U.S. Department of
Transportation

Federal Railroad
Administration

Driver Behavior Analysis at Highway-Rail Grade Crossings using Field Operational Test Data—Light Vehicles

Office of Research
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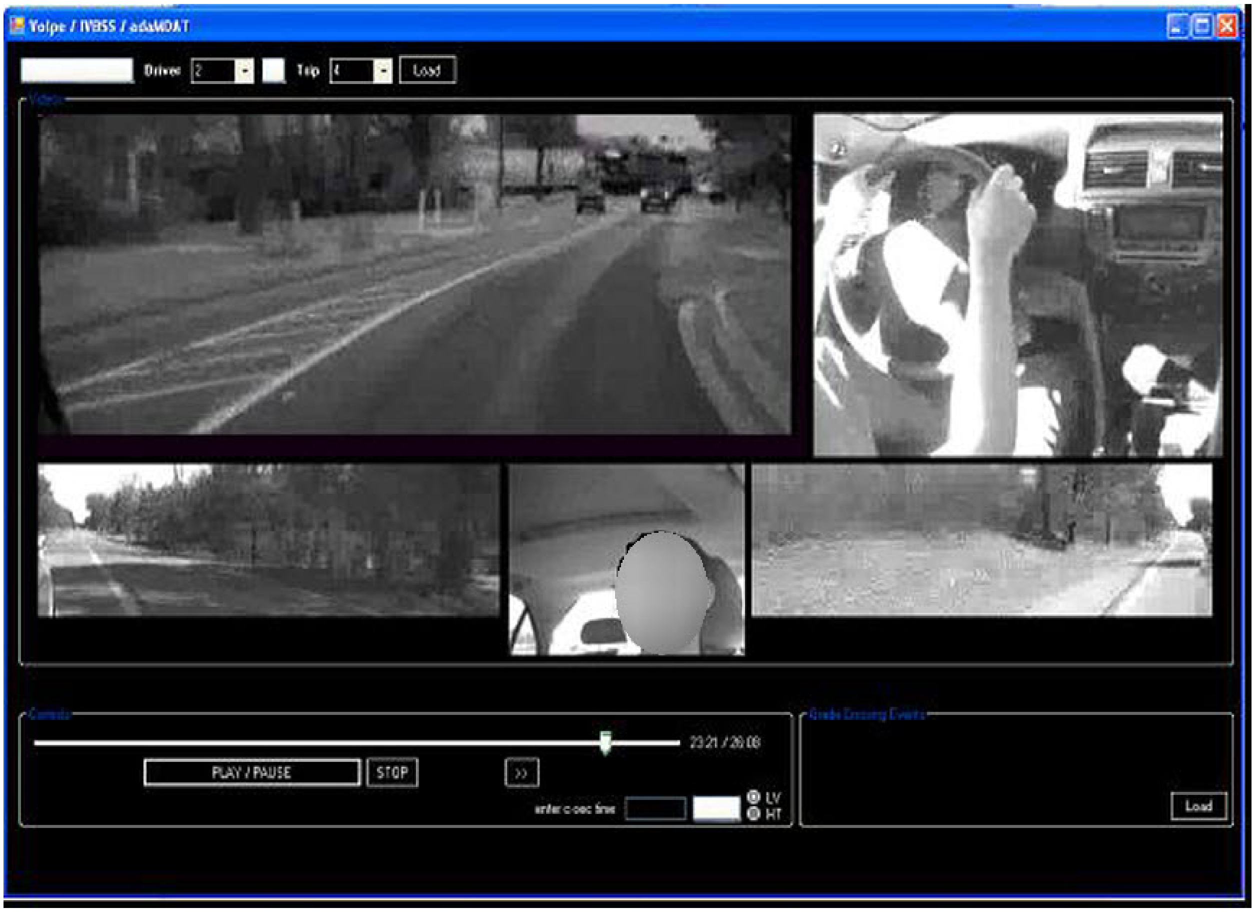
Washington, DC 20590



Driver: 2

Trip: 4

DOT/FRA/ORD-13/28

Final Report
May 2013

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 2013	Final Report August 2009–March 2012

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Driver Behavior Analysis at Highway-Rail Grade Crossings using Field Operational Test Data—Light Vehicles	RR97A3/JMC48 RR97A4/KT333
6. AUTHOR(S) Tashi Ngamdung and Marco daSilva	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
U.S. Department of Transportation Research and Innovative Technology Administration John A. Volpe National Transportation Systems Center 55 Broadway Cambridge, MA 02142	DOT-VNTSC-FRA-12-02

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
U.S. Department of Transportation Federal Railroad Administration Office of Research and Development Washington, DC 20590	DOT/FRA/ORD-13/28

11. SUPPLEMENTARY NOTES
Program Manager: Tarek Omar, D.Sc.

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
This document is available to the public through the FRA Web site at http://www.fra.dot.gov or by calling (202) 493-1300.	

13. ABSTRACT (Maximum 200 words)

The U. S. Department of Transportation's (U.S. DOT) Research and Innovative Technology Administration's (RITA) John A. Volpe National Transportation Systems Center (Volpe Center), under the direction of the U.S. DOT Federal Railroad Administration (FRA) Office of Research and Development (R&D), conducted a research study focused on collecting and analyzing data related to driver behavior at or on approach to highway-rail grade crossings. Volpe Center reviewed and coded 4,215 grade crossing events involving light vehicle drivers collected during a recent field operational test of vehicle safety systems. The data collected for each grade crossing included information about drivers' activities, driver and vehicle performance, driving environment, and vehicle location at or on approach to highway-rail grade crossings.

One of the findings of the data analysis was that, on average, drivers were likely to engage in secondary tasks 46.7 percent of the time. Additionally, results showed that drivers failed to look either left or right on approach to passive grade crossings approximately 35 percent of the time. The ultimate objective of this research study is to assess basic driver behavior at highway-rail grade crossings so as to identify potential driver education/awareness strategies that would best mitigate risky driver behavior at grade crossings.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Driver behavior, highway-rail intersection, grade crossing, accident reduction, video data, violation reduction	52
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI
Std. 239-18
298-102

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
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 yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)

1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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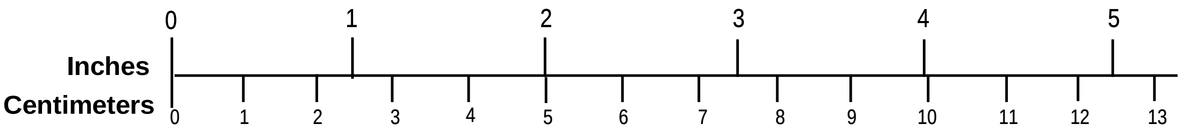
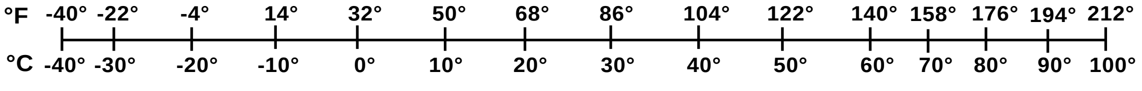


QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

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Acknowledgements

The U.S. Department of Transportation (U.S. DOT) Federal Railroad Administration (FRA) Office of Research and Development (R&D) sponsored the work leading to this report. The authors would like to thank Sam Alibrahim, Chief of the Train Control and Communications Division, and Tarek Omar, Program Manager, Train Control and Communications Division, for their guidance and direction during the project and in developing this report.

The authors would also like to acknowledge Bernard Kennedy, Ryan Brown, Frank Foderaro, Jaclyn Buonopane, all of the Systems Safety and Engineering Division; Stephanie Chase, Scott Gabree, Danielle Eon, Alison Busch, Michelle Yeh (formerly), all of the Surface Transportation and Human Factors Division; and Adam Bailin, formerly of the Advanced Vehicle Technology Division, U.S. DOT Research and Innovative Technology Administration's (RITA) John A. Volpe National Transportation Systems Center (Volpe Center), for their support in software development, data collection, and analysis. Additional thanks to Chris Cicchitelli of Computer Science Corporation, Volpe Center onsite contractor, for his technical support in software development.

Special thanks to Wassim Najm, Emily Nodine, and Andy Lam, all of Volpe Center's Advanced Vehicle Technology Division, who graciously satisfied all of our data requests.

Executive Summary

To improve safe driving behavior at highway-rail grade crossings, it is important to understand driver actions at or on approach to those crossings. Accordingly, the Federal Railroad Administration (FRA) Office of Research and Development (R&D) funded a project to review and analyze driver's activities at or on approach to highway-rail grade crossings. This effort was conducted under the auspices of the Highway-Rail Grade Crossing Safety and Trespass Prevention Research Program at the John A. Volpe National Transportation Systems Center (Volpe Center). The research team used data obtained in 2010 from the Integrated Vehicle-Based Safety System (IVBSS) Field Operational Test (FOT) sponsored by the U.S. DOT National Highway Traffic Safety Administration (NHTSA) for analysis of driver behavior at or on approach to highway-rail grade crossings.

Analysis of the IVBSS FOT data yielded a subset of 4,215 grade crossing events, or instances, where the IVBSS research vehicle traversed a grade crossing. The research team then reviewed and coded the 4,215 grade crossing events. The data collected for each grade crossing event included information about drivers' activities, driver and vehicle performance, driving environment, and vehicle location at or on approach to highway-rail grade crossings.

The results of the data analysis revealed that, on average, drivers were likely to engage in secondary tasks, an indicator of driver distraction, approximately 46.7 percent of the time. The data also indicated that younger and middle-aged drivers are more likely to be engaged in secondary tasks compared with older drivers.

Analysis of looking behavior on approach to grade crossings showed that drivers looked at least one way at or on approach to highway-rail grade crossings approximately 33.7 percent of the time. When analyzed by age group, the results showed that older drivers were much more likely to look at least one way at or on approach to highway-rail grade crossings than either middle-aged or younger drivers. The analysis of looking behavior by warning devices indicated that drivers were most likely to look at least one way at crossings equipped with STOP signs and least likely to look at least one way at crossings equipped with flashing lights. The data also indicated that drivers looked at least one way in 65 percent of the events at passive crossings, but failed to look either way (remained looking straight) in the other 35 percent of passive crossing events.

Evaluating the effectiveness of motorist and pedestrian signs and treatment is a top research priority. The authors hope the results presented in this report provide the basic driver behavior information needed to identify and guide potential driver education and awareness strategies that would best mitigate risky driver behavior at grade crossings.

1. Introduction

The U. S. Department of Transportation's (U.S. DOT) Research and Innovative Technology Administration (RITA) John A. Volpe National Transportation Systems Center (Volpe Center) provides technical support to the U.S. DOT Federal Railroad Administration (FRA) in all aspects of highway-rail grade crossing safety and trespass prevention research. Notable progress has been made over the past 10 years in improving safety at highway-rail grade crossings. Collisions at grade crossings have declined 38 percent, and fatalities at grade crossings have also declined approximately 38 percent between 2001 and 2010 [1].

In 1994, the U.S. DOT's *Rail-Highway Crossing Safety Action Plan* [2] set a goal to reduce grade crossing collisions and fatalities nationwide by 50 percent over 10 years. The U.S. DOT came close to meeting its goal. From 1994 to 2003, incidents between trains and highway-users were reduced by 40.4 percent—from 4,999 to 2,977. Over that same period, fatalities were reduced by 45.9 percent—from 617 to 334 [1]. Despite significant reductions in grade crossing incidents, they still represent a significant portion of overall accident risk for the railroad industry.

According to a 2004 report by the U.S. DOT Office of Inspector General [3], "Risky driver behavior or poor judgment accounted for 31,035 or 94 percent of public grade crossing accidents" from 1994 to 2003. The need to conduct research on driver behavior issues at grade crossings was highlighted in the FRA-sponsored *U.S. DOT Federal Railroad Administration's Third Research Needs Workshop on Highway-Rail Grade Crossing and Trespass Prevention* [4]. That workshop, held in 2009 as a forum to exchange ideas, concepts, and strategic planning, resulted in the identification of high-priority research needs. Researching driver behavior and evaluating the effectiveness of motorist and pedestrian signs and treatment were top priorities.

To improve safe driving behavior at highway-rail grade crossings, it is important to understand driver actions at or on approach to grade crossings. Thus, the FRA Office of Research and Development (R&D) funded a project to review and analyze drivers' activities at or on approach to highway-rail grade crossings. Volpe Center used data obtained in 2010 from the Integrated Vehicle-Based Safety System (IVBSS) Field Operational Test (FOT) sponsored by the U.S. DOT National Highway Traffic Safety Administration (NHTSA) for this effort.

