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NSTSCE

National Surface Transportation
Safety Center for Excellence

Large Truck Safety at Highway Railroad Grade Crossings

Developing a Naturalistic Commercial Motor Vehicle Database of Railroad Grade Crossings

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EXECUTIVE SUMMARY

Reducing collisions, injuries, and fatalities between vehicles and trains is the primary mission of the Federal Railroad Administration's (FRA's) Risk Reduction Program Division. As part of this mission, the FRA aims to collect new incident data that can help identify and provide a better understanding of events and behaviors leading to collisions and to provide data and recommendations to improve safety (FRA, 2019a). These data are just as important as ever, as there were 2,131 collisions, 237 fatalities, and 653 injuries at highway-railroad grade crossings (RGCs) in 2021 (Operation Lifesaver, 2022). However, these data do not include the full scope of incidents at RGCs, as they do not account for vehicle-to-vehicle collisions (e.g., a rear-end collision when a lead vehicle stopped prior to traversing the RGC). This is especially true for the classes of commercial motor vehicles (CMVs) required to stop at all RGCs prior to crossing the tracks.

Naturalistic driving studies (NDSs) provide a unique opportunity to gather and analyze data to understand precursors to the incidents that occur at RGCs. Without video data, it is difficult to fully understand the contributing factors associated with driver behavior. The video data included in an NDS capture what the driver is doing behind the wheel directly before a safety-related event (i.e., near-crash and crash). Although there have been a few studies to use NDS data to investigate passenger vehicle driver behavior at RGCs (Lautala et al., 2016; Salim et al., 2018), there has not been any research using NDS data to investigate CMV safety at RGCs.

As the leader in conducting NDSs, and the holder of 90% of the world's NDS data, the Virginia Tech Transportation Institute offers access to valuable data that may be used to better understand CMV driver behavior (and the behavior of other drivers near the CMV) at RGCs. One NDS, the On-Board Monitoring System Field Operational Test (OBMS FOT), includes classes of CMVs required to stop at all RGCs: tanker trucks carrying oil/gas and motorcoaches. The objective of this project was to combine the OBMS FOT datasets with the Roadway Information Database and the FRA's Highway-Rail Crossing Inventory. Specifically, the purpose of this study was to:

- Identify all RGCs traversed by CMVs in the OBMS FOT (Hammond et al., 2021) datasets.
- Identify which of those CMVs traversing an RGC were required to stop (i.e., a placarded CMV or motorcoach).
- Identify the number of trips included in the OBMS that involved crossing an RGC.
- Create a database of RGCs that can be used in a future study to examine driver behavior of CMV and passenger vehicle drivers at RGCs.

The final database included 1,733 RGCs traversed by a CMV that were in the OBMS FOT study. These vehicles made 52,358 trips across the 1,733 RGCs. This includes 17,990 trips of a tanker truck and 10,087 trips of a motorcoach traversing an RGC. This newly created database can be used in future research efforts to investigate CMV driver behavior at RGCs and to develop new countermeasures to reduce RGC crashes and their resulting injuries and fatalities.

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LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
CFR	Code of Federal Regulations
CMV	commercial motor vehicle
DAS	data acquisition system
FMCSA	Federal Motor Carrier Safety Administration
FOT	field operational test
FRA	Federal Rail Administration
GCIS	Grade Crossing Information System
GPS	Global Positioning System
IIJA	Infrastructure Investment and Jobs Act
NDS	naturalistic driving study
OBMS	on-board monitoring system
RR	railroad
RGC	railroad grade crossing
SCE	safety-critical event
SQL	Structured Query Language
VTTI	Virginia Tech Transportation Institute

INTRODUCTION

Per Sarah Feinberg of the Federal Railroad Administration (FRA), "Few issues have been as important, and risen to the top as quickly, as has improving safety at grade crossings. It is a top priority because we are simply losing too many people at grade crossings" (2/25/16 remarks to American Association of State Highway and Transportation Officials Legislative Panel). A highway railroad grade crossing (RGC) is defined as a location where a public highway, road, street, or private roadway, including associated sidewalks, and pathways, crosses railroad (RR) tracks at grade. In 2015, there were over 210,000 public and private RGCs in the U.S. (FRA, 2019b). Although RGCs are designed to safely allow trains, vehicles, and other road users to intersect, collisions do occur. Collisions at RGCs between trains and vehicles or other road users result in many fatalities, a rate of fatalities second only to pedestrians trespassing on RR tracks (FRA, 2020).

Commercial motor vehicles (CMVs) that are placarded for hazardous materials are forbidden from crossing RR tracks without first stopping within 50 feet, but no closer than 15 feet, of the tracks, listening, and looking both ways for an approaching train. CMV drivers may cross the RR tracks once it is safe to do so, although they are not permitted to shift gears while crossing (49 CFR 392.10). In 2020, there were 1,901 highway-RGC incidents (478 involved a CMV), including 186 fatal crashes and 518 injury crashes (FRA, 2022b). In 2021, there were 2,131 collisions at an RGC, resulting in 237 fatalities and 653 injuries (Operation Lifesaver, 2022). However, these data do not capture the entire picture. At many RGCs, the real fatality risk also includes a passenger vehicle driver dying after rear-ending a stopped CMV, though if the two vehicles do not encounter a train, then the incident is not reported as an RGC crash. FRA adopted the RGC stopping regulation in the 1930s, which made sense at that time; however, today's passenger car drivers may have no reason to expect a CMV to stop at an RGC, as their experience with non-placarded CMVs has generally been otherwise. Thus, when the truck unexpectedly comes to a stop, especially at night, a passenger vehicle may have to brake hard to avoid a rear-end crash with the CMV.

IMPORTANCE OF THE STUDY

Improving safety at RGCs has long been an emphasis at FRA, and the recent approval of the Infrastructure Investment and Jobs Act (IIJA; Pub. L. 117-58) continues support for the Railway-Highway Crossing Program and other initiatives to improve safety at RGCs. The IIJA, also known as the "Bipartisan Infrastructure Law," was signed by President Joseph R. Biden on November 15, 2021, to provide unprecedented Federal funding for rail improvement projects in America (FRA, 2022a, 2022c). These funds will improve the U.S. network of RRs to increase safety, reliability, sustainability, and equity.

This law aims to fund highway-rail or pathway-rail grade crossing improvement projects that focus on improving the safety and mobility of people and goods through Advanced Appropriations of $600 million per year and Fully Authorized Funds of $500 million per year during the fiscal period of 2022 to 2026. These funds will support improvements to the rail network and will aim to reduce the number of crashes, injuries, and fatalities at RGCs.

