In-Service Evaluation of Railroad Signal and Stop Arm Pole Protection

Final Report
March 2020

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16. Abstract

While the effectiveness of active warning devices, such as crossing signals and gates, at railroad crossings is well documented, their presence introduces the risk of errant vehicles striking the devices. To mitigate the impacts of such crashes, guardrail or crash cushions are sometimes installed near crossings.

The main objective of this study was to provide guidance on the design of railroad-highway at-grade crossings, specifically in terms of the location of railroad mast arms/poles and the viability of using guardrails to shield these devices from crashes with errant motor vehicles. Ten years of police-reported crash data for more than 1,800 active crossings in Iowa, along with supplemental data from the Iowa Department of Transportation (DOT) and the Federal Railroad Administration (FRA), were reviewed.

A total of 156 crashes involving signal masts or related hardware occurred from 2007 through 2016 (10 years). Crashes involving signal masts were the most prevalent, followed by vehicles striking the guardrail. Crash rates were higher at crossings with guardrails or barrier, although the differences were not statistically significant. Crash severity was slightly lower when the vehicle struck a guardrail versus a signal mast, but the result was not statistically significant.

Simulation analyses were conducted using the Roadside Safety Analysis Program (RSAP) to compare the benefit-cost ratios of five alternative scenarios. The analyses showed that guardrails appear to provide only a marginal benefit from an economic standpoint; while they tend to reduce crash severity and cost, crashes with railroad signal arms are infrequent, and the small available deflection distance tends to limit their effectiveness. In the optimal scenario, the mast was located 10 feet from the edge of the traveled way without a guardrail. The results also suggest that adding 4 feet of lateral space between the signal support and the edge of the traveled way (from a 6-foot to 10-foot offset) would reduce the probability of a vehicular strike and eliminate the need for a guardrail.

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Cyr, J. D., J. W. Shaw, and P. T. Savolainen. 2019, July. Motor Vehicle Crashes Involving Railroad Crossing Signal Masts and Guardrails. *Transportation Research Record: Journal of the Transportation Research Board*. https://journals.sagepub.com/doi/full/10.1177/0361198119857952#articleCitationDownloadContainer.

1. INTRODUCTION

1.1 Background

Safety at railroad-highway at-grade crossings has been a longstanding concern of transportation agencies for nearly a century (Muntz 1931). The magnitude of this problem can be quantified through crash statistics available through the Federal Railroad Administration (FRA) and the Iowa Department of Transportation (DOT).

The FRA crash reporting requirements are codified in Federal Regulation 49 CFR 225 and through Form FRA F 6180.57. Any impact, regardless of severity, is to be reported; however, this only includes crashes between railroad on-track equipment and a highway user (FRA 2018a). Meanwhile, crossing-related crashes in Iowa are identified through police-reported crash data (Iowa DOT 2018a). These records are accessible through the Iowa DOT's Iowa Crash Analysis Tool (ICAT) database. Within the ICAT system, crossing-involved crashes can be identified using the "Type of Roadway Junction/Feature" field (where "railroad grade crossing" is specified).

Given the differences in reporting mechanisms, the number of crashes at railroad-highway at-grade crossings varies, as shown in Table 1.

Table 1. Comparison of reported railroad crossing crashes from two databases

Year	Public Crossing Incidents Reported by Railroads in FRA Database in Iowa (FRA 2018b)	Public Crossing Crashes Reported by Iowa DOT in ICAT
2007	74	200
2008	64	182
2009	47	182
2010	49	190
2011	38	156
2012	41	170
2013	43	150
2014	45	162
2015	43	171
2016	35	145
Total	479	1,708

From 2007 through 2016 (10 years), the annual average number of railroad-highway incidents reported to the FRA was 47.9. In comparison, Iowa law enforcement agencies reported over three and a half times as many crossing-involved crashes, an average of 170.8 per year. Iowa ranked 13th in the nation in the number of incidents at public at-grade crossings and 15th in non-fatal injuries over the same 10 years (FRA 2018b).

While there are significantly fewer crashes at railroad-highway grade crossings than at highway intersections, the consequences of crashes at grade crossings tend to be much more severe. Trains differ significantly from highway vehicles in terms of their physical and operational characteristics, including mass, ground clearance, and resistance to rollover. In addition to fatal and serious injuries, railroad-highway crossing crashes can result in derailments that result in considerable property damage, as well as disruptions to both the rail and roadway systems, including the possibility of contamination from hazardous materials.

In light of these concerns, the installation of active warning devices to reduce the risk of train-involved crashes has been a major focus of crossing safety efforts in the US and many other countries. For example, a commonly installed active warning device is train-activated flashing lights. Higher risk crossings (e.g., sites that are geometrically skewed, have visibility constraints, have high traffic volumes, have high train traffic, or are unusually wide) are often supplemented with gates or overhead cantilever beams outfitted with additional flashing lights. In general, these treatments tend to be quite effective, as the Federal Highway Administration (FHWA) Railway-Highway Crossing (Section 130) Program reported a 57% decrease in fatalities between 1987 and 2014 from at-grade crossings that received funds to eliminate hazards (FHWA 2018a).

While substantial efforts have focused on investigating train-involved crashes, guidance as to crashes involving the railroad infrastructure is limited. While the damage to signals and track structures (e.g., controller boxes) can be used to meet the reporting damage cost thresholds of Form FRA F 6180.54 (in 2017 this value was $10,700), the FRA does not report crashes that only involve the apparatus. Similarly, state-level databases such as ICAT, as well as federal crash databases such as the Fatality Analysis Reporting System (FARS) (NHTSA 2018), generally do not include fields to identify crashes involving rail infrastructure. This creates challenges for identifying crashes that involve a motor vehicle striking a railroad crossing signal apparatus, such as a signal pole or controller box (Figure 1).

Metropolitan Transportation Authority (MTA) Metro-North Railroad
(https://www.flickr.com/photos/mtaphotos/28645736131)

(a) Motor vehicle crash with signal mast and cantilever (Danbury, Connecticut)

© 2019 Patch Media, reused in accordance with site terms and conditions (Busby 2012)

(b) Motor vehicle crash with controller box (Smyrna, Georgia)

Figure 1. Examples of motor vehicle crashes with railroad signal apparatus

These types of crashes can generally be identified using general fields from federal and state crash databases. For example, the National Highway Traffic Safety Administration (NHTSA) compiles statistical information on various types of fixed-point-hazard crashes in FARS, such as crashes involving trees, utility poles, and lighting fixtures. Nationwide, crashes with fixed objects account for 14.7% of all reported crashes but result in 30.9% of the fatal crashes (NHTSA 2017).

To mitigate the impacts of crashes involving rail infrastructure, barriers (e.g., guardrails or crash cushions) are sometimes installed at or near at-grade crossings to protect motorists (e.g., from traversing down a steep embankment) or to shield the signal mast (e.g., from a tractor-trailer making too sharp of a turn). While the effectiveness of active signal warning devices in reducing vehicle-train crashes and the number of fatalities is well documented (Meeker et al. 1997, Raub 2006, Lenné et al. 2011), research on crashes involving these infrastructure elements is limited.

1.2 Research Objectives

This study aims to provide guidance on the design of railroad-highway at-grade crossings, specifically as it relates to the location of railroad mast arms/poles and the viability of using guardrails to shield these devices from crashes with errant motor vehicles. Under this broad framework, the specific objectives of this study are as follows:

- To synthesize current practices of state transportation agencies with respect to the design of railroad signal masts, including the installation of protective barriers.
- To examine the frequency and severity of crashes involving rail-highway grade crossing infrastructure in the state of Iowa.
- To examine the potential impacts of design alternatives, such as increasing the offset to the mast/pole arm or installing guardrails at grade crossings.

1.3 Report Organization

This report is organized into seven chapters, with this first chapter providing an introduction and background to the research, in addition to defining the study objectives. A brief overview of the subsequent chapters is as follows:

- Chapter 2 presents the results of a review of existing policies and practices as they relate to the design of railroad-highway at-grade crossings.
- Chapter 3 includes a review of research literature as it relates to driver behavior at grade crossings, as well as a summary of research on guardrail performance.
- Chapters 4 and 5 detail the data collection processes and explain the methods used to gather and compile these data.
- Chapter 6 presents the statistical analyses conducted using these data. This chapter includes a brief summary of the statistical methods, as well as the presentation of results and an accompanying discussion as to the policy implications of these results.
- Chapter 7 summarizes the key findings from the research and provides recommendations based on the findings, in addition to identifying areas where additional research is warranted.

2. STATE-OF-THE-PRACTICE REVIEW

2.1 Crashworthiness Practices

2.1.1 Overview and Guidelines

The 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) includes guidance on the crashworthiness of railroad crossing warning devices (FHWA 2012). It states that passive (unsignalized) crossings must be mounted on frangible (breakaway) posts or poles; meanwhile, the use of use of breakaway hardware for railroad overhead or cantilever structures is prohibited. The MUTCD does not specify whether breakaway bases are needed at crossings with flashing lights but no gates. In practice, signal masts at crossings with flashing lights only are almost always installed in accordance with the American Railway Engineering and Maintenance-of-Way Association (AREMA) standards, which defines very rigid, non-crashworthy poles.

The use of non-frangible masts at railroad crossings contradicts the current practice for similar hardware supports located in clear zones, including pedestal-style traffic signals and pedestrian crossing signals (Figure 2).

© 2019 Google (Google 2013)

(a) Pedestal-style traffic signal (Ames, Iowa)

© 2019 Best Foot Forward, used with permission (Best Foot Forward 2015)

(b) Pedestrian crossing signal (North Reddington Beach, Florida)

Figure 2. Example of two crashworthy hardware supports

Typically, these devices are designed to conform to the requirements of the American Association of State Highway and Transportation Officials (AASHTO) *Roadside Design Guide* (RDG) (AASHTO 2011). AASHTO also provides specifications for structural supports; a widely used approach is to mount the signal mast on a frangible base (AASHTO 2015). Ultimately, an errant vehicle will impact the side of the base, causing the signal mast to pivot and fall away from the point of impact (Figure 3).

Figure 3. Traffic signal hardware that has fallen away from the direction of impact (New York, New York)

Conversely, photos of crashes involving railroad signal masts show the pole remaining upright after it has been subjected to impact energies that appear to be well beyond those sufficient to knock over RDG-compliant masts (Figure 4).

Scott Cyr 2018, used with permission

(a) Signal mast damage from motor vehicle crash (Brimson, Minnesota)

Scott Cyr 2018, used with permission

(b) Motor vehicle damage from striking signal mast (Brimson, Minnesota)

Figure 4. Comparison of damage to (a) railroad signal mast and (b) motor vehicle after a crash

Railroad signal masts can experience little damage when involved in a vehicle crash. The only noticeable damage to the mast is often to the counterweights for the gate assembly; however, the vehicle can become disabled and undriveable from the scene of the crash.

In regard to protecting railroad crossing signal devices, the Federal Highway Administration (FHWA) *Railroad-Highway Grade Crossing Handbook* and the RDG both recommend shielding the supports at high-speed locations using a crash cushion (not guardrail) (Ogden 2007, AASHTO 2011). The reasons to avoid using guardrails are the lack of room for proper treatment, the potential to create a larger roadside hazard, and the possibility that the guardrail may direct an errant vehicle into an oncoming train, if one is present. In practice, only one impact attenuator exists that is intended to protect a pole on both sides, and this device has only been accepted at National Cooperative Highway Research Program (NCHRP) Test Level 1 (TL-1) (impact speed of 35 mph) (Lindsay Transportation Solutions 2014).

The two handbooks note that guardrails may be used when there is a steep slope and state that, if used, the guardrail should protect motor vehicles and not to be used to protect the mast itself. In low-speed locations with high truck traffic, such as industrial areas, the FHWA Handbook does suggest protecting the signal mast using a ring-style guardrail (Figure 5) (Ogden 2007).

Justin Cyr 2018, CTRE

Figure 5. Ring-style guardrail example (Garden City, Iowa)

The language within the MUTCD regarding low-speed areas is similar. Section 8C.01 Paragraph 13 states, as an option, “In industrial or other areas involving only low-speed highway traffic or where signals are vulnerable to damage by turning truck traffic, guardrail may be installed to provide protection for the signal assembly” (FHWA 2012). The difference between the two handbooks lies in the ambiguity in the MUTCD, which simply states “guardrail,” allowing for different interpretations. The MUTCD also explains, “[A] lateral escape route to the right of the highway in advance of the grade crossing traffic control devices should be kept free of guardrail or other ground obstructions. Where guardrail is not deemed necessary or appropriate, barriers should not be used for protecting signal supports" (FHWA 2012).

The MUTCD also describes the minimum horizontal clearances for signal systems. Its guidance requires controller cabinet boxes to have a lateral offset of at least 30 feet from the edge of the roadway. For signalized crossing signals, a minimum horizontal offset of 2 feet is required from the face of the vertical curb or paved shoulder, with at least six feet of clearance from the edge of the traveled way when there is no curb. At passive crossings, the offsets remain the same distances; however, they are only to be considered as guidance. In rural areas, there also exists a guidance offset of 12 feet from the edge of the traveled way. On the railroad standard drawings in Iowa (RD-6 and RD-7), this 12-foot specification is included for signs as well as active warning signals (Iowa DOT 2018b). There is no maximum horizontal offset stipulated in the MUTCD for railroad crossing signals.

