Driver Behavior at Highway-Rail Grade Crossings Using Naturalistic Driving Study Data and Driving Simulators

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Abstract

While it has been long recognized that a full understanding of driver behavior at highway-rail grade crossings (grade crossings) is one of the key elements to improve safety, collection of data to analyze the behavior has been challenging. Various approaches such as statistical, observational, and driver survey studies, have been tried over time with limited success. This paper discusses two promising new approaches for such analysis: the use of a Naturalistic Driving Study (NDS) database, and analysis conducted with driving simulators. The NDS data contains video and vehicle sensor data of drivers in their own vehicles driving routes they use in their normal daily routines. This data can be mined to look at driver behavior at grade crossings, including the behavior of drivers who pass through grade crossings without an incident. The current work at Michigan Tech has concentrated on developing tools for reduction and organization of the NDS data, so it’s more appropriate for mining efforts. The second approach uses driving simulators to study driver behavior at grade crossings, as simulators are quickly becoming a leading tool for researching various aspects of driver behavior. Current simulator research at Michigan Tech has investigated driver behavior in the grade crossing environment. Although driving simulators are an excellent tool for analyzing driver behavior, additional work is needed to validate the results in the grade crossing environment. A combination of NDS and simulator data may provide the link needed for this validation and is highlighted as one of the key objectives for future research.
Introduction
Since 1990, the number of highway-rail grade crossing (grade crossing) collisions per year has decreased by nearly 60 percent, but according to the USDOT Federal Railroad Administration (FRA), grade crossing and trespasser deaths still account for 96 percent of all rail-related fatalities [1]. Furthermore, both the number of collisions and fatalities have shown a ‘plateau’ effect since approximately 2008, as seen in Figure 1 [2]. As a result, the current FRA Administrator has made grade crossing safety one of her key priorities and has established a task force to coordinate the effort [3].

A review of accident causes reveals that one of the main causal factors is human driving behavior. Driver ignorance of rules for passive and active warning devices at grade crossings is also a problem. There have been several documented attempts to analyze driver behavior at grade crossings [4,5] that have used different approaches, such as after-the-fact statistical evaluation of traffic control measures implemented at crossings, and external observation of driver actions (direct observation and/or video analysis of crossings). These approaches have shortcomings, such as taking years to reveal the effects of implemented safety measures (statistical evaluation), or providing no insight into what the driver is doing during the approach to a crossing (external observation).

Two promising approaches that allow a direct observation of drivers include in-vehicle video recordings of drivers in natural environment and observation of drivers in driving simulators. One study that collected forward camera and head position video during naturalistic driving was used for after-the-fact study driver behavior at grade crossings [6]. Driver simulator studies have also received growing attention, such as work at Colorado State University, and the work already done at Michigan Tech in this area [7,8,9,10,11,12].

Project Description and Goals
This research concentrates on a direct and detailed observation of the drivers. The approach relies on two major components; the analysis of Strategic Highway Research Program 2 Naturalistic Driving Study
data and observation of driver behavior in a driving simulator. The goal of this research is to utilize the NDS data to analyze natural driver behavior at grade crossings and to later use the results for validation of simulator research. The NDS data contains video and vehicle sensor data of drivers in their own vehicles driving routes they use in their normal daily routines. The primary focus of this study revolves around whether a driver’s reaction to grade crossings and related warning devices matches the message provided by the warnings. For example, are drivers looking for trains and are they slowing down when seeing warning signs at the approach to the crossing? By using the data set from the NDS to develop a method of evaluating driver response to traffic control devices at grade crossings, we can start to assess whether drivers are responding in a manner expected by the engineers who designed the devices. We will also be able to assess whether further improvements can be made to these warning/control devices to enhance driver safety in an efficient and cost effective manner.

**Approach and Methodology**

The research team collaborated with the Virginia Tech Transportation Institute (VTTI) to secure an initial set of NDS data for drivers approaching and traversing grade crossings. Federal Railroad Administration grade crossing database and NDS trip maps were used to identify/select crossings of interest for analysis. The work to date has included three different crossing locations and approximately 100 traversals per crossing. Figure 2 shows the flowchart for the NDS data analysis and follow-up work with driver simulators.

![Flowchart of NDS data analysis](image)

**Figure 2. Michigan Tech Research Process**

After receiving the initial dataset of approximately 300 crossing traversals, the key data, such as vehicle network speed, acceleration, gas pedal depression, brake pedal release/application, and driver head tracking were extracted and organized in a spreadsheet format.