The IVBSS program was established in November of 2005 to develop and test an integrated, vehicle-based, crash warning system that would help reduce rear-end, lane change, and roadway departure crashes for light vehicles and heavy commercial trucks. It is a cooperative research agreement between the U.S. DOT and an industry team led by University of Michigan Transportation Research Institute (UMTRI) to conduct field operational test and collect data to objectively assess the potential safety benefits and driver acceptance of prototype integrated crash warning systems [5].

The Volpe Center, in support of the NHTSA, is currently using Advanced Vehicle Technology to perform an independent evaluation of the IVBSS program; the evaluation includes analysis of video and numerical data collected during the IVBSS FOT. The Volpe Center's Highway-Rail

Grade Crossing Safety and Trespass Prevention Research Program leveraged the Center's current NHTSA-sponsored evaluation program to perform research on driver behavior at or on approach to highway-rail grade crossings.

1.1 Project Objectives

The main objectives of this project were as follows:

- To conduct a feasibility assessment of using the IVBSS Light Vehicle FOT data to perform highway-rail grade crossing driver behavior analysis.
- To collect and analyze drivers' activities at or on approach to highway-rail grade crossings.

These objectives were achieved through the analysis of video and numerical data gathered from the IVBSS FOT. The data collection and analysis focused on events where the test vehicles were on approach and traveled over grade crossings. The ultimate objective of the research is to provide the basic driver behavior information needed to identify potential driver education and awareness strategies that would best mitigate risky driver behavior at grade crossings.

2. Overview of the IVBSS Light Vehicle FOT Data

The report titled *"Integrated Vehicle-Based Safety Systems Field Operational Test Plan"* [5] contains test information and the plan for the field operational test. The majority of the background information presented in this section was obtained from that report.

The IVBSS Light Vehicle (LV) FOT spanned more than a year from April 16, 2009 to May 13, 2010. The FOT included 108 participants and 16 research vehicles. Each participant drove a research vehicle for a period of approximately six weeks. The data collected for FOT amount to approximately 648 weeks or 12 years' worth of driving data.

2.1.1 Characterization of the IVBSS LV FOT Fleet

The research vehicles included 16 late-model Honda Accords (4 2006 and 12 2007 models), with 1 2006 model serving as a backup unit. The light vehicle platform provided the following crash warning functions:

- *Forward crash warning (FCW)—warns drivers of the potential for a rear-end crash with another vehicle;*
- *Lateral drift warning (LDW)—warns drivers that they may be drifting inadvertently from their lane or departing from the roadway;*
- *Lane-change/merge warning (LCM)—warns drivers of possible unsafe lateral maneuvers based on adjacent vehicles, or vehicles approaching in adjacent lanes, and includes full-time side-object-presence indicators. LCM included a blind-spot detection (BSD) component that provided drivers with information about approaching vehicles, as well as vehicles in their blind spot; and*
- *Curve speed warning (CSW)—warns drivers when they are traveling at a rate of speed too high to safely negotiate an upcoming curve.* [6]

2.1.2 Participants

The 108 participants consisted of 54 male and 54 female randomly sampled drivers ranging in age from 21 to 69 years old. The participants, each of whom drove a research vehicle for a period of six weeks, were classified into six groups based on gender and age group for the IVBSS LV FOT. The age groups consisted of younger (between 20 and 30 years old), middle-aged (between 40 and 50 years old), and older (between 60 and 70 years old) individuals. Table 1 shows the breakdown of the participants in the IVBSS LV FOT by gender and age group.

Participants were recruited with the assistance of the Michigan Secretary of State (Michigan's drivers licensing bureau). A random sample of several thousand drivers from the eight counties surrounding Ann Arbor (all within a 1.5-hour drive of UMTRI) was contacted to solicit the individuals' participation in the FOT. It was proposed that the sample drivers be screened to exclude anyone matching the following criteria: (1) having one crash resulting in a fatality within the past 36 months, and (2) having been convicted of either driving while intoxicated or driving under the influence of alcohol or a controlled substance within the past 36 months. The respondents to the solicitation were then screened by an UMTRI research assistant to ensure that selected participants met the predetermined qualification criteria (i.e., age, gender, and miles driven in the past year) to satisfy the proposed experimental design. [5]

Table 1. Number of Participants by Gender and Age Group

	Age	Male	Female	**Total**
Younger	20-30	18	18	**36**
Middle-aged	40-50	18	18	**36**
Older	60-70	18	18	**36**
Total		**54**	**54**	**108**

2.1.3 IVBSS LV FOT Data

A wide range of video and numerical data was collected during the IVBSS LV FOT. The data were collected and stored in a Data Acquisition System (DAS) that was installed in each research vehicle. Both video and numerical data were collected continuously throughout a trip. A trip was defined by the vehicle ignition cycle (i.e., from the time the vehicle ignition was turned on until it was turned off) [6]. Data was retrieved from the DAS at the end of the testing period when a participant returned the research vehicle to UMTRI.

The numerical data were collected using the integrated system installed in each research vehicle. The system collected data related to vehicle performance, driver performance, vehicle location, and driving environment. The raw numerical data were stored in a Structured Query Language (SQL) database format. The complete list of numerical data collected for the analysis of grade crossing events is provided in Appendices A, B, and C.

The video data were collected from five cameras that were installed inside each research vehicle. The cameras were placed strategically to capture the forward view, driver's face, instrument panel, exterior left side of the vehicle, and exterior right side of the vehicle.

For the IVBSS Light Vehicle FOT, the data set consisted of 22,656 trips covering a total of 213,395 miles. Figure 1 shows the geographical range of FOT travel based on destination points [6]. The majority of travel was within the Lower Peninsula of Michigan, with the greatest concentration in the metropolitan areas of Detroit and Ann Arbor. Travel ranged as far north as the Upper Peninsula of Michigan, west to south central Missouri, and east to eastern Pennsylvania, Washington, DC, and eastern North Carolina. Based on drivers' end destinations, the study area selected for this research consisted of highway-rail grade crossings in Michigan, Indiana, and Ohio. Grade crossings in these three States, where most of the travel took place, were cross-referenced with the routes traveled by each research vehicle to determine research vehicle presence at highway-rail grade crossings.

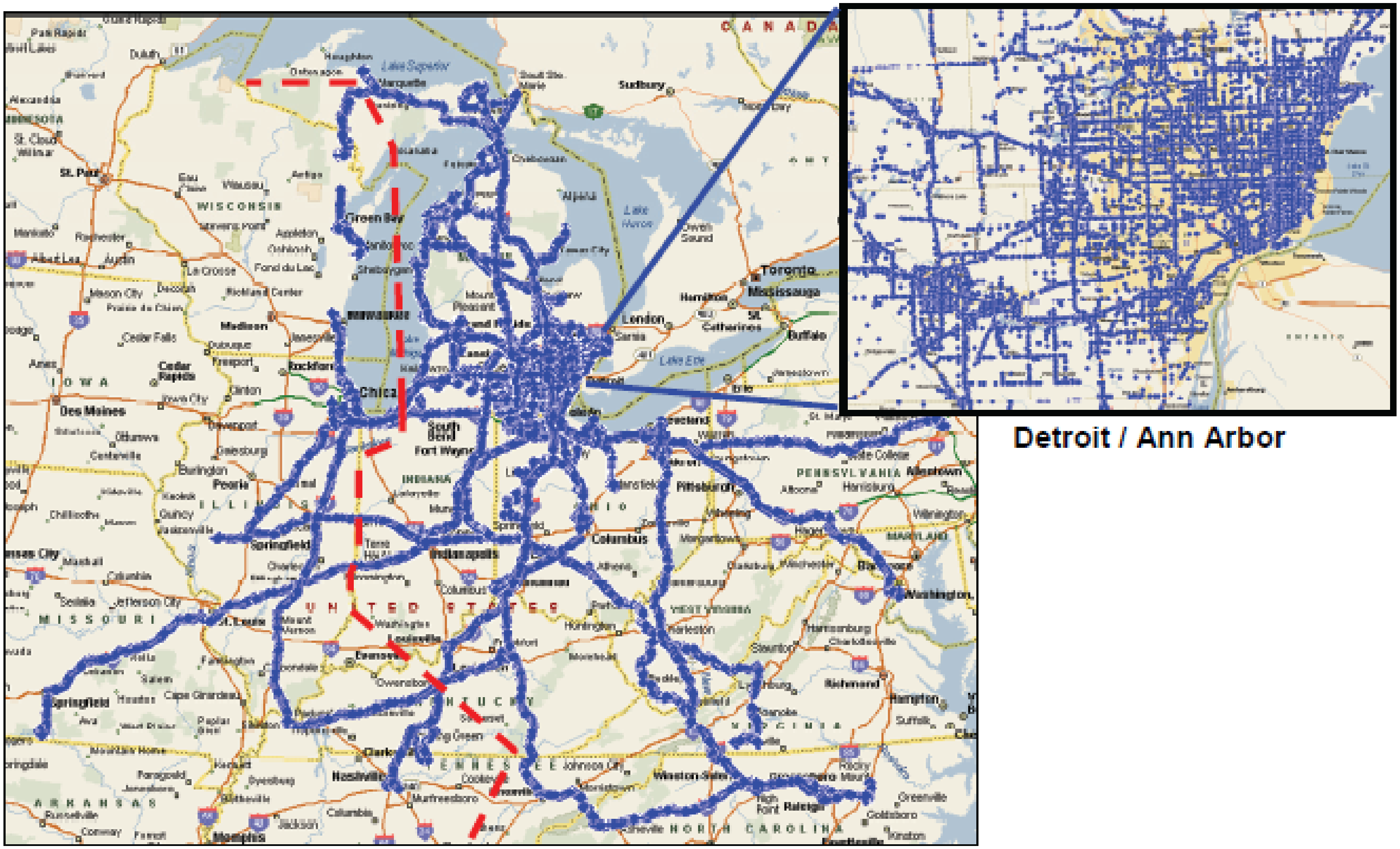


Figure 1. Geographical Range of Travel by FOT Drivers

3. Grade Crossing Data Collection

The first step to analyzing driver behavior at highway-rail grade crossings was to collect driver activities and obtain numerical data at or on approach to such grade crossings. To perform this data collection, the Volpe Center research team developed the following four customized data collection tools to interface with and query the IVBSS FOT data:

- Grade Crossing Locator
- Video Data Viewer
- Grade Crossing Coder
- Data Exporter

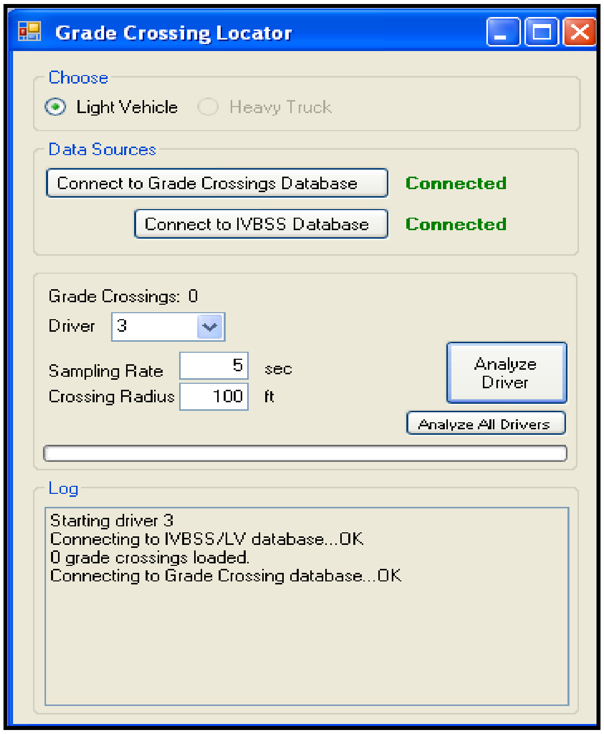
3.1 Grade Crossing Locator

The Grade Crossing Locator tool cross-referenced each grade crossing's geolocation with the research vehicle geolocation to calculate if and when a vehicle was present at a crossing. Samples of drivers' end destinations were mapped to determine the participants' travel destinations. Based on this result, grade crossings in Michigan, Indiana, and Ohio were selected and cross-referenced with routes traveled by each research vehicle to determine vehicle presence at highway-rail grade crossings. The latitude (lat) and longitude (long) coordinates of each highway-rail grade crossing within those three States were obtained from the Bureau of Transportation Statistics National Transportation Atlas Database 2008. The geolocation of each research vehicle was obtained from the lat/long coordinates recorded by an on-board Global Positioning System (GPS). Due to accuracy errors for both crossing and research vehicle geolocation, a radius of 100 feet around each grade crossing was used in querying the vehicle data to capture the events in which a research vehicle traveled over a highway-rail grade crossing. The tool generated a list of possible trips with crossing ID and the estimated time that a research vehicle was present at a crossing. Figure 2 shows the snapshot of the Grade Crossing Locator tool.