2.1.2 State Standard Drawings

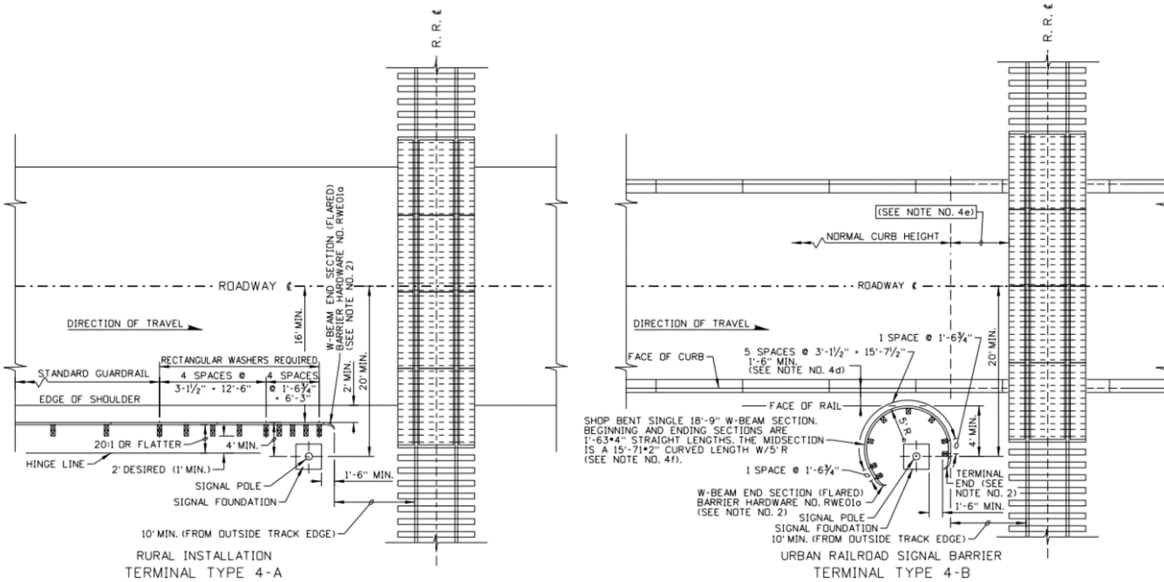
A search was conducted of available standard drawings and specifications currently used by state DOTs. This search led to the identification of seven states, including Iowa, that provide design standards and guidance related to guardrail installations to shield railroad signals (FHWA 2018b). Guardrails are generally installed to reduce the severity of crashes under the premise that a vehicle striking the barrier will experience a less severe crash than if the vehicle rolls over or strikes a roadside object. A summary of all the states is shown in Table 2. A set of all of the standard drawings can be found in Appendix A.

Table 2. State standard drawings summary

State	Longitudinal Guardrail: Length	Longitudinal Guardrail: Roadway Offset – Guardrail to edge of shoulder	Longitudinal Guardrail: Roadway Offset – Signal mast to guardrail	Longitudinal Guardrail: Railroad Offset – Guardrail to railroad	Longitudinal Guardrail: Notes	Ring-style Guardrail: Radius	Ring-style Guardrail: Roadway Offset – Guardrail to edge of shoulder	Ring-style Guardrail: Roadway Offset – Signal mast to guardrail	Ring-style Guardrail: Railroad Offset – Guardrail to railroad	Ring-style Guardrail: Notes
Arkansas	75 ft on secondary roads 100 ft on primary roads	1 ft	Not explicit	8 ft	≥50mph & ≥750 ADT					
Idaho	Varies	2 ft (min)	2 ft* (desired) 1 ft* (min) 4 ft** (min)	10 ft (min)	N/A	5 ft***	18 in. (min)	4 ft** (min)	10 ft (min)	Requested by RR, ≤40mph, Pedestrian traffic
Iowa	Varies (approx. 70 ft)	Not explicit (2 ft)	Not explicit (5 ft** preferred, 4 ft** min)	Not explicit	N/A					
Mississippi						3 ft	Not explicit	Not explicit	Not explicit	N/A
Nevada	Varies	2 ft	7 ft**	Not explicit	N/A	5 ft***	2 ft	18 in. ***** (min)	10 ft**** (min)	Engineer Approval
Oregon	Varies	0 ft	Not explicit (18 in.***** min)	11 ft**** (normal) 10 ft**** (min)	N/A	5 ft	0 ft	18 in. ***** (min)	11 ft**** (normal) 10 ft**** (min)	N/A
Washington	Varies	2 ft (min)	5 ft**	12 ft**** (min)	>35mph					

*- measured from back of guardrail post to signal mast; **- measured from guardrail face to center of railroad signal mast; ***-measured from guardrail face to signal foundation; ****-measured from end of guardrail to center of nearest railroad tracks; *****- measured from back of guardrail post to signal foundation

In Idaho, standard drawing G-1-J (Figure 6) illustrates both longitudinal and ring-style designs, which the agency labels as rural installation and urban railroad signal barriers, respectively.

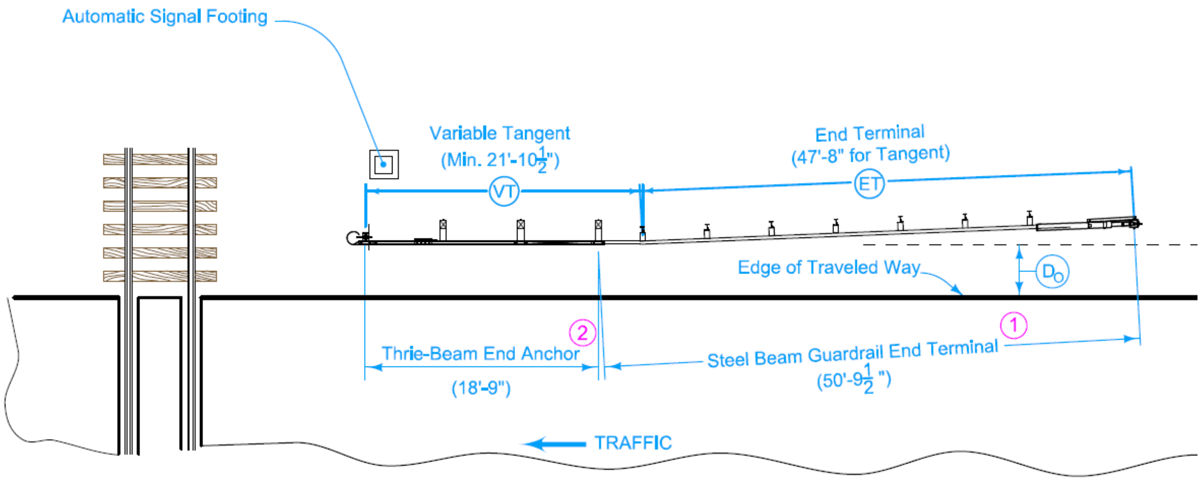


Idaho Transportation Department (ITD 2018)

Figure 6. ITD Standard Drawing G-1-J Revision 6 dated May 3, 2006

The back of the posts on the longitudinal guardrail are desired to have a 2-foot offset from the center of the pole and a 4-foot minimum offset from the guardrail face. In the ring-style design, The Idaho Transportation Department (ITD) indicates a 5-foot radius from the signal foundation and a minimum of 4 feet of clearance from the guardrail face. In urban areas, the ITD sets a maximum threshold of 40 miles per hour (mph) for these installations, which are set a minimum of 18 inches behind the face of the curb when no pedestrian traffic is present.

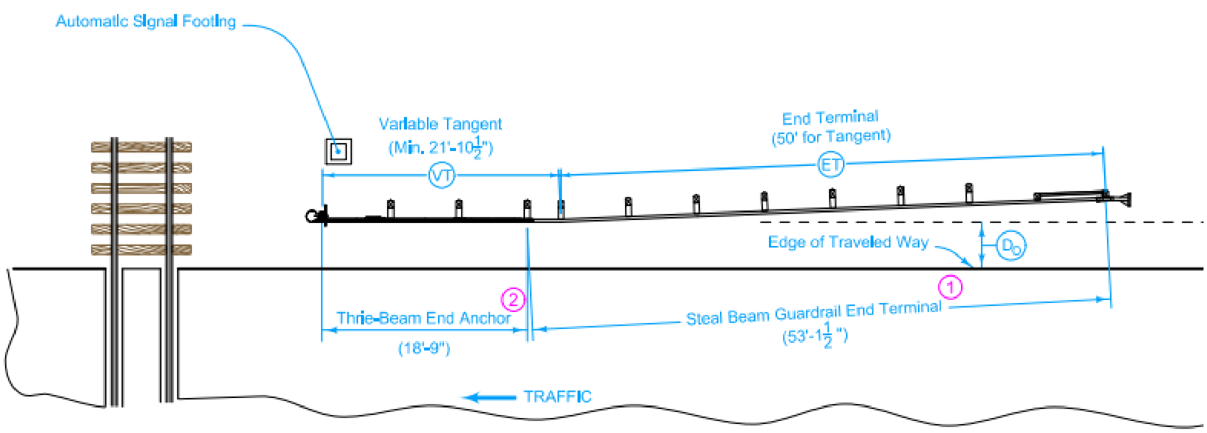
In the state of Iowa, Standard Road Plan BA-253 (Figure 7) calls for a longitudinal guardrail with a crashworthy end terminal to be installed at railroad crossings on federal-aid highways.



Iowa DOT 2018b

Figure 7. Iowa DOT Standard Road Plan BA-253 Revision 3 dated April 19, 2016

Iowa also has Standard Road Plan LS-633, part of the Local Systems series, which differs from Standard Road Plan BA-253 only in the flared guardrail piece and the end terminal (Figure 8).

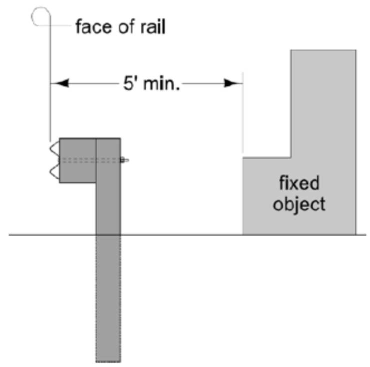


Iowa DOT 2018b

Figure 8. Iowa DOT Standard Road Plan LS-633 dated April 19, 2016

Since the revision to Standard Road Plan BA-253 is dated 2016, most existing crossings in Iowa are built on a previous standard that included a Sequential Kinking Terminal (SKT), following NCHRP 350 TL-3.

These designs are intended to prevent vehicles that run off the road to the right from striking the signal mast. To avoid encroaching on the railroad, the guardrail can only extend a short distance past the signal mast; consequently, the downstream end of the guardrail provides limited protection to vehicles that run off the road to the left. The distance between the signal mast and the guardrail is not explicitly stipulated within the design standards. While the state's guardrail guidelines call for 5 feet of clearance distance between the guardrail and the fixed object (reduced to 4 feet if the posts are installed at half of the standard spacing) (Figure 9) (Iowa DOT 2017), this is rarely the case for railroad signals. This problem can be encountered because the railroad signal mast is usually installed prior to the installment of the guardrail.



Iowa DOT 2017

Figure 9. Guardrail placement in front of a fixed object

Chapter 8C of the MUTCD states that there should be a horizontal offset of 2 feet from the face of the vertical curb or the edge of the paved road surface to the closest part of the signal, with an offset of at least 6 feet from the edge of the traveled way (FHWA 2012). In the Iowa Design Manual, it is recommended that longitudinal guardrails have a minimum offset of 2 feet from the edge of the shoulder to reduce the number of nuisance hits (Iowa DOT 2017). A 3-foot shoulder in this scenario would only leave 1 foot of clearance between the guardrail and the closest point of the signal mast. Intruding on the clearance zone may affect the guardrail's ability to safely contain or redirect a vehicle, since the guardrail would not allow proper deflection.

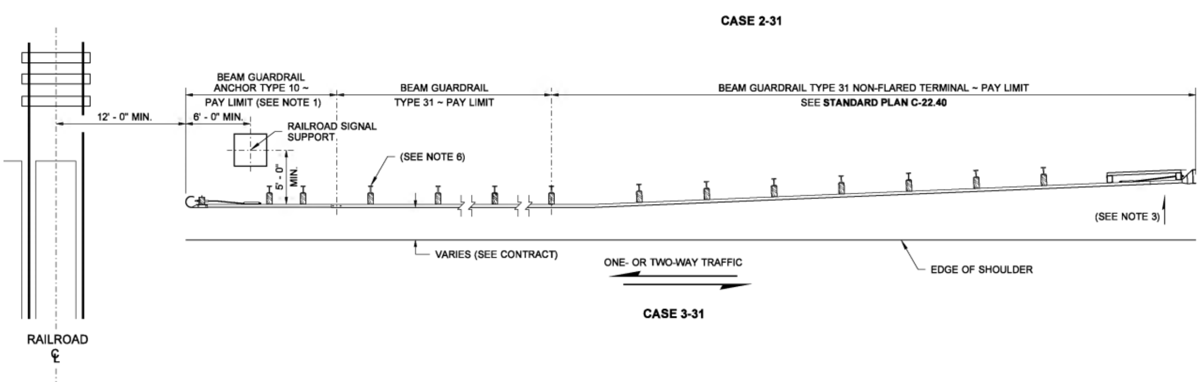
The guardrail design detailed thus far is from the third revision of Standard Road Plan BA-253. Figure 10 shows an example of a previous design, one that does not include the crashworthy end treatment.

Justin Cyr 2018, CTRE

Figure 10. Longitudinal guardrail design from a previous standard (Elkhart, Iowa)

In 2009, the Iowa DOT adopted a modified W-beam guardrail as the standard for the state. This type is referred to as the Midwest Guardrail System (MGS) and uses a mounting height of 31 inches, whereas the prior standard called for 27 inches. The blockout depth also increased from 8 inches to 12 inches in the new design (Iowa DOT 2011, Iowa DOT 2017). In most cases, the practice is to use wood posts at railroad crossings instead of steel posts.

