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Using Naturalistic Driving Study Data to Investigate Driver Behavior at Highway-Rail Grade Crossings

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ABSTRACT

Although accidents at Highway-Rail Grade Crossings (HRGCs) have been greatly reduced over the past decades, they continue to be a major problem for the rail industry, causing injuries, loss of life, and loss of revenue. Recently, the Strategic Highway Research Program sponsored a Naturalistic Driving Study, the SHRP2 NDS, which produced a unique opportunity to look at how drivers behave while traversing HRGCs. This research deviates from previous studies by concentrating on day-to-day actions of drivers who traverse the HRGCs without an incident, instead of focusing on the accident events that have formed the foundation most earlier studies. This paper will focus on the effects of the external environment, weather and day/night conditions, on driver behavior at HRGCs. We will present the methodology and data used for the study and provide some early results from the analysis, such as differences in compliance during poor versus clear weather. We will use both a compliance score based on scanning and speed reduction and an analysis of brake and gas pedal usage during the approach to a HGRC. The paper will conclude with a brief discussion of future research concepts.

Key words: grade crossing, crossbuck, naturalistic driving study, traffic control device

INTRODUCTION

Driver's behavior and response to the traffic control devices (TCDs) at highway-rail grade crossings (HRGCs) are key elements in both the cause and prevention of accidents at these locations. Recently, the Strategic Highway Research Program sponsored a Naturalistic Driving Study, the SHRP2 NDS [1], which produced a unique opportunity to look at how drivers behave while traversing HRGCs. This research deviates from previous studies by concentrating on day-to-day actions of drivers who traverse the HRGCs without an incident, instead of focusing on the accident events that have formed the foundation most earlier studies. Previous studies have shown that driver behaviors or poor judgement account for over 90 percent of HRGC accidents, and over 85 percent of the fatalities [2]. Analysis of driver behaviors and knowing how the drivers respond to TCDs in place at HRGCs under different conditions (i.e. day vs. night, clear vs. rain and snow) may help to understand and predict driver behavior and to improve certain aspects of the HRGC environment. Improved understanding of driver behavior at HRGCs will help develop better resources to mitigate the dangers and challenges found at these locations. The Michigan Tech research team is using data from over 300 HRGCs and more than 12,000 traversals of those HRGCs in this analysis.

METHODOLOGY

In our research, comparison between various factors is accomplished throughout the use of a "compliance score" that evaluates driver preparations during the approach to an HRGC [3]. This compliance score was developed as a means to translate qualitative data found in the SHRP2 NDS data set into quantitative data suitable for statistical analysis. All types of HRGCs, (active lights with gates, active lights without gates and passive) should have the R15-1 crossbuck installed as required by the MUTCD. Drivers are required to respond to this sign by yielding the right of way to rail traffic at the HGRC. Drivers should cross the HGRC only after they make sure it is safe to cross and there is no train in their vicinity that would create a hazard to traversing the HGRC. The score uses a combination of head rotation and vehicle speed changes to evaluate whether the driver has looked for a train and prepared to stop as expected, if a train were present. A 3-point compliance criterion is used for performance analysis of driver behaviors during each traversal consisting of one point for scanning to the right, one point for scanning to the left and one point for speed reduction while approaching grade crossings. The total compliance score is the sum of scanning and speed changing scores.

The SHRP2 NDS data set also includes information about gas pedal and brake applications during each vehicle trip. The brake data is a binary reading, either the brake is applied or it is not. The gas pedal data is collected with a range score, with values from 0-100, and essentially gives the percent depression of the pedal. However in this initial analysis the gas pedal results were also treated in a binary fashion, any reading above zero was considered as a depression, with the driver's foot on the pedal. Only data records with complete continuous data throughout the approach to the HRGC were used in this analysis.

There are different ways to evaluate and compare the behavior at HRGCs. We have performed some preliminary statistical evaluations using Average Annual Daily Traffic (AADT), roadway speed limit, train speed limit, and passive vs. active grade crossings and reported on them in a previous paper [3]. However, comparisons between multiple crossings are challenging, as environmental, geometrical and traffic conditions vary between crossings, reducing the ability for unbiased comparison. On the other hand, comparison of driver behavior within a single crossing reduces the complexity, as it allows extraction of specific parameters for comparison, while other aspects remain static. This paper will focus on effects of different weather conditions (i.e. clear, rain, snow) on the total compliance score for HRGCs, and will also discuss the relationship between weather conditions and brake and gas pedal application during traversals.