3.2 Video Data Viewer

The drivers' activities at or on approach to a highway-rail grade crossing were collected from analysis of the video data recorded with the five video cameras installed on each research vehicle. A tool called "Video Data Viewer" was developed to combine all five camera views and play them simultaneously so that the driver's activity and the surrounding scene from different angles could be viewed concurrently.

Figure 3 shows a snapshot of the Video Data Viewer as the research vehicle approached a crossing that is occupied by a train. A drop-down menu on the top left corner of the screen provided an option to select driver and trip for possible grade crossing events. All grade crossing events for the selected driver and trip were displayed on the bottom right corner of the screen with Crossing ID and the time the research vehicle was present at that crossing.



Choose

● Light Vehicle ○ Heavy Truck

Data Sources

Connected

Connected

Grade Crossings: 0

Driver: 3

Sampling Rate: 5 sec

Crossing Radius: 100 ft

Log

```
Starting driver 3
Connecting to IVBSS/LV database...OK
0 grade crossings loaded.
Connecting to Grade Crossing database...OK
```

Figure 2. Grade Crossing Locator Tool

Figure 3. Video Data Viewer

3.3 Grade Crossing Coder

Figure 4 shows a snapshot of the Grade Crossing Coder. This tool was developed and used to record drivers' activities observed through the video data viewer. The data collection of driver activity for a grade crossing event started at the moment a research vehicle arrived at the grade crossing pavement marking (this is designated in the Grade Crossing Coder as t1) and ended when it cleared the crossing (this is designated in the Grade Crossing Coder as t3). For any grade crossing event in which a research vehicle did not encounter the pavement marking, the data collection started eight seconds before the research vehicle arrived at the crossing (this is designated in the Grade Crossing Coder as t2). This 8-second value was calculated based on the average time it took a research vehicle to cover the distance from a pavement marking to a crossing, as observed during the study. The data collected from the video scene included information about crossing inventory, driving conditions, driver's activities, and crossing violations.

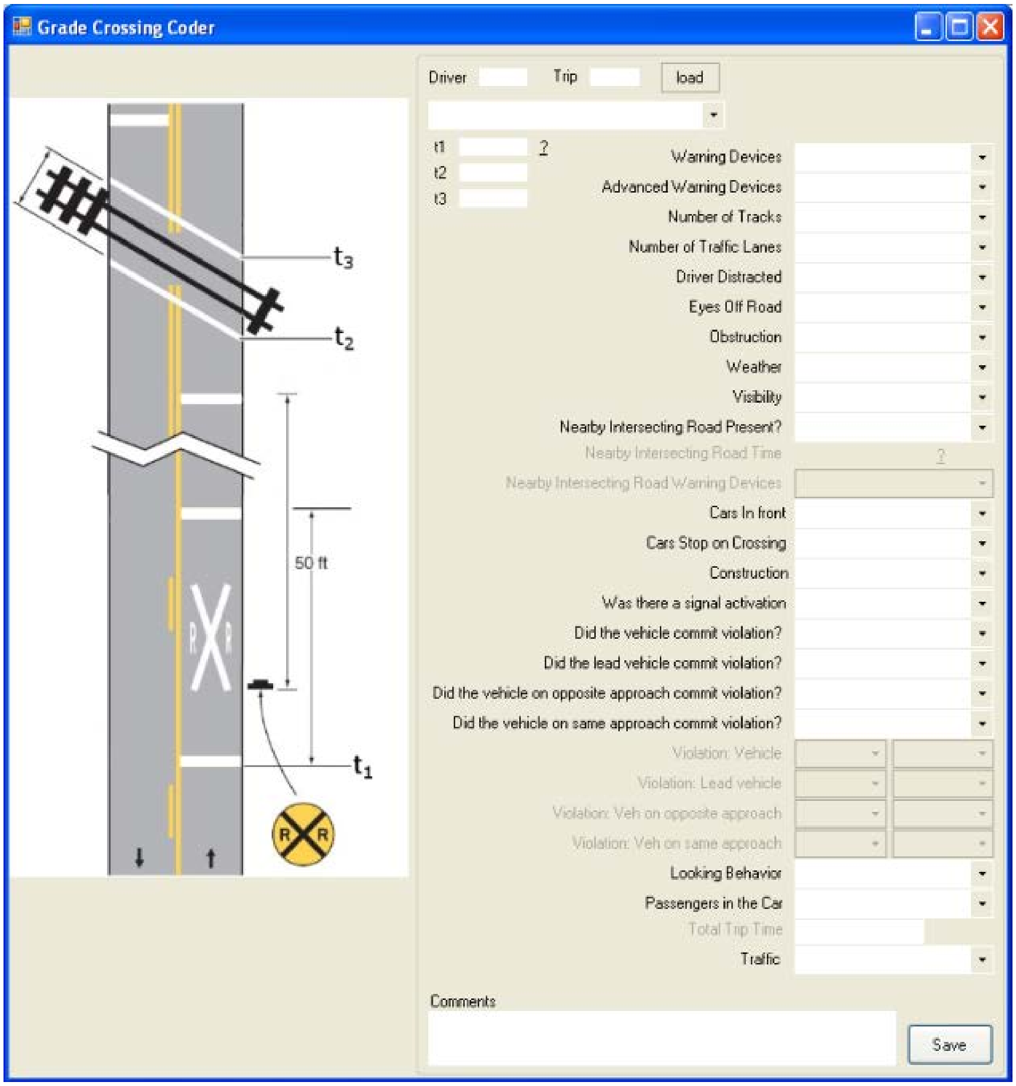


Figure 4. Grade Crossing Coder

The left side of the screen in Figure 4 shows a schematic of a typical single track highway-rail grade crossing with the location of t1, t2, and t3. The menus on the right were used to enter drivers' characteristics and surrounding scene for a grade crossing event. The first step in entering the data was to input the driver and the trip ID and then select the crossing ID for which the data was collected. Once the information was entered, the save button on the bottom right corner of the screen was used to save the coded information for the event as a data table.

Table 2 provides a list of the data gathered from analysis of the video data for each grade crossing event through the Grade Crossing Coder. Appendix D provides the data dictionary and instruction on how the video was coded.

Table 2. Data Dictionary for Grade Crossing Events

Driver ID	Driver ID
Trip ID	Trip ID
crossing_event_id	Crossing ID for which the data is collected
t1_time	Time a research vehicle arrives at the crossing pavement marking
t2_time	Time a research vehicle arrives at the crossing (used the stop line at the crossing as a reference for arriving at the crossing)
t3_time	Time a research vehicle exits the crossing
warning devices	Lists highest warning device at a crossing
adv_warning_devices	Identifies whether advanced warning is present for a crossing
num_tracks	Number of tracks
num_traffic_lanes	Number of traffic lanes that intersect with a crossing
driver_distracted	Secondary task that driver was involved in
eyes_off_road	Identifies whether driver's eyes were off road
obstruction	identifies whether a crossing was obstructed
weather	Provides weather condition
visibility	Provides visibility
nearby_intersecting_road	Identifies whether intersecting road is present 10 sec within a crossing
nearby_intersecting_road_time	Time research vehicle arrives at an intersecting road
nearby_intersecting_road_warning_devices	Warning devices at the intersecting road

cars_in_front	Identifies whether cars are present in front of the research vehicle
cars_stop_on_crossing	Identifies whether any car is stopped on a crossing
construction	Identifies whether construction work is performed at or on approach to the crossing
signal_activation	Identifies whether crossing was activated for the grade crossing event
veh_commit_violation	Identifies whether research vehicle committed violation
lead_veh_commit_violation	Identifies whether lead vehicle committed violation
veh_opposite_approach_commit_violation	Identifies whether vehicle in opposite direction committed violation
veh_same_approach_commit_violation	Identifies whether vehicle on same approach committed violation
violation_veh_type	Research vehicle violation type
violation_veh_when	Violation before or after a train for research vehicle
violation_leadveh_type	Lead vehicle violation type
violation_leadveh_when	Violation before or after a train for lead vehicle
violation_oppoapproachveh_type	Opposite approach vehicle violation type
violation_oppoapproachveh_when	Violation before or after a train for vehicle from opposite approach
violation_sameapproachveh_type	Same approach vehicle violation type
violation_sameapproachveh_when	Violation before or after a train for vehicle from same approach
looking_behavior	Looking behavior as driver approached the crossing
passengers_in_car	Number of passengers in the car
total_trip_time	Total trip time
traffic	Traffic conditions on approach to a crossing
comments	Comments

3.4 Data Exporter

Figure 5 shows a screenshot of the Grade Crossing Exporter tool. This tool was used to export both video and numerical data that was collected for each grade crossing event. The top section titled “Available Grade Crossings” exported a list of possible grade crossing events per driver that were identified with the Grade Crossing Locator tool. The file was exported in a spreadsheet format with a list of possible trips, crossing ID, and the time a research vehicle was present at a crossing for that trip.

The middle section titled "Grade Crossing Responses" exported all the user generated grade crossing responses for the selected driver as inputted in the Grade Crossing Coder. This data was also exported in a spreadsheet format.

The last section titled "Numerical Data" was used to export both video and numerical data for a single grade crossing event. The data was exported in a spreadsheet format with three different tabs. The first tab included numerical data collected at 10 Hz during the IVBSS FOT; the second tab included data collected at 5 Hz; and the final tab included summary data of the trip and the video data that was collected for that grade crossing event. Refer to Appendices A, B, and C for the complete list of both numerical and video data that were collected for each grade crossing event.

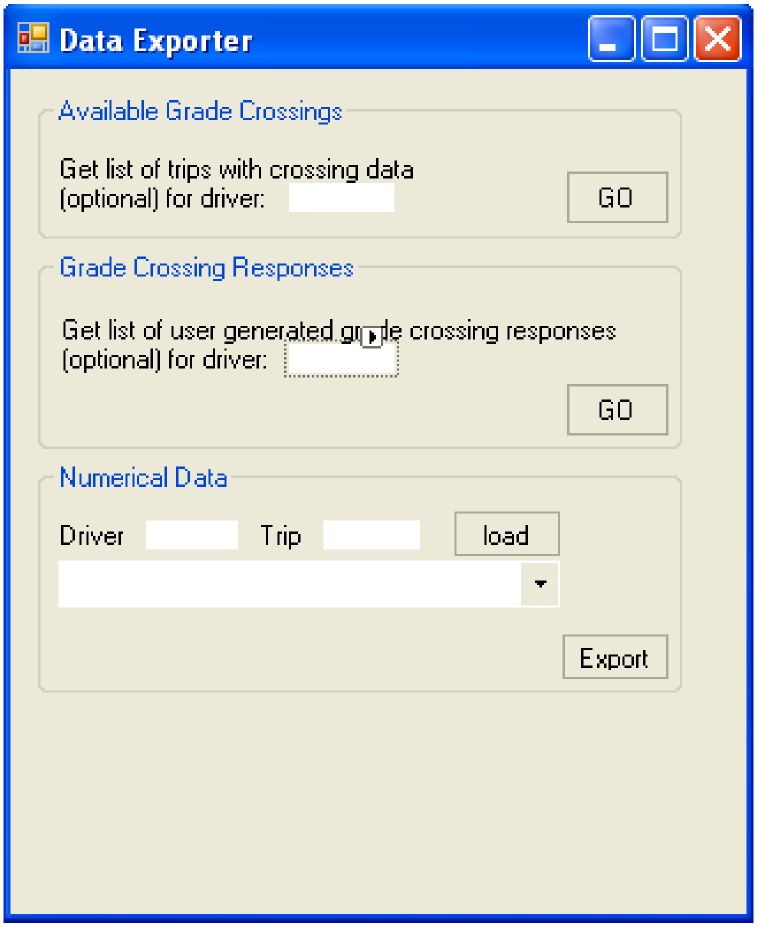


Figure 5. Data Exporter

4. Data Analysis

Analysis of the driver behavior data at grade crossings focused on distribution of crossing events by warning devices, vehicle exposure, grade crossing violation, and identification of patterns of driver behavior. Examples of driver behavior characteristics include looking behavior (looked one way, looked both ways, or looked neither way) and the presence of distractions (phone, eating, talking to passenger, etc.). The analysis presented in this section focuses on the light-vehicle part of the IVBSS FOT.

