Identification of Railroad Requirements for the Future Automated and Connected Vehicle (AV/CV) Environment

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16. Abstract

The Federal Rail Administration (FRA) Highway-Rail Grade Crossing Inventory database from 2019 states that there are approximately 127,000 public, at-grade highway-rail grade crossings in the U.S. Despite this large number of direct intersections between the public highway and largely private rail systems, little current intelligent transport systems automated/connected vehicle (AV/CV) research is focused on how to incorporate the railroad system and its operations effectively into future roadway AV/CV system planning. This initial scanning project examined how transportation agencies, engineering firms, researchers, and other highway system stakeholders designing future AV/CV systems could best consider freight and passenger railroad operational and infrastructure needs in the development of future AV/CV system architecture. The project explored the following:

- Information/data requirements for roadway vehicles to operate effectively near rail crossings.
- Impediments to collecting and exchanging rail operations data between public roadway agencies, public commuter/transit rail systems, and the largely private freight rail operators.
- Potential AV/CV implementation approaches near rail system assets that could benefit both systems.
- Critical, necessary additional research efforts in both the short- and long-term to address future joint railroad/highway AV/CV architecture challenges.

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Acknowledgements

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Introduction

According to the Federal Rail Administration (FRA) inventory data from December 2019, there are approximately 127,000 identified public, at-grade highway-rail grade crossings (HRGCs) in the U.S. Despite this large number of direct intersections between the public highway system and largely private rail network, at the time this project was initiated, there was little focus on research for Automated and Connected Vehicles (AV/CVs) concerning how these types of advanced technology road vehicles with would interact with HRGCs. Even less research was underway on how to coordinate rail system operations effectively into future roadway AV/CV system planning. During this Safe-D project's original timeline in 2017 and early 2018, several FRA studies were initiated and/or completed that began to address some AV/CV issues in the at-grade HRGC environment. However, the results of these studies were not made public until December 2018. In light of the new information and findings from those studies, remaining research issues associated with this important topic were evaluated and are discussed in this report. Much remains to be investigated regarding the future of HRGCs and AV/CV interactions—especially in regard to the railroad system's perspective of HRGC safety as AV/CV operations are implemented throughout the U.S.

Background

The purpose of this initial scanning project for Safe-D was to examine how transportation agencies, engineering firms, researchers, and other highway system stakeholders involved in designing and planning future AV/CV systems can best take into account freight and passenger railroad operational and infrastructure needs in the development of future AV/CV roadway system architecture. The project activities were designed to review and/or identify the following:

- The specialized information and data requirements needed for AV/CV roadway vehicles to operate effectively near rail crossings.
- Impediments (and potential impediments) to collecting and exchanging rail operational data between public roadway agencies, public commuter/transit rail systems, and the largely private freight rail operators.
- Potential AV/CV implementation approaches near rail system assets that could benefit both rail and highway systems.
- Critical, necessary additional research efforts in both the short- and long-term that would be required to address joint railroad/highway AV/CV architecture challenges.

Method

Literature Review

An initial literature review for the scoping project conducted in late 2017 and early 2018 found that few studies had been completed that specifically examined interactive operations of AV/CVs and their impacts on rail operations. Search terms/areas explored in this initial literature review included the following:

- Recognized, previously identified issues regarding highway-rail operations that might be impacted positively or negatively by introduction of AV/CVs.
- Rail infrastructure requirements that should be considered in future AV/CV system planning.
- Current agency and contractor concerns regarding AV/CVs in and around HRGCs.
- Emerging railroad and vendor approaches to addressing passenger and freight railroad and AV/CV interactions.

Results of the initial literature searches returned information related either to AV/CVs or to rail operations near HRGCs, but little or no information was found explicitly addressing the interaction between emerging AV/CV technologies in the HRGC environment.