ANALYSIS AND DISCUSSON

A study performed earlier at Michigan Tech using the same data and methodology indicated that crossings with passive TCDs have the higher compliance scores when compared to crossings with active gates and active flashing lights. This could imply that drivers rely more on performance of the active TCDs rather than their own analysis of the crossing environment. Other attention-grabbing early outcomes of the basic trending analysis performed so far indicate that the compliance score decreases both when the highway traffic volume increases and when the number of trains per day decreases. [2] However, the simple single variable analysis performed to date does not account for the variety of factors that affect driver behavior, such as the geometric differences mentioned above or the fact that as highway traffic volume increases HRGCs are more likely to be protected by active TCDs. Future analysis work will use a multi-variate analysis to evaluate both the TCD impact and traffic volume impact together.

Weather Impact on Driver Performance at HRGCs

Driving is a multi-task action and visual performance is a large part of the driver performance. The driving task also requires other activities such as controlling the vehicle direction, adjusting speed and evaluating inputs from TCDs and other environmental variables. Many of these actions require a visual input to begin the process. Considering that, poor visibility situations such as snow, rain, and fog weather could impact driver's behavior and their ability to collect and use the necessary visual information.

The literature includes several studies that have been done in different climate conditions to document weather impact on general driver behavior, traffic signal operation, traffic flow and number and types of accidents. For example, precipitation (type, rate, start/end times) negatively impacts pavement friction, visibility distance and lane obstruction causing reduction in roadway capacity and traffic speed and increase in travel time delay and crash risks. [4] Visibility challenges (clear day, fog, etc.) resulting from different weather conditions has an impact on driving performance of older adults (M age = 70.8 years). [5] Compared to crashes under clear-visibility conditions, fog or smoke related crashes result in more severe injuries and involve more vehicles. [6] Inclement weather has significant impacts on car following behaviors resulting in a higher frequency of rear-end crashes. [7] Finally, one study indicates that rain is one of the adverse weather conditions which causes the most significant negative impacts on traffic safety. When it is raining, driver's visibility, skid resistance and vehicular stability (such as braking stability and steering operation) are affected causing reduction in traffic operational speed and increase in potential traffic crashes [8]. We found no evidence in the literature that directly discussed weather impacts on driver behavior at HRGCs.

The basic premise for performing weather impact analysis of driver behavior at HRGCs in general was that if the weather condition impacts driver performance, traffic flow, traffic accident occurrence and type as indicated in the literature, one could expect an adjustment in driver behavior during adverse weather condition traversals of HRGCs as well. This study investigated whether such adjustments could be observed in the compliance scores already developed.

Table 1. Weather Impact on Average Compliance Score – (POMP is Percent of Maximum Possible)								
Weather Condition	**#Crossings**	**#Traversals**	**Avg. Speed Score**	**Avg. Scan Score**	**Avg. Total Score**	**Speed Score (POMP)**	**Scan Score (POMP)**	**Total Score (POMP)**
Clear	299	11608	0.75	1.24	1.98	75%	62%	66%
Cloudy	35	296	0.84	1.41	2.25	84%	70%	75%
Rain	212	595	0.73	1.22	1.96	73%	61%	65%
Fog	8	9	0.78	1.00	1.78	78%	50%	59%
Snow	64	196	0.85	1.22	2.07	85%	61%	69%

Table 2. Summary of paired T-Test for Different Weather Conditions, 95% Confidence Interval and Null Hypothesis of Means are the Same

Condition Pair	df	t Stat	P(T<=t) two-tail	t Critical two-tail
Rain vs. Clear	652	-0.6269	0.5309	1.9636
Cloudy vs. Clear	315	-5.3965	0.0000	1.9675
Fog vs. Clear	8	1.3997	0.1992	2.3060
Snow vs. Clear	139	-1.0639	0.2892	1.9772
Rain vs. Snow	216	-1.2465	0.2139	1.9710
Rain vs. Cloudy	682	-4.6270	0.0000	1.9634
Rain vs. Fog	9	1.1822	0.2674	2.2622
Cloudy vs. Fog	10	3.0508	0.0122	2.2281
Cloudy vs. Snow	246	2.0229	0.0442	1.9697
Fog vs. Snow	13	-1.7388	0.1057	2.1604

In this study, the data from 12644 traversals of 299 crossings was used to study effects of weather (clear, cloudy, rain, for, or snow) on total compliance score. This preliminary work is based on single variable analysis, but we recognize that additional work will be needed to include impacts of other variables on this result. The average compliance scores for each category of the weather conditions were calculated and are shown in Table 1. The three right most columns are percent of maximum possible (POMP) values.