4.1 Vehicle Exposure

The IVBSS LV FOT spanned a little more than a year from April 16, 2009, to May 1, 2010. During this period, the 108 participants drove research vehicles a total of 213,395 miles and made a total of 22,656 trips. On average, each participant drove approximately 1,976 miles during the test period. Figure 6 shows the average distance in miles travelled by age group and gender. As can be seen from the chart, male drivers drove more miles on average than female drivers across all age groups. In fact, male drivers drove 56.1 percent more miles than female drivers (2,409 versus 1,543 miles). Table 3 shows the participants' exposure by Vehicle Miles Traveled across gender and age group. [6]

Table 3. Participants' Exposure by Gender and Age Group

	Younger		**Middle–aged**		**Older**		**All Drivers**	
	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent
Male	39,623	19	51,147	24	39,312	18	130,932	61
Female	29,274	14	30,617	14	23,423	11	82,462	39
Total	68,897	32	81,763	38	62,734	29	213,395	100

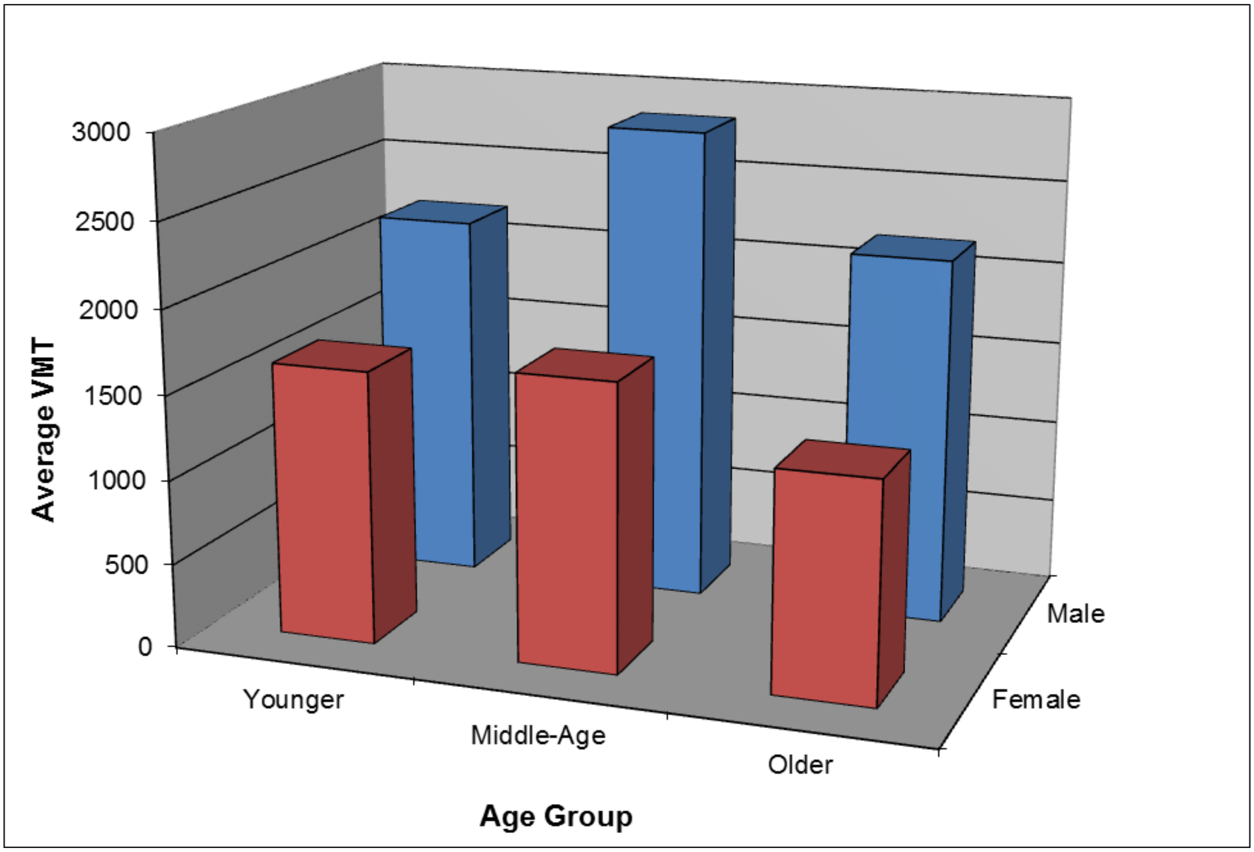


Figure 6. Average Distance Travelled by Age Group and Gender

4.2 Grade Crossing Events

For the IVBSS Light Vehicle FOT, the 108 participants made a total of 22,656 trips in the research vehicles. Of those trips, the Grade Crossing Locator tool identified 4,898 trips within which there was a possible grade crossing event. As previously discussed in Section 3.1, the Grade Crossing Locator tool cross-referenced each grade crossing's geolocation with the research vehicle's geolocation to calculate if and when a vehicle was present at a crossing. Due to coordinate accuracy errors for both crossing and research vehicle location, a radius of 100 feet around each grade crossing was used in querying the vehicle data to capture the events in which a research vehicle traveled over a highway-rail grade crossing. The tool generated a list of possible grade crossing events, which amounted to 9,736, by using the 100-foot zone around the crossing GPS coordinates. The research team reviewed the video from all of these potential grade crossing events and identified 3,137 trips containing a total of 4,215 grade crossing events. The remaining potential events identified by the tool turned out to be false positives. Many of those were grade-separated grade crossing events, which were identified since the grade crossing GPS data set used for the study contained GPS information for both at-grade and grade-separated grade crossings. Many others contained events in which the vehicle's direction of travel was parallel to the railroad and any grade crossing at cross-streets within the 100-foot buffer zone would classify it as a grade crossing event.

The 4,215 valid grade crossing events occurred at 499 unique grade crossings over the three States (Michigan, Indiana, and Ohio) selected for analysis. The results of this report are based on the analysis of this data set. Table 4 shows the breakdown of the grade crossing events by age group and gender. Overall, about two-thirds of the events involved male drivers, nearly half of which were in the younger (20–30 years old) age group.

Table 4. Grade Crossing Events by Age Group and Gender

	Male	Female	**Total**
Younger	1,292	276	**1,568**
Middle-aged	872	663	**1,535**
Older	580	532	**1,112**
Total	**2,744**	**1,471**	**4,215**

4.3 Summary of Grade Crossing Event Data

The identification of the warning devices present at each grade crossing was one of the data elements coded during the analysis of the video data for each grade crossing event. The analyst was instructed to select the highest level of warning device that was present at the crossing. Figure 7, Figure 8, and Figure 9 show some examples of warning devices identified at selected grade crossings. A drop-down menu, arranged in descending order with highest level of warning device at the top, was used for this data element. The drop-down menu contained the following devices:

- Four Quadrant Gate
- Gate
- Flashing Lights
- STOP sign
- Crossbucks
- Other
- Unknown

Volpe / IVBSS / adaMDAT

Driver 74 Trip 32

45:01 / 47:13

Figure 7. Snapshot of a Grade Crossing Event at a Highway-Rail Crossing Equipped with Gates

Volpe / IVBSS / adaMDAT

Driver 3 Trip 58

07:03 / 09:17

Figure 8. Snapshot of a Grade Crossing Event at a Highway-Rail Crossing Equipped with Flashing Lights

Driver 3

Trip 26

18:42 / 26:15

Figure 9. Snapshot of a Grade Crossing Event at a Highway-Rail Crossing Equipped with Crossbucks Only

Figure 10 shows the distribution of the 4,215 grade crossing events by warning device present at the crossing. As can be seen, the majority of the grade crossing events (93 percent or 3,901) occurred at crossings equipped with active warning devices. The active warning devices for this data set include gates and flashing lights. The remaining grade crossing events (7 percent or 314) occurred at passive crossings. The passive crossings in this data set included those equipped with STOP signs, crossbucks, and unknown. The unknown category indicates a crossing where the warning device was not identifiable from the video data due to poor video quality or environmental factors. Although two other warning device categories, “Four Quadrant Gate” and “Other,” are listed in the study’s coding drop-down menu, none of the 4,215 grade crossing events were coded under those categories.

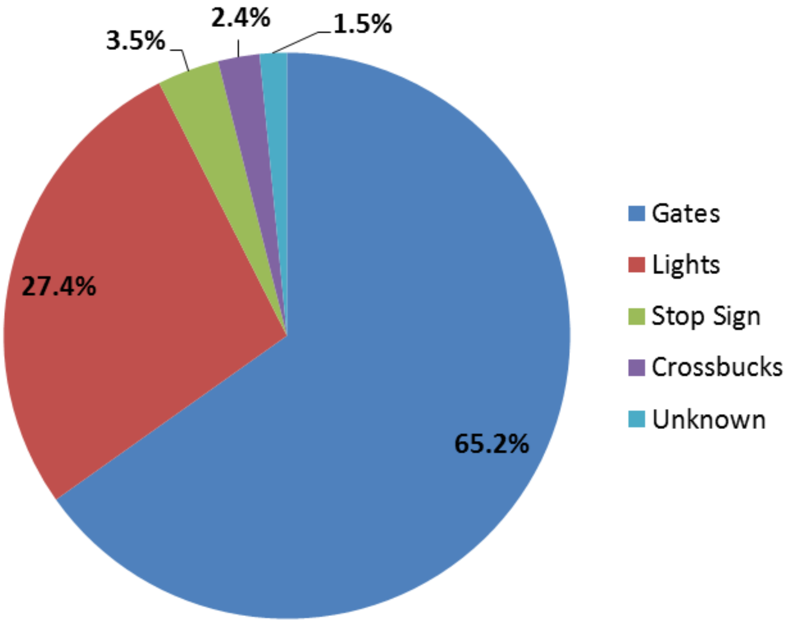


Figure 10. Distribution of Grade Crossing Events by Warning Device

Figure 11 shows the distribution of grade crossing events by number of tracks at the crossing. As shown, 75.7 percent (3,189) of the grade crossing events occurred at single track highway-rail grade crossings.

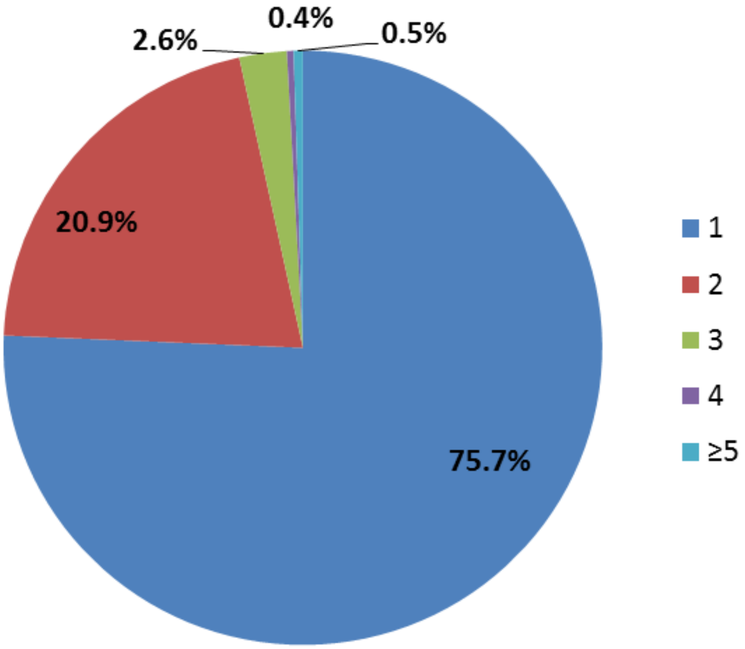


Figure 11. Distribution of Grade Crossing Events by Number of Tracks

Figure 12 shows the distribution of grade crossing events by number of traffic lanes traversing the crossing. As shown, approximately two-thirds (2,799) of the grade crossing events occurred at highway-rail grade crossings on single lane roadways. Additionally, roughly 28 percent of the events occurred on two-lane roadways.