As a result, the literature review strategy for this project switched to a more exploratory, investigative, and inferential approach. Development of AV/CV technology and how it might relate to known HRGC infrastructure safety issues, emerging Intelligent Transportation System architecture for HRGCs and general roadway intersections, and known safety improvement methods for HRGCs were subsequently reviewed. The potential for incorporating information from Positive Train Control (PTC) signaling systems, which were then first being implemented under an FRA mandate with a deadline of December 31, 2018, for much of the national freight rail system and many commuter rail systems also became a focus of the review.

Safety of AV/CV Operations at HRGCs

Current/General Safety Issues

The majority of safety issues relevant to highway-rail operations/infrastructure are related to the environment near at-grade HRGCs. Around 92% of rail-related fatal collisions are because of trespassing or collisions with motor vehicles where a road intersects railroad tracks at the same level (i.e., at-grade) [1]. Although railroads work with public highway agencies to make safety improvements or to vertically separate roadways and railways, 262 people were killed and 840 people were injured in vehicles at HRGCs during 2018 according to FRA preliminary statistics for that year [2]. FRA's HRGC resource guide states that 94% of train-vehicle collisions are related to driver behavior or poor judgement [3]. It would appear that both presence in a vehicle crossing and driver behavior/decision-making might be addressed by the introduction of AV/CVs. However, it is important to remember that the introduction of AV/CVs will also create new potential safety issues unless thorough and appropriate information and design factors related to both modes of travel—rail and roadway—are accounted for in planning. Introduction of AV/CVs could be offset by different crash dangers or create new situations in which crashes might occur.

Evaluation of Safety Scenarios

Drawing upon experience from the current, conventional safety issues associated with HRGC locations, several conclusions can be made about the issues needing to be addressed in their future operations with AV/CVs. Given each HRGC's individual geometric design, varying roadway width of the vehicle crossing/roadway, and numerous potential driver errors, there are multiple unsafe situations that might occur. Previous literature has found, after reviewing various scenarios, that the type of information that needs to be transmitted among AV/CVs, rail vehicles, and railroad infrastructure can be defined. Possible safety factors/features that should be considered when evaluating the potential for incidents within the HRGC environment are listed below [4]. Figure 1 which graphically shows the potential hazards.

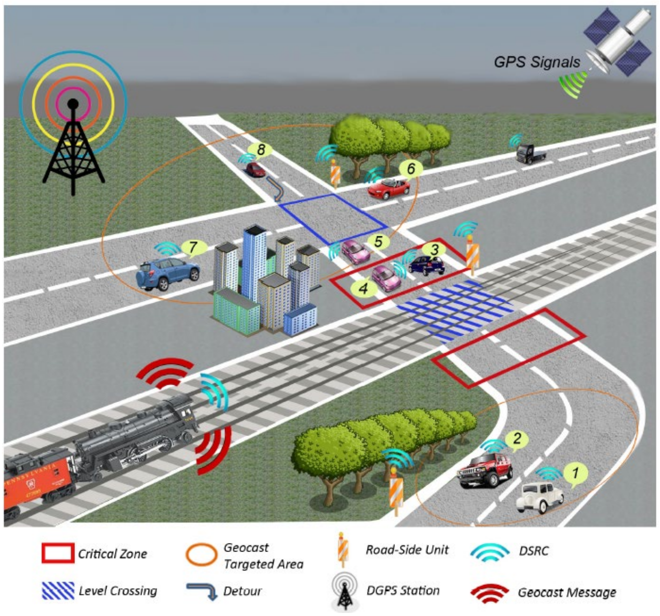

Figure 1. Various Potential Safety Situations at an At-Grade HRGC [4].

1. **Complicated intersection:** Multiple at-grade HRGCs located at a single intersection, complicated lane markings, multiple signs, and sight interference could affect drivers' decision-making processes.

2. **Train visibility:** Geometric design of HRGCs or vehicles driving alongside a train can reduce or limit the visibility of a nearby train. Vehicle drivers may not be aware of the approaching train until they reach the HRGC.