Paired t-tests were run for all weather condition pairs to establish statistical validity of the results, and are reported in Table 2. The scores in Table 1 indicate that drivers have the lowest scores in all categories for fog conditions and the highest in cloudy conditions. Speed, scanning, and total scores for clear and rain conditions are nearly the same, and paired t-tests showed that to be true. The compliance scores for cloudy conditions are the highest, and are statistically different from all four of the other categories.

We also took a first look at the difference between daytime and nighttime results. Table 3 compares compliance scores for these conditions.

A paired t-test revealed there is no statistical difference between driver's compliance at HRGCs during the day vs. night conditions.

Table 3. Day vs. Night Condition Impact on Driver Compliance Score – (POMP is Percent of Maximum Possible)

Time	**No. Crossings**	**No. Traversals**	**Speed Score**	**Scan Score**	**Total Score**	**Speed Score (POMP)**	**Scan Score (POMP)**	**Total Score (POMP)**
Day	298	10400	0.75	1.24	1.99	75%	62%	66%
Night	295	2223	0.73	1.24	1.97	73%	62%	66%

Brake and Pedal Depression Analysis under Different Conditions

Braking and gas pedal application while crossing the HRGCs were considered to further understand driver performance at HRGCs under different time and weather conditions. To achieve that objective, we looked at the data from 296 crossings consisting 5592 traversals. The gas pedal and braking actions of drivers within 600 ft. of the HGRC were used to find the percentage of time within this distance for three conditions: brakes applied; gas pedal applied; and neither brake nor gas pedal applied. Table 4 compares different weather conditions with the brake and gas pedal data. There were only three valid traversals for braking and gas pedal applications in foggy weather, which is too small a sample to make any conclusions. Fog conditions are not shown in Table 4.

being fully depressed. This may offer some additional ways to investigate gas pedal behavior in future research.

RESULTS

Compliance score vs Weather

Much of the analysis done to date has focused on single variables. In this paper we looked at weather and day/night comparisons of driver behavior at HRGCs. In Tables 1 and 2 we used compliance scores to look for difference in behavior, expecting that drivers would behave differently given the different environmental conditions. We found that cloudy conditions resulted in the highest compliance scores, and that fog conditions gave the lowest. However, the fog low number of fog condition records limit the reliability of that result. Interestingly there does not appear to be a statistical difference

Table 4. Weather Impact on Brake & Gas Pedal Depression at HRGCs

Condition	#Crossings	#Traversals	*Brake Pedal Depression (%)*	*Gas Pedal Depression (%)*	*Not Applying any Pedal (%)*
Clear	296	5135	19%	60%	21%
Cloudy	32	120	20%	60%	20%
Rain	145	271	17%	62%	21%
Snow	45	63	18%	51%	31%

Table 5. Day vs. Night Impact on Driver's Braking and Speeding Behaviors

Time	#Crossings	#Traversals	*Brake Pedal Depression (%)*	*Gas Pedal Depression (%)*	*Not Applying any Pedal (%)*
Day	296	4673	19%	59%	22%
Night	252	917	18%	61%	21%

A two-sample t-test shows that the brake application for these conditions are not statistically different. However, the results for gas pedal application under snow conditions are statistically different, and it appears drivers remove their foot from the gas pedal more often under snow and fog conditions while approaching a HRGC.

As shown Table 5, day versus nighttime driving did not have major impact on driver braking or gas pedal depression behaviors as the small difference shown in the Table is not statistically significant.

In this preliminary work gas pedal depression was considered in a binary fashion, either the gas pedal was depressed, or it was not. However, the data available provides a range of pedal depression on a scale of 0-100, with 100

between the clear and rain conditions or the clear and snow conditions. As illustrated in Table 3 and the paired t-test that was done for the Day/Night comparison there is no significant difference between these categories.

Brake/Gas Pedal Application vs Weather

Brake application is seen in about 20% of the traversals (Table 4) in all weather conditions, and the gas pedal is released in about 40% of traversals in clear, cloudy, and rain conditions, with t-tests that confirm the values are statistically equal. However, gas pedal release is significantly higher, at just under 50% in snow conditions.

There is no significant difference between either the brake or gas pedal application rates when comparing day and night traversals.

