (km)	=	0.6 mile (mi)
AREA (APPROXIMATE)			**AREA (APPROXIMATE)**		
1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)	1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)	1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)	10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)			
MASS - WEIGHT (APPROXIMATE)			**MASS - WEIGHT (APPROXIMATE)**		
1 ounce (oz)	=	28 grams (gm)	1 gram (gm)	=	0.036 ounce (oz)
1 pound (lb)	=	0.45 kilogram (kg)	1 kilogram (kg)	=	2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)	1 tonne (t)	=	1,000 kilograms (kg)
				=	1.1 short tons
VOLUME (APPROXIMATE)			**VOLUME (APPROXIMATE)**		
1 teaspoon (tsp)	=	5 milliliters (ml)	1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	=	15 milliliters (ml)	1 liter (l)	=	2.1 pints (pt)
1 fluid ounce (fl oz)	=	30 milliliters (ml)	1 liter (l)	=	1.06 quarts (qt)
1 cup (c)	=	0.24 liter (l)	1 liter (l)	=	0.26 gallon (gal)
1 pint (pt)	=	0.47 liter (l)			
1 quart (qt)	=	0.96 liter (l)			
1 gallon (gal)	=	3.8 liters (l)			
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)	1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)	1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)			**TEMPERATURE (EXACT)**		
[(x-32)(5/9)] °F	=	y °C	[(9/5) y + 32] °C	=	x °F