3. **Driver error/human behavior:** As noted above, up to 94% of train-vehicle collisions are related to drivers' behavior or poor judgement. Drivers' misjudgment of train speed, failure to account for the speed and length of their vehicles, and the time necessary to clear the track could lead to a crash.

4. **Second train coming:** At many HRGCs, it may be difficult to notice an oncoming second train, since the first train may hinder drivers from seeing and recognizing the second train's approach or presence.

5. **Congested at-grade crossing:** A train passing through an at-grade HRGC can often lead to a vehicle back up on adjacent or nearby roads, resulting in heavy congestion. In this case, additional queue storage space or interconnected signals for the adjacent roadway may be warranted.

6. **Large trucks/other vehicle types:** Under various conditions, such as the slope of an at-grade crossing (humped crossing), a particular truck undercarriage configuration, or when trucks pass under descending or ascending gates, a truck or other long wheelbase vehicle can become stuck on a track and cause a crash with an oncoming train. This can result in severe injuries or fatalities to vehicle occupants and serious damage to train and railroad equipment.

Note: A more developed list of specific AV-related scenarios at HRGCs was further developed in an FRA-released released study (December 2018) and is discussed and referenced later in this report.

Technology Developments Impacting HRGC Use by AV/CVs and Trains

AV Development

AV development across the SAE-defined levels will continue to evolve indeterminately. No one knows exactly what the eventual impact of AV/CVs might be. One study by Hazan et al. explored the possibility of AVs replacing commuter trains as public transportation in the future [5]. The analysis in this study showed that shared AVs, which could pick up passengers and take them door-to-door, could be less expensive and more convenient than trains [5]. Hazan et al. encouraged rail executives to evaluate the impact AVs could have on their operations, hone their competitive value propositions, stress test their investments against different AV scenarios, and even consider investing in AVs [5]. Federal studies completed in 2018 concluded that AVs will likely need to be augmented with CV features in order to successfully navigate the HRGC environment. This requirement is due to the complexity of the intersection and the need for either the train itself or the wayside equipment to provide information about train location(s) to vehicles approaching an HRGC.

CV Development

CVs are able to send and receive messages from other vehicles or infrastructure through either Dedicated Short Range Communications (DSRC) or 5G cellular networks. Such messages comply with the SAE's standardized DSRC Message Set Dictionary J2735, which was designed to be a standard message format for CV messages sent by any communication technology [6]. This standard ensures that anonymous messages will follow an expected format for use in all AV/CV applications.

Positive Train Control (PTC) Development and System Implementation

The most widely known emerging control technology for the rail system is Positive Train Control (PTC), which is a communications-based rail signaling system devised to avert several human factors related errors. PTC is defined by the Federal Communications Commission as:

> …a system designed to prevent train-to-train collisions, derailments caused by excessive speeds, unauthorized train movements in work zones, and movements of trains through switches left in the wrong position. PTC networks enable real-time information sharing between trains, rail wayside devices, and "back office" applications, regarding train movement, speed restrictions, train position and speed, and the state of signal and switch devices. [7]

Many segments of the U.S. railroad system (on routes where either passengers or toxic inhalation hazard materials are moved) were mandated by the FRA in the Rail Safety Improvement Act of 2008, as amended by the Surface Transportation Extension Act of 2015, to implement PTC systems prior to December 31, 2018, with some waivers extending this deadline through December 31, 2020. [**Error! Bookmark not defined.**] In the early stages of the current project, researchers thought that train location information available from PTC technology deployment might be leveraged for more advanced warning of train arrivals at upcoming HRGCs. We believed that this information might, in concept, be provided to both wayside equipment at HRGCs and to approaching AV/CVs. Ultimately, this concept proved to be non-implementable under current PTC data-sharing conditions.