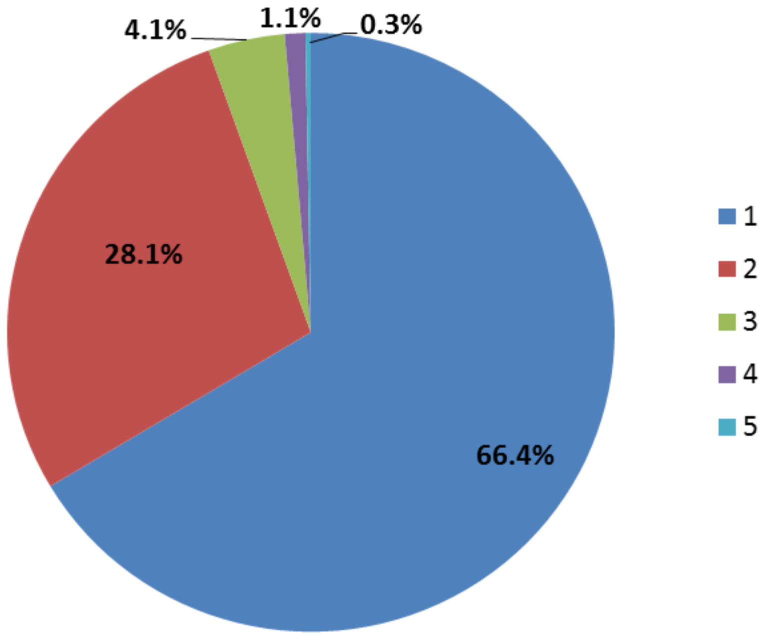


Figure 12. Distribution of Grade Crossing Events by Number of Road Traffic Lanes

4.4 Grade Crossing Activation

For an active crossing, grade crossing activation is defined as any time the crossing warnings are activated, either when a train is on approach or in the event of a false activation [7]. For a passive crossing, grade crossing activation is defined as when a highway-rail crossing is occupied by a train. Out of the possible 4,215 crossing events analyzed in this study, the research team identified 52 events (1.2 percent) involving grade crossing activation. The 52 grade crossing activation events were comprised of 42 at crossings equipped with gates, 8 at crossings equipped with flashing lights, and 2 at crossings equipped with STOP signs. Eight out of the 52 grade crossing events were identified as false activation, meaning that the warning devices were activated without a train being present.

Grade crossing violations were collected for the 52 grade crossing activation events. A grade crossing violation occurs when motorists disobey the warning devices at a highway-rail grade crossing. Grade crossing violations were collected for the research vehicle as well as for other vehicles in the vicinity, as captured by the research vehicle's external cameras. The violations committed by other vehicles included other vehicles in front or parallel to the research vehicle traveling in the same direction and vehicles on opposite approaches to the grade crossing. For those 52 grade crossing activation events, the research team identified 73 violations. This is an average of 1.4 violations per grade crossing activation event during the study period.

Three types of vehicle violations were collected for the 42 grade crossing activation events that occurred at crossings equipped with gates. The definition of each type is provided below [7].

- A Type I violation occurs when a violator traverses the crossing while the lights are flashing, the bells are ringing, but before gate descent.
- A Type II violation occurs when a violator traverses the crossing during gate descent or ascent with audible devices sounding.
- A Type III violation occurs when a violator traverses the grade crossing after the gates finish their descent and are fully deployed in a horizontal position.

The research team identified 63 violations for the 42 grade crossing activation events that occurred at crossings equipped with gates. The 63 violations were comprised of no Type I violations, 55 Type II violations (all after a train), and 9 Type III violations (8 before and 1 after a train).

The research team identified 10 violations for the 8 grade crossing activation events that occurred at crossings equipped with flashing lights. These violations occurred when motorists traversed the crossing while the lights were flashing either before or after a train event. The 10 violations consisted of 6 before train arrival and 4 after a train had cleared the crossing but while lights were still flashing.

The two grade crossing activation events that occurred at crossings equipped with a STOP sign did not include any violations. For both train activation events, the crossing was occupied by a train when a research vehicle arrived at the crossing.

Research vehicles were the lead vehicle at an activated crossing event on 16 occasions. The drivers committed a violation in half of those events. As shown in Table 5, 9 crossing events occurred at crossings equipped with gates, 5 at crossings equipped with flashing lights, and 2 at crossings equipped with STOP signs. For the nine grade crossing activation events at a gated crossings, research vehicles committed five violations. The violations included four Type II (all after a train) and one Type III (before a train). Figure 13–15 show examples of each type of violation.

Table 5. Breakdown of Grade Crossing Events at Activated Crossings where Research Vehicles Were the Lead Vehicle

	Violations?			Total
	Yes		No	
	Before a train	After a train		
Gates	1	4	4	**9**
Flashing Lights	1	2	2	**5**
Stop Sign	0	0	2	**2**
Total	**2**	**6**	**8**	**16**

Driver 18
Trip 135

Figure 13. Type I Violation

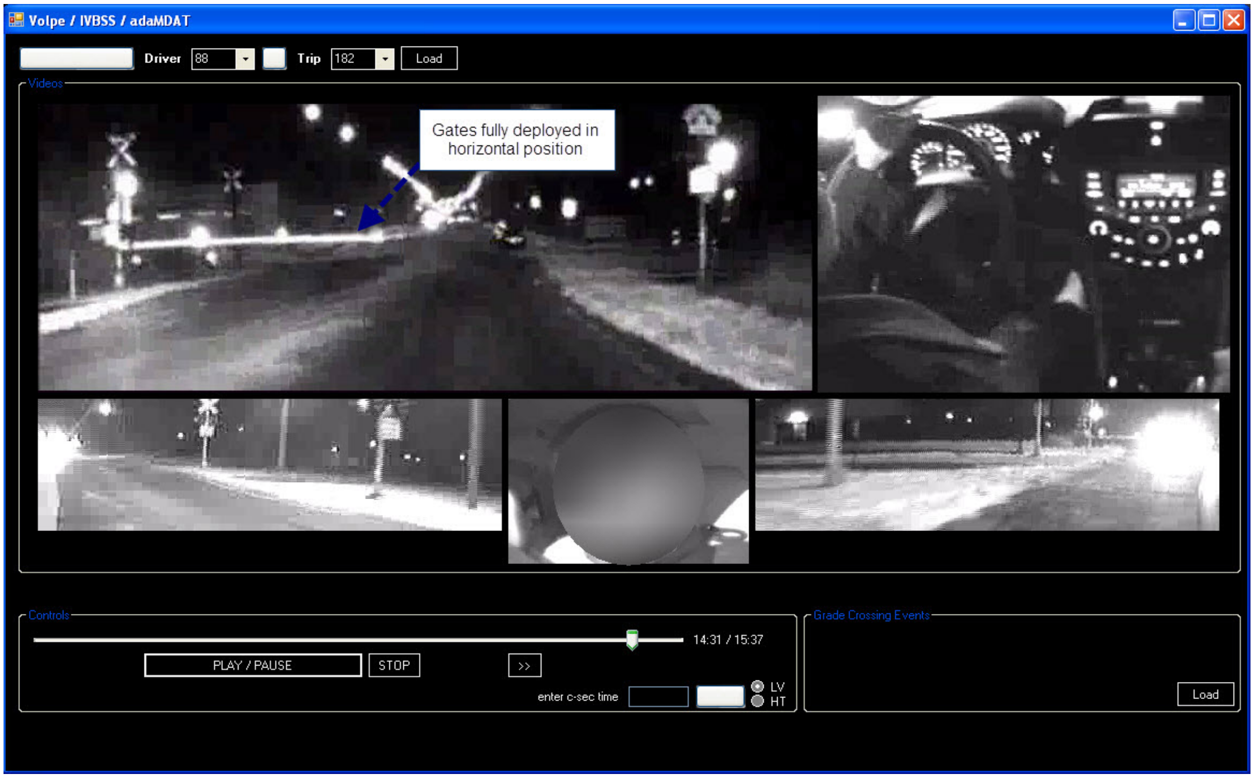

Gates in ascending position

Driver 34

Trip 488

30:51 / 40:46

Figure 14. Type II Violation


Gates fully deployed in horizontal position

Driver 88

Trip 182

14:31 / 15:37

Figure 15. Type III Violation

4.5 Distraction

For the purpose of this analysis, drivers were identified as being distracted if they were engaged in any secondary tasks that may have prevented them from safely operating the vehicle any time between arriving at the pavement marking (t1) and exiting the crossing (t3). The secondary task categories for this project were developed based on the set used for the IVBSS project. The secondary tasks were identified by viewing face, cabin, and two sides' video data of grade crossing events. Out of possible 4,215 grade crossing events, 1,968 (or 46.7 percent) of the grade crossing events involved the driver performing a secondary task. The most frequently observed secondary task involved drivers talking to or looking at a passenger (654 or 15.5 percent), followed by talking on or listening to the phone (280 or 6.6 percent), an example of which is shown in Figure 16. Figure 17 and Figure 18 show some other examples of drivers distracted on their approach to a highway-rail grade crossing. Table 6 lists all possible secondary tasks along with their frequency.


Driver 98
Trip 93

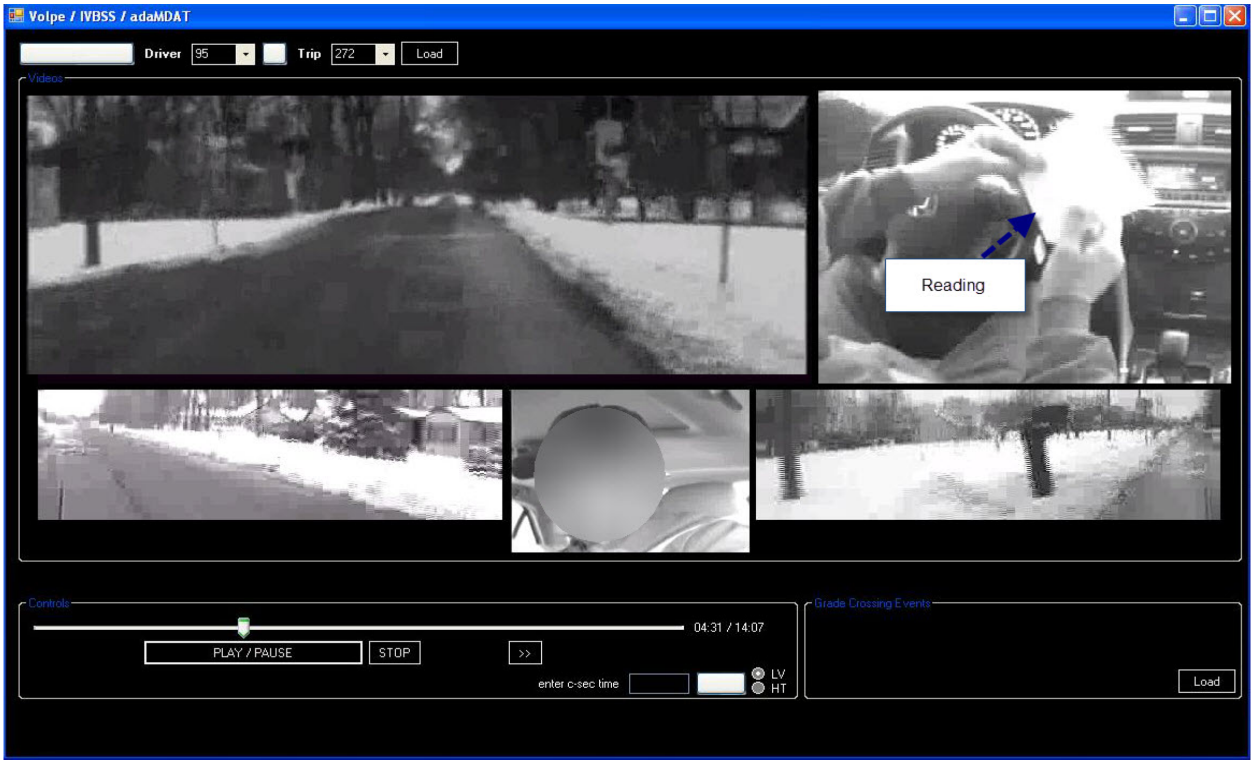
Figure 16. Snapshot of a Driver Talking on Phone on an Approach to a Highway-Rail Grade Crossing

Driver 25 Trip 17

07:35 / 26:37

Text Messaging

Figure 17. Snapshot of a Driver Text Messaging on an Approach to a Highway-Rail Grade Crossing



Driver 95 Trip 272

04:31 / 14:07

Reading

Figure 18. Snapshot of a Driver Reading on an Approach to a Highway-Rail Grade Crossing

Data was analyzed to determine whether the distraction was any different based on gender or age group. Overall, male drivers were engaged in secondary tasks slightly more often than their female counterparts (47.3 percent of male drivers were engaged in secondary tasks compared with 45.5 percent of female drivers). A paired t-test indicated that the overall change in rate between male and female drivers involved in secondary tasks was not statistically significant ($p = 0.2762$). Figure 19 shows the comparison of secondary task frequency as a percentage of the total for each gender.

