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Analysis of Speed Compliance in Rural Variable Speed Limit System

ABSTRACT: Many previous studies found that speed compliance has a strong relationship with both the frequency and severity of the traffic accident. Variable speed limit (VSL) system as a tool to improve the traffic safety enables the freeway system to change its posted speed limit based on various road conditions help the driver to recognize the upcoming events to reduce the speed variation. In Wyoming, most of the freeways are in rural area accordance with the unique characteristics of the rural freeway its speed limits are mainly influenced by the adverse weather and specific geometric characteristics. A series of analyses were conducted in this paper to figure out how drivers' speed behavior were affected by VSL system and the factors effecting the driver speed compliance in the Interstate 80 corridor in Wyoming.

Keywords:

Speed, Speed variation, Variable speed limit, Speed Compliance, Linear regression, WYDOT

1. INTRODUCTION

Speed, speed variation, and speed compliance are important factors related to both frequency and severity of traffic crashes. The National Highway Safety Administration reports 10,530 speeding related lives were lost in road accidents in 2010 (Tuss 2012). The cost of speeding related crashes in the United States is estimated at $40.4 billion each year. Although many efforts have been made in safety improvements and safety research, speed related fatalities in U.S. still represent 31% of the total traffic fatalities in 2010, a 7% increase compared to 2000.

Variable speed limits (VSL) system along rural roadways is an operational strategy used to address speed related safety problems. VSL systems use real-time information such as traffic volumes, speeds and weather to set enforceable speed limits. In urban areas, VSL systems are primarily used to reduce congestion while in rural corridors the focus is on safety. In rural corridors subject to frequent and severe winter weather conditions, VSL systems can aid drivers in selecting safe speeds for the current conditions. To ensure that the VSL systems will be effective, the posted variable speeds must reach the highest degree of speed compliance from drivers in the corridor.

The focus of this paper is to evaluate driver speed responses to VSL system in a rural environment subject to winter storm conditions where speed reduction and high compliance rate to improve safety are desired. A series of analyses were conducted in this paper to figure out how drivers' speed behavior was affected by VSL system and the factors effecting the driver speed compliance.

2. PROJECT DESCRIPTION

The rural interstate highway corridor used in this study paper is the Elk Mountain corridor, which located in the southeastern of Wyoming on Interstate 80 (I-80) between the towns of Laramie and Rawlins. The frequent adverse weather conditions cause this corridor to have higher crash rates than other segments of I-80 in Wyoming. In order to improve safety on the corridor the Wyoming Transportation Department (WYDOT) installed a Variable Speed Limit System in this corridor in February of 2009.

The project corridor is 52 miles long and begins east of Rawlins at milepost 238and ends west of the Laramie at milepost 290. The entire corridor is a four-lane interstate with two lanes in each direction separated by a median area. The project corridor is very rural in nature with very few services and most of the interchanges providing access to adjacent range land. According to WYDOT records the ADT on this corridor is near 11,000 per day with 50 to 60% of the vehicles being trucks depending on the time of year. The VSL corridor has seven VSL sign pairs (one on the inside and outside of the road) in each direction with an average spacing of 7 miles between signs. The signs use either scrolling film or LED technology as shown in Figure 1. The flashing beacon on top of each sign is activated whenever the speeds are reduced below the maximum speed of 75 mph. The scrolling film signs are limited to posing 75, 65, 60, 55, 50, 45, 40, and 35 mph. The LED signs can be posted at any speed but the current protocol for WYDOT is to close the road if the recommended speed would be less than 35 mph. During the initial implementation of the VSL corridor a seasonal speed limit of 65 mph was in place from October 15 through April 15 of each year. Beginning in the 2010-2013 winter season the seasonal speed limit was removed so the maximum speed limit was 75 mph year-round.

Figure 1: VSL Scrolling Film and LED Sign Types

Protocol for setting the variable speed limits for each sign was established for initial implementation of the VSL system. This protocol included coordination with Wyoming Highway Patrol (WHP) troopers, maintenance foreman, and the Traffic Management Center (TMC) and relied heavily on visual inspection of the road conditions preferably by WHP troopers. If a WHP trooper felt the conditions warranted a change in speed limits there was a set procedure to make the adjustment. If a WHP trooper was not on duty then a maintenance foreman could initiate a change in speed limits. Finally, if neither party were present to visually inspect the roadway, the lead TMC operator could follow a procedure to change the speed limits. Part of this research effort is to develop an automated protocol for setting speeds. It is anticipated that the automated protocol will be implemented in the near future.