Emerging/Existing Prior AV/CV Intelligent Transportation System HRGC Approach Warning Systems

There are several potential designs for AV/CV warning systems for vehicles approaching HRGCs. One previous set of prototype systems using radios to transmit warnings about approaching trains was developed by the U.S. Department of Transportation (U.S. DOT) and the FRA in 1994, though development occurred prior to the existence of AV/CV technology. [**Error! Bookmark not defined.**] Vehicle Proximity Alert System (VPAS) prototype system testing found that warning vehicles about the approach of a train was feasible, but that none of the three prototype methods tested was suitable for additional testing [8]. One VPAS method had detection ranges that were too long, leading to high potential for false alarms; another failed to consistently detect train horn signals; and the third transmitted alarms excessively, leading to excessive false warnings [**Error!**

Bookmark not defined.]. The research does note that a three point system (train to roadside infrastructure and roadside infrastructure to vehicles) shows the most promise since it has the ability to base the warning off the distance between the train and the intersection, which is consistent with potential designs of more recent AV/CV systems [**Error! Bookmark not defined.**]. Figure 2 depicts an overview of the developed system as it relates to infrastructure communications between rail and roadway systems.

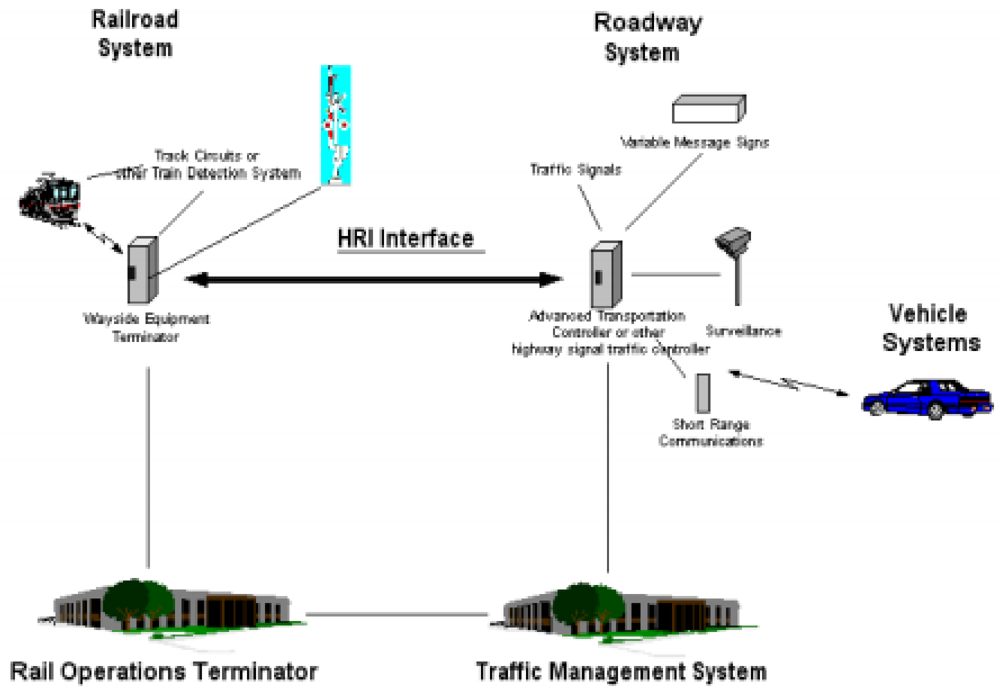

Figure 2. Highway Rail Intersection Interface Overview, IEEE Std 1570-2002 [Error! Bookmark not defined.**].**

A later 2013 U.S. DOT report listed several potential concepts of operations for vehicle-to-infrastructure CV safety applications, including a Railroad Crossing Violation Warning (RCVW) application [9]. This proposed system architecture assumes that there is a method for the vehicle to localize itself and determine if its trajectory conflicts with the grade crossing [9]. The concept also lists several possible options for detecting an approaching train, either through a detection product (e.g., radar, LIDAR, cameras, etc.) or technologies utilized by the railroad industry (PTC or radio frequency identification readers) [9]. The RCVW application would issue an alert to motorists approaching an at-grade crossing and would present a more urgent warning if the vehicle was determined to be in a potentially crash imminent conflict [9]. Figure 3 shows a schematic of the proposed RCVW application and Figure 4 is a graphic depiction of the general locations of the alert and warning as vehicles approach an HRGC.