The forward facing video and the grade crossing characteristics were used to classify each transit. The classification included crossing location ID, direction of traversal, and transit ID, as well as key environmental factors. Figure 3 breaks down the data based on time of day, weather condition, and traffic conditions. Other standardized identifiers, such as the advanced warning device location, crossing location, and the location of any intersecting roads were also recorded with respect to the video timestamp. These factors will be used in the next phases for comparing driving behavior based on the...
variation between crossing environments. Driver demographics are also available from the NDS, which will allow us to compare driving behavior based on age, gender, and other factors.

Figure 3. Distribution of Key Environmental Factors for Current Sample of Traversals

After classification, a computer algorithm was developed to automate the display of key data sets. Our initial vehicle data graph displayed such interests as vehicle acceleration, throttle position, brake pedal release/application, and vehicle speed. The crossing environment database streamlined the process for developing location specific graphs. A researcher would enter the preset crossing location as well as the transit direction and identification number, and the specific plot would be generated by the program (Figure 4). The plot shows vehicle acceleration, throttle position, brake release/application, and vehicle speed with respect to time. The red vertical line shows the location of the advance warning device and brown the location of the tracks in the crossing. Black is used for intersecting roads and other objects of interest. The environmental factors recorded previously such as time of day, weather, and traffic are also included as labels for ease of analysis.

**Driver Head Tracking Analysis**

Head tracking data provided with each traversal is one of the key components for analyzing a driver's behavior at crossings. Split-second decisions that impact driver safety are made based on drivers’ visual observations. Looking for a train is the best defense a driver has against a potential collision, especially at crossings, where no active warnings are present (passive warning only).
Driver looking behavior can be extracted with two different methods:

- A staff member at VTTI can watch the video segments in the driver facial video feed and develop a visual narrative based on the looking behavior observed.
- In-vehicle automatic detection and computer facial recognition can be used to record raw head rotation and position data.

The visual narratives are expected to be a more accurate method, but extracting frame-by-frame looking behavior from the driver video can be extremely time consuming and costly. This method also involves the use of personally identifiable data, as a researcher would need to see the drivers face to record looking behavior. By the terms of the original NDS’s research plan, personally identifiable analysis can only be done at VTTI.

The use of facial recognition head tracking data offers a promising alternative for analysis, but the head tracking data is dependent on how well the tracking sensors and software can record the actual head position. A head confidence value; a measure of how confident the system is in the values provided, is part of the data set. While most of the traversals have high head confidence values, low values can create sporadic or inaccurate data. Our work has focused on investigating the correlation between head rotation and narrative data. A positive correlation would allow the sole use of head tracking in place of visual narratives, increasing the efficiency and removing the restrictions posed by personally identifiable data.

A small set of traversals was selected for comparative analysis and to develop the automated method from raw data. The methodology developed includes a coding scheme for the narrative data that evaluates the line-of-sight angles for different “objects of interest” noted in the coded narratives obtained...
from VTTI, as seen in Figure 5. The equivalent angle values, which can be correlated with the head tracking data for each object of interest provided in the narrative, are presented in Table 1.

**Figure 5. Line-of-Sight for Various Objects of Interest**

**Table 1. Coding Legend for VTTI Narrative**

<table>
<thead>
<tr>
<th>Objects of Interest</th>
<th>Head Rotation Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward</td>
<td>0</td>
</tr>
<tr>
<td>Left Window/Mirror</td>
<td>33.69</td>
</tr>
<tr>
<td>Right Window/Mirror</td>
<td>-61.82</td>
</tr>
<tr>
<td>Left Windshield</td>
<td>14.04</td>
</tr>
<tr>
<td>Right Windshield</td>
<td>-45.12</td>
</tr>
<tr>
<td>Interior Object</td>
<td>0</td>
</tr>
<tr>
<td>Instrument Cluster</td>
<td>0</td>
</tr>
<tr>
<td>Cell Phone</td>
<td>-5</td>
</tr>
<tr>
<td>Rearview Mirror</td>
<td>-29.48</td>
</tr>
<tr>
<td>Center Stack</td>
<td>-29.48</td>
</tr>
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</table>