3. LITERATURE REVIEW

There are number of studies focused on identifying the relationship between the traffic safety and speed variation and speed compliance. In 1988, a study was conducted to investigate the relationship between the speed variation and the accident rate (Garber and Gadirau 1988) . The results indicated that speed variation was significantly affected by the type of highway, roadway geometrics, and design speed. It was also revealed that as the speed variation increased the accident rate also increased. Similar results were found by Liu and Popoff in 1997 based on 26 years of data in Saskatchewan, Canada (Liu and Popoff 1997). This research indicated that casualties and casualty rate are correlated to speed variation.

The rational speed limit was selected with driver's common perception of the appropriateness of driving speed which helps to reduce the speed deviation and improve the road safety. A study regarding the use of rational speed limits in Virginia found that driver compliance increased substantially when the posted speed limit increased from 55 mph to 65 mph (Son, Fontaine and Park 2009). Other research looking at factors influencing speed found congestion level, weather conditions and visibility to be important (M. Giles 2003). Following up on a previous study, Giles created a multivariate analysis model which indicated that 62% of the speed variance could be explained by road environment and vehicles related variables (M. J. Giles 2004).

There are research studies looking at driver compliance and safety in a VSL corridor. A simulation was conducted in a VSL freeway corridor in Florida and the results indicate VSL has a significant improvement on safety by choosing the appropriate strategies (M. D. Abdel-Aty 2006). Lee and Abdel-Aty conducted a driving simulator experiment on a freeway section with VSL signs, the simulator results found VSLs are beneficial in reducing speed variation and crash risk (Chris 2008). A study conducted in Finland found that a VSL system where speeds were reduced during slippery road conditions decreased the risk of injury accidents, especially in harsh weather conditions, by efficiently helping drivers recognize hazardous weather and road conditions (Rama 1999). The Finnish VSL corridor had a fixed speed reduction when slippery road conditions and is not a fully variable speed limit corridor.

Another simulation based research study revealed that VSL impacts and safety benefits are very sensitive to driver compliance and that the level of safety was positively correlated with compliance level (Mandelzys and Hellinga 2011). This work supports previous results from Abdel-Aty et al. for a simulation study of a Florida freeway where safety benefits were also determined (Abdel-Aty, et al. 2008).

4. DATA ANALYSIS

Observed speed data from six storm events during the winter 2010-2013 was analyzed in this section. The individual data was obtained through the TMC in Cheyenne and analyzed as below:

1. 85th Percentile Speeds: 85th % speeds for cars, trucks, and combined vehicles are calculated for every 15 minute period and plotted with posted speeds for each storm event
2. Standard Deviation: The standard deviation for cars, trucks, and combined vehicles are calculated for every 15 minute period and plotted against time for each storm event.
3. Further Analyses of Standard Deviation and Speeds: The standard deviation of speeds and the difference between observed and posted speeds are further analyzed through the use of Box Plots and then analyzed relative to different deployment categories, which are based on the magnitude of the speed reductions.
4. Statistical Analysis: Linear regression model is estimated for the speed difference to determine factors affecting speed compliance.

Each of these analysis tasks are described in the followings. Data collected from all storm events was merged into one large file with multiple indicator factors to complete a more comprehensive analysis. The five categories created for this merged dataset were:

1. **DiffSpeed**, which is the actual difference in speed of the individual vehicle either positive or negative, above or below the posted VSL speed limit respectively.
2. **Direction** the vehicle was traveling either eastbound (EB) or westbound (WB).
3. **MP** the milepost the observation was collected from.
4. **Truck** factor indicating if the observation was of a car or truck. Vehicles are considered to be cars if their length is less than or equal to 24 feet and trucks if their length is greater than 24 feet.
5. **DeployCat** which is a categorical indication of what the speed limit was at the time the observation was collected.

The “DeployCat” consisted of five different categories:

1. ‘**a**’ indicated the speed limit was displayed at its maximum value, either 65 or 75 mph.
2. ‘**b**’ indicated the observation was collected during the transition period as previously defined.

3. ‘**c**’ indicated the speed limit was 15 mph or less below the maximum speed limit.
4. ‘**d**’ indicated the speed limit was 25 mph or less below the maximum speed limit.
5. ‘**e**’ indicated the speed limit was 30 mph or more below the maximum speed limit.