Naturalistic driving data provides a unique opportunity to study vehicle kinematics (e.g., approach speed and braking response), driver behavior (including driver eye-glance patterns), and conspicuity at several types of RGCs to develop potential train crash countermeasures. It is important to note that in addition to the type of RGC warning device, other factors such as pavement markings, channelization, signage, and lighting also affect the overall safety of the RGC. These components are all essential for increasing visibility and driver awareness of potentially hazardous situations, ideally resulting in reduced speeds and fewer violations. However, traditional methods of understanding crash risk and driver behavior at RGCs are limited. Additional research is needed to better understand the impact of infrastructure at RGCs on driver behavior.

Driver Behavior at RGCs

Crashes between trains and vehicles at RGCs are the second leading cause of all train-related fatalities. Each year, more than 2,200 crashes occur at RGCs, with more than 40% percent of these resulting from vehicles not stopping. RGCs can have passive or active systems; in the U.S., roughly half of public RGCs are equipped with passive systems. And while 90% of rail-highway traffic occurs at RGCs with active systems, 40% of all incidents, injuries, and fatalities occur at RGCs with passive systems (Hellman & Lampugh, 2015). Improving safety at RGCs requires an improved understanding of driver behavior before, during, and after the crossing, as well as insight into how that behavior is affected by the type of warning device(s), geometric characteristics, traffic channelization device(s), delineation, traffic signs, environmental factors, and surrounding environment at RGCs.

Researchers studying driver behavior and the effectiveness of countermeasures at RGCs have primarily used simulators and observations at fixed locations (data collected outside of vehicles), with limited studies based on in-vehicle data. Liu et al. (2016) analyzed driver distraction by posting cameras at two RGCs. They used external video collection systems to evaluate LED-enhanced signs at two rural RCGs with dynamic envelope pavement markings. A recent study that used a vehicle with eye-tracking technology to examine the behavior of 24 participants found that over 50% of participants did not check for an approaching train before crossing (regardless of the system) and crossed at higher speeds than drivers who did check for a train (Grippenkoven & Dietsch, 2016). Further, another study by Lautala (2016) using a driving simulator found the percentages of drivers who did not look to both sides before crossing were 30% for crossbuck and 27% for crossbuck and yield. Although the limitations of the above methods have been recognized, studies based on in-vehicle data are rare due to the high cost of naturalistic data collection.

Naturalistic Data to Investigate Risk at RGC

While passenger vehicle driver behavior when approaching RGCs has been studied mostly with simulators or video data collected outside vehicles, several studies used Virginia Tech Transportation Institute's (VTTI's) Second Strategic Highway Research Program naturalistic driving study (NDS) data to investigate driver behavior at RGCs. One of these studies evaluated vehicle kinematics, head position data measured with machine learning, and environmental conditions at 100 RGCs with a total of only 1,017 crossings (Lautala et al., 2016). The second study included 300 RGCs and a total of 12,644 crossings but only analyzed environmental conditions and speed data (Salim et al., 2018). Neither study included an in-depth review of the driver video data at the RGCs. The review of driver video would add critical context for identifying driver behavior to inform countermeasure development. For example, video review can be used to assess RGC violations (violations vs. safe crossings), glance locations (including fixation points, which is not possible using machine learning), the presence of other vehicles queuing at the RGC, the functionality/conspicuity of RGC features, and other factors. Further, CMV naturalistic driving data can be used to examine CMV driver behavior at RGCs and provide new insight into the behavior of passenger vehicles around trucks that must stop at all RGCs.

OBJECTIVE

Naturalistic truck datasets represent a unique opportunity to research truck driver behavior and the behavior of following passenger vehicles at RGCs. Such research may help uncover important aspects of driver behavior around RGCs, which has previously been mainly studied using simulators or observational data at limited or fixed locations. Further, such research may inform new countermeasures to prevent crashes associated with RGCs. Thus, the purpose of this project was to combine a CMV naturalistic dataset with the RID and the FRA's Highway-Rail Crossing Inventory. Specifically, the purpose of this study was to:

- Identify all RGCs traversed by CMVs in the OBMS FOT (Hammond et al., 2021) datasets.
- Identify which of those CMVs traversing an RGC were required to stop (i.e., a placarded CMV or motorcoach).
- Identify the number of trips included in the OBMS that involved crossing an RGC.
- Create a database of RGCs that can be used in a future study to examine driver behavior of CMV and passenger vehicle drivers at RGCs.

METHOD

As mentioned above, the main purpose of this project was to link two major databases—the FRA RGC database and the OBMS FOT CMV naturalistic database—and filter the dataset for future analysis of CMV and passenger vehicle behavior at RGCs.

FRA DATABASE

The FRA maintains its own inventory database and crash database for all RGCs in the U.S. (FRA's Highway-Rail Crossing Inventory). This inventory is maintained for each state and includes the location (GPS) as well as the attributes of that specific RGC (infrastructure, crashes, train traffic, etc.). This database uses the Grade Crossing Inventory System (GCIS), which is a web-based application allowing railroad, state, and transit users to directly submit crossing records via three methods: (1) a web user interface, (2) upload of multiple records using FRA pre-approved Excel template(s), and (3) a web application programming interface. The data received are stored within a SQL server database. This document contains the names of tables used in the GCIS, and includes details such as field names and valid field values. The complete FRA database has about 18,275 rows of RGCs with 194 variables to characterize the RGC attributes.

NDS DATASET

For the current study, NDS data was sourced from the OBMS FOT project. The OBMS FOT was a naturalistic data collection effort, sponsored by the Federal Motor Carrier Safety Administration (FMCSA), conducted in 2012–2015 (Hammond et al., 2021). Naturalistic data from over 245 participants was collected from seven truck and motorcoach fleets at 10 locations across the continental U.S. (Figure 1).

Figure 1. Map. Location of OBMS FOT participating fleets (Hammond et al., 2021).

More than 3.8 million miles of data were collected during the study. Study participants operated their regular work truck or motorcoach, which was instrumented with a VTTI data acquisition system (DAS). When the vehicle was turned on and in motion, the DAS collected continuous video data through a camera system and kinematic data through a series of sensors. The DAS included five video cameras, with views of the forward roadway, participant's face, over-the-shoulder, left mirror, and right mirror. Figure 2 shows a single image with the five camera views in clockwise order. In addition to the DAS, vehicles were also instrumented with an OBMS. Additional information on the OBMS FOT study methods can be found in Hammond et al., (2021) and Boyle et al. (2016).

Figure 2. Photos. Five camera views collected during OBMS FOT naturalistic driving study.