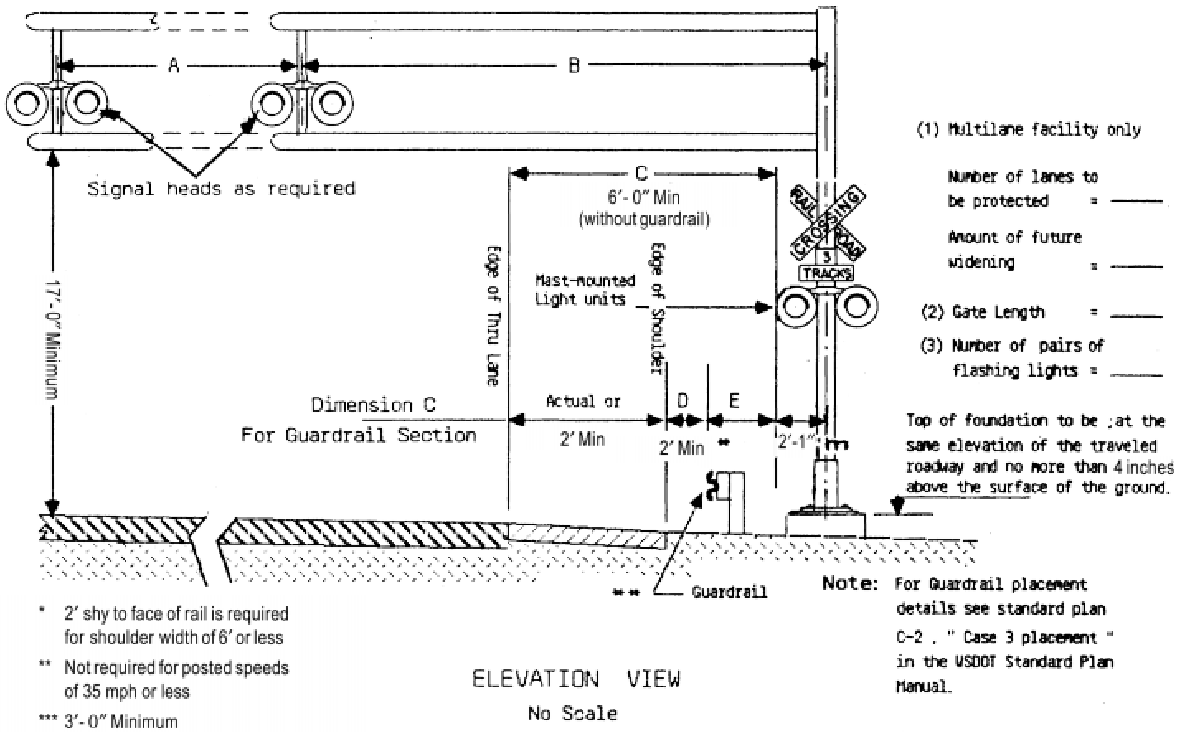
In Washington State, Standard Plan C-20.14-03 Beam Guardrail Type 31 Placement Case 3-31 includes an example of a longitudinal guardrail at a railroad crossing (Figure 11). In this design from the Washington State DOT (WSDOT), the signal support offset is a minimum of 5 feet from the guardrail face, and it is noted that the distance from edge of the shoulder and the face of the guardrail varies by case.



WSDOT 2018b

Figure 11. WSDOT Standard C-20.14-03 Beam Guardrail Type 31 Placement Case 3-31 dated June 11, 2014

Chapter 32 of the WSDOT Local Agency Guidelines describes a minimum of 2 feet between the guardrail face and the edge of the shoulder (WSDOT 2018a) (Figure 12).



WSDOT 2018a

Figure 12. WSDOT Shoulder Section Elevation View for Submittal from WSDOT Local Agency Guidelines M 36-63.36 (June 2018)

The document also states that "a railroad signal may be a point hazard warranting the use of a traffic barrier or crash cushion" and that "a guardrail should be installed if the speed limit is greater than 35 mph."

In other countries, railroad at-grade crossings can differ significantly in appearance and the types of traffic control devices used to warn drivers. Even remote locations within the US can differ, such as crossings in Hawaii (Figure 13).

Figure 13. Example of a signalized railroad crossing on Oahu (Kapolei, Hawaii)

Although Hawaii does not have a railroad division within its state transportation agency, it does have some at-grade crossings. Figure 13 shows a signalized railroad crossing with separate apparatus for its gate assembly and signal mast. It also appears to have traffic signal hardware for the flashing lights. Other countries, such as Australia, Finland, Germany, and Japan, do install devices to shield the mast from being struck.

Even though there are design standards in place, this does not guarantee that the construction and implementation will be as designed. Often, the warning system device is installed first by a rail company, and then the guardrail is installed at a later time. If the signal mast is installed too close to the edge of the shoulder or roadway, this leaves little room for either lateral clearance or deflection of the guardrail (see previous Figure 13). A potential problem with the guardrail being installed too close to the signal mast is that the flashing light assembly is prone to damage even if a motorist does not strike the guardrail, ultimately defeating the purpose of installing the barrier in the first place. If the signal mast is placed too close to the railroad tracks, proper treatment is no longer possible because it begins to impede on the clearance needed for a train to pass through the intersection (see Figure 14).

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Figure 14. Example of a railroad crossing with guardrail terminating before reaching the signal mast (St. Paul, Minnesota)

Another problem can also occur when a roadway is improved or widened while the signal and guardrail are kept in their existing locations. Solutions to these problems could include defining explicit locations for the placement of railroad signals and encouraging communication between the various agencies involved.

2.2 State-of-the-Practice Survey

Engineers, administrators, and law enforcement officials from various transportation agencies (including both railroad and highway) were surveyed to explore the prevalence of crashes involving railroad infrastructure at railroad at-grade crossings and to gather information on design standards for protective barriers for warning systems. The survey is provided in Appendix B. The survey was distributed and responses were gathered via the internet, and the study was designated as exempt by the Institutional Review Board (IRB) at Iowa State University. Surveys were distributed to all 50 state DOTs, and 18 complete responses were received. Figure 15 shows a map of the states that participated.

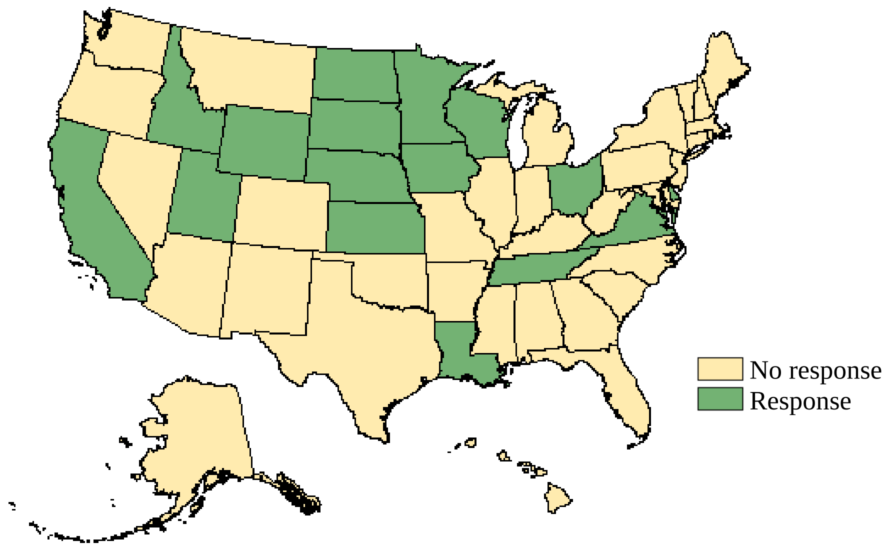


Figure 15. States that participated in the survey

When respondents were asked if they had received reports of motorists striking railroad signals or control boxes in their areas or had observed evidence of hit-and-run crashes involving this equipment, 61% stated that they had. Almost all of the comments from these responses indicated that such incidents were very rare occurrences, and only one agency reported that there were fatalities associated. Respondents were also asked if railroad signal equipment was protected by various types of safety features. Three-quarters of respondents indicated that at least one form of barrier was used in their area; a graph showing the distribution of the types of barriers can be seen in Figure 16.

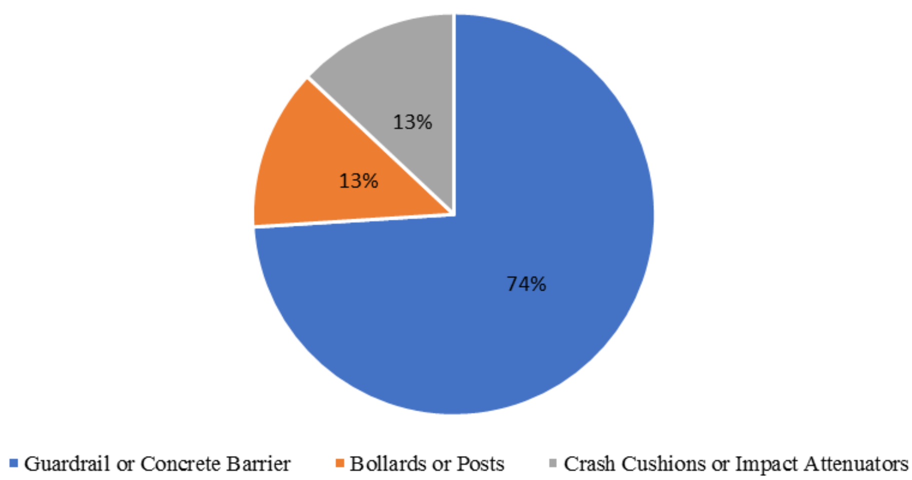
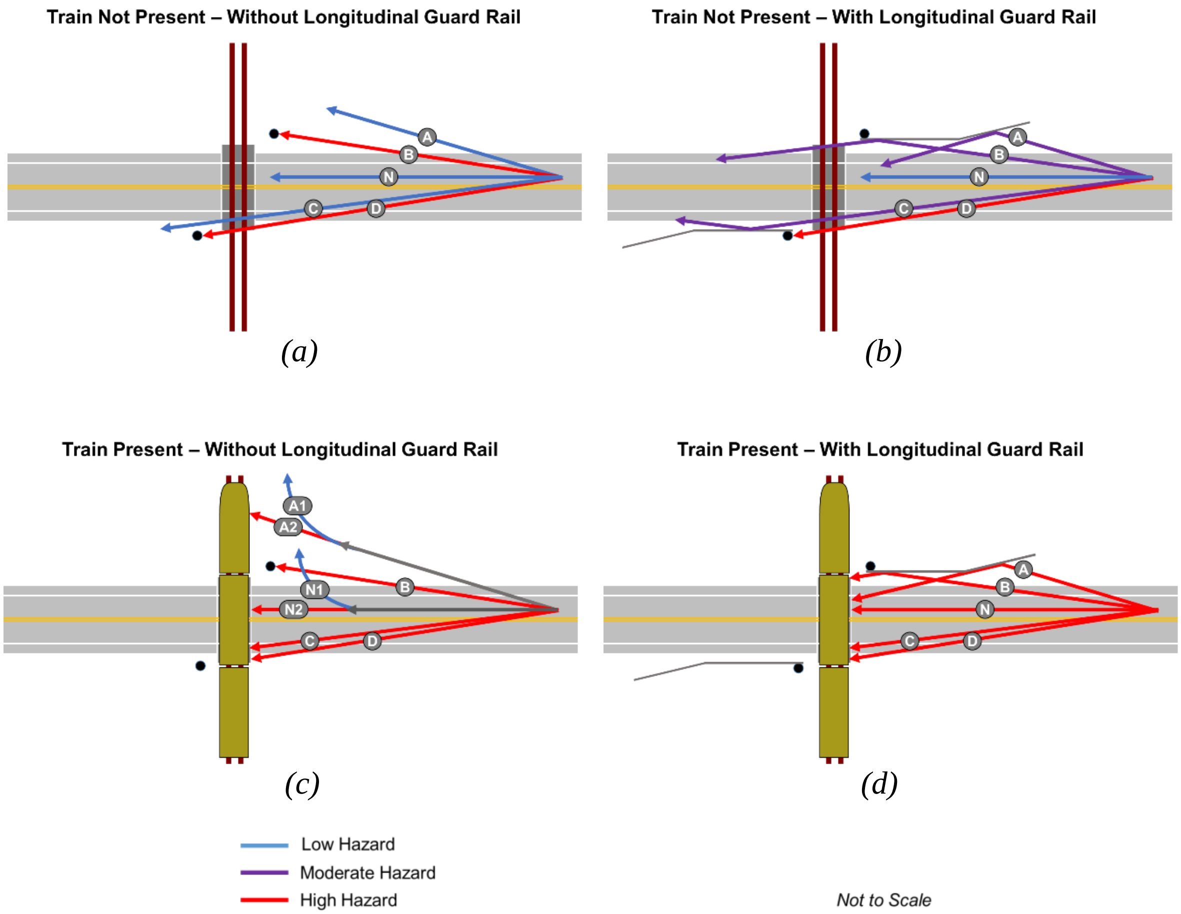


Figure 16. Distribution of safety devices to protect railroad warning signal systems

The most common type of protective device was guardrail, which was mostly used in urban regions. In most of these cases, this is likely a ring-style guardrail placed near a commercial driveway, as a few respondents noted in their comments. The remaining types (bollards or posts and crash cushions or impact attenuators) were used in both urban and rural areas.

3. LITERATURE REVIEW

The presence of a guardrail affects the path a vehicle would normally take in a run-off-road (ROR) situation. Figure 17 outlines a few basic scenarios under two different conditions (with and without a train present).



Justin Cyr 2018, CTRE

Figure 17. Hypothetical vehicle trajectories for various conditions

These examples illustrate various ROR scenarios (paths A, B, C, and D), as well as a nominal lane position base case (path N). Although the guardrail system is intended to reduce the severity of path B crashes, it may also affect the other paths to varying degrees.

When a train is present, the guardrail has potentially unintended effects. For example, Figure 18(c) (without guardrail) shows that a driver on path A can potentially avoid colliding with the train by steering to the right (path A1). Similarly, a driver who is in-lane but approaches the crossing too rapidly could also avoid the train by turning parallel to the track (path N1). At high speeds, these evasive maneuvers are more challenging, and a vehicle would be more likely to strike the train (paths A2 and N2). Without the guardrail, an errant driver on path B would hypothetically strike the signal mast, while paths C and D could result in the vehicle striking the train. Figure 18(d) shows that with both the guardrail and a train present, vehicle-train crashes could be expected with greater frequency in each scenario.