Table 6. Frequency of Secondary Tasks

ID	Secondary Tasks	Number of Grade Crossing Events with Secondary Task		Total
		Male	Female	
0	None	1,446	801	2,247
1	Talking to/looking at passengers	446	208	654
2	Talking on/listening to phone	186	94	280
3	Looking to the side/outside car	150	107	257
4	Smoking/lighting cigarettes	127	32	159
5	Adjusting controls	81	46	127
6	Text messaging	76	13	89
7	Other	46	42	88
8	Eating	33	39	72
9	Reaching for object in vehicle	29	27	56
10	Singing/whistling	39	15	54
11	Drinking	40	8	48
12	Dialing phone	22	15	37
13	Grooming	14	16	30
14	Reading	7	6	13
15	Eyes closed > 1s	3	1	4
	Total	2,745	1,470	4,215

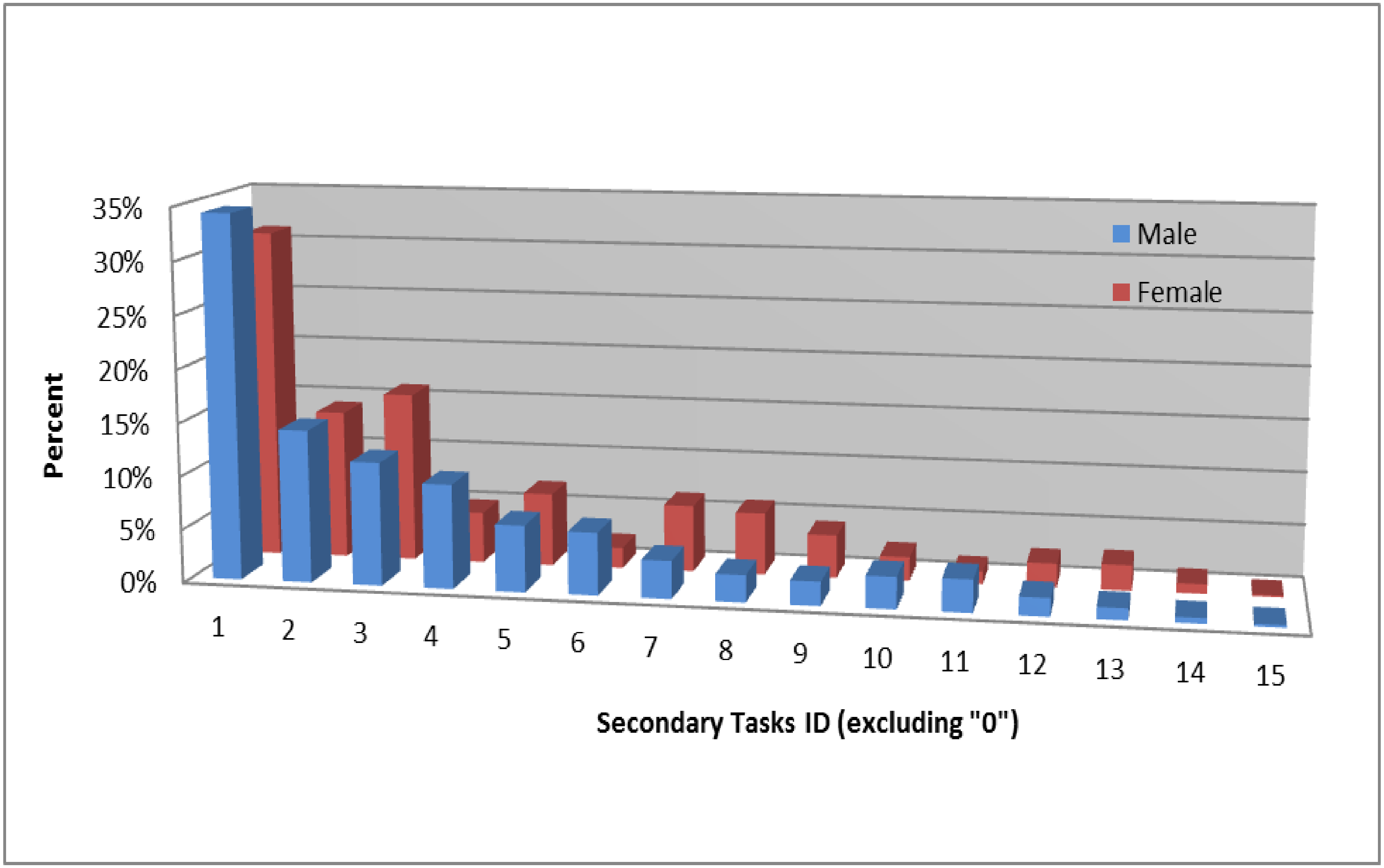


Figure 19. Comparison of secondary tasks by gender

Analysis of secondary tasks based on age group (younger, middle-aged, and older) indicated that younger and middle-aged drivers were likelier than older drivers to engage in secondary tasks during a grade crossing event. Approximately 42.8 percent of older drivers were engaged in secondary tasks during grade crossing events compared with 47.9 percent for middle-aged drivers and 48.3 percent for younger drivers. A paired t-test indicated that between older and middle-aged drivers, the overall change in rate of drivers involved in secondary tasks was statistically significant (p=0.0097), as was also the case between older and younger drivers (p = 0.0051). Table 7 shows the distraction rate by age group.

Table 7. Distraction Rate by Age Group

	Age Group		
	Younger	Middle-aged	Older
Grade Crossing Events with Distraction	757	735	476
Total Grade Crossing Events	1,568	1,535	1,112
Distraction Rate	0.483	0.479	0.428

4.6 Looking Behavior

Looking behavior was measured by the amount of head movement as the driver approached the crossing from the pavement marking (t1) until the research vehicle cleared the crossing (t3). The research team viewed the face video data of a grade crossing event to observe whether the driver looked one way (to the left or to the right), both ways, or straight ahead. It is important to note that the focus was on head movement because no eye tracking data was collected. Analysis of the data collected suggests that drivers did not move their heads 66.3 percent of the time as they approached a highway-rail grade crossing. Only 15 percent of head movements were in both directions and 18.8 percent of head movement was in one direction (looked left or looked right). Figure 20 shows the distribution of grade crossing events by looking behavior.

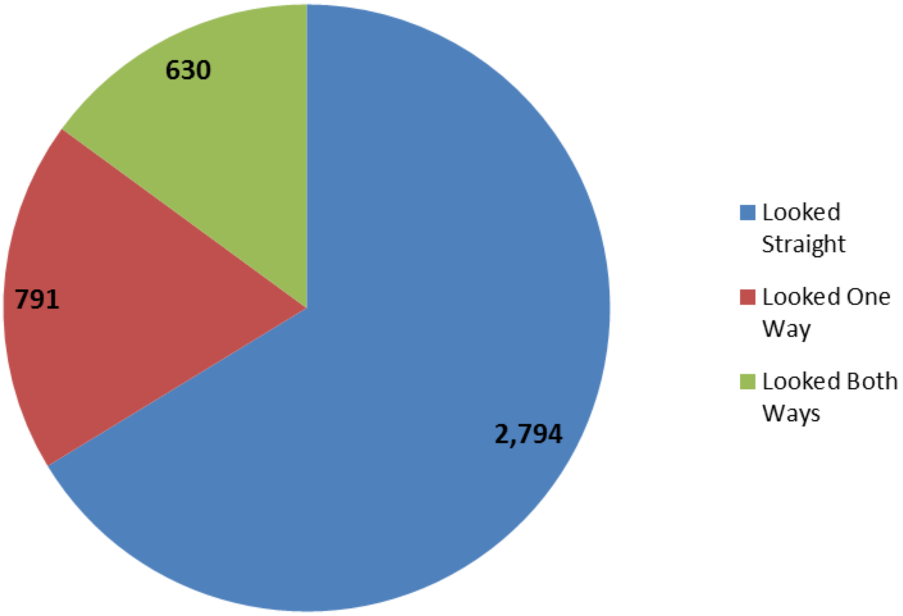


Figure 20. Distribution of Grade Crossing Events by Looking Behavior

The data was analyzed to determine whether the looking behavior was any different based on gender and age group. Looking behavior was further categorized into either looked straight or looked at least one way. At or on approach to a grade crossing, male drivers looked at least one way 33.9 percent of the time and female drivers looked at least one way 33.4 percent of the time. This observed difference in driver looking behavior was not statistically significant based on a pair t-test (p=0.789). Table 8 shows looking behavior rate by gender.

Table 8. Looking Behavior Rate by Gender

	Gender	
	Male	Female
Grade Crossing Events where drivers looked at least one way	929	492
Total Grade Crossing Events	2,744	1,471
Looking Behavior Rate	0.339	0.334

Grade crossing events with drivers that looked at least one way on their approach to grade crossings were analyzed per age group (younger, middle-aged, and older). The data analysis of the looking behavior indicated that younger drivers were 25.3 percent likely to look at least one way compared with 35 percent for middle-aged drivers and 43.8 percent for older drivers at or on an approach to a grade crossing. Based on the paired t-test, the observed difference between both younger and middle-aged drivers and younger and older drivers was statistically significant (p<0.001). Figure 21 illustrates the distribution of looking behavior by age group.

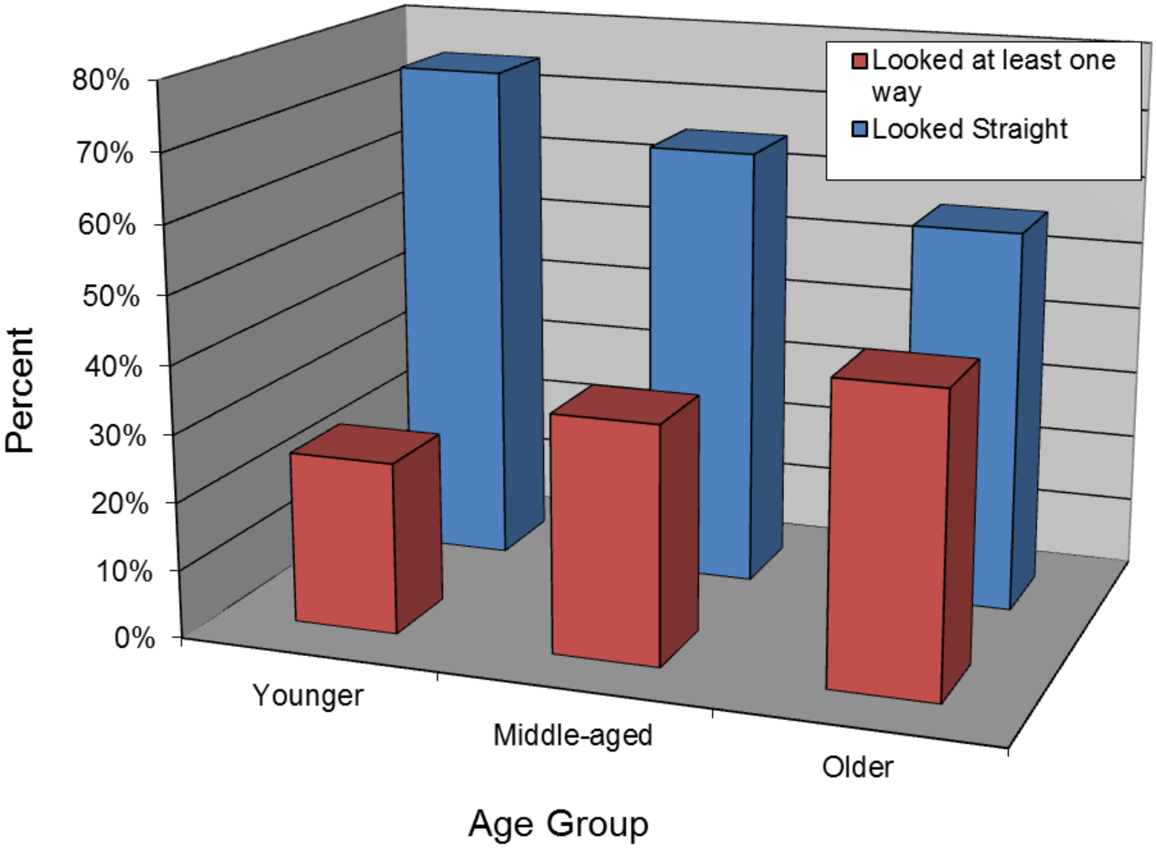


Figure 21. Distribution of Looking Behavior by Age Group

Data was further analyzed to determine whether warning devices had any effect on drivers' looking behavior at or on approach to highway-rail grade crossings. The data analysis of the looking behavior indicated that drivers were most likely to look at least one way at crossings equipped with STOP sign warning devices (97.3 percent exhibited this behavior) and least likely to look at least one way at crossings equipped with flashing lights or where warning devices were unknown (29.2 percent exhibited this behavior in each of these two categories). It should be noted that the sample data set related to these two warning device categories was very limited, as previously shown in Figure 10. Figure 22 illustrates the distribution of looking behavior by warning device.