BUILDING THE RAILROAD AND NDS MATCHED DATASET

Two key datasets were needed to identify traversals of RGCs in the NDS data: (1) the FRA database and (2) the map-matched NDS data. The map-matched NDS data was generated during a previous study (Krum et al., 2021), where GPS trace data was fitted or "matched" onto road segments of a road network dataset. A detailed description of the map-matching process can be found in Krum at al.'s work (2021). To briefly summarize the process, GPS points from the NDS driving data were matched to a proprietary digital geographic map dataset.

In the current study, the FRA database was overlaid on the map-matched NDS data. A query selected the closest RGC to the driving data and filtered out any RGC greater than 50 meters in distance from the study vehicle. In addition, the query pulled the name of the road the vehicle was on. From the query results, a researcher hand verified each instance to confirm the FRA database roadway names at the RGC matched the map-matched roadway name the vehicle was using. The final verified dataset included key variables describing features of the RGC, as provided in the FRA database.

Each matched RGC had an associated road segment link ID, which is a unique number assigned to the roadway area. The link IDs were matched to the NDS data during the Krum at al. (2021) study. Each link ID references a single road segment, with distinct roadway features. Link IDs have varied lengths, as length is determined by the length of the distinct roadway features. A single driving trip could be associated with many link IDs over the trip duration.

All NDS driving files that contained link IDs associated with verified RGCs were identified. NDS driving files have a single vehicle source. The vehicle data was used to summarize the NDS driving data by total number of trips traversing each RGC by vehicle type. If, for a single file, the timestamp for a safety-critical event (SCE) overlapped with the timestamp of the link ID, the event was counted as occurring near or at an RGC. The total number of SCEs per unique RGC was tabulated, both overall and by CMV type. Summarizing the traversal count and SCE data by vehicle type was important, as different CMV types have different authorized RGC driving behaviors (i.e., certain CMV types are required by law to stop at an RGC before proceeding). Figure 3 shows the step-by-step process of how the FRA database was overlaid with the map-matched naturalistic data using Link ID and further filtered to include only valid sites by considering Crossing Road (Open), Pavement Marking (Stop Lines, RR Crossing Symbols, and Dynamic Envelops) and Crossing Position (at Grade). Then, the dataset was further cleaned by manually reviewing matching road names in Google Earth where the anticipated trajectory of trucks would cross the highway-RGCs.

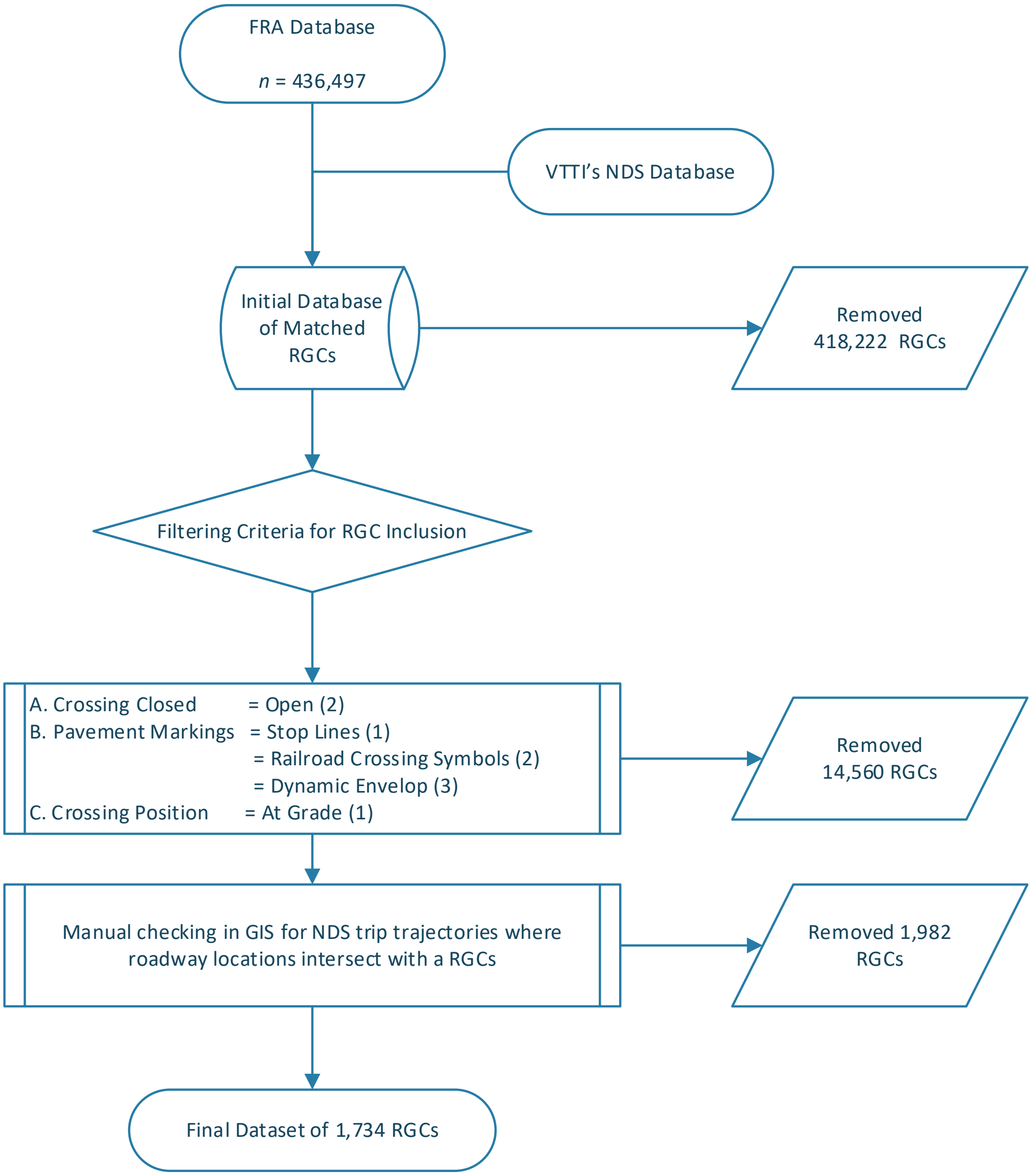

Figure 3. Flowchart. Data linkage and overall filtering process for highway and RGC dataset.

ANALYSIS METHODS

The final dataset of 1,734 RGCs was investigated for frequency of several important parameters from the FRA database. These parameters included the following:

- crossing
- lane use
- frequency of trains per week
- pavement markings
- signal pre-emption
- type of train service
- nighttime through trains
- maximum speed range over crossing
- traffic signals
- pre-signals

- number of lanes
- functional class of roadways
- percent of trucks
- lane type
- highway speed
- annual average daily traffic on the roads.