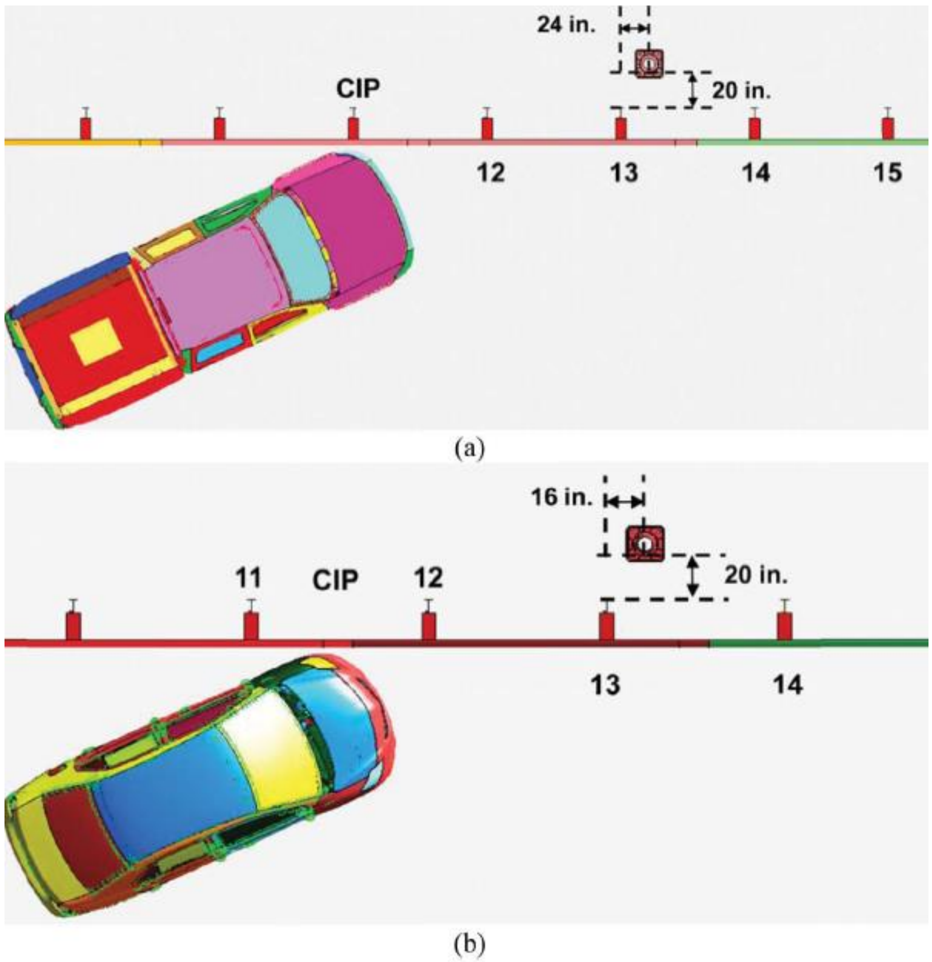
Although Figure 18 represents hypothetical scenarios, it indicates the complexity in examining the potential impacts associated with guardrail installation at rail-grade crossings. It is important to note that the frequency of such crashes is quite small given the relatively low number of train-vehicle interactions that occur at most crossing locations.

No research literature to date has focused on the installation of guardrails at railroad-highway crossings. However, several studies have focused on the effectiveness of guardrails in shielding vehicles from crashes with other fixed objects. The structural performance of guardrails has been tested through full-scale crash tests, simulations, and finite element analysis. This literature review focuses on evaluations of guardrail performance, as well as driver behavior at rail-grade crossings.

3.1 Guardrail Performance Research

Luminaire pole placement behind MGS was studied using nonlinear finite element analysis (Pajouh et al. 2017a). Using LS-DYNA, results showed that poles placed within 16 inches behind steel guardrail posts might cause unacceptable crash test performance. Within this study, only one of the four simulations that were run passed the crash test according to Manual for Assessing Safety Hardware (MASH) test criteria, and in that simulation there was significant damage to several components of the vehicle, including the tires/wheels and the suspension. The simulation only passed because the passenger compartment was not harmed.

Pajouh et al. (2017b) conducted another study using computer simulations and compared the results with full-scale crash testing. Based on the simulation, it was found that the most critical pole offset was 20 inches laterally behind the back of the guardrail post and 24 inches longitudinally downstream from post number 13 for a pick-up truck. For a passenger car, offsets of 20 inches laterally and 8 inches longitudinally downstream from post number 13 were found to be the most critical pole placement. In comparison to the crash tests according to TL-3 MASH test designations 3-10 and 3-11 (Figure 18), the MGS contained and safely redirected both vehicles, which indicated that the 41 inch offset between the face of the guardrail and the front face of the pole leads the guardrail system to perform safely.



Pajouh et al. 2017b

Figure 18. Recommended pole placement: (a) MASH test designation 3-11 and (b) MASH test designation 3-10

3.2 Crash Severity in Crashes with Guardrails and Roadside Objects

Roadside barriers such as guardrails are installed to prevent more dangerous crashes from occurring, such as crashes with poles, trees, or steep slopes. Zou et al. (2014) found that colliding with almost any barrier, regardless of its offset from the roadway, reduced the probability of an injury compared to colliding with a high-risk object. The two exceptions were closely located concrete barriers and guardrail end terminals. Thus, these barriers may also contribute to fatal and serious injury crashes.

A study in Washington State between 1993 and 1996 looked at the severity of crashes with roadside objects in urban areas (Holdridge et al. 2005). The authors found that the greatest number of crashes with roadside barriers were with concrete barrier faces (32.0%), guardrail faces (16.0%), and poles (including railroad signal masts) (11.7%). The proportion of severe injuries for these three barriers was found to be the reverse of the crash frequencies, in that crashes with poles accounted for about 6.3% of severe injuries, guardrail faces accounted for about 3.0%, and concrete barrier faces accounted for about 2.8%. Holdridge et al. (2005) also found that striking a guardrail face or concrete barrier decreases the likelihood of an injury, indicating that striking one of these barriers carries a significant injury prevention benefit compared to directly striking a pole. Drivers were more likely to suffer injuries if they were committing any driving violations, such as operating a vehicle under the influence of alcohol, exceeding the speed limit, or engaging in inattentive driving. Guardrail end terminals and railroad poles showed a significant association with fatal and severe injuries, leading to the conclusion that it is important to use properly designed end treatments and upgrade poorly performing treatments.

The injury risk in striking a guardrail end terminal was found to be not statistically distinguishable from the injury risk in striking another high-risk object (e.g., rigid roadside object or tree) or experiencing a high-risk event (e.g., conditions that would lead to rollover) (Zou et al. 2014). More specifically, Zou et al. (2014) found that the odds of injury associated with hitting a guardrail face are 65% lower than those associated with striking a high-risk object or experiencing a high-risk event.

Gabauer and Gabler (2010) studied the deployment of seatbelts and airbags in terms of their effects on occupant injuries resulting from crashes with guardrails and other longitudinal barriers. In vehicles with airbags, the authors found a seatbelt usage rate of 86%, comparable to the national average (Li and Pickrell 2018). In these vehicles, the airbags deployed in almost 75% of the tow-away severity crashes, which indicates that airbag deployment is not a rare event. In approximately 96% of the crashes, the occupants sustained either minor injuries or only experienced property damage. Odds ratios for fully restrained (airbag and seat belt) occupants and occupants restrained only by seat belts were similar, suggesting that airbags have a small safety benefit; however, both seat belts and airbags were found to reduce the odds of a serious occupant injury, and the risk of a serious injury was dramatically reduced risk if the occupant was restrained by both methods. Other research has found that impacts with barriers may cause late deployment of an airbag, potentially increasing the changes of occupant injury (Grzebieta et al. 2005).

Crash severity should be treated in a special way for cases that involve motorcycles. While a barrier may protect and serve as a safety treatment for most motorists, it may have consequences for other road users. Motorcycles were found to comprise about 3% of the vehicle fleet but accounted for almost half of all fatalities in guardrail crashes from 2003 to 2008 (Daniello and Gabler 2011a). In a different study, the authors also found that crashes with guardrails are seven times more likely than crashes with just the ground to result in a fatality for a motorcyclist (Daniello and Gabler 2011b). Railroad crossings can also present problems with vehicle control for motorcycles, potentially heightening the risk of a crash.

3.3 Driver Behavior at Rail-Highway Grade Crossings

Driver behavior at railroad-highway crossings can differ from that under normal driving conditions. Railroad crossings can be some of the most dangerous locations for distracted driving, due to the possibility that drivers will not detect the warning signals and collide with an oncoming train. There have been several studies conducted on driving behavior and the decisions made by drivers at railroad-highway crossings. Approximately 30% of the time a vehicle is in motion, the driver is engaged in a potentially distracting secondary task (Sayer et al. 2005, Ranney 2008). A secondary task is defined as a task that diverts the driver's attention to an object, person, or event not related to driving. The frequency and complexity of the secondary task have an important role in determining its impact on driver performance. It is possible that a task that is less complex but has a much higher occurrence is as influential as a highly complex task that has a lower occurrence. At railroad crossings, drivers of light vehicles were likely to engage in secondary tasks 46.7% of the time (Ngamdung and daSilva 2013), while drivers of heavy trucks were likely to engage in secondary tasks about 21% of the time (Ngamdung and daSilva 2012).

Shinar and Raz (1982) studied the behavior of driving speed at three different types of railroad crossings: passive, active with flashing lights, and active with flashing lights and gates. They found that drivers slowed before crossing the tracks under all conditions, with the largest reduced approach speeds at crossings with activated lights and gates lowered, and the smallest reductions at crossings with gates raised and flashing lights not active. It was also found that all drivers in the study came to a stop in the presence of flashing lights; however, more than one-third ended up crossing the tracks.

An observational study was conducted at a suburban Indiana at-grade crossing that compared differences in driving behavior before and after the crossing was upgraded from flashing lights to flashing lights with gates (Meeker et al. 1997). The two-lane, paved county highway saw light traffic volumes (500 vehicles/day) with 30 to 40 trains daily. The authors described the crossing as remaining unchanged throughout the five years after it was upgraded. The study looked at drivers who arrived at the crossing after the flashing lights were activated but before a train had arrived during daylight hours. Upgrading the crossing with gates significantly lowered the number of vehicles crossing in front of an oncoming train; however, fewer drivers halted at these intersections before proceeding to cross, and significantly more drivers neither stopped nor slowed down. The likelihood of vehicles crossing the tracks was found to decrease as trains neared, but no relationship was found between that likelihood and the speed of the train. This possibly suggests that it is difficult to perceive trains' speeds as they approach the crossing.

An on-road analysis was performed in Australia on a predetermined urban route where drivers gave verbal feedback while two observers in the vehicle studied their behavior and situational awareness (Salmon et al. 2013). The study used a network analysis methodology to form relationships among the data the researchers received from the drivers. The route included four railroad at-grade crossings and focused on a comparison between experienced and novice drivers. The feedback provided by novices was found to have higher word counts and include concepts relating to the novices' own actions, while the key concepts in the feedback provided by experienced drivers were related to other road users and other road users' actions. Experienced drivers extracted less raw information from the driving situation but were able to generate more connected models. Within these models, it is interesting to note that pedestrian crossings near railroad crossings showed more prominence than the rail crossings themselves. The authors suggest that drivers may not necessary be focused on the warning devices and could pass through the crossing without integrating them into their schema, which could lead to a potential problem when a train is approaching. Unsafe driving behavior at railroad crossings is location-specific; however, responses to the same safety treatment have been found to be similar in magnitude (Khattak 2009).

Driver behavior was studied at six railroad crossings in Nebraska in 2013 using high-resolution surveillance cameras (Tung and Khattak 2015). The crossings consisted of two tracks on multiple-lane highways with flashing lights, audible bells, and dual-quadrant gates. About one-third of the observed drivers were found to be distracted, with the most common task being talking to the front seat passenger. A binary probit model was estimated for the dataset, and the authors found that distracted driving behavior was most frequent at crossings where intersection roadways were within 250 feet, and distracted driving behavior decreased in the proximity of a potentially distracting activity or object (e.g., work zone or unattended vehicle). Another finding was that fewer drivers were distracted as traffic volumes increased. An analysis of gender did not reveal any significant differences in terms of distracted driving; this was also the case in Ngamdung and daSilva (2013). While weather was not found to be significant in a study by Tung and Khatak (2015), Kirsch (2018) used naturalistic driving data to find that engagement in a distracting secondary task was reduced by 42% in foggy conditions on freeways.

Another study in Nebraska that analyzed crashes at or near railroad crossings found, on average, higher injury and fatality rates at these locations compared to highway locations outside of railroad crossings. The effects of inattentive driving at or near railroad crossings on driver injuries were statistically comparable to those of driving under the influence of alcohol or drugs (Zhao and Khattak 2017a). Zhao and Khattak (2017b) later studied inattentive drivers through a survey questionnaire. Their findings showed that females had a higher risk of inattentive driving compared to males, and younger drivers (< 30 years old) had a higher risk compared to older drivers (>= 60 years old). The authors also found that drivers who had less patience to wait for trains were associated with a higher risk of inattentive driving. These results are comparable to those of Ngamdung and daSilva (2013), which found that younger and middle-aged drivers were more likely to engage in secondary tasks than older drivers (Ngamdung and daSilva 2013).

Driving behavior can also be affected by the presence of roadside objects and barriers. While striking the barrier results in reduced injury severity compared to striking the fixed object itself (Lee and Mannering 2002), the barrier may also be perceived as a hazard (Michie and Bronstad 1994). Drivers were found to move away from the guardrail unless a full lane (12 feet) was present separating the travel lane from the barrier (van der Horst and de Ridder 2007). Van der Horst and de Ridder (2007) also found that speeds were reduced when an obstacle (tree or guardrail) was 2 meters (6.6 feet) or less from the driver, but no effect on speed was found when the object was more than 4.5 meters (14.8 feet) from the driver. Ben-Basset and Shinar (2011) found similar results, in that higher speeds were found with 3-meter (9.8-foot) shoulders compared to 0.5-meter (1.6-foot) shoulders. The authors also found that simulation participants drove significantly faster than their perceived safe speed. Perceived safety was evaluated after the participants completed their driving simulation via a questionnaire that showed various scenarios. Perceived safety was evaluated by asking participants to assess safety on a scale from 1 to 10. Results showed that mean estimated safety was comparable between roadways with or without guardrails when shoulder widths were narrow; as the right shoulder width widened, the presence of guardrails increased the perceived safety. Drivers in the simulation tended to shift away from the guardrail as a result and drove significantly closer to the left lane (Figure 19).