4.1 85TH PERCENTILE SPEEDS

Figure 2 shows the representative 85th percentile speeds of observations for 15 minute periods of cars, trucks and combined all vehicles for the March storm event at milepost 330. The other storm events show similar results. Posted speed limits for eastbound and westbound are the same. From these graphs a general trend was observed that car speeds seemed to be higher than truck speeds. The individual vehicle data was further analyzed to statistically prove this observation. The speed data from the cars and trucks for all cases were compared using a two sample t-test for mean assuming unequal variance was run at a 95% confidence level. For every milepost for all three storm events there was a statistically significant difference in speed between cars and trucks, with cars traveling faster in every case.

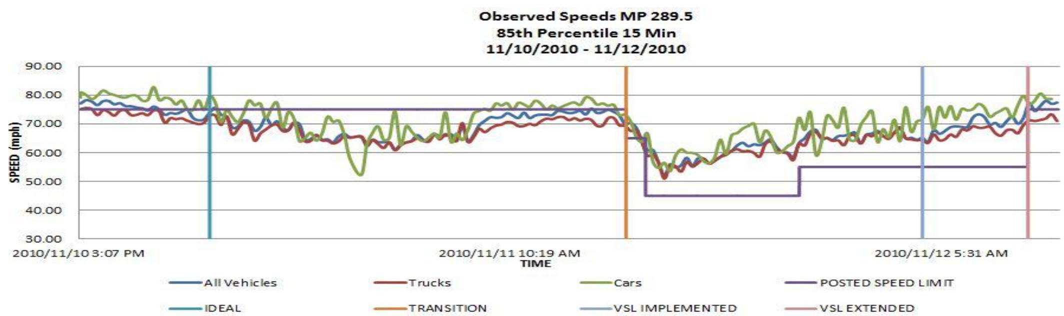

Figure 2: Observed 85th% Speeds on Elk Mountain corridor, November Storm at MP 289.5

4.2 STANDARD DEVIATION ANALYSIS

The standard deviation of speeds as an indicator of the speed variation was also calculated to see the influence of the VSL and determine if there was a significant difference in the standard deviation of speeds for cars as opposed to trucks. Reduction in standard deviation is believed to be related to improved safety of the roadway and is a goal of the VSL system. The standard deviation was calculated for 15 minute intervals of the individual observed speed data for cars, trucks and all vehicles for each milepost and storm event. Figure 3 shows the standard deviation for the March storm event at milepost 330 and is a representative example of the standard deviation graphs created for all three speed sensors for all three storm events.

The blue vertical line in Figure 3 marks the start of the VSL implementation, while the gray vertical line marks the end of the VSL implementation. In general during ideal time periods, before the storm events, the standard deviations of both cars and trucks are in the range of 5-10 mph. Also, during weather incidents the standard deviations of cars can be quite high (15 mph). The standard deviation data from the cars and trucks were compared using the standard deviation of the difference in the mean of the standard deviations. An F-test assuming independent variables and unequal variance was run at a 95% confidence level for all cases. Cars statistically are proved to have a higher standard deviation than Trucks at all mileposts for all the three storm events.

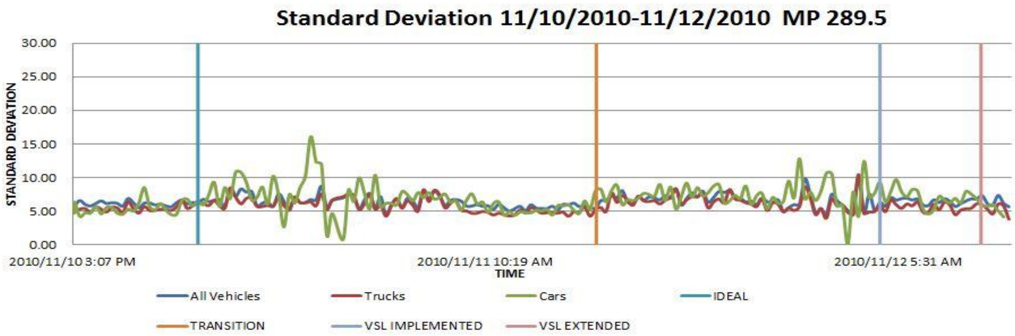

Figure 3: Standard Deviation of Speeds on Elk Mountain corridor, November Storm at MP 289.5