The data was summarized using tables and plots, first for data from all vehicles. The parameters include levels with no observations in the study final dataset. These parameter levels have been excluded from the summary tables. The analysis of all vehicle data was followed by a summary of the data from tanker trucks and motorcoaches only.

RESULTS

The final RGC dataset included 1,734 RGCs in 33 states (Figure 4). CMVs made 52,358 trips across these RGCs. There were four states where the number of RGC observations were above 100. The final dataset included 520 RGCs in Texas, 294 in Louisiana, 216 in North Carolina, and 202 in Florida.

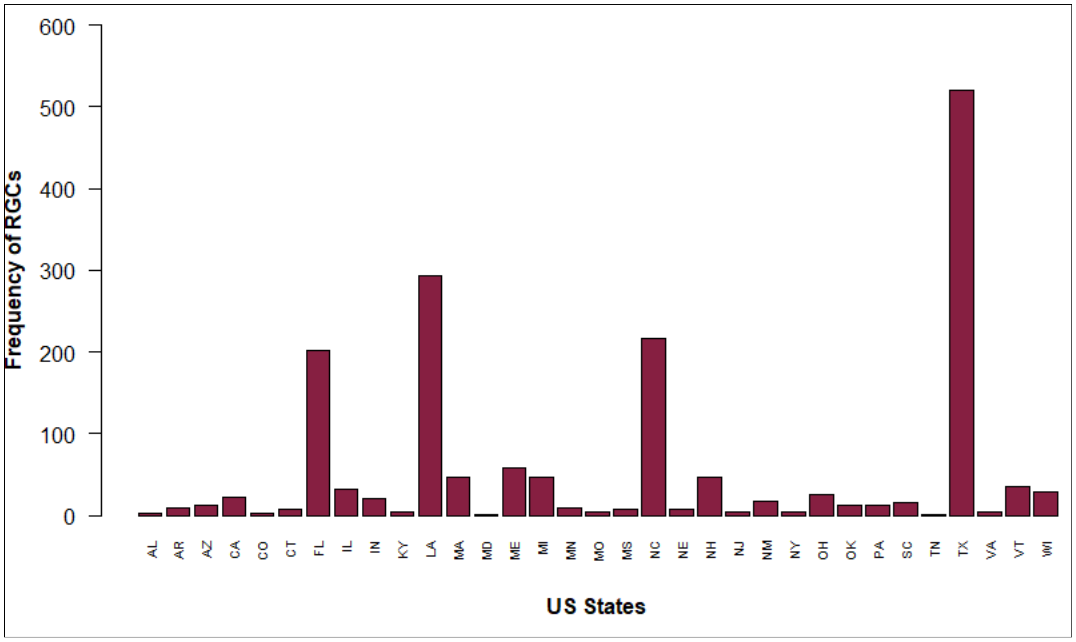

Figure 4. Chart. Number of RGCs by state.

SUMMARY STATISTICS FOR ALL RGCS

Table 1, Table 2, and Table 3 summarize the final dataset based on various RGC characteristics. The dataset contained 1,729 highway crossings, 3 pedestrian pathway crossings, and 2 pedestrian station crossings (Table 1). There were 832 RGCs in commercial areas, 304 in open space, 291 in industrial areas, and 245 in residential areas (Table 2). Finally, most of the RGC were used for general freight train service (1,215) or freight or intercity passenger service (228; Table 3).

Table 1. Location of RGCs.

Crossing Location	Count
Highway	1,729
Pathway, Pedestrian	3
Station, Pedestrian	2

Table 2. Type of land use at RGCs.

Land Use Description	Count
Commercial	832
Open Space	304
Industrial	291
Residential	245
Farm	30
Institutional	26
Recreational	6
RR Yard	0

Table 3. Type of train service at RGCs.

Train Service Description	Count
Freight	1,215
Intercity Passenger	2
Commuter	10
Transit	17
Tourist	20
Freight & Intercity Passenger	228
Freight & Commuter	18
Freight & Tourist	44
Intercity Passenger & Commuter	1
Commuter & Freight	1
Commuter & Transit	1
Commuter & Tourist	6
Freight, Intercity Passenger, & Commuter	8
Freight, Intercity Passenger, & Shared Transit	43
Freight, Intercity Passenger, & Tourist	2
Freight, Commuter, & Tourist	8

Figure 5 shows the distributions of RGCs based on the number of trains that passed through in the night. The majority of RGCs (696) in the dataset do not have trains that traverse them at night. There were 900 RGCs that experienced between 1 and 10 nighttime trains, 109 RGCs with between 11 and 20 nighttime trains, 8 with between 21 and 30 nighttime trains, 4 with between 31 and 40 nighttime trains, and 17 with over 40 nighttime trains.

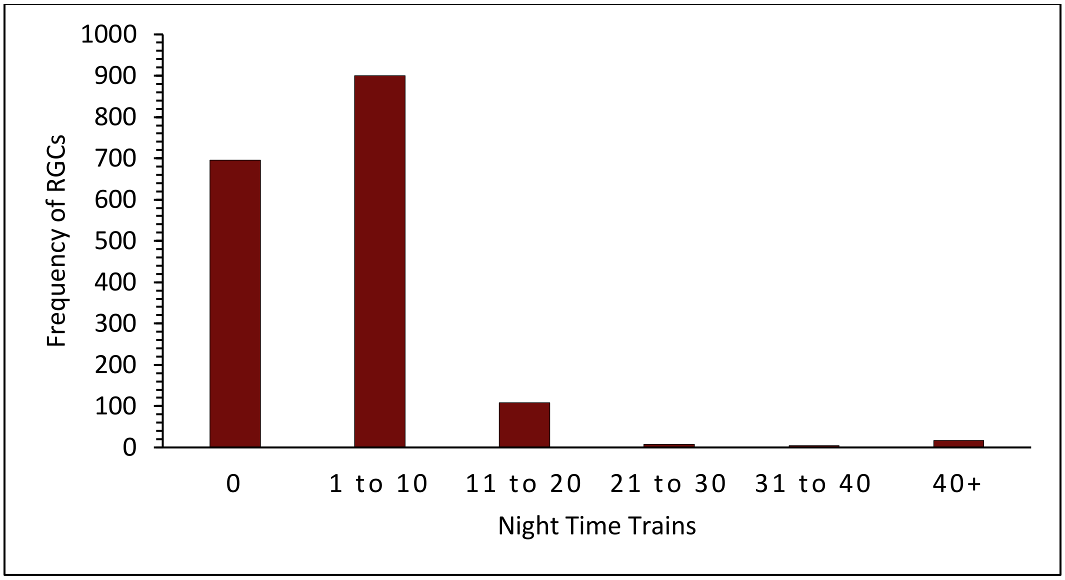

Figure 5. Chart. Distribution of nighttime trains through RGCs.