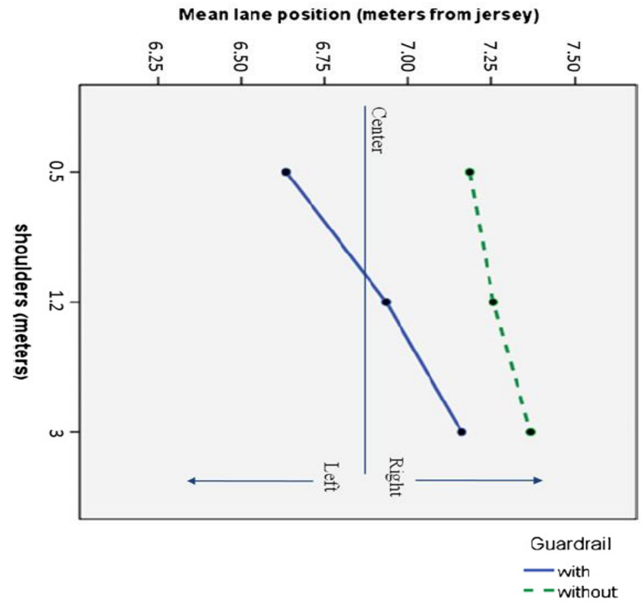
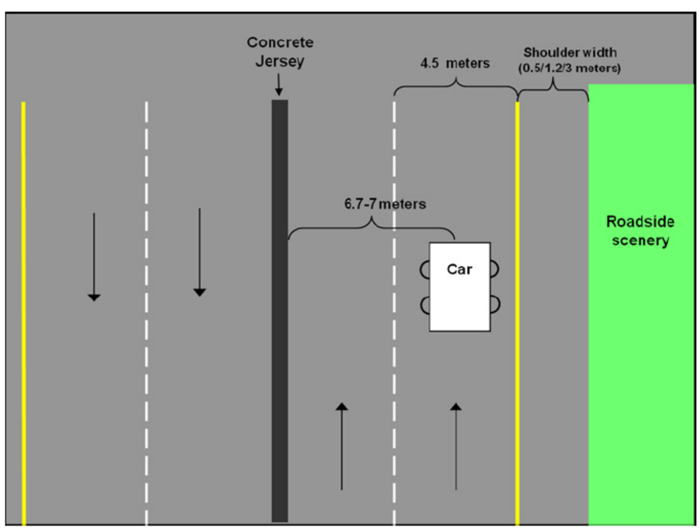


Figure 19. Mean lane position of a motor vehicle in the right lane of a four-lane road during a driving simulation with and without guardrails

Figure 20 shows a diagram of the driving simulation.



Ben-Bassat and Shinar 2011, © 2011 Elsevier Ltd., used with permission

Figure 20. Diagram of the driving simulation

4. DATA COLLECTION

4.1 Data Background

Data were collected from a variety of sources over the course of this study. This section describes the different resources used and the applicability of these data to the research questions of interest. A 10-year study period was utilized, covering the period for which Iowa crash data were available (from 2007 through 2016). Ten years of data represents the range over which the Iowa DOT maintains historical crash data, and this analysis period has been used as a part of several research studies in this general topic area (Raub 2006, Russo and Savolainen 2013, Liu et al. 2015).

4.1.1 Railroad Information

4.1.1.1 Iowa Department of Transportation Information

A statewide railroad crossing database from the Iowa DOT was used to create an inventory of the railroad crossings of interest. This database was available online in the Geographic Information Management System (GIMS) and the Roadway Asset Management System (RAMS) through the Iowa DOT's Open Data platform. The railroad networks used in this study corresponded to those documented in the available datasets from the year preceding the study period until the present day. From the two data portals, seven separate years of information were retrieved from GIMS (2006 to 2011 and 2013) and one year of information was retrieved from RAMS (2017). The Iowa DOT converted its GIMS to RAMS during this study, which is the reason for using two separate data portals. A total of 5,349 unique crossings were found in the combined Iowa DOT databases, with 4,291 unique public at-grade crossings.

4.1.1.2 Federal Railroad Administration Information

A nationwide crossing database from the FRA was also used in this study, namely the Highway-Rail Crossing Inventory Database, which contains all current crossings and is updated continuously. From this dataset, only crossings within the state of Iowa were selected, which included 15,028 unique records at the time the data were downloaded. Of this total, 9,696 records were not included within the Iowa DOT's database. This large difference is due to the Iowa DOT's database being primarily public crossings, including very few pedestrian and private crossings, whereas the FRA's database includes all crossing types. In both of the railroad databases, the crossings were geocoded as singular points in order to identify the center of the roadway that intersected the railroad. The FRA database was used as a secondary resource and only utilized for special cases.

4.1.2 Roadway Information

Several fields of information relating to the roadway, such as average annual daily traffic (AADT), state system identifier, federal function classification, and surface type were already included within the railroad crossing database. However, additional roadway features were also provided through the GIMS and RAMS portals. These portals were accessed to provide clarity on certain features in instances where the values within the railroad database were blank, zero, or coded as "other."

For this study, specific information on guardrail and concrete barrier locations was requested. Data on both were obtained from the Iowa DOT in the form of geocoded line segments, but the dataset only included the barriers that were located on roadways under state jurisdiction. The two datasets did include a field indicating whether the barrier was at a railroad crossing and were used for quality control.

4.1.3 Crash Information

Crash data were obtained from the Iowa DOT in two different formats: crash codes and crash narrative summaries. Both information sets were important to accurately identify the crashes of interest for this study.

4.1.3.1 Crash Code Information

Crashes within the state of Iowa were gathered from the Iowa DOT through the Traffic and Criminal Software (TraCS) reporting system. This reporting system is a collection of crash report forms submitted by law enforcement officers that is updated annually and stores the 10 most recent years. The TraCS system was accessible through the ICAT. These data contained three levels of relevant information: crash, vehicle, and person. The crash-level information includes general information regarding the specifics of the crash, such as location, type, and severity level. Vehicle-level information breaks down each crash and includes information on each individual vehicle involved in the crash, with fields such as the sequence of events, vehicle type, and damages. The person-level information includes information on each of the occupants in the vehicle. Demographics, such as age and gender, are recorded, as well as the degree of injury sustained. Other fields of interest include airbag deployment and restraint used. As mentioned previously, two fields signify that the crash occurred at a railroad crossing; however, there is not a railroad signal–specific fixed-object field. There were 1,708 crashes that were reported to have occurred at railroad crossings (active and passive) based on the law enforcement identification in the crash codes (Table 1).

4.1.3.2 Crash Narrative Information

Law enforcement crash report narratives were requested from the Iowa DOT so that the number of crashes of interest could be counted accurately and the crash events and driver processes pertaining to the crashes could be fully understood. The narratives were provided with the crash identifiers, allowing the crash code and narrative datasets to be linked and analyzed together.

4.1.4 Cost Information

To perform benefit-cost analyses, cost information was requested from the Iowa DOT. The different costs included guardrail installation, guardrail maintenance and repair, railroad insurance, and flagging. Some traffic signal crash repair costs were obtained from WisDOT to compare to the repair costs of railroad signal masts. Details on how the information was used can found in Section 5.3.3.

4.2 Data Collection

This section describes how the data from these sources were collected and integrated for the purposes of the subsequent analyses. This summary includes how the active crossings were inventoried and how crashes with the railroad signal mast, guardrail, or nearby railroad equipment (e.g., controller box) were identified.

4.2.1 Inventory Construction

From both railroad databases, a combined listing of all unique crossings was created to form the inventory for this project. Each railroad crossing is assigned a crossing inventory number by the U.S. DOT, commonly referred to as the FRA number. This identifier consists of six digits and one letter and is unique to each particular crossing in the country. The process of constructing an inventory involved locating all public at-grade crossings within the state of Iowa that were signalized at any time between 2007 and 2016.

The list of all unique FRA numbers in both the Iowa DOT and FRA datasets included 15,045 crossings. This total is of all records, including pedestrian, private, and grade-separated crossings. While constructing this listing, the first and last available years of information about the specific crossing were included, as well as the AADT values for every year there was information at the crossing. The crossing information includes fields relaying whether the crossing is public (TYPEXING = 3) and at-grade (POSXING = 1). Determining whether the crossing was signalized followed a more complex process because this was not a field within the dataset. Several fields provided information that aided in the identification of signalized intersections (capitalized text indicates the specific field within the GIMS or RAMS datasets):

- Flashing lights (FLASHPAI > 0 OR MASTFLASH + OTHFLASH > 0)
- Flashing lights on cantilever (CANTFLASHLANE + CANTFLASHNOT > 0)
- Gate arms (REFLECTGATE + OTHGATE > 0 OR GATES > 0)
- Power available (POWERAVAIL = 1)
- Crossing angle (CROSSANGLE)
- State highway system (STATESYS)
- Federal functional classification (FEDFUNC)
- Paved roadway (PAVEDHWY = 1)

If any of the first three features were present, a field created for the analysis was populated with a “TRUE” indication to denote that this crossing likely included warning devices. If the data for any of the fields listed above changed between the first and last year for which data were available, a different field corresponding to the field that had changed was populated with a value of “1” (one) (overwriting the default “0” (zero) value). Crossings labeled with a “1” were further examined using the Google Street View feature of Google Earth to visually inspect the crossing and update fields as needed. During this process, several additional fields of information were recorded, such as crossing length; indicators for flashing lights, gates, and cantilever beams; and data about the guardrail (type, number of sides, etc.). While the information retrieved from the various data sources is valuable, additional information on the crossing pertinent to the study was needed for further analysis. Although data from the years directly before (2006) and after (2017) the analysis period were used to locate the crossings, they were not used in the analysis.

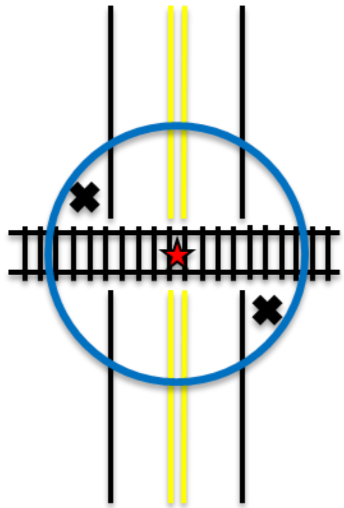
Another quality control process involved inspecting the roadway datasets to confirm the locations of concrete barriers and guardrails. If either feature had been coded as being at a railroad crossing, it was examined in Google Earth to confirm because most of these features at such locations were in relation with grade-separated crossings.

At the end of the construction, 1,853 public at-grade crossings in Iowa were found to have active warning devices present during any period between 2007 and 2016. Crossings where the tracks were abandoned or removed but the signals remained were still counted and analyzed in this study due to the potential impacts that still may occur. The inventory is based on the best available data provided, and while variables such as traffic volume can vary over time, discrepancies within the datasets were expected to have a minimal effect on the analyses.

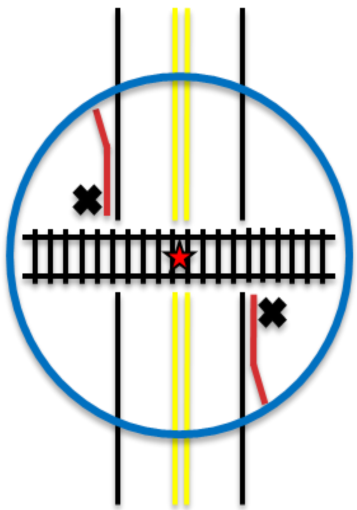
4.2.2 Crash Collection

All crashes from the Iowa DOT database from 2007 through 2016 were linked to the nearest signalized railroad crossing (in the constructed inventory described above) using ArcGIS. Using the “join” feature of this software, the distance to the nearest linked crossing was also recorded. During the inventory’s construction, the item “crossing length” was calculated for each crossing using the measuring tool in Google Earth. This value indicates the distance from the geocoded point representing the railroad crossing to the railroad signal mast. If a guardrail was present, the length extended to the outer limits of the system.

Figure 21 is a diagram outlining the procedure used to gather crashes.



(a)



(b)

Figure 21. Buffer zone radii used to collect crashes of interest: (a) railroad crossing without guardrail and (b) railroad crossing with longitudinal guardrail

The red star in Figure 21 indicates the GPS coordinates of the railroad crossing from the Iowa DOT GIMS database, the black X represents the railroad signal mast, the red lines show the presence of longitudinal guardrails, and the blue circle shows the buffer zone within which crashes were collected and analyzed for this study. This distance was restricted so that it would not include crashes not pertaining to the railroad crossing, such as on nearby perpendicular streets or at a closely located traffic signal. A filter was performed on the set of all crashes to only include those that were within the crossing length. Another filter was applied to restrict the crashes to only include those that occurred during the time in which the crossing signals were present. Most of the crossings had signals for all 10 years of the study, but 72 crossings were abandoned, removed, or blocked off, with the signal masts removed from the former crossing, and another 41 were newly installed or upgraded from passive to active during the study period.

A total of 1,874 crashes were retrieved and represent all crashes at the crossing. While these crashes may yield insights in future railroad safety research, most of these crashes did not pertain to the research questions of interest in this study. Many of the crashes within the buffer zone involved rear-end crashes near the crossing or were undecipherable as to the main reason for the crash.

For this study, specific crashes were needed for analysis. Crashes relevant to the research objective were those where a vehicle struck a railroad signal mast, a railroad controller box, or a barrier at the crossing. These crashes are referred to in this report as "railroad-related" crashes. Crashes involving a vehicle driving through the gates (without damaging the signal mast), hitting a pedestrian, or colliding with a train were irrelevant for this study. Since the railroad-related crashes could generally not be located strictly using the crash codes, law enforcement narrative summaries of the crashes were used for identification.

The crashes of interest were collected through various query searches and reviews of the crash code narratives. From the 1,874 crashes that occurred within the radius of the crossings, 200 crashes did not include a narrative. Filtered searches included variations and misspellings on the following words: "railroad," "train," "crossing," "pole," "mast," "signal," "guardrail," and "barrier." A total of 156 railroad-related crashes were found and can be seen in Figure 22.