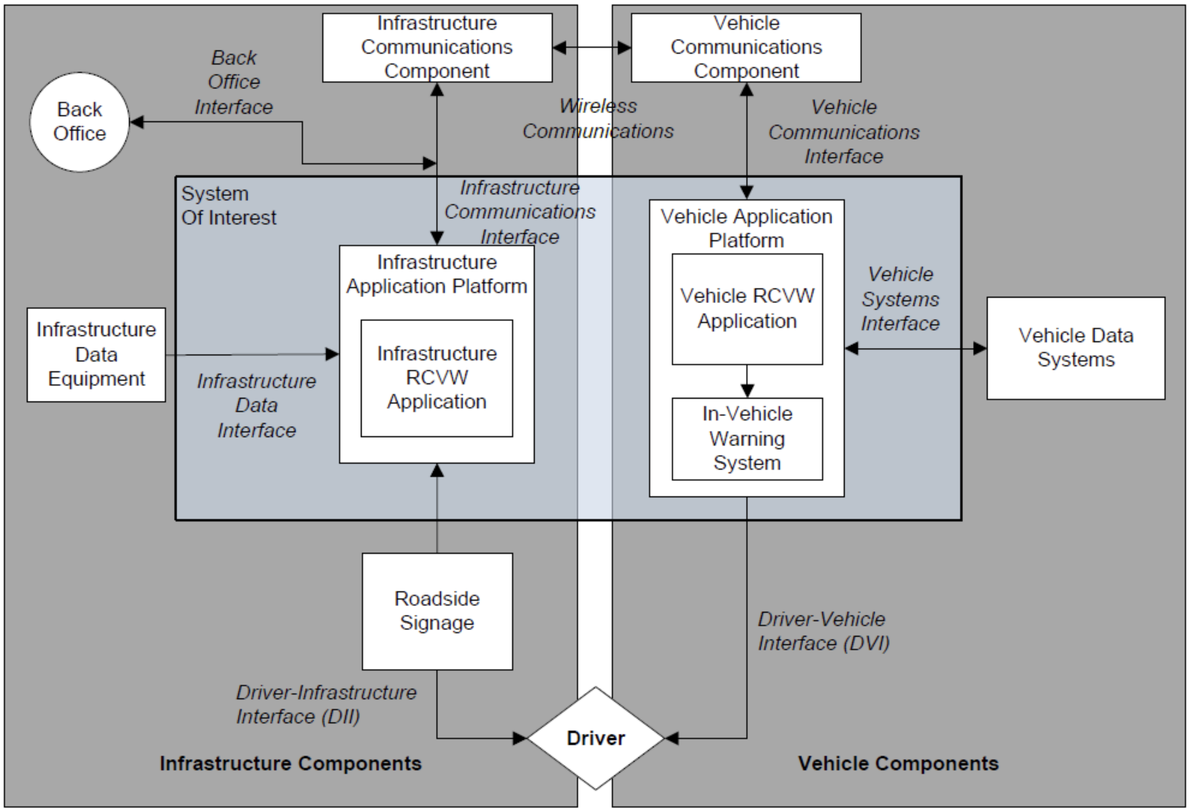

Figure 3. Railroad Crossing Violation Warning Application Diagram [9]