Table 4 shows the distribution of RGCs based on average train speed when traversing the crossing. As shown in Table 4, there were 798 RGCs with an average train speed under 25 mph, 327 with an average train speed between 25 mph to 35 mph, 188 with an average train speed between 36 mph and 45 mph, 158 with an average train speed between 46 mph and 55 mph, 155 with an average train speed between 56 mph and 65 mph, 55 with an average train speed between 66 mph and 75 mph, and 47 with an average train speed above 75 mph.

Table 4. Average train speed at RGCs.

Average Train Speed at RGC	Count
Under 25 mph	798
Between 25 to 35 mph	327
Between 36 to 45 mph	188
Between 46 to 55 mph	158
Between 56 to 65 mph	155
Between 66 to 75 mph	55
Above 76 mph	47

RGC Safety Attributes

Table 5 shows the number of RGCs with highway traffic signals. There are two types of traffic signals: highway traffic signals that control the RGC, and highway traffic pre-signals to notify drivers of an approaching RGC. Both traffic signals can be present at an RGC. Only 41 RGCs had a traffic signal that controlled the crossing, while 1,280 RGCs did not have a pre-signal.

Table 5. Traffic signal information over crossing.

	Highway Traffic Signals Controlling Crossing	Highway Traffic Pre-Signals
Yes	41	10
No	1,676	1,280

Table 6, Table 7, and Table 8 show the types of traffic safety attributes at the RGCs such as pavement markings, non-train active warnings, and signal preemption. Of the 1,734 RGCs included in the final dataset, 85% had pavement markings that included stop lines and an RGC symbol (1,478; Table 6). Further, 874 RGCs had 0 non-train active warnings (Table 7), and 218 had simultaneous signal preemption (Table 8).

Table 6. Pavement markings at RGCs.

Pavement Markings	Count
RGC Symbols	91
Stop Lines	83
Stop Lines & RGC Symbols	1,477
RGC Symbols & Stop Lines	72
Stop Lines & Dynamic Envelope	1
RGC Symbols, Stop Lines, & Dynamic Envelope	9

Table 7. Non-train active warnings at RGCs.

Non-Train Active Warnings	Count
None	874
Flagging/Flagman	21
Manually Operated Signal	1
Watchman	1

Table 8. Highway traffic signal pre-emption at RGCs.

Highway Traffic Signal Preemption	Count
None	6
Simultaneous	218
Advance	95

Physical Characteristics of RGCs

Table 9, Table 10, and Table 11 summarize the characteristics and classification of roadways at each of the RGCs. There were 1,162 RGCs with two-way traffic, 101 with divided traffic, and 62 with one-way traffic lanes (Table 9). These included 1,111 urban RGCs and 608 rural roadway RGCs (Table 10). Further, 15 RGCs were on interstates, 15 were on freeways and expressways, 479 were on principal arterial roadways, 408 were on minor arterial roadways, 424 were on major collector roadways, 86 were on minor collector roadways, and 290 were on local highways or roadways (Table 11).

Table 9. Roadway traffic lane type at RGCs.

Traffic Lane Type	Count
Two-Way Traffic	1,162
Divided Traffic	101
One-Way Traffic	62

Table 10. Road classification at RGCs.

Road Classification	Count
Urban	1,111
Rural	608

Table 11. Highway type at RGCs.

Type of Highway	Count
Principal Arterial	479
Major Collector	424
Minor Arterial	408
Local	290
Minor Collector	86
Freeways and Expressways	15
Interstate	15

Figure 6 shows the distribution of number of traffic lanes at crossings. There were 1,012 RGCs with two traffic lanes and 402 RGCs with four traffic lanes.

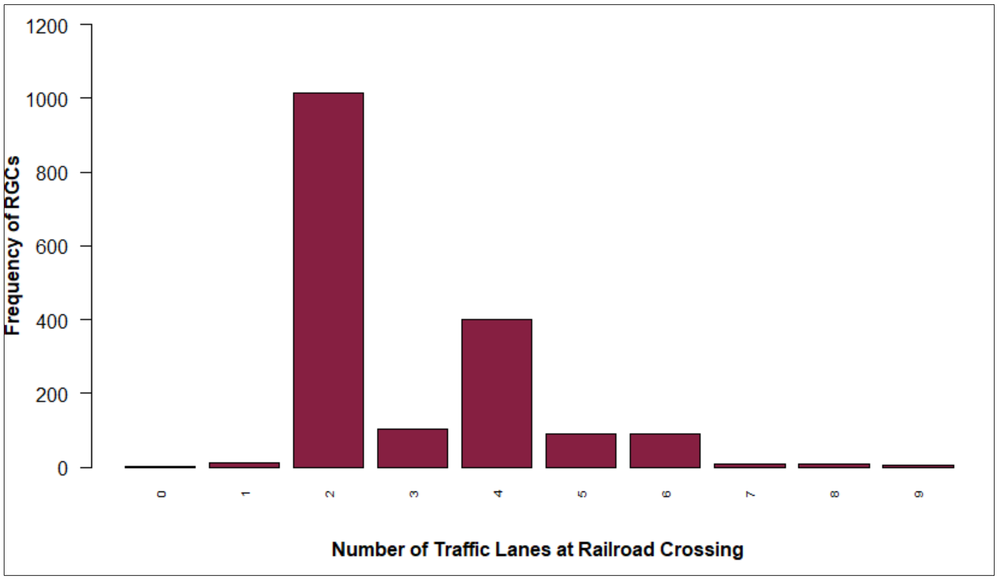

Figure 6. Chart. Distribution of traffic lanes at RGCs.

Table 12 shows the distribution of RGCs based on roadway speed limit. As the table indicates, there were 44 RGCs with a highway speed limit under 20 mph, 895 RGCs with a highway speed limit between 21 mph and 40 mph, 537 RGCs with a highway speed limit between 41 mph and 60 mph, and 35 RGCs with a highway speed limit above 60 mph.

Table 12. Speed limit of highways near RGCs.

Highway Speed Limit	Count
Highway Speed Under 20 mph	44
Highway Speed Between 21 and 40 mph	895
Highway Speed Between 41 and 60 mph	537
Highway Speed Above 61 mph	35

Table 13 shows the estimated percentage of trucks that passed through the RGCs. At 1,355 RGCs, truck traffic was less than 10% of the total vehicle traffic, 265 RGCs had between 10% and 20% truck traffic, and 70 RGCs experienced between 21% and 30% truck traffic. There were only 4 RGCs in the dataset where the estimated percentage of trucks passing through the crossing was between 50% and 60%.