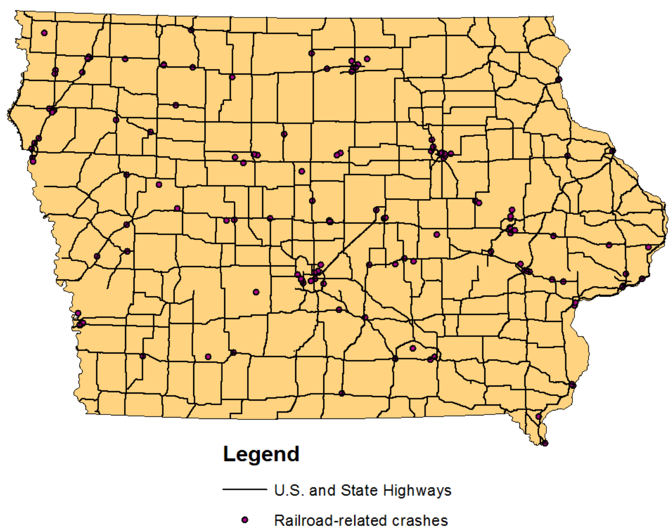


Figure 22. Railroad-related crashes in Iowa 2007–2016

Although train-vehicle crashes were not crashes of interest, they were still looked at to identify possible crashes that involved a vehicle first striking the guardrail or signal mast. However, none of these crashes were found in this study.

4.3 Data Summary

4.3.1 Railroad Crossing Data

Table 3 provides a summary of the data for 1,853 public, at-grade, active railroad crossings.

Table 3. Summary railroad-highway crossing statistics

Statistic	Count (Crossings)	Percentage (%)
Crossing Type		
Flashing light mast only	688	37.1
Flashing light mast with gates only	855	46.1
Flashing light mast with cantilever beam only	178	9.6
Flashing light mast with gates & cantilever beam only	110	5.9
Crossing type changes during study	22	1.2
Barrier Type		
No barrier	1,595	86.1
Barrier (any) on both sides only	161	8.7
Barrier (any) on one side only	88	4.7
Longitudinal guardrail on both sides only	126	6.8
Longitudinal guardrail on one side only	7	0.4
Ring-style guardrail on both sides only	29	1.6
Ring-style guardrail on one side only	57	3.1
Other barrier (e.g., concrete barriers, bollards)	29	1.6
Multiple barriers used	1	0.1
Barrier type changes during study	9	0.5
Roadway Type		
Non-primary highway (county/local)	1,682	90.8
Non-primary highway (rural)	595	32.1
Non-primary highway (urban)	1,087	58.7
Primary highway (state)	171	9.2
Primary highway (rural)	65	3.5
Primary highway (urban)	106	5.7
Motor Vehicle Traffic Volume (AADT)		
0–299	403	21.7
300–749	372	20.1
750–1,499	368	19.9
1,500–2,999	323	17.4
3,000–7,499	264	14.2
7,500–14,999	92	5.0
15,000 +	31	1.7
Crossing Length (Radius)		
0–50 ft	1,256	67.8
51–75 ft	336	18.1
76–100 ft	178	9.6
101–150 ft	69	3.7
151–200 ft	13	0.7
201–250 ft	1	0.1

Crossing type describes the active warning devices used: flashing lights, gates, overhead cantilever structures with flashing lights, and combinations of these device types. Barrier type describes the barrier, if present, and indicates whether it is protecting both of the signal masts. There were several locations with protective barriers that were classified as “other,” and this category included concrete barriers, concrete bollards, plastic barriers, wooden barriers, and wooden posts. Roadway type is the coded value from the state system field within the Iowa DOT’s railroad databases, where primary highways represent US highways and numbered state highways and non-primary roads are under county or municipal jurisdiction. The rural and urban roadway designations indicate whether the crossing is within a city’s limits; this information was also extracted from the Iowa DOT’s railroad databases. Traffic volumes were averaged among the available data for the crossing over the study period (2007 through 2016). Within this study, traffic volumes (AADT) ranged from 10 to 30,767. As mentioned in Section 4.2.2, crossing length reflects the distance between the coded coordinates of the crossing and the furthest signal mast or the end of the protective barrier, if one is present, and is sorted into six categories.

4.3.2 Crash Data

Several fields within the crash-level dataset were valuable, including injury and crash severity, which were imperative in this study to evaluate crash risk and perform benefit-cost analyses. Crash severity is categorized on the KABCO scale, which classifies each crash based upon the most severe injury sustained by any of the occupants within any of the vehicles involved in the crash. There are five classifications: crashes that include a fatality (K), severe injury (incapacitating) (A), minor injury (non-incapacitating) (B), possible injury (C), and no injury or property damage only (PDO) (O). A fatality is defined as a death that resulted within 30 days of the crash (Iowa DOT 2015).

For analysis purposes, a five-point weighting scale was used to provide an assessment of the average degree of injury sustained during the crashes in the analysis dataset. A scale was used with 1 representing a fatal crash severity and 5 representing an uninjured or PDO crash severity. An initial investigation on injury severity was conducted on the 156 crashes of interest (Table 4). Three of the crashes involved vehicles striking multiple objects from different categories; two of these crashes involved a signal and guardrail, and one involved a signal and additional railroad infrastructure.

Table 4. Summary crash severity statistics

Crash Severity	Number of crashes: Hit railroad pole	Hit guardrail or barrier	Hit other railroad equipment	All railroad-related crashes	Train into railroad apparatus or barrier crashes
1 – K (fatal)	1	0	1*	1	0
2 – A (serious injury)	4	0	0	4	2
3 – B (minor injury)	10	2	1	13	2
4 – C (possible injury)	21	3	1	25	2
5 – O (Uninjured/PDO)	90	17*	8	113	2
Average (1-5)	4.55	4.68	4.36	4.57	3.50
Total	126	22	11	156	8

* Includes crashes that also struck railroad signal pole

A statistically significant difference in crash severity was not found between crashes where a vehicle struck a railroad signal mast (4.55) versus those where a vehicle struck a guardrail or other barrier (4.68). The only significant differences were observed when crashes involving a train pushing a vehicle into a railroad apparatus were compared to other crash types. Only 13 crashes occurred when a train was present or was soon to be present, with two crashes resulting in minor injuries. Due to the small sample of railroad-related crashes in which a vehicle hit a guardrail or other barrier, these crashes were also compared to all single-vehicle crashes during the same time period (2007–2016) in Iowa on non-Interstate roads in which the guardrail (face or end) was a part of the sequence of events. The comparison yielded similar findings. The crash severities of crashes with railroad signal masts also had a distribution similar to those of the guardrail crash types. A graph comparing the three crash types can be seen in Figure 23.

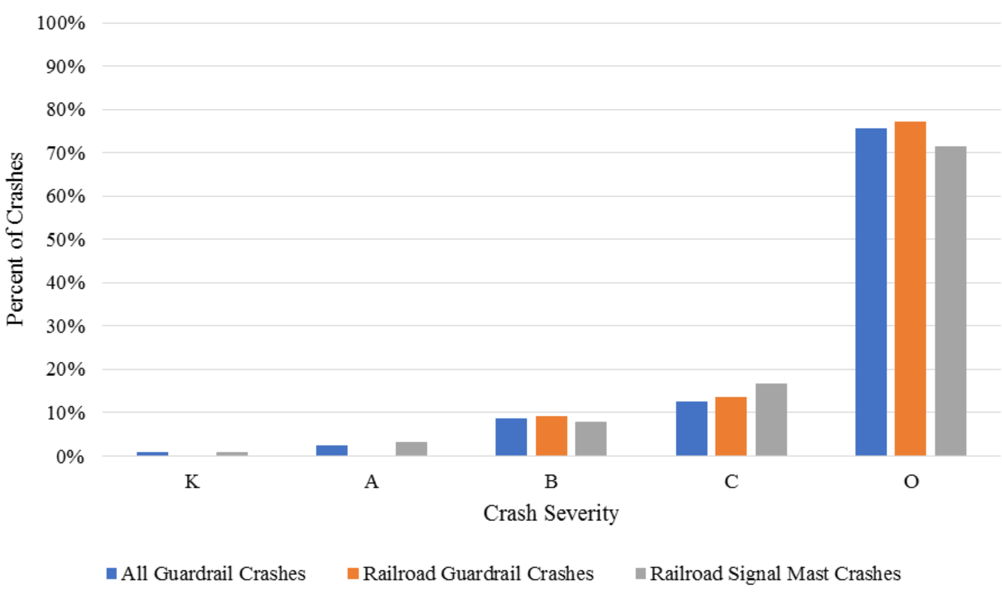


Figure 23. Comparison of crash severity distributions between three types of crashes

Additional investigation of different variables was conducted to discover possible relationships among them (Table 5).

Table 5. Average crash severity across various factors

Statistic	Railroad-Related Crashes	Percentage (%)	Average Crash Severity (1–5)
Crossing Type			
Flashing light mast only	46	29.5	4.52
Flashing light mast with gates only	76	48.7	4.66
Flashing light mast with cantilever beam only	17	10.9	4.41
Flashing light mast with gates & cantilever beam only	14	9.0	4.36
Gates present (w/ or w/out cantilever beam)	90	58.3	4.61
Cantilever beam present (w/ or w/out gates)	31	19.9	4.39
Barrier Type			
No barrier	109	69.9	4.50
Barrier (any) on both sides only	20	12.8	4.70
Barrier (any) on one side only	14	9.0	4.85
Longitudinal guardrail on both sides only	20	12.8	4.70
Longitudinal guardrail on one side only	3	1.9	5.00
Ring-style guardrail on both sides only	0	0.0	N/A
Ring-style guardrail on one side only	10	6.4	4.80
Other barrier (e.g., concrete barriers, bollards)	1	0.6	5.00
Roadway Type			
Non-primary highway (county/local)	136	87.2	4.54
Non-primary highway (rural)	48	30.8	4.46
Non-primary highway (urban)	88	56.4	4.59
Primary highway (state)	20	12.8	4.75
Primary highway (rural)	11	7.1	4.73
Primary highway (urban)	9	5.8	4.78
All rural roads	59	37.8	4.51
All urban roads	97	62.2	4.61
Speed Limit (mph)			
30 or under	63	40.4	4.70
35–45	50	32.1	4.50
50 or greater	43	27.6	4.47
Driver Gender			
Male	108	69.2	4.56
Female	36	23.1	4.58
Unknown	12	7.7	4.67
Driver Age			
12–20	25	16.0	4.52
21–35	53	34.0	4.59
36–59	46	29.5	4.63
60 or older	20	12.8	4.65
Unknown	12	7.7	4.67

Statistic	Railroad-Related Crashes	Percentage (%)	Average Crash Severity (1–5)
Airbag Deployment			
All or some airbags deployed	35	22.4	4.06
No airbags deployed	104	66.7	4.76
Unknown	17	10.9	4.47
Alcohol Involved			
Yes (known)	25	16.0	4.12
No or unknown	131	84.0	4.66
Distracted Driving Involved			
Yes (known)	8	5.1	4.38
No or unknown	148	94.9	4.58
Vehicle Type			
Passenger vehicle (car, pick-up truck, minivan)	111	71.2	4.45
Farm vehicle	4	2.6	5.00
Motorcycle	1	0.6	2.00
Small truck (single unit)	7	4.5	4.86
Large truck (tractor-trailer)	30	19.2	4.97
Unknown	3	1.9	4.67
Weather Conditions			
Clear or cloudy	99	63.5	4.59
Precipitation (falling or on roadway)	48	30.8	4.56
Sight restricted (fog, blowing sand)	9	5.8	4.44
Time of Day			
Day (light)	90	57.7	4.64
Night (dark)	63	40.4	4.44
Unknown	3	1.9	5.00
Total	156	100.0	4.57

While the crossings with flashing lights and gates had more crashes, less severe injuries resulted from these crashes. Conversely, crossings with cantilevers had fewer crashes, but these crashes involved more severe injuries. Crossings that provided protection via a barrier in front of the signal mast saw a crash severity reduction. Crashes on rural roadways and non-primary highways were found to have higher severities. This is likely due to the increased speeds associated with rural roadways; as speed increased, crash severity also increased.

Driver demographics were also studied. Male drivers were overrepresented in the sample; however, there was little difference in the severity of crashes involving male drivers compared to crashes involving female drivers. As the driver's age increased, the crash severity was found to decrease. This is different from what would normally be expected. Past research has indicated that older drivers (> 55 years old) have higher odds of injury (Gabauer and Gabler 2010, Zou et al. 2014). Crashes in which any of the airbags deployed tended to result in more severe injuries. This finding is likely a result, in part, of the higher impact forces involved in such crashes rather than a reflection of the efficacy of airbags. Twenty-five alcohol-involved crashes were found (zero crashes involved other drugs), and a higher crash severity was associated with these crashes. Only eight known distracted driving crashes were found. It is suspected that this number is severely underestimated. Nevertheless, these crashes had higher severities.

Vehicle type was recoded to five major classifications to narrow down the numerous categories. Commercial trucks (single-unit and tractor-trailers) were found to have less severe crashes than passenger vehicles (car, pick-up truck, minivan). There was one motorcycle crash as a part of this study, which resulted in a severe injury, underlining the previously noted concern regarding these motorists. The conditions of the roadway did not strongly affect crash severity. Lastly, it was found that crashes occurring at night (dusk to dawn) showed a higher crash severity than those that occurred during daylight hours.

Seatbelt use was also examined. This was done at the person level rather than at the crash level. A seatbelt usage rate of 91.6% was found for all persons involved in railroad-related crashes. In 2017, it was reported that Iowa had a seatbelt usage rate of 91.4% (National Center for Statistics and Analysis 2018). Of the 186 total occupants involved in this study, the injury severity for those not restrained was 3.00, with one fatality and three severe injuries. In comparison, those who were restrained had an injury severity of 4.60, with one severe injury. For the occupants whose restraint use was unknown, the injury severity was 4.77, with one severe injury.