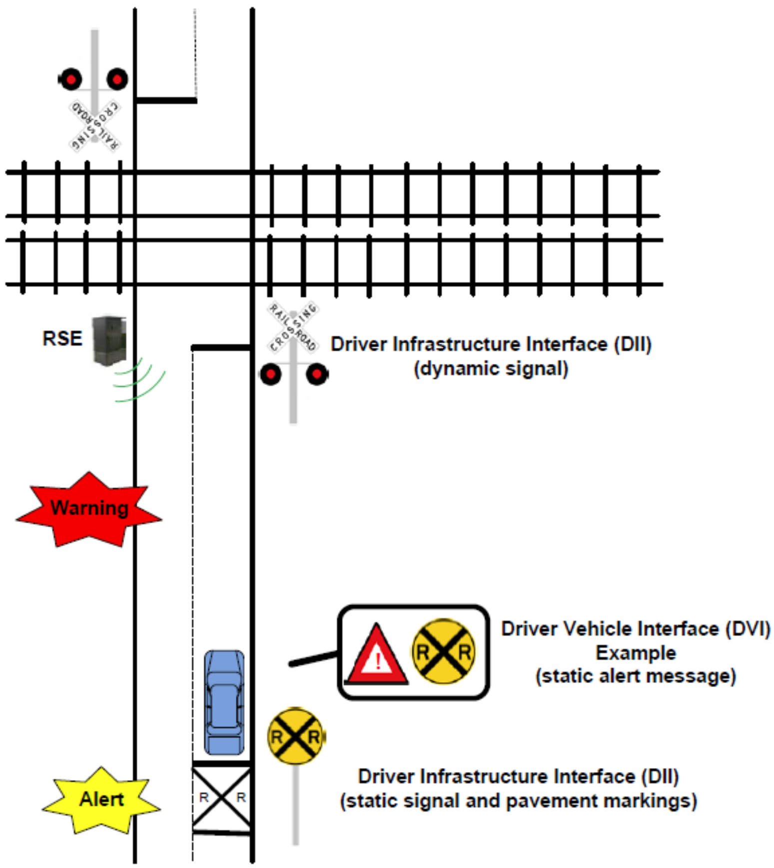

Figure 4. Prior CV Railroad Crossing Violation Warning Layout [9]

Subsequent studies have continued to look at the potential effectiveness of driver notification and it is assumed that a similar notification system could provide information to AV/CV-equipped automobiles and trucks.

Another paper by Verma et al. discussed the potential benefits of combining DSRC and PTC technologies [10]. PTC allows advanced monitoring and controlling of train movements, which could potentially work in conjunction with DSRC to provide additional approaching vehicle information to rail operators [10]. The authors also note that AV/CVs can benefit from PTC as a reliable method of detecting an approaching train and that PTC can use information from roadside infrastructure to detect roadside incidents [10].

Unfortunately, the authors concluded that the currently mandated PTC system implementation in the U.S. only requires installation on approximately 53,372 miles of railroad track. The overall freight rail system consists of approximately 136,898 miles, meaning that a maximum of only 39.2% of rail miles where HRGCs exist would have such augmented train location information available. Even if PTC location data were available to and useable by AV/CVs and associated systems, this percentage of coverage would not be an adequate solution to HRGC location needs for AV/CV interaction.

Impacts and Results of Other Current Studies/National Policy Changes

Ongoing federal studies impacting this Safe-D study continued throughout the summer and fall of 2018, after the original planned completion of this report. Although several related elements of those projects were complete or nearing completion during the original project schedule, study results were not published by Battelle and the FRA until December 2018. In the meantime, several additional studies/changes in national policy were announced that could impact AV/CVs near HRGCs. These are discussed in the following sections.

Work Toward PTC Implementation

As discussed previously, implementation of PTC in much of the Class I rail system was underway with a deadline of December 2018. This meant that many of the knowledgeable signaling and crossing experts were busy and thus unavailable to provide input to our study during its originally scheduled period. As a result, we were unable to engage rail company officials to the planned degree. Thus, the primary source for railroad opinions/policy on HGRC safety related to AV/CVs was primarily drawn from statements submitted to the U.S. DOT by the Association of American Railroads (AAR) on behalf of their member railroads. These statements generally reflect the prevailing Class I rail systems thoughts on the topic. [11]

FRA Request for Comments on Rail Automation

The FRA issued a docket (request for comments) on potential "rail automation" in March 2018, requesting input from the rail industry and other stakeholders. The comment period continued through May 2018. This developmental step towards automation of train operations emphasized the need to further review the conclusions made when the research portion of this study ended. Subsequent to receiving input on automation, in May 2019, the FRA also rescinded a prior mandate for minimum two-person crews for railroad operations, potentially opening the door for future automation of train operations with fewer crew members. This potential change further increases the complexity and level of engineering and planning required at future HRGCs.