Table 13. Percentage of trucks traversing through RGCs.

Estimated Percent of Trucks	Count
Under 10%	1,355
Between 10% and 20%	265
Between 21% and 30%	70
Between 31% and 40%	21
Between 41% and 50%	5
Between 51% and 60%	4

SUMMARY STATISTICS FOR RGCS WITH TANKER TRUCK AND MOTORCOACH DATA

Figure 7 and Figure 8 show the distribution of trips made by fuel tanker trucks and motorcoaches that passed through the RGCs in the dataset. As shown in Figure 7, fuel tanker trucks made 1–5 trips across 266 RGCs, 6–10 trips across 51 RGCs, and 11–50 trips across 66 RGCs. The dataset did include RGCs with more than 100 trips from fuel tanker trucks. For example, fuel tanker trucks had 101 to 200 trips that passed over 12 RGCs, and another 3 RGCs had 600 or more trips from fuel tanker trucks.

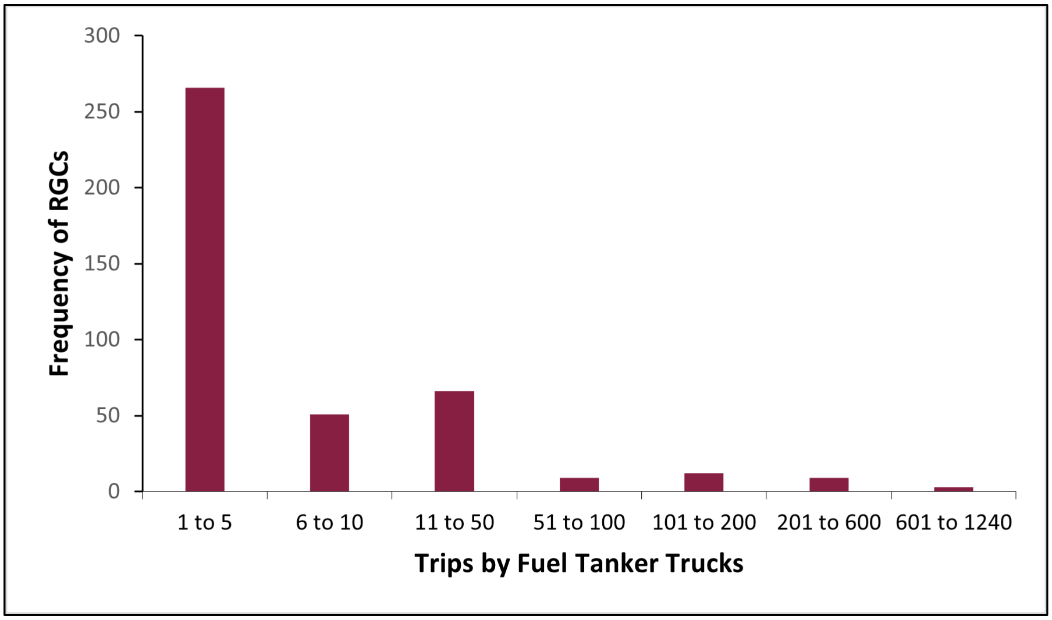

Figure 7. Chart. Number of trips by fuel tanker trucks traversing an RGC.

As seen in Figure 8, motorcoaches made 1–5 trips across 543 RGCs and 6–10 trips across 63 RGCs. There were 2 RGCs that had between 201 and 5,900 motorcoach trips.

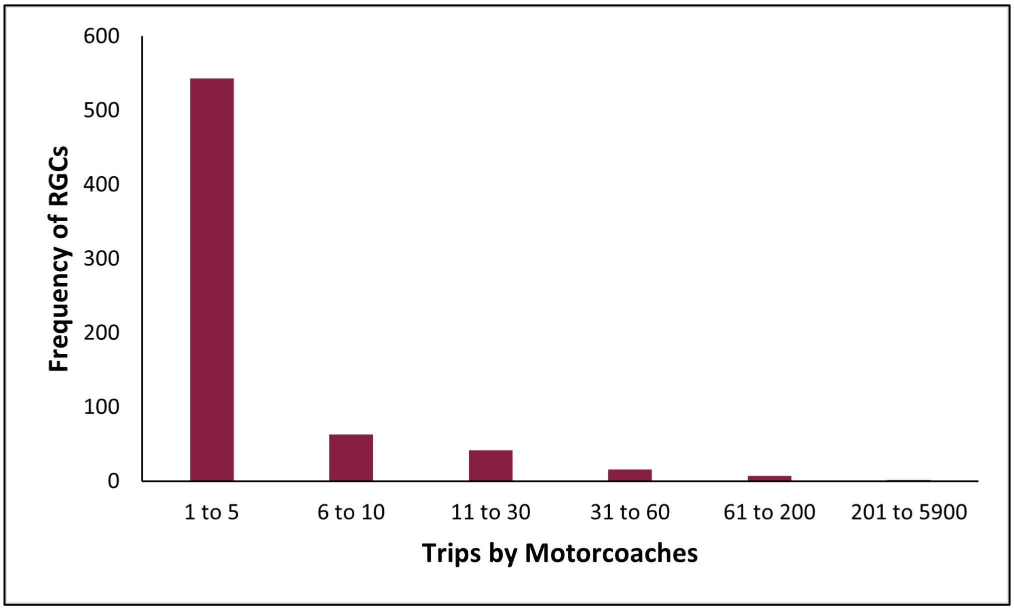

Figure 8. Chart. Number of trips by motorcoaches traversing an RGC.

Table 14, Table 15, and Table 16 summarize characteristics of the RGCs traversed by fuel tanker trucks and motorcoaches. Fuel tanker trucks traversed 416 highway RGCs and motorcoaches traversed 669 highway RGCs (Table 14). Fuel tanker trucks traversed 230 commercial RGCs, and motorcoaches crossed 328 commercial RGCs (Table 15). Fuel tanker trucks traversed 308

RGCs with freight train service, whereas motorcoaches passed through 465 RGCs with freight train service (Table 16).

Table 14. Location of RGCs crossed by fuel tanker trucks and motorcoaches.

Crossing Location	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
Highway	416	669
Pathway, Pedestrian	-	2
Pathway, Station	-	2

Table 15. Type of land use at RGCs crossed by fuel tanker trucks and motorcoaches.