5. METHODOLOGY

5.1 Crash Rate Analysis

A simple comparison of the number of crashes occurring at various types of at-grade crossings provides limited insight about the safety performance of these configurations. A more meaningful comparison considers the rates of crashes, normalized by exposure levels (i.e., traffic volumes). A crash rate analysis was therefore performed on the crashes that involved railroad infrastructure. The rate was calculated using equation (1), which treated the roadway as an intersection since the segments of roadway involved in the analysis are very short (less than 0.1 miles). The exposure is expressed through the number of motor vehicles crossing the facility, and due to the magnitude of this number, the value is presented in units that can be more easily understood (i.e., crashes per 100 million entering vehicles).

$$R_i = \frac{100{,}000{,}000 \times C_i}{365 \times N_i \times V_i} \tag{1}$$

In this equation, R_i expresses the crash rate in terms of the number of crashes per hundred million crossing vehicles (HMCV) at crossing *i*. In addition, C_i is the total number of crashes, N_i is the number of years, and V_i is the daily motor vehicle traffic volumes (both directions) during the study period when crossing *i* had active warning devices. To find the average crash rates by different aggregations, equation (2) was used.

$$R_{avg} = \frac{100{,}000{,}000 \times \sum_{\forall i} C_i}{\sum_{\forall i}(365 \times N_i \times V_i)} \tag{2}$$

This calculation accounts for the crossings that are not present for all 10 years within the study.

5.2 Statistical Modeling

Misleading results could occur if correlated independent variables are not accounted for with count analysis data such as crash rates. A statistical modeling approach allows for simultaneous interactions between factors and describes the significance of the influence of each independent variable on the dependent variable.

5.2.1 Crash Rate Model

A negative binomial model was chosen to estimate the combined effects due to the discrete, non-negative integer crash data. Other count models exist, such as a Poisson regression, but because crash data tend to exhibit a variance that is significantly greater than the mean, a negative binomial model is often used because it overcomes the dispersion. As a result, the expected number of crashes (λ) at crossing *i* was calculated using equation (3).

$$\lambda_i = e^{(\beta X_i + \varepsilon_i)} \tag{3}$$

In this equation, X_i is a vector of predictor variables (e.g., AADT, presence of gates, presence of cantilever beam, urban/rural locale) expected to influence the number of crashes occurring at location i, β is a vector of parameter estimates associated with these variables, and ε_i is the gamma-distributed error term (also called the overdispersion parameter) with a mean of one and a variance of α. The model is estimated using the standard maximum likelihood method.

5.2.2 Crash Severity Model

Injury and crash severity values are based on the police-reported KABCO rating scale, which is ordinal in nature. A common method for analyzing this type of dataset due to its simplicity and ease of interpretation is the ordered logit model (Savolainen et al. 2011). Savolainen et al. (2011) noted that sample size is an important factor affecting the performance of the model, and simpler models may be preferred for smaller samples. There are differing viewpoints on the size of a "small" sample for injury severity data; 200, with an absolute minimum of 100 (Lord 2006), and 1,000 (Ye and Lord 2014) have been recommended by different studies, with both studies stating that crash severity models should not be estimated with smaller sample sizes.

5.3 Roadside Safety Analysis Program

Given the limited number of crashes that involved a vehicle striking a railroad warning signal device, guardrail, or other protective barrier or other railroad-related infrastructure at the crossing, simulation software was utilized to further estimate the impacts of various factors on the likelihood of a crash occurring. For this study, the Roadside Safety Analysis Program (RSAP) Version 3 (RSAP 3.0.1 release 150507) was chosen to evaluate the crossings. At the time of this study, this was the latest version of this software, which was developed under NCHRP Project 22-27, completed in 2012. RSAP was also utilized to analyze benefit-cost ratios (BCRs) for different alternatives.

5.3.1 Scenarios

A two-lane rural highway was selected for comparison of different scenarios. The design was based on the most generic situation in which a decision to implement a guardrail would be made. The roadway and project information are shown in Table 6. Many of the default values within the software were selected. When a default value was chosen over a known value, the value is noted with an asterisk.

Table 6. Project characteristics used in the RSAP analysis

Characteristic	Value or Description
Project Information	
Design life	15 years
Construction year	2019
Rate of return (discount rate)	4 %
Gross domestic product (GDP) deflator	1.07 (*)
Value of statistical life (VSL)	$4.5 million, $9.6 million
Encroachment adjustment	1 (*)
Decision point benefit-cost ratio	2.00
Roadway Information	
Roadway type	Rural primary highway
Terrain	Flat
Divided or Undivided	Undivided
Number of lanes (total in both directions)	2
Posted speed limit	55 mph
Construction AADT	1,000, 2,500, 5,000
Annual traffic growth rate	1 %
Percent of traffic in primary direction	50 % (*)
Percent trucks	10 % (*)
Lane width	12 ft (*)
Shoulder width	3 ft
Segment length	500 ft
Lateral distance between signals	75 ft

* Default RSAP values

The rate of return (or discount rate) remained at the default (4%), because this was consistent with Iowa DOT policy (Iowa DOT 2018c). The design life of the guardrail was changed from 25 to 15 years because this is the value the Iowa DOT uses (Iowa DOT 2018c). Although the service life for railroad signals and warning devices is currently 10 years, 15 years was used instead because this is the lifecycle of the treatment being tested. The value of statistical life (VSL) is defined in the RSAP User's Manual as "the average comprehensive crash cost of a fatal crash" (RoadSafe LLC 2012a). In this research, a VSL of $4.5 million was assumed based upon the current practices of the Iowa DOT (Harmon et al. 2018, Iowa DOT 2018c). The same model was generated using different VSL values to see the changes in BCR. A VSL of $9.6 million using a base year of 2015, suggested by the US Department of Transportation, was also utilized in this research (US DOT 2016).

The average traffic volume on rural primary highways from the railroad inventory was approximately 2,500 vehicles per day. To study the impact of traffic volume on crash likelihood, AADTs of 1,000 and 5,000 were also studied. AADT values larger than 5,000 were not analyzed due to the unnatural encroachment frequency curve (see Figure 24).

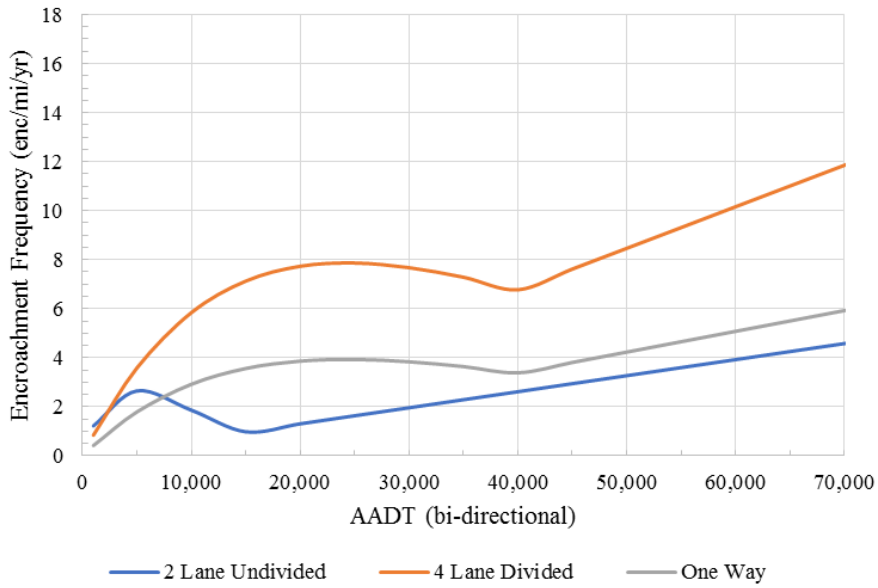


Figure 24. Encroachment module used in RSAP v3

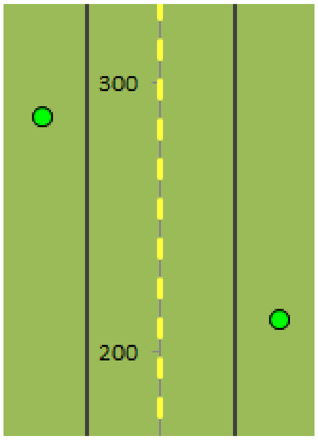
An annual traffic growth rate of 1% was used because this is the default value in the Benefit/Cost Worksheet for the Iowa DOT (Iowa DOT 2018c); the mid-life AADT was used in this analysis. Primary directional traffic remained at 50% because the analysis is a general case. The percent of traffic encroaching right was maintained at 50% because this value is difficult to calculate with certainty and is also site-specific. Default values for the vehicle fleet were also used, which included 70% passenger cars, 20% pick-up trucks, 4% average single-unit trucks, and 6% average tractor-trailers.

5.3.2 Alternatives

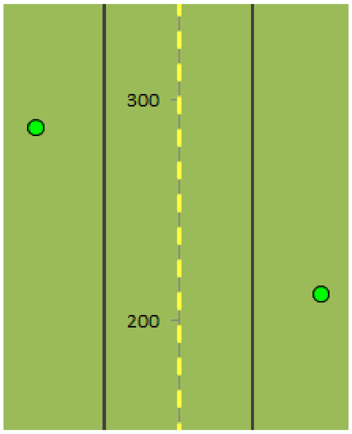
Five alternatives were created and tested to evaluate the effects of their designs on crash likelihood. Table 7 details the conditions of each alternative, and Figure 25 shows them as they appear within the software.

Table 7. RSAP alternatives

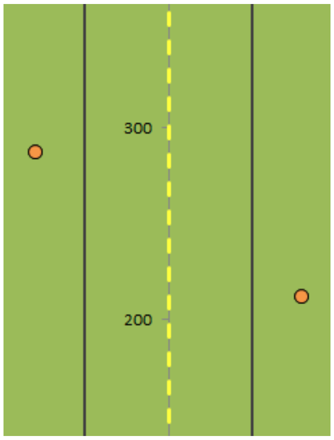
Condition	Alt. 1 (a)	Alt. 2 (b)	Alt. 3 (c)	Alt. 4 (d)	Alt. 5 (e)
Railroad signal mast?	Yes	Yes	Yes	Yes	Yes
Is it breakaway?	No	No	Yes	No	No
Offset from edge of traveled way	6 ft	10 ft	6 ft	6 ft	10 ft
Longitudinal guardrail?	No	No	No	Yes	Yes
Offset from edge of traveled way	N/A	N/A	N/A	5 ft	5 ft



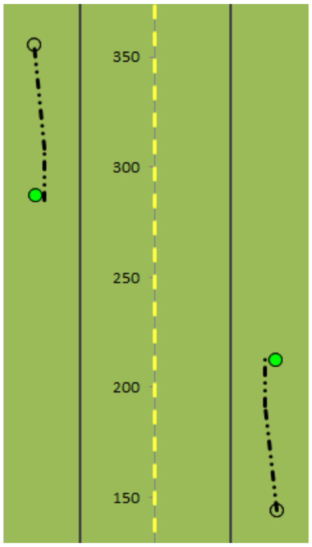
(a) Alternative 1



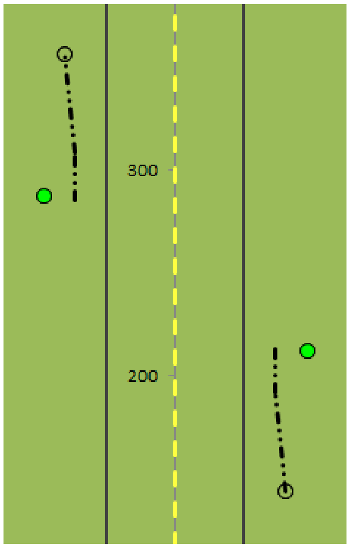
(b) Alternative 2



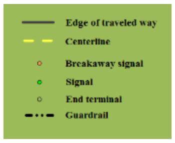
(c) Alternative 3



(d) Alternative 4



(e) Alternative 5



Legend

Figure 25. Diagram of the five alternatives used in the RSAP analysis

Two different signaling systems were tested: a railroad flashing light mast (with or without gates) and a breakaway railroad flashing light mast. Since neither of these specific devices are readily available within the software, a general fixed object and breakaway sign, respectively, were substituted. The radius used for the signal mast represented the distance from the center of the pole to the outer edge of the flashing light assembly. This value was found to vary from 25 inches (WSDOT 2018a) to 27 inches (Michigan DOT 2009), so a midpoint between these (26 inches) was used. Two different horizontal offsets for the signals were analyzed, 6 and 10 feet. Six feet matches the minimum requirement in Chapter 8C of the MUTCD (FHWA 2012). While the maximum distance the signal can be offset is not explicitly mentioned in the MUTCD, the Michigan DOT uses a value of 10 feet in its R-122-C design as a maximum (Michigan DOT 2009). Using the 10-foot value allows the signal mast to meet the 5-foot clearance guideline from the face of the guardrail (Iowa DOT 2017).

Two of the alternatives included longitudinal guardrail systems, which followed the Iowa DOT's Standard Road Plan BA-253 design. There is only one semi-rigid guardrail design within RSAP (W-beam), which was selected for this analysis. If a guardrail was included, an offset of 5 feet from the traveled way was used to meet the preferred minimum (Iowa DOT 2017). RSAP only includes one generic end terminal, and this was used.

5.3.3 Costs

The benefit-cost analysis is strongly influenced by the costs associated with each type of crash. The data in Table 8 were requested from the Iowa DOT and reflect various sources used to calculate the proper installation, maintenance, and repair costs.

Table 8. Costs used in RSAP analysis

Item	Average Installation Cost	Average Annual Maintenance	Average Typical Repair Cost per Crash
Railroad Signal Mast			
Fixed Signal Mast	$350,000	$10,000	$50,000
Breakaway Signal Mast	$350,000	$10,000	$50,000
Guardrail	$6,600	$1,000	$1,710

The costs are broken down into guardrails, railroad signal masts, and breakaway railroad signals. For each case, the values of the features included in the alternative were combined. These values were then used to overwrite the preset values included in the RSAP software. The maintenance and repair costs for the breakaway railroad signal are based on breakaway traffic signals, and the installation cost is assumed to be comparative to that of the railroad signal.