4.3 FURTHER ANALYSIS OF STANDARD DEVIATION AND SPEEDS

For the storm events from the winter of 2010-2013 the standard deviations and the speeds were further analyzed by categorizing the observations into four periods:

1. Observations under **ideal** conditions based on RWIS data to represent conditions before the storm event began.
2. Observations in the **transitional** period where RWIS data indicates worsening conditions but the variable speed limit not yet deployed.
3. Observations in the **initial** period of the VSL deployment.
4. Observations in the **extended** period of VSL deployment where speeds are starting to increase but the VSL speeds remain reduced.

Further analysis was done on all the six storm events. For each of these time periods the average speed, 85th percentile speed, and standard deviations are calculated and summarized a table.

Speeds were expected to be high and close to the maximum posted speed limit during the Ideal period and decrease during the weather becomes worse, VSL Implemented period was expected to have the lowest speeds due to the appropriate cooperate between the real time weather condition and the VSL system; Standard deviations are expected to be relatively low during the ideal periods and increase as the conditions worsen. Table 1 shown in this section is a representative of the corridor.

After implementation of the VSL system ideally the standard deviations would be lowered but due to the existence of the standard deviation of the posted speed limit this observation seems hard to achieve for most of cases. Thus, standard deviations of the speed difference for different deployment categories were analyzed to more accurately determine the speeds variation.

Figure 4 and Table 2 show the standard deviations of the speed difference changed by different deployment categories which represent the change of speed variation during the storm events. From the above analysis it can be seen that cars have higher standard deviation than trucks for every deployment category, and the standard deviation of the speed difference is the smallest when the posted speed limit is maximum; the transition period has a high standard deviation caused by the existence of the time lag between when the weather worsens and the implementation of the VSL where there is no speed choice guidance for drivers. Comparing with the transition period the standard deviation of speed difference decreased after the VSL implementation. However, there is an apparent trend that the speed variation increases with the magnitude of the decrease in posted speed limit.

Table 1: Further Analyses of Speed and Standard Deviation for November 2010 Storm for Elk Mountain

November 1-2 ,2010 Milepost 289.5				
TRUCKS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	11/1/2011 4:18:00 PM TO 11/1/2011 4:35:00 PM	11/1/2011 4:35:00 PM TO 11/1/2011 5:09:00 PM	11/1/2011 5:09:00 PM TO 11/2/2011 12:48:00 PM	11/2/2011 12:48:00 PM TO 11/2/2011 3:54:59 PM
# OBSERVATION	621	182	2509	2501
AVG SPEED	67.18	54.40	51.96	63.20
85% SPEED	73.10	64.59	62.10	69.60
STDEV	5.52	9.05	9.68	6.33

November 1-2 ,2010 Milepost 289.5				
CARS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	11/1/2011 4:18:00 PM TO 11/1/2011 4:35:00 PM	11/1/2011 4:35:00 PM TO 11/1/2011 5:09:00 PM	11/1/2011 5:09:00 PM TO 11/2/2011 12:48:00 PM	11/2/2011 12:48:00 PM TO 11/2/2011 3:54:59 PM
# OBSERVATION	276	88	703	716
AVG SPEED	74.09	57.72	52.05	67.67
85% SPEED	80.58	69.48	62.49	76.80
STDEV	7.08	10.75	9.87	8.26

Table 2: Standard Deviation of Speed Difference Analysis under Different Deployment Categories for Elk Mountain

	Standard Deviation of Speed Difference		
Deploycat	**Trucks**	**Cars**	**All Vehicles**
a	6.58	7.11	7.56
b	8.45	9.76	9.31
c	6.84	8.26	7.85
d	8.43	9.64	9.08
e	8.82	10.45	9.49

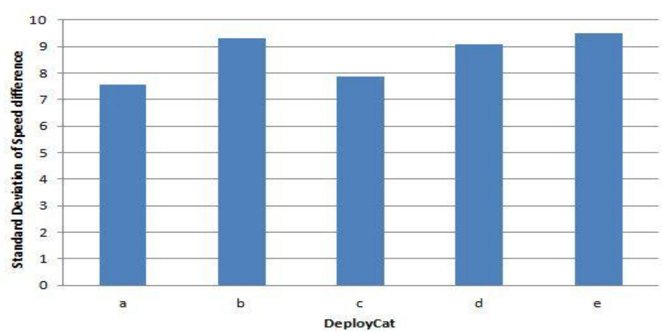

Figure 4: Summary of Standard Deviation of Speed Difference by Deployment Category for Elk Mountain