Land Use Description	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
Commercial	230	328
Open Space	29	155
Industrial	93	89
Residential	39	81
Farm	13	7
Institutional	9	12
Recreational	3	1
RR Yard	-	-

Table 16. Type of train service at RGCs crossed by fuel tanker trucks and motorcoaches.

Train Service Description	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
Freight	308	465
Intercity Passenger	-	-
Commuter	-	3
Transit	-	17
Tourist	4	-
Freight & Intercity Passenger	26	131
Freight & Commuter	-	9
Freight & Tourist	9	10
Intercity Passenger & Commuter	-	1
Commuter & Freight	-	-
Commuter & Transit	-	1
Commuter & Tourist	-	6
Freight, Intercity Passenger, & Commuter	2	7

Train Service Description	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
Freight, Intercity Passenger, & Shared Transit	40	-
Freight, Intercity Passenger, & Tourist	-	-
Freight, Commuter, & Tourist	-	6

RGC Service Characteristics

Table 17 and Table 18 present the counts of nighttime trains and average train speeds at RGCs traversed by fuel tanker trucks and motorcoaches, respectively. Fuel tanker trucks passed through 409 RGCs with 0–10 daily nighttime trains and motorcoaches passed through 582 RGCs with 0–10 daily nighttime trains (Table 17). As shown in Table 18, most of the RGCs traversed by fuel tanker trucks and motorcoaches had average train speeds under 25 mph.

Table 17. Nighttime trains at RGCs crossed by fuel tanker trucks and motorcoaches.

Nighttime Trains	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
0 to 10 Daily Nighttime Trains	409	582
10 to 20 Daily Nighttime Trains	7	69
20 to 30 Daily Nighttime Trains	-	1
30 to 40 Daily Nighttime Trains	-	4
More than 40 Daily Nighttime Trains	-	17

Table 18. Average train speed at RGCs crossed by fuel tanker trucks and motorcoaches.

Average Train Speed at the RGCs	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
Under 25 mph	286	327
Between 25 and 35 mph	13	54
Between 36 and 45 mph	38	93
Between 46 and 55 mph	22	78
Between 56 and 65 mph	18	84
Between 66 and 75 mph	4	25
Above 76 mph	10	11

RGC Safety Attributes

Table 19, Table 20, and Table 21 show traffic control characteristics of the RGCs traversed by fuel tanker trucks and motorcoaches. For both vehicle types, the most common pavement markings at RGCs were stop lines and RGC symbols together (Table 19). Fuel tanker trucks passed through 385 RGCs and motorcoaches passed through 615 RGCs with pavement markings of stop lines and crossing symbols. There were 381 and 196 RGCs without active warnings crossed by fuel tanker trucks and motorcoaches, respectively (Table 20). RGCs crossed by fuel tanker trucks included 70 crossings with simultaneous traffic signal pre-emption and 20 with advance traffic signal pre-emption (Table 21). RGCs crossed by motorcoaches included 93 crossings with simultaneous traffic signal pre-emption and 57 with advance traffic signal pre-emption (Table 21).

Table 19. Pavement markings at RGCs crossed by fuel tanker trucks and motorcoaches.

Pavement Markings	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
Stop Lines	8	31
RGC Symbols	15	18
Stop Lines & RGC Symbols	385	615
Stop Lines & Dynamic Envelope	-	1
RGC Symbols & Stop Lines	5	4
Stop Lines, RGC Symbols, & Dynamic Envelope	3	4

Table 20. Non-train active warnings at RGCs crossed by fuel tanker trucks and motorcoaches.

Non-Train Active Warnings	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
None	381	196
Flagging/Flagman	12	4
Manually Operated Signal	-	-
Watchman	1	-

Table 21. Highway traffic signal preemption at RGCs crossed by fuel tanker trucks and motorcoaches.

Highway Traffic Signal Preemption	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
None	-	-
Simultaneous	70	93
Advance	20	57

The presence of highway traffic signals at RGCs is presented in Table 22. Fuel tanker trucks crossed 409 RGCs without a highway traffic signal controlling the crossing and crossed 394 RGCs with highway traffic pre-signals. Motorcoaches travelled through 651 RGCs that did not have traffic signals controlling the crossings and 524 RGCs that did have traffic pre-signals.

Table 22. Traffic signals at RGCS crossed by fuel tanker trucks and motorcoaches.

Highway Traffic Signal Type	Highway Traffic Signal Type Present	Number of RGCs Crossed by Fuel Tanker Trucks	Number of RGCs Crossed by Motorcoaches
Highway Traffic Signals Controlling Crossing	Yes	3	21
Highway Traffic Signals Controlling Crossing	No	409	651
Highway Traffic Pre-Signals	Yes	-	4
Highway Traffic Pre-Signals	No	394	524

Physical Characteristics of RGCs

Table 23, Table 24, and Table 25 show the roadway attributes at RGCs traversed by fuel tanker trucks and motorcoaches. Fuel tanker trucks travelled through 226 RGCs with two-way traffic, and motorcoaches passed through 498 RGCs with two-way traffic (Table 23). Tanker trucks traversed 267 urban RGCs and 146 rural RGCs (Table 24). Motorcoaches traversed 477 urban RGCs and 191 rural RGCs (Table 25). Further, fuel tanker trucks traversed 129 RGCs on principal arterials, four RGCs on freeways and expressways, and 90 RGCs on major collector highways (Table 25).

Table 23. Roadway traffic lane type at RGCs crossed by fuel tanker trucks and motorcoaches.

Traffic Lane Type	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
One-Way Traffic	-	46
Two-Way Traffic	226	498
Divided Traffic	66	14

Table 24. Road classification at RGCs crossed by fuel tanker trucks and motorcoaches.

Road Classification	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
Urban	146	191
Rural	267	477

Table 25. Highway type at RGCs crossed by fuel tanker trucks and motorcoaches.

Type of Highway	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
Principal Arterial	129	210
Major Collector	90	163
Minor Arterial	87	164
Local	72	98
Minor Collector	28	24
Freeways and Expressways	4	4
Interstate	-	6

Table 26 and Table 27 summarize the highway speed limits and the percentage of CMV traffic at RGCs traversed by fuel tanker trucks and motorcoaches in the dataset. There were 186 RGCs traversed by a fuel tanker truck and 358 RGCs crossed by a motorcoach on roads with a highway speed limit between 21 and 40 mph (Table 26). As shown in Table 27, most of the RGCs traversed by a fuel tanker truck or motorcoach in the dataset did not experience heavy CMV traffic, with the majority of RGCs estimated to have traffic consisting of less than 10% of trucks.

Table 26. Highway speed limit near RGCs crossed by fuel tanker trucks and motorcoaches.