Release of U.S. DOT AV 3.0 Policy Document and AAR Response

In October 2018, the U.S. DOT released *Preparing for the Future of Transportation: Automated Vehicles 3.0* (AV 3.0) as a new policy statement regarding future development of AVs in the U.S. [12]. In response, the AAR submitted comments regarding how automation of private vehicles, and potentially rail operations, would be viewed by the rail industry. AAR said forthrightly that longer advance warning times for crossings through prior notification using PTC system train location information or other PTC system functions could not be a part of train/roadway vehicle interaction improvements [11]. The AAR position is that PTC is a rail signaling system and designed for that purpose alone. They claim that to use PTC-based information for any other purpose violates the parameters of the entire PTC network design and architecture. Investigating this concept was a key component of this project, causing the research team to rethink our conclusions about what might actually be possible in terms of data sharing—at least in the near-term future. AAR did, however, allow for some benefits of AV development in private vehicles:

> Designing motor vehicles to eliminate human error and poor judgement by automating vehicular behavior at grade crossings to obey traffic laws and yield to trains could achieve a significant reduction in fatalities and injuries at grade crossings. [11]

Release of FRA AV at HRGC Study Results

In early December 2018, the FRA published the results of several studies on the topic of AV/CVs at HGRCs that took place throughout 2017 and early 2018. The primary final report, titled *Automated Vehicles at Highway-Rail Grade Crossings: Final Report* [13] also incorporated the results of two previous major research components as appendices. Appendix A, an October 2017 report titled *Highway-Rail Grade Crossing Requirements for Autonomous Vehicles Technology Survey Report*, gave the detailed results of a CV/AV, freight, and transit systems analysis and presented lessons learned in tangential industries. [13] Appendix B was a May 2018 concept of operations document titled *Highway-Rail Grade Crossings for Automated Vehicles Concept of Operations and Requirements,* which documented numerous possible scenarios and use cases that could be expected for AV/CVs at HRGC locations. [13] These studies concluded that AVs would likely need to employ a variety of CV features in and around HRGC locations in order to maximize safety at HRGCs. [13]

Next Steps/Additional Needed Research

There remain many areas of research where efforts should be made to more fully address future joint rail/highway AV/CV architecture challenges. These are broken down below into short- and long-term needs. Ongoing changes could further impact the speed at which each of the suggested topics would need to be studied.

Short-term research/needs:

- Continue to seek opportunities for roadway AV/CV planning to better incorporate rail system operations and planning.

- Continue to monitor railroad company experience with PTC implementation/operations and evaluate potential for future data sharing between highway and rail automation systems.

- Examine methods of engaging railroad companies and/or public agencies operating rail services (i.e., both freight and passenger operations) into future AV/CV system architecture development.

- Evaluate safety of AV trucks and other longer/low clearance vehicles in and around HRGCs given limited train location information currently available.

Long-term research/needs:

- Examine potential HRGC scenarios with more complex crossing types (i.e., road and track meeting at acute angles, multiple tracks, sight distance limitations, nearby roadway crossings with limited storage, etc.).
- Determine how best to address AV/CV operations at passive HRGCs, as most current solutions depend on active HRGC technologies to alert AV/CVs of approaching trains.
- Review interoperability of roadway and railway automation equipment as both modes become more automated.
- Explore impacts of the trend toward reduced train crew personnel on HRGC safety both with and without AV/CV operations.
- Conduct research into policy and legal issues associated with AV/CV operations in and around the HRGC environment (e.g., liability for accidents, paying for alert systems, data-sharing protocols between agencies and private companies, etc.).
- Conduct research on standardization of equipment associated with operation of AV/CVs in the HRGC environment.