Figure 6 shows both the automated head tracking and narrative data displayed together. The upper plot shows lateral head rotation (looking left or right). Red is the visual coded narrative, blue is the head tracking data. The lower plot illustrates the correlation between the two head rotation plots. Based on early results, the method looks promising, but to date only ten traversals have been analyzed in this manner. For about half of them, the correlation seems fairly good; for the rest there are some discrepancies. However, it appears that the use of improved baseline and minimum head confidence values to interpret the data, may enhance the correlation. Within the programming code, the algorithm could be set to remove low confidence points and interpolate between points with a higher level of head confidence and create a more consistent representation of the driver’s looking behavior. We also realized that for the narrative coding process, we may need to make adjustments for peripheral vision instead of using direct line-of-sight for the head rotation. As research continues, modification to the narrative coding process and improvements in plotting techniques will be investigated to achieve a better match between the head tracking and narratives; and to obtain a valid method for using the head tracking data in ongoing research.
Integration with Driver Simulator Research

Driver simulators are quickly becoming a leading tool to research various aspects of driver behavior, but concerns have been raised by the rail industry about whether behaviors in a simulator setting accurately reflects those in real life. The driver simulator research to date has included two studies.

The first study used a simulator to investigate driver looking behavior, and the second one concentrated on developing in-vehicle auditory warnings of approaching grade crossings and evaluating their effect on the driver behavior [9, 10]. The first study recorded behavior for a total of 35 drivers. Eye-tracking software was used to track the visual scanning pattern by the drivers when approaching grade crossings. Figure 7 presents an eye-tracking plot for the first study. The axes show deviation in inches on the forward screen, from the drivers “normal” straight ahead vision position, both vertically and horizontally. The forward screen in the simulator is 24 inches tall, and 40 inches wide. The blue points represent eye tracking locations of one participant for the ‘pre- critical zone’ with the red locations of the critical zone superimposed. Both zones were 20 seconds in length. The x and y axis represent (in inches) the location on the windshield matching the drivers sight line. Note that the red points show the driver looking further right and left in the critical area. The study found that scanning patterns improved in the simulator after a train was presented. However, trends were not extracted from the data due to issues with timing and position of the looking behavior. “Proper” looking can take place at different locations for different drivers, and it is equally valid to first scan either left or right during the approach. It was also later recognized that the timing of eye tracking was not optimal, a “critical” zone of 20 seconds before the crossing was used, when a zone of 5-10 seconds would have been more appropriate.
Our second study focused on in-vehicle warnings and their effectiveness in modifying driver behavior [12]. In response to the problems found in the first study with identifying trends, a "compliance score" was developed to evaluate the effectiveness of warnings in the simulator environment. Table 2 shows the coding scheme.

Table 2. Modified compliance coding scheme for study 2.

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Figure 7. Eye tracking data for a single participant
With this coding scheme behaviors of a group of participants can be aggregated and displayed. Figure 8 shows some of the results to date. The study group for this effort included 20 university students randomly assigned to either Group A or B. Each group drove six circuits of the scenario, Group A started with no in vehicle audio warnings (IVAA) for Track 1 (the first three circuits) and then received IVAA for Track 2. Group B reversed the order, and received IVAA for Track 1 and none for Track 2. Note that a train was presented in both cases on the 23rd crossing (full gate). The results suggest that the IVAA improve the behavior significantly, even after the IVAA’s were removed for Group B. Also note that the gated crossings were not active, except when the train was present on the 23rd crossing.

![Compliance Over Time by Group](image)

**Figure 8. Compliance scores with and without In Vehicle Auditory Alert (IVAA) notification over time.**

A future objective is to investigate the utility of using the NDS data to help validate the results obtained from the simulator research. The planned process is to use NDS data to identify crossings for research and then model the actual crossing as closely as possible in the simulator. For comparative driver behavior evaluation, we continue to work with the "compliance score" noted in Table 2 that can be used in both environments. This score will include looking behavior, throttle position, brake activation, and other factors yet to be determined to compare the reactions of simulator participants to the NDS data. An iterative process can be used to validate the simulator environment for experimental work. Once the simulator environment is validated we can design different types of active or passive warnings in the road scenario, and test driver response to them.