CONCLUSION

From this preliminary analysis, it appears that the weather conditions do not greatly affect driver behavior at HRGCs in comparison with weather impact on general driver behavior, traffic signal operation, traffic flow and number and types of accidents as seen in the literature. The data shows, there is no statistical difference between average compliance scores under rain, fog, and snow conditions versus clear weather condition. However, driver compliance scores under cloudy weather conditions are statistically different and drivers recorded higher compliance scores under cloudy conditions compared to other situations. This result is somewhat surprising, as we expected to see a difference in adverse weather conditions, like rain. It's difficult to speculate on what might cause the cloudy weather increase, it could be that with the improved visibility available on cloudy days (no rain, snow, or glare from bright sunshine) drivers pay more attention to their surroundings and focus less on the road ahead. The data also shows that drivers get the lowest compliance score under fog conditions, however, more data is needed to get a statistically acceptable sample size for this situation. Future improvements in the compliance score methodology may improve our understanding of the weather impacts.

The weather condition does not impact the brake pedal depression results found in this analysis of driving behavior at HRGCs, however the data shows the drivers remove their foot from the gas pedal more often under snow condition compared to other weather conditions. This is consistent with the idea that drivers are a little more cautious in approaching a HRGC in slippery conditions than in conditions with more traction. This finding would also be consistent with the idea that traction does not change dramatically on many roads under light or moderate rain conditions. The brake and gas pedal results were statistically the same for night vs day situations. We expected drivers would be more cautious at night, but it is unclear at this point why we don't see that result.

FUTURE RESEARCH

Future work on this research will include deeper analysis of driver behavior. We are investigating the use of the brake/gas pedal data to supplement or replace the speed reduction data used in the speed score. We will compare crossings with lowest and highest compliance scores to see if there are environmental similarities or differences. We plan to investigate driver behaviors at HRGCs that have had accidents in recent years to see if driver behaviors at those crossings might lead to accident conditions. Finally, we intend to investigate influence of other crossing environment variables including obstructions preventing a clear view down the tracks and crossing surface roughness on driver behavior. As we move further into the analysis we will begin to use multivariate analysis to find the factors that most affect observed behavior. The ongoing research program at Michigan Tech will provide more detailed analysis of these factors, and will also begin to compare the results found in the SHRP2 NDS work with analysis performed in a driving simulator environment.

Disclaimer: "The findings and conclusions of this paper are those of the authors and do not necessarily represent the views of VTTI, SHRP2, the Transportation Research Broad, or the National Academies."

REFERENCES

[1] Jon Hankey, "Transportation Institute will share massive trove of driver research data", *Virginia Tech News*, May 1, 2015. Available: https://vtnews.vt.edu/articles/2015/05/050115-vtti-datasharingproject.html

[2] Audit of the Highway-Rail Grade Crossing Safety Program, Office of the Inspector General, Report No. MH-2004-0650 June 16, 2004 Available: https://www.oig.dot.gov/library-item/30001

[3] Pasi Lautala, Modeste Muhire, Alawudin Salim, Myounghoon Jeon, David Nelson, and Aaron Dean, "The Assessment of Driver Compliance at Highway-Railroad Grade Crossings Based on Naturalistic Driving Data", Submitted, TRB 2018

[4] L. Goodwin and P. Pisano, "Weather-Responsive Traffic Signal Control", *ITE Journal*, June 2004, pg 28-30. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.376.4152&rep=rep1&type=pdf

[5] Lana Trick, Ryan Toxopeus, David Wilson, "The effects of visibility conditions, traffic density, and navigational challenge on speed compensation and driving performance in older adults", *Accident Analysis & Prevention*, Volume 42, Issue 6, November 2010, Pages 1661-1671 Available: https://doi.org/10.1016/j.aap.2010.04.005

[6] Mohamed Abdel-Atya, Al-Ahad Ekrama, Helai Huangb, Keechoo Choi, "A study on crashes related to visibility obstruction due to fog and smoke", *Accident Analysis & Prevention*, Volume 43, Issue 5, September 2011, Pages 1730-1737 Available: https://doi.org/10.1016/j.aap.2011.04.003

[7] Ye Lia, Lu Xing, Wei Wang, Hao Wang, Changyin Donga, Shanwen Liub, "Evaluating impacts of different longitudinal driver assistance systems on reducing multi-vehicle rear-end crashes during small-scale inclement weather", *Accident Analysis & Prevention*, Volume 107, October 2017, Pages 63-76

Available:
https://doi.org/10.1016/j.aap.2017.07.014
[8] Xiaonan Cai, Jian John Lu, Yingying Xing, Chenming Jiang, Weijie Lu, “Analyzing Driving Risks of Roadway Traffic under Adverse Weather Conditions: In Case of Rain Day”, *Procedia-Social and Behavioral Sciences*, Volume 96, 6 November 2013, Pages 2563-2571 Available:
https://doi.org/10.1016/j.sbspro.2013.08.287