Conclusions and Recommendations

This was an initial scoping-level study of the issues associated with AV/CVs at HRGCs that examined how rail companies are preparing for AV/CV introduction. The study produced information on several of the perceived issues and identified potential problems that might occur at this special type of roadway intersection as AV/CV operations begin on highways. Pressing issues, such as the mandated introduction of PTC during 2018, prevented most of the planned railroad company participation originally envisioned for the study. However, AAR responses to several U.S. DOT and FRA requests for information provided evidence that further coordination and research are necessary. The initial idea that the introduction of PTC might produce a general solution for providing train location information to roadway vehicles was not supported by the project's findings, as data sharing from PTC does not seem to be an option at this time and, moreover, PTC implementation covers less than 40% of the nation's rail miles. Other ongoing federal research on related topics was reviewed during the project's extension period. Findings suggested that additional research paths in areas such as train automation and/or crew size reduction that may also impact research related to rail and AV/CV operations would be beneficial.

Additional Products

The Education and Workforce Development (EWD) and Technology Transfer (T2) products created as part of this project can be downloaded from the project page located on the Safe-D website. As this project did not produce any data, no datasets are available from this project on the Safe-D Collection of the VTTI Dataverse.

Education and Workforce Development Products

A PowerPoint presentation covering the results of the project and describing railroad requirements for future AV/CV operations at HRGCs is available at the Safe-D website for use in both educational and outreach environments. This presentation was given at the National Highway-Rail Grade Crossing Safety Conference in Pittsburgh, Pennsylvania on August 22, 2019. A similar presentation covering the Safe-D project and its findings was delivered by Dahye Lee, the student worker supported by this project at the ASME Joint Rail Conference in Salt Lake City, Utah on April 11, 2019. The lack of direct railroad company input experienced due to the project occurring concurrently with rail company implementation of PTC limited the development of some of the other EWD materials anticipated at the outset of the project.

Technology Transfer Products

The findings of this study produced several technology transfer products and opportunities. These included:

1. Pre- TRB 2019 Human Factors Workshop Session F - "*Safety Issues of Co-Existing Human and Autonomous Machine Operations*," January 13, 2019. Presentation on rail mode/ vehicle automation issues before a panel of SMEs from a variety of transportation modes covering the Human Factors aspects of the Safe-D project findings.

2. TRB 2019 Lectern Session: *Considering Railroad System Interaction with Automated/ Connected Vehicle Planning*, Lectern Session 1353, *Autonomous Train Technology: The Challenges of Implementation, Part 2*. January 14, 2019. Presentation regarding rail automation and interaction with AV/CVs at grade crossings. Overview of 2018 research impacting this technology area and their impacts upon the Safe-D project.

3. Discussion Agenda Item at TRB AR070 Rail Operational Safety Committee Meeting: Autonomous Technology Discussion, Transportation Research Board Annual Meeting, Washington, DC, January 15, 2019.

4. ASME Joint Rail Conference: Presentation on Railroad Requirements for AV/CV Infrastructure Planning, April 11, 2019.

5. FHWA-FRA Joint Webinar: AVs and CAVs at Rail Crossings (SR500A), April 17, 2019. Presentation/Archived in the FHWA-FRA Joint Webinar Series section at: https://safety.fhwa.dot.gov/hsip/xings/.

6. National Highway-Rail Grade Crossing Safety and Training Conference, August 19-22, Pittsburgh, Pennsylvania. Presentation/Session on this topic at this biennial, national conference jointly sponsored by FHWA and FRA. TTI is also a co-host of the conference.

Data Products

Due to the nature of this project as primarily a scanning and issues identification effort, no new data products were directly produced. Data sources in several references were identified for future study.

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