Highway Speed Limit	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
Highway Speed Under 20 mph	16	8
Highway Speed Between 21 and 40 mph	186	358
Highway Speed Between 41 and 60 mph	206	174
Highway Speed Above 61 mph	3	28

Table 27. Percentage of trucks traversing through RGCs crossed by fuel tanker trucks and motorcoaches.

Estimated Percent of Trucks	No. of RGCs Crossed by Fuel Tanker Trucks	No. of RGCs Crossed by Motorcoaches
Under 10%	346	497
Between 10% and 20%	57	112
Between 21% and 30%	7	41
Between 31% and 40%	1	10
Between 41% and 50%	1	3
Between 51% and 60%	1	3

DISCUSSION

The purpose of this project was to develop a database of RGCs that overlap with VTTI's previously collected CMV NDS data with motorcoaches and trucks hauling hazardous materials. This resulted in a database of 1,734 RGCs across 33 states where CMV naturalistic data is available. Of these RGCs, 416 were traversed by fuel-tanker trucks and 673 were traversed by motorcoaches during the OBMS study.

Most of the RGCs included in the new CMV RGC database were for freight trains (70.07%), were on highways (99.71%), and were located on open (17.53%), residential (14.13%), industrial (16.78%), and commercial land (47.98%). The majority of the RGCs were in an urban setting (64.07%). The most common roadway types at RGCs were two lane (58.36%), two direction (67.01%) with speed limits between 20 and 40 mph (51.61%) and 40 and 60 mph (30.97%). Most of the RGCs had limited CMV traffic, with CMVs accounting for less than 10% of the average traffic (78.14%). Additionally, many of the RGCs were non signalized (96.66%), and the majority were simply controlled by stop lines with RGC signage/crossbucks (85.18%).

This sample of RGCs provides some unique opportunities to learn about CMV and passenger vehicle driver behavior. As CMV traffic was not common at many of the RGCs, passenger vehicle drivers may not expect to encounter a stopped CMV. Further, many of the RGCs did not have active warning devices. Thus, passenger vehicle drivers may be less aware of an upcoming RGC at which a CMV may be required to stop. Finally, it may be possible that CMV drivers behave differently at RGCs with active warning devices compared to how they behave at crossings with passive warning devices.

This unique database of RGCs, which includes in-vehicle video data and vehicle sensor data, provides an opportunity to examine how CMV drivers perform at RGCs and how passenger vehicle drivers operate around CMVs at RGCs. Most previous research that examined safety at RGCs only utilized FRA incident data and FRA's RGC dataset. However, these datasets do not provide data on specific driver behaviors at RGCs that may contribute to an SCE.

OPPORTUNITIES FOR FUTURE RESEARCH

The intent of this project was to create the CMV RGC database to support future research opportunities. In a future effort, analysts will review the NDS video from the CMVs traversing RGCs and code environmental, infrastructure, and behavioral reduction questions. One potential reduction question includes information about the CMV driver's glance location while approaching the RGC as they are coming to a stop (for tanker trucks and motorcoach drivers), and while traversing the RGC. Another set of reduction questions may focus on identifying RGC violations for CMVs that are required to stop. A third set of potential reduction questions may focus on CMV driver behavior (e.g., distraction, fatigue, speeding, etc.) while traversing the RGC. A fourth set of potential reduction questions may focus on passenger vehicles surrounding the CMV at RGCs (e.g., following distance). Other potential research questions may focus on roadway lighting, signage, and warnings present at RGCs.

Another future opportunity involves linking this CMV RGC database with FRA's incident datasets (based on the common RGC identifier). FRA maintains four incident datasets: rail equipment accident/incidents (Form 54), injury/illness summary – operational data (Form 55), injury/illness summary – casualty data (Form 55a), and highway-RGC accident/incident data (Form 57). These databases have additional data on crash, vehicle, injury, temporal, spatial, and ambient attributes that could be included in future analyses. This combined dataset of naturalistic driving data and FRA incident data could provide insight into CMV driver behavior as well as operating speed, location characteristics, ambient weather conditions, and other related information at RGCs. Further, these analyses may offer data to support the development of new countermeasures to prevent future incidents.

The CMV RGC dataset could also be linked to the U. S. Department of Transportation's Fatality Analysis Reporting System (FARS) database and Crash Report Sampling System (CRSS) data. This pairing may also provide a better understanding of CMV crashes at RGCs and non-railroad junctions. These databases document the environmental conditions, driver and passenger details, number and types of crash-involved vehicles, and vehicle speed, in addition to several other data elements. The use of the FRA crash database, FARS, and CRSS would greatly expand the number of crashes included in the analysis, as these databases include several years of data outside of the period collected in the naturalistic driving studies.

The current study's methodology could also be extended to naturalistic driving studies featuring light vehicle drivers (e.g., the Second Strategic Highway Research Program). An evaluation of light vehicle driver behavior and CMV driver behavior at RGCs could highlight problematic features of RGCs affecting all roadway users. Alternatively, differences in data from light vehicles and CMVs may illustrate opportunities for CMV driver education regarding safe behavior at RGCs, with varying characteristics, conditions, and locations.

Based on the results from this future research, RGC factors associated with increased crash risks can be identified and new countermeasures to prevent crashes and their injuries and fatalities can be developed. As part of this future work, a computer-vision algorithm could be developed and tested using the NDS side-view cameras to primarily obtain presence of a vehicle and position of the vehicle in the adjacent lanes, including distance from the CMV. Additionally, this new database may also provide support to connected vehicle/autonomous vehicle efforts.

LIMITATIONS

Some limitations were encountered when creating the CMV RGC database. The final step in cleaning the database involved a manual inspection of the RGCs to identify road segments that might be near an RGC but not physically cross it. During this manual inspection, researchers had to make an assumption about the direction of travel. In a small sample of RGCs, the CMV included in the NDS may have entered the roadway next to the RGC and not physically traversed it. A limitation for future analyses is that the CMV RGC database does not include many SCEs at the RGC. Although this does limit the use of the database, there are many research questions for which this unique database is applicable. A final limitation is that the map-matched data is based on the accuracy of the FRA RGC database. If the FRA includes inaccuracy in location information, those are reflected in the CMV RGC database.

CONCLUSIONS

NDS data offer unparalleled insight into contributing factors associated with SCEs, especially contributing factors associated with driver behavior. Although there are some results examining safety at RGCs using NDS, none have focused on CMV safety at RCGs or the safety of other road users around a CMV at an RGC. This database provides a unique opportunity to develop a better understanding of CMV driver behavior when approaching and traversing RGCs as well as the infrastructure at RGCs traversed by CMVs.

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