4.4 STATISTICAL ANALYSIS

In order to further analyze the factors influencing driver speed compliance a linear regression was also estimated. The speed difference (DiffSpeed) was used as the dependent variable in the regression model. As defined previously, the speed difference is the difference in miles per hour between the observed speeds and the posted speed limit so as the strict definition positive values indicate speeding. The base condition was selected as: passenger car driving at the east bound direction at the mileposts 256.2 and the VSL system is under the category of “DeployCat a”. Ideal period was selected as the base condition during this period the posted speed limit is maximum. Other selected factors in the model were described in the Data Analysis section. The results from the initial linear regression model with all variables included are shown in the Table 4.

Table 4: Linear Regression Model for Speed Difference for Elk Mountain Corridor

Variables	Coefficient	p-value
(Intercept)	-1.27	<0.001
DeployCat b	-4.76	<0.001
DeployCat c	6.72	<0.001
DeployCat d	9.82	<0.001
DeployCat e	15.29	<0.001
Truck	-5.12	<0.001
MP273.1	1.65	<0.001
MP289.5	2.01	<0.001
Direction (West Bound)	-1.63	<0.001

All of the variables included in the initial estimation of the model were found to be statistically significant at the 95% confidence level. The results show there is good speed compliance for the base condition. Based on the results in the regression, which indicates under the base condition the average speed difference is -1.27 indicating for deployment category a (Ideal road conditions and the posted speed limit is maximum) vehicles on average are traveling almost 1.3 mph hour lower than the posted speed. For the deployment category b (road conditions have worsened but no speed reduction implemented) the speed difference is as low as 6 mph below the posted speed limit this speed reduction is mainly caused by deteriorated weather and road conditions. Of the most interest are all the other deployment categories indicate increased speed difference (i.e. higher speeding) with increases in the speed difference from 6.72 mph to 15.29 mph. Compared to the base condition a 15 mph or less reduction in posted speed (DeployCat c) resulted in an average of 6.7 mph increase in the speed difference. Since the base case averaged 1.3 mph below the posted speed this result indicates there was a speed difference of 5.4 mph above the posted speed. For posted speed reductions greater than 15 mph but less than or equal to 25 mph (DeployCat d) there was a 9.8 mph increase in the speed difference resulting in an 8.5 speed difference above the posted speed. While the model estimate is slightly higher than deployment category c it should also be considered that the requested speed reduction was also higher so the overall magnitude of the speed reduction from drivers was higher even though the compliance was less. The last deployment category of posted speed reductions equal to or greater than 30 mph (DeployCat e) showed the largest increase in speed difference with an average of near 15.3 mph increase and an average driver traveling 13 mph above the posted speed. Once again the magnitude of the speed reduction requested must be considered although the results likely indicate that drivers have lower tolerance for very large speed reductions.

Trucks have better speed compliance than passenger cars since the truck variable decreases the speed difference by 5.12 mph. The speed difference at mileposts 273.1 and 289.5 is slightly higher than the milepost 256.2 by 1.65 mph and 2.01 mph respectively which is likely caused by differences geometric characteristics at those locations. Predominate wind direction is likely another cause for speed differences for vehicles traveling in the eastbound is higher than eastbound by 1.63 mph.

5. CONCLUSIONS

According to the analysis, the statistical tests indicated for most of the cases cars are traveling faster than trucks and also have higher variation in speed. For every storm event, milepost and period, trucks have a better speed compliance rate than cars. The results of the speed profile and standard deviation of the difference between the observed speed and posted speed analyses, it was found that implementation of

VSL helped to reduce the speed variation during the storm events by providing speed selection guidance to drivers.

The regression analysis result show the difference between the observed speed and posted speed continuously increases with the increasing of the reduction on posted speed limit. This means the speed compliance becomes worse with large posted speed reductions. This is likely due to low tolerance by drivers for the large reductions of the posted speed limit indicating the posted speed may be too conservative for most of storm event.

A good speed compliance rate is highly sensitive with the rational and timely implementation of speed reductions so an improved VSL control strategy would result in improved compliance.

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