Looking behavior was also analyzed between active and passive crossings. For this analysis, active crossings included highway-rail grade crossings equipped with gates and flashing lights; passive crossings included highway-rail grade crossings equipped with stop sign, cross bucks, and unknown. The data analysis of the looking behavior indicated that drivers looked at least one way 64.6 percent of the time at passive crossings compared with 31.2 percent at active crossings. Based on the paired t-test, the observed difference in looking behavior at active and passive crossings was statistically significant (p=0.000). Figure 23 illustrates the distribution of looking behavior between active and passive crossings.

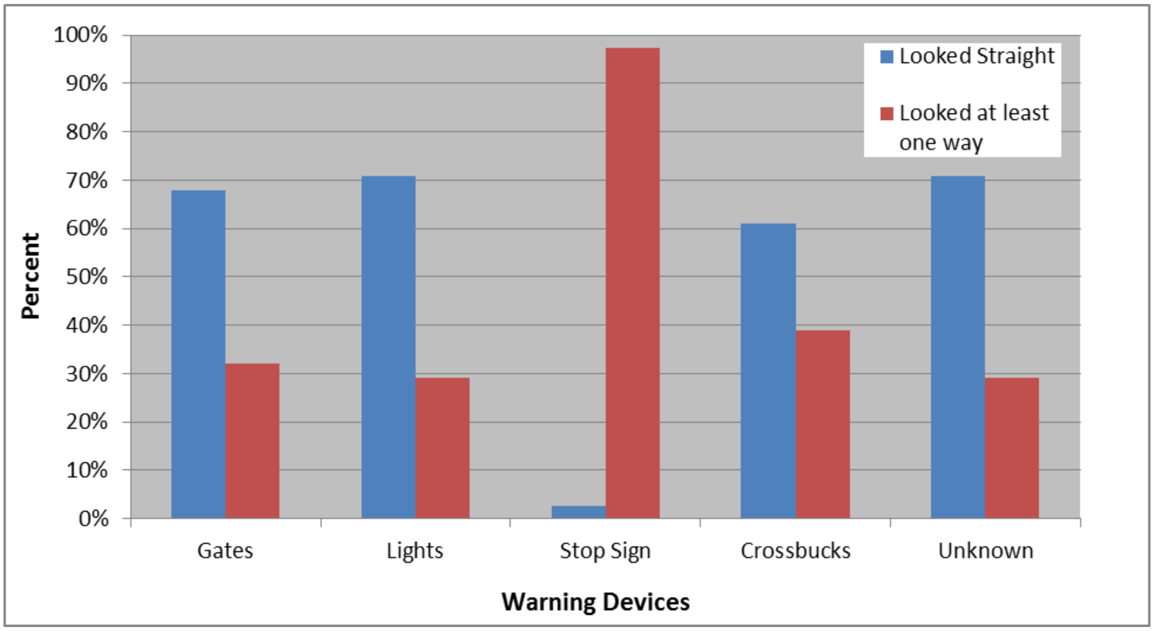


Figure 22. Distribution of Looking Behavior by Warning Devices

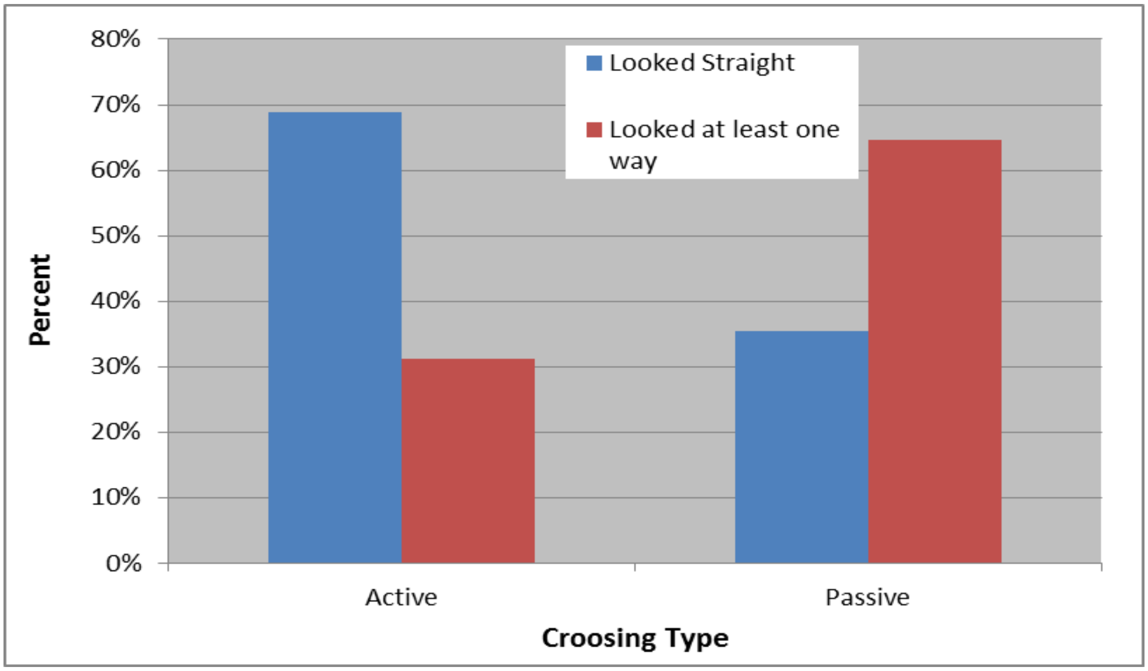


Figure 23. Distribution of Looking Behavior by Type of Crossing

5. Conclusion

Although previously studied and acknowledged to be a key factor in highway-rail grade crossing accidents, little is known about driver behavior and its contribution in such incidents. Thus, to gain a better understating of the problem, the FRA Office of R&D funded this project to review and analyze drivers' activities at or on approach to highway-rail grade crossings. This research had two main goals. The first goal was to conduct a feasibility assessment of using the IVBSS FOT data to perform grade crossing driver behavior analyses. The second goal was to collect and analyze drivers' activities at or on approach to highway-rail grade crossings. Both of these were achieved through the research documented herein.

It should be noted that this report only covers driver behavior analysis using the IVBSS Light Vehicle FOT data set. The LV IVBSS FOT participants took 22,656 trips over the study period. Out of those trips, the research team identified 3,137 trips containing 4,215 grade crossing events or instances where the IVBSS research vehicle traversed a grade crossing in the three States selected for this study. The research team then reviewed and coded the 4,215 grade crossing events. The data collected for each grade crossing event included information about drivers' activities, driver and vehicle performance, driving environment, and vehicle location at or on approach to highway-rail grade crossings.

The results of the data analysis revealed that, on average, drivers were likely to engage in secondary tasks, an indicator of driver distraction, approximately 46.7 percent of the time and look at least one way at or on approach to highway-rail grade crossings approximately 33.7 percent of the time.

The analysis of secondary task by gender and age group revealed that the distraction did not differ significantly between male and female drivers. Male drivers were engaged in secondary tasks 47.3 percent of the time compared with 45.5 percent for female drivers. The data further indicated that younger and middle-aged drivers were more likely to be engaged in secondary tasks compared with older drivers. Approximately 43 percent of older drivers were engaged in secondary tasks at or on approach to highway-rail grade crossings compared with approximately 48 percent of both middle-aged and younger drivers.

Looking behavior also did not differ significantly between male and female drivers. Male drivers looked at least one way 33.9 percent of the time compared with 33.4 percent for female drivers. But when analyzed by age group, the data revealed that older drivers were much more likely to look at least one way at or on approach to highway-rail grade crossings than either middle-aged or younger drivers. Approximately 43.8 percent of older drivers looked at least one way at or on approach to highway-rail grade crossings compared with 35 percent for middle-aged drivers and 25.3 percent for younger drivers.

The analysis of looking behavior by warning devices indicated that drivers were most likely to look at least one way at crossings equipped with STOP signs and least likely to look at least one way at crossings equipped with flashing lights or where the warning device type was unknown. When analyzed between active and passive crossings, the data indicated that drivers looked at least one way in 64.6 percent of the events at passive crossings compared with 31.2 percent of the events at active crossings.

Follow-on research already being conducted by the research team will focus on analysis of additional data elements, including vehicle speed profiles on approach to grade crossings; the research will also offer a deeper analysis of the driver behavior elements presented in this report. A similar study analyzing professional truck driver behavior will be documented in a subsequent report and is also being conducted using the IVBSS Heavy Truck FOT data set.

Evaluating the effectiveness of motorist and pedestrian signs and treatments, and examining driver behavior was identified as a top research priority in the 2009 FRA-sponsored Research Needs Workshop [4]. The authors hope the results presented in this report provide the basic driver behavior research needed to identify and guide potential driver education/awareness strategies that would best mitigate risky driver behavior at grade crossings.

6. References

[1] http://safetydata.fra.dot.gov/OfficeofSafety/default.aspx, last accessed June, 2011.

[2] U.S. Department of Transportation, Secretary of Transportation, *Rail-Highway Crossing Safety Action Plan*, Washington, DC: U.S. DOT, June 1994.

[3] U.S. Department of Transportation, Office of Inspector General, *Audit of the Highway-Rail Grade Crossing Safety Program*, Washington, DC: U.S. DOT, June 2004.

[4] Carroll, A., daSilva, M., and Ngamdung, T., **USDOT Federal Railroad Administration's Third Research Needs Workshop on Highway-Rail Grade Crossing Safety and Trespass Prevention: Volume I - Summary of Results**. Report No. DOT/FRA/ORD-10/01.I. Washington, DC: Federal Railroad Administration, January 2010. http://www.fra.dot.gov/eLib/details/L01319

[5] Sayer, J., LeBlanc, D., Bogard, S., Hagan, M., Sardar, H., Buonarosa, M. L., and Barnes, M., *Integrated Vehicle-Based Safety Systems Field Operational Test Plan*, prepared for Research and Innovative Technology Administration, ITS Joint Program Office, Ann Arbor, MI: U.S. DOT/RITA, December 2008.

[6] Sayer, J., Bogard, S., Busnarosa, M. L., LeBlanc, D., Funkhouser, D., Bao, S., Blankespoor, A., and Winkler, C., **Integrated Vehicle-Based Safety Systems Light-Vehicle Field Operation Test Key Findings Report**, prepared for Research and Innovative Technology Administration, ITS Joint Program Office, Ann Arbor, MI: U.S. DOT/RITA, January 2011.

[7] Sposato, S., Bien-Aime, P., and Chaudhary, M., **Public Education and Enforcement Research Study**, prepared for Federal Railroad Administration, Cambridge, MA: U.S. DOT/FRA, December 2006.