**Conclusion**

Collisions between trains and highway vehicles at grade crossings continue to be a problem for the rail industry. Understanding the behavior of drivers as they approach crossings can help to restart the
downward trend from the recent plateau in the collisions, and the injuries and fatalities they cause. The NDS data provides an extensive database that allows the research of driver behavior as they encounter crossings in their natural settings. The NDS data contains video and vehicle sensor data of drivers in their own vehicles driving routes they use in their normal daily routines, providing an insight into driver behavior. Automated methods for using head-tracking data are showing good correlation to narratives of the same crossing traversal, and look promising for large scale research. Other components of the NDS data set will be easy to integrate into our research program. The next step will be to acquire additional data to begin looking for relationships between the behavioral and environmental variables.

Driver simulators offer a controlled setting to research driver behavior at grade crossings. The studies conducted to date at Michigan Tech have found that simulators provide the ability to directly observe driver actions and behaviors, and that those observations can be used to design methods to improve driver response at Railroad-Highway grade crossings.

In addition to expanding the NDS data analysis to much larger data sets, future research will also concentrate on synchronizing the NDS research with driver simulator research and using the outcomes to investigate the correlation of results in simulator vs. natural setting. One of the first steps has been to develop a compliance score usable in both environments. The next steps include the development of simulator scenarios that mimic existing environment and operational pattern. Once established, it is expected that synchronized datasets can be used to investigate the validity of simulator outcomes.

References


Table of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Pg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Grade Crossing Collisions and Fatalities per Year</td>
<td>3</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Michigan Tech Research Process</td>
<td>4</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Distribution of Key Environmental Factors for Current Sample of Traversals</td>
<td>5</td>
</tr>
<tr>
<td>Figure 4</td>
<td>NDS data plot</td>
<td>6</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Line-of-Sight for Various Objects of Interest</td>
<td>7</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Head-tracking and narrative data compared</td>
<td>8</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Eye tracking data for a single participant</td>
<td>9</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Compliance scores with and without In Vehicle Auditory Alert (IVAA) notification over time</td>
<td>10</td>
</tr>
</tbody>
</table>

Table of Tables

<table>
<thead>
<tr>
<th>Table</th>
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</tr>
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<tbody>
<tr>
<td>Table 1</td>
<td>Coding Legend for VTTI Narrative</td>
<td>7</td>
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<tr>
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OVERVIEW

- Background
  - Naturalistic Driving Study
  - Simulator Research
- NDS Research Program
- Simulator Research Program
- Combining These Programs
- Conclusions

BACKGROUND

Strategic Highway Research Program
Naturalistic Driving Study (NDS)

- Instrumented over 3,500 private vehicles
- Over 5 million trip records
- Includes front and rear video, throttle, brake, speed, acceleration and head tracking
- Can be “mined” to collect data at Highway-rail grade crossings
- Our Plan – Use NDS to study driver behavior at crossings

Collecting Data

- Local institutional review board approval and data sharing with Virginia Tech
- First data set 300 crossing traversals at three crossing locations
- Enough data to build reduction and analysis tools
- Not enough to establish relationships between crossing variables
- Data provided in Excel spreadsheet format

Data Analysis

- Throttle position and brake data offer straightforward analysis

Data Analysis

- Head tracking needed more work
  - Incomplete and low confidence data
  - Matlab code developed
  - Compare machine vision with narrative

Head Tracking Results vs Narrative

Blue line shows machine vision, red our coded narrative
Head Tracking Results vs Narrative

Driver Simulator Studies
- NADS Mini Sim
- Can build scenarios to match any driving situation
- Can guarantee a grade crossing incident for every study participant
- Controlled environment for observation and data collection

Phase 1 – Eye Tracking and System Calibration
- Established data collection techniques
- Began development of crossing scenarios
- Small scale, inconclusive results

Sample data from Phase 1 – Eye focus position on simulator screen
Red in critical zone, blue rest of “trip”

Phase 2 – In Vehicle Auditory Alerts
- New Scenario - Both urban and rural
- Passive crossings with stop signs and yield signs

Current Work
- Effectiveness of warning systems and auditory cues
- Developed compliance scoring

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CURRENT WORK

**COMBINING NDS AND SIMULATOR**

**NDS**
- gives long-sought info on what drivers actually do at crossings, including drivers who have no incidents
- No ability to test new ideas

**Simulator**
- Can test both existing and new systems
- Relatively easy to modify scenarios
- Can control activities that affect drivers (trains/warning devices)
- Unclear if results match “real life”

**CONCLUSIONS**
- Driver behavior/response to various warnings at crossings still poorly understood
- The NDS can provide valuable insight through direct observation
- Driving simulators provide a productive research environment
- Two programs together expected to improve the quality/credibility of results

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