Appendix A.
10 Hz Numerical Data Dictionary

Driver	Driver ID
Trip	Trip ID
Time	Time in centiseconds since das started
ImuIndex	
LcmIndex	Lane change merge index
RadarFrontExtendedIndex	Front Radar extended scan Index
AccelPedal	Accelerator pedal
Brake	Brake active
Distance	Trip distance
Engaged	Cruise control active
Speed	Vehicle speed from transmission
Steer	Steering wheel angle, cw is negative
TurnSignal	Turn signal
Wipers	Wiper switch state
GpsHeading	Gps heading from Ublox Gps
GpsValid	True if gps data is valid
Latitude	Latitude from Ublox Gps
Longitude	Longitude from Ublox Gps
CswAvailable	Csw availability
CswWarning	Csw warning generated from arbitration
FcwAccel	Fcw target acceleration
FcwAvailable	Fcw availability
FcwAzimuth	Fcw azimuth
FcwRadarIndex	ExtendedBosch radar scan index for fcw target
FcwRange	Fcw range
FcwRangeRate	Fcw range rate
FcwTargetId	Fcw Target Id (handle)
FcwTargetType	Fcw Target Type
FcwValidTarget	Fcw Valid Target
FcwWarning	Fcw warning generated from arbitration
LcmRearAvailable	Lcm Rear Availability
LcmTTCAvailable	Lcm TTC Availability
LcmWarning	Lcm warning generated from arbitration
Leds	Mirror Leds
BoundaryLeft	Lane boundary type, left
BoundaryRight	Lane boundary type, right
DistancePastEdge	#N/A
LaneChange	Lane change
LaneOffset	Vehicle offset from lane center
LaneOffsetConf	Lane offset confidence
LaneWidth	Lane width

LdwAvailableLeft	Ldw left side availability
LdwAvailableRight	Ldw right side availability
LdwCaution	Ldw caution generated from arbitration
LdwLateralSpeed	Vehicle speed lateral to lane direction from ldw
LdwThreatLeft	Ldw left threat type
LdwThreatRight	Ldw right threat type
LdwWarning	Ldw warning generated from arbitration
Time	Time in centiseconds since das started
AcPressureSwitch	Ac Pressure Switch
AtmPressure	Atmospheric Pressure
BatteryVoltage	Battery voltage
DasVoltage	DAS input voltage
CoolantTemp	Engine coolant temperature
EngineSpeed	Engine speed
FuelUsed	Fuel used
Gear	Gear actual
GpsSpeed	Speed from gps
IntakeTemp	Intake Temperature
MCPressure	Master cylinder pressure
Odometer	Odometer
OutsideTemperature	Outside temperature (uncalibrated)
PulseActivated	True means brake pulse is activating
PulseRefused	true means brake pulse command is rejected
ReferenceDistance	Reference Distance Travelled
TargetThrottle	Current target throttle
Throttle	Current throttle
ArbitratedWarning	Arbitrated warning enum
ArbReason	Reason for arbitrated warning bitmap
DviAlert	Dvi alert response flags bit0 = audio , bit1 = haptic, bit2 = lvisual, bit3 = vsa
DviEnable	Dvi enable flags bit0 = audio & haptic, bit1 = led, bit2 = vsa
PulseRequest	Brake pulse request
PulsePressure	Brake pulse pressure request
PulseCalcPressure	Brake pulse pressure calculation
SnoozeTime	Time remaining until snooze expires
CswAlertRequest	Csw imminent warning request
FcwAlertRequest	Fcw alert request
LcmAlertRequest	>0 if Lcm is requesting a warning
LdwAlertRequest	Ldw alert request
AdhIndex	Adh index
ArbIndex	Arb transaction index
GwIndex	Gateway index

Appendix B.
5 Hz Numerical Data Dictionary

Driver	Driver ID
Trip	Trip ID
Time	Time in centiseconds since das started
Ax	Longitudinal acceleration from InertiaLink IMU
Ay	Lateral acceleration from InertiaLink IMU
Az	Vertical acceleration from InertiaLink IMU
PitchRate	Pitch rate from InertiaLink IMU
RollRate	Roll rate from InertiaLink IMU
YawRate	Yaw rate from InertiaLink IMU
Pitch	Pitch angle from InertiaLink IMU
Roll	Roll angle from InertiaLink IMU
Yaw	Yaw angle from InertiaLink IMU
ImuTime	#N/A

Appendix C.
Summary Numerical Data Dictionary

Driver	Driver ID
Trip	Trip ID
StartTime	First time of test
EndTime	Last time of test
IvbssEnable	HMI (Ivbss functionality) enabled
Das	Das number
BrakeCount	Count of brake applications
Distance	Trip distance
LdwDayDistance	#N/A
WiperDistance	#N/A
EmergencyShutDown	Shut down request from Blue Earth micro because of out-of-range
Latitude	Latitude from Ublox Gps
Longitude	Longitude from Ublox Gps
Odometer	Odometer
Prndl	Prndl
Speed	Vehicle speed from transmission
TurnSignalCount	Count of turn signal application
LaneChangeCount	Count of lane change
Vgt25Distance	Distance above 25 mph
VgtRearMinDistance	#N/A
VgtTTCMinDistance	#N/A
CswRequestCount	Count of Csw Alert requests
FcwRequestCount	Count of Fcw Alert requests
LcmRequestCount	Count of Lcm Alert requests
LdwRequestCount	Count of Ldw Alert requests
CswWarningCount	Count of Csw warnings
FcwWarningCount	Count of Fcw warnings
LcmWarningCount	Count of Lcm warnings
LdwCautionCount	Count of Ldw cautions
LdwWarningCount	Count of Ldw warnings
TODTripStart	Absolute date/time corresponding to test time = 0 in access date/time format based on computer clock
TripStart	Absolute date/time corresponding to test time = 0 in access date/time format
Vehicle	Vehicle number
WarmStart	True if ignition happened with the das already running

Appendix D.
Grade Crossing Video Data Coding Instructions

1. Enter driver and trip ID for which you are collecting driver information and click “load” button.

2. All the grade crossing associated with that driver and trip will load in the drop-down menu.

3. Select the crossing from drop-down menu.

4. **T1:** Enter the time (hh:mm:ss) when the test vehicle arrives at the crossing pavement marking. If no pavement markings are present, then subtract 8 seconds from the time found for T2. In this case you would figure out the time for T2 and then go back and enter the time for T1.

5. **T2:** Enter the time (hh:mm:ss) when the test vehicle arrives at the crossing. Use the stop line at the crossing as a reference for arriving at the crossing.

6. **T3:** Enter the time (hh:mm:ss) when the test vehicle exits the crossing. Since there is no rear camera, you can usually tell the test vehicle has exited the crossing when the vehicle has stopped vibrating from going over the tracks.

7. **Warning Devices:** Select the highest level of warning devices that is present at the crossing. The drop-down menu is arranged in descending order with highest level of warning devices at the top. The drop-down menu contains the following devices:
    - Four Quadrant Gate
    - Gate
    - Flashing Lights
    - STOP sign
    - Crossbucks
    - Other
    - Unknown

8. **Advanced Warning Devices:** Identify whether advanced warning devices are present at the crossing. Advanced warning devices are usually located before or at the pavement marking.
    - Yes
    - No
    - Unsure

9. **Number of Tracks:** Select number of tracks at the crossing from the drop-down menu.
    - 1
    - 2
    - 3

  - 4
  - >4

10. **Number of Traffic Lanes:** Select the number of traffic lanes approaching the crossing. If the traffic lanes merge or expand at the approach of the crossing, select the number of traffic lanes that intersect with the crossing.
    - 1
    - 2
    - 3
    - 4
    - 5

11. **Driver Distracted:** From the drop-down menu, select the distraction that the driver experiences anytime between t1 and t3. If the driver was not distracted, then select "None."

    - None
    - Dialing phone
    - Talking on/listening to phone
    - Text messaging
    - Singing/whistling
    - Talking to/looking at passenger
    - Adjusting controls
    - Eyes closed >1s
    - Eating
    - Drinking
    - Grooming
    - Smoking/lighting cigarettes
    - Reading
    - Reaching for object in vehicle
    - Looking to the side/outside
    - Other (please specify in the comment section)

12. **Eyes off Road:** Identify from the drop-down menu whether the driver's eyes were off the road anytime between t1 and t3.
    - Yes
    - No
    - Unsure

13. **Obstruction:** From the drop-down menu, select the category that best describes the obstruction of the crossing on the approach to the crossing.
    - None
    - Trees/Bushes
    - Other vehicles
    - Building
    - Other train

14. **Weather:** Select from the drop-down menu the weather category that best describes the weather condition.
    - Clear
    - Foggy
    - Rain
    - Snow

15. **Visibility:** Select from the drop-down menu the visibility category that best describes the visibility on approach to the crossing.
    - Dawn
    - Day
    - Dusk
    - Dark

16. **Nearby Intersecting Road Present:** Identify whether there is a crossing intersection (not side street) 10 seconds after (t2) the test vehicle enters the crossing.
    - Yes
    - No

17. **Nearby Intersecting Road Time:** If there is a nearby intersection present, enter time (hh:mm:ss) the test vehicle arrives at the intersection.

18. **Nearby Intersecting Road Warning Devices:** If there is a nearby intersection present, select the warning device that is present at the intersection.
    - Traffic Lights
    - Stop Sign
    - Yield Sign
    - Rotary

19. **Cars in front:** Select from the drop-down menu whether there is a car present in front of the test vehicle in the same lane anytime between t1 and t3.
    - Yes
    - No
    - Unsure

20. **Cars Stop on Crossing:** Select from the drop-down menu whether the test vehicle or any other vehicle is stopped on the crossing.
    - Yes
    - No
    - Unsure

21. **Construction:** Identify whether there is construction work being performed anytime between t1 and t3.
    - Yes
    - No

  - Unsure

22. **Was there signal activation:** Identify from the drop-down menu whether there was any kind of activation at the crossing. The drop-down menu contains the following activation types:
    - **Train activation:** When a train is present at the crossing, the train triggers the track circuitry to activate the safety devices at the crossing. If a passive crossing, if there is a train present at the crossing.
    - **False activation:** When the safety devices at the crossing are activated without train's presence at the crossing. This choice is only applicable for active crossings, not passive crossings.
    - **No activation:** When the safety devices at the crossing are not activated; or, at a passive crossing, if there is no train present at the crossing.

23. **Did the vehicle commit a violation:** Identify from the drop-down menu whether the test vehicle commits any one of the three violations.
        - **Type I:** A type I violation occurs when a violator traverses the crossing while the lights are flashing, the bells are ringing, but before gate descent.
        - **Type II:** A type II violation occurs when a violator traverses the crossing during gate descent or ascent with audible devices sounding.
        - **Type III:** A type III violation occurs when a violator traverses the grade crossing after the gates finish their descent and are fully deployed in a horizontal position.

24. **Did the lead vehicle commit a violation:** Identify from the drop-down menu whether the lead vehicle (vehicle in front of the test vehicle) committed any of the above three violations.
    - Yes
    - No
    - Unsure

25. **Did the vehicle on opposite approach commit a violation:** Identify from the drop-down menu whether any of the vehicles from the opposite approach committed any of the above three violations.
    - Yes
    - No
    - Unsure

26. **Did the vehicle on same approach commit a violation:** Identify from the drop-down menu whether vehicle on same approach committed any of the above three violations.
    - Yes
    - No
    - Unsure

27. **Violation_Vehicle: S**elect the type of violation and identify whether the test vehicle caused a violation before or after the train arrival at the crossing.

- Type I
- Type II
- Type III
- Before
- After

28. **Violation_Lead Vehicle:** Select the type of violation and identify whether it was before or after the train arrival at the crossing.
    - Type I
    - Type II
    - Type III
    - Before
    - After

29. **Violation_Vehicle on opposite approach:** Select the type of violation and identify whether it was before or after the train arrival at the crossing.
    - Type I
    - Type II
    - Type III
    - Before
    - After

30. **Violation_Vehicle on same approach:** Select the type of violation and identify whether it was before or after the train arrival at the crossing.
    - Type I
    - Type II
    - Type III
    - Before
    - After

31. **Looking Behavior:** Select from the drop-down menu the option that best describes the driver's looking behavior anytime between t1 and t3. Looking behavior does not mean that the driver is distracted; he or she may be looking at the surroundings to assess if a train is arriving or has left. If the driver looked straight ahead, select the "*None of the above*" option.
    - Looked Left
    - Looked Right
    - Looked Both Ways
    - None of the Above

32. **Passengers in the car:** Select from the drop-down menu the number of passengers in the car. You can identify whether there are passengers in the car from reviewing the cab and face view.
    - 0
    - 1
    - 2
    - 3
    - N/A

33. **Total Trip Time:** Enter the total trip time in hh:mm:ss format. The total trip time can be found at the top right corner of the navigation control box.

34. **Traffic:** Identify the traffic condition (density) on approach side to crossing between t1 and t3. Please do not consider traffic condition on the opposite approach.

  - **None:** Select this category if there is no traffic (no vehicles) in front of the test vehicle.
  - **Light:** Select this category if there are few vehicles (2–3 vehicles) in front and traffic is most likely moving at or near roadway speed limit.
  - **Moderate:** Select this category if there are several vehicles in front (4–6 vehicles) and traffic is most likely significantly slower than the normal roadway speed.
  - **Heavy:** Select this category if the traffic (6+ vehicles) condition is stop and go.

35. **Comment:** Add any comments that describe driver activities or roadway characteristics that are not collected. This field does not have to be filled out for every trip.

Abbreviations and Acronyms

BSD	Blind Spot Detection
CSW	Curve Speed Warning
DAS	Data Acquisition System
FCW	Forward Crash Warning
FOT	Field Operational Test
FRA	Federal Railroad Administration
GPS	Global Positioning System
Hz	Hertz
IVBSS	Integrated Vehicle-Based Safety Systems
lat	Latitude
LCM	Lane-Change/Merge
LDW	Lane Departure Warning
long	Longitude
LV	Light Vehicle
NHTSA	National Highway Traffic Safety Administration
R&D	Research and Development
RITA	Research and Innovative Technology Administration
SQL	Structured Query Language
UMTRI	University of Michigan Transportation Research Institute
U.S. DOT	United States Department of Transportation
VMT	Vehicle Miles Traveled
Volpe Center	John A. Volpe National Transportation Systems Center