One important item to note here is that changing the offset value from 6 feet to 10 feet would increase the length of the gates required for the signal masts. According to the list of bidders for the traffic signal standard obtained from Washington State Department of Enterprise Services (WSDOES), the cost of the mast arm (cantilever) for both offsets is the same (WSDOES 2010). Cost data provided by a supplier of barrier gates indicated that the costs of the gates remain similar up to 23 feet in length (Nice Apollo Gate Operator 2019). Consequently, this study assumes that the cost of the gate would remain the same if the offset is increased from 6 feet to 10 feet. However, this parameter could have substantial impacts on design, and additional consideration is warranted if larger offset distances are considered.

6. ANALYSIS RESULTS

This chapter summarizes the results of the analyses of crash frequency/rate and severity data, as well as the simulation studies conducted using RSAP.

6.1 Crash Frequency/Rate Analyses

Crash rate analyses have been performed at railroad-highway at-grade crossings in several previous studies (Meeker et al. 1997, Lenné, et al. 2011, Raub 2006), but these studies focused only on the crash rate between trains and motor vehicles. No research was found on the prevalence of crashes occurring near railroad crossings, nor with the signal mast or any safety barriers potentially shielding the mast. While active crossings (controlled by warning devices such as flashing lights and gates) have shown lower crash rates with trains compared to passive crossings (controlled by devices such as cross bucks, yield signs, and stop signs), the degree to which crashes with the actual infrastructure may be a concern is unclear.

Table 9 provides a summary of the frequency and rate of railroad-related crashes occurring at highway-rail grade crossings under various scenarios. Only crossings that were active for the 10-year study period are included in this summary table.

Table 9. Crash rate comparison between signal systems with and without guardrails

	Without any barriers		With longitudinal guardrail	
Signal system	**Number of crossings**	**Railroad-related crashes per HMCV**	**Number of crossings**	**Railroad-related crashes per HMCV**
Flashing lights only	594	1.30	54	2.20
Flashing lights and gates only	752	1.31	36	2.86
Flashing lights and cantilever beam only	143	0.32	21	1.30
Flashing lights with gates and cantilever beam	90	0.61	12	1.32

For a crash to be classified as railroad-related, the vehicle would have had to leave the roadway and collide with the railroad signal mast arm or guardrail assembly. Overall, the rate of railroad-related crashes was 1.08 per HMCV. For comparison purposes, the average rate of total crashes (regardless of whether the rail infrastructure was involved) was found to be 12.93 crashes per HMCV at these same locations.

Crossings with flashing lights and gates only were found to have the highest number of crashes, number of railroad-related crashes, and railroad-related crash rate among the four different types of crossings. Some 65% of the railroad-related crashes at flashing-lights-and-gates-only crossings occurred where there was no guardrail or barrier provided. However, the corresponding crash rate was lower, only 1.31, than the crash rate when a guardrail or barrier was present, meaning that guardrails or barriers were associated with higher rates of railroad-related crashes. This suggests that there is likely an increase in crashes due to incidental strikes with the roadside barrier that may not occur otherwise in its absence.

Cantilever beams are generally installed at locations with visibility issues, nearby traffic signals, high speeds (either on the roadway or railway), or greater exposure to crashes (i.e., high traffic volumes). In these cases, a higher crash rate might be expected; however, crossings with flashing lights and cantilever beams only had the lowest railroad-related crash rate at 0.46 per HMCV. This could suggest that the cantilever beam is performing well at making drivers aware of the crossing or that since the structure is more rigid, some unreported crashes could be occurring that are not included in this analysis. Additionally, cantilevers are often used on multi-lane roadways, where vehicles in certain lanes must be severely out of position to hit the structure.

Table 10 summarizes the number and rate of railroad-related crashes for various roadway types.

Table 10. Crash rates for various crossing, barrier, and roadway types

Group	Number of crossings	Number of crashes	Railroad-related crashes	Railroad-related crashes per HMCV
Roadway Type				
Non-primary highway	1,682	1,460	136	1.19
Non-primary highway (rural)	595	257	48	3.49
Non-primary highway (urban)	1,087	1,203	88	0.88
Primary highway	171	414	20	0.65
Primary highway (rural)	65	83	11	1.72
Primary highway (urban)	106	331	9	0.37
All rural roads	660	340	59	2.93
All urban roads	1,193	1,534	97	0.78
Total	1,853	1,874	156	1.08

Primary highways had less than 13% of the total railroad-related crashes and a crash rate nearly half that of the secondary roadways. Meanwhile, urban roads had over 60% of the total railroad-related crashes, but rural roads had a crash rate three times as high. On urban roads, drivers generally use slower speeds and are more likely to anticipate stopping, even unexpectedly, whereas drivers on rural roads may not immediately perceive the need to stop at the crossing until it is too late to stop normally and therefore have to make an evasive maneuver. Other circumstances, such as weather conditions in rural areas, may also have an effect on the ability of vehicles to maintain control, with or without a train present.

A negative binomial regression model was estimated to provide a comparison of the frequency of railroad-related crashes under various conditions (Table 11).

Table 11. Results of negative binomial model for railroad-related crashes

Term	Estimate	Std. Error	Chi Square	p-value
Intercept	-12.300	1.476	69.451	<0.0001
Ln (Total Traffic Volume)	0.656	0.098	44.508	<0.0001
Gates not installed (base)	-	-	-	-
Gates installed	0.337	0.179	3.530	0.0603
Cantilever beam not installed (base)	-	-	-	-
Cantilever beam installed	-0.602	0.207	8.481	0.0036
Inside city limits – Rural (base)	-	-	-	-
Outside city limits – Urban	-0.848	0.251	11.440	0.0007
Dispersion	3.675	1.093	11.302	0.0008

This analysis included several crossings that were closed at some point during the 10-year study period, and only the period during which the crossing was active was considered. As such, total traffic volume during the study period was used as an exposure measure.

As expected, as traffic volumes increased, the likelihood of a crash also increased. Crashes tended to be less frequent if cantilevers were installed at a crossing. In contrast, if gates were present, more crashes with signal supports occurred, although this result was not statistically significant at a 95% confidence interval. Roadway classification (primary versus non-primary) was not significant, but roadway location (rural versus urban) did have an effect on crash likelihood. Roads within city limits were found to have a lower likelihood of crashes with railroad signals.

This analysis included the presence of a longitudinal guardrail as a predictor variable. However, the results did not show that the presence of a longitudinal guardrail made a substantial difference in crash likelihood, which is partially attributable to the limited number of locations where a guardrail was installed, as shown in Table 9. A graph visualizing the eight possible combinations of crossing can be seen in Figure 26.

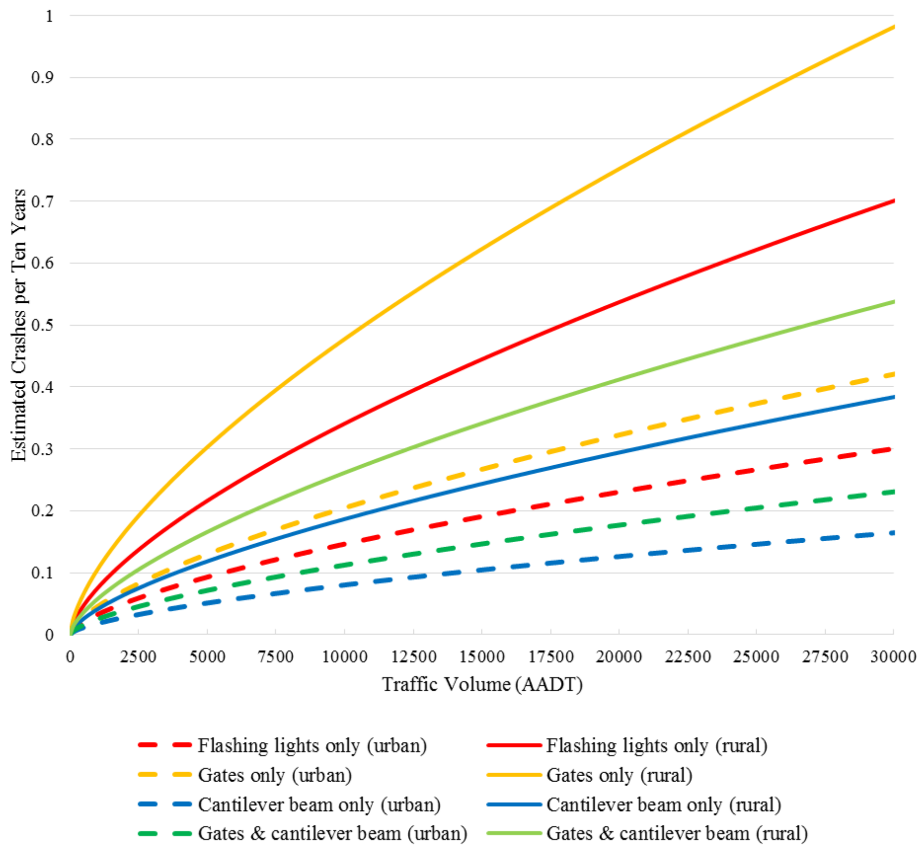


Figure 26. Estimated railroad signal mast strikes per 10 years given traffic volume

6.2 Crash Severity Analysis

In addition to examining crash frequency, an ordered logit regression model was estimated to identify variables that were associated with differences in the degree of injury severity sustained by occupants involved in railroad-related crashes. Many variables were tested, including roadway characteristics such as speed limit and traffic volume; driver characteristics such as age, gender, seating position, number of occupants, alcohol use, and presence of a distraction; type of crash; and weather conditions. However, none of these variables were found to be statistically significant.

Table 12 shows the results of this analysis, which includes three variables of interest: seatbelt use, airbag deployment, and vehicle type.

Table 12. Results of ordered logit model for railroad-related crashes

Term	Est.	Std. Error	Chi Square	p-value
A – Intercept	-3.510	0.851	17.01	<0.0001
B – Intercept	-1.075	0.564	3.64	0.0565
C – Intercept	0.235	0.560	0.18	0.6750
O – Intercept	6.953	1.208	33.14	<0.0001
Seatbelt Not Used	1.761	0.463	14.48	0.0001
Seatbelt Used (base)	-	-	-	-
Airbag Not Deployed	-0.928	0.251	13.64	0.0002
Airbag Deployed (base)	-	-	-	-
Passenger vehicle (car, pick-up, minivan)	1.079	0.499	4.67	0.0307
Commercial truck (single-unit, tractor-trailer) (base)	-	-	-	-

Due to the limited data about seatbelt use at the person level, more than half of the data was excluded (102 of 186 total occupants involved), severely restraining the application of these results. This purge also excluded the sole fatality from the dataset. The findings, though, do show that the results are consistent with other research, such as the finding that passengers wearing a seatbelt and those whose airbag did not deploy experience lower injury severity (Schneider et al. 2009). Occupants of heavier vehicles (i.e., commercial trucks) also tended to be less severely injured.

6.3 RSAP Scenario Evaluation

Collectively, the results of the in-service evaluation provide several insights into crashes involving railroad signal infrastructure throughout Iowa. However, given the limited sample sizes across various crossing configurations, it is not feasible to distinguish the potential safety impacts of guardrail installation. Other research suggests that to completely remove the potential sources of bias from an in-service performance evaluation, both reported and unreported crashes would need to be analyzed (Mak and Sicking 2002). Unreported crashes need to be considered because they represent the “successes” of the roadside safety treatment, in that these crashes likely result in neither injury nor serious property damage. Studies have attempted to estimate the number of unreported crashes based on maintenance records (Carlson et al. 1978), video camera surveillance (Fitzpatrick et al. 1999), and periodical inspections (Ray and Weir 2001, Galati 1967). This research has found that crashes involving guardrails are underestimated, often significantly, at many locations. The rate of unreported guardrail strikes ranges from 59% (Ray and Weir 2001) to 90% (Galati 1967, Carlson et al. 1978, Ray and Hopp 2000). Research on guardrail-involved crashes suggests a rate of serious or fatal injuries of 6% (Michie and Bronstad 1994).

Upon investigation, unreported crashes were found to be present in this study and were identified at the quality control stage. Damage was found at several crossings either on the signal support or on the protection device. No railroad-related crash was recorded at eight of these crossings during the study, meaning that the crash was either unreported or a narrative of the circumstances was not provided. An example of a crossing that had visible damage but no corresponding crashes can be seen in Figure 27.

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Figure 27. Example of guardrail damage at a crossing that had no railroad-related crashes during the study period

However, it was not possible to estimate the rate of underreporting across locations given available resources. As such, RSAP was used to estimate total crashes and the costs associated with each design scenario of interest.

After running the RSAP models using the conditions detailed in Table 7 and Figure 25, several summary reports were derived. In the Segment and Alternative Cost Summary, information on the annual expected number of crashes, annual repair costs, and annual crash costs were included. From the estimated crashes, the crash rate in terms of crashes per HMCV was calculated using equation (1). Under two different VSL values, only the annual crash costs were affected. Table 13 details the results of the models.

Table 13. Estimated crashes from RSAP

Alt.	AADT	Crashes Per Year	Crash Rate (per HMCV)	Annual Repair Costs	VSL	Annual Crash Costs
1	1,000→1,077	0.00869	2.2094	$501	$4.5 M	$1,136
					$9.6 M	$2,424
	2,500→2,694	0.01546	1.5722	$892	$4.5 M	$2,022
					$9.6 M	$4,315
	5,000→5,387	0.01772	0.9011	$1,022	$4.5 M	$2,318
					$9.6 M	$4,945
2	1,000→1,077	0.00779	1.9812	$449	$4.5 M	$903
					$9.6 M	$1,927
	2,500→2,694	0.01386	1.4098	$800	$4.5 M	$1,607
					$9.6 M	$3,429
	5,000→5,387	0.01589	0.8081	$917	$4.5 M	$1,842
					$9.6 M	$3,930
3	1,000→1,077	0.00869	2.2094	$241	$4.5 M	$114
					$9.6 M	$242
	2,500→2,694	0.01546	1.5722	$428	$4.5 M	$202
					$9.6 M	$431
	5,000→5,387	0.01772	0.9012	$491	$4.5 M	$232
					$9.6 M	$495
4	1,000→1,077	0.03328	8.3374	$553	$4.5 M	$1,584
					$9.6 M	$3,378
	2,500→2,694	0.05834	5.9329	$985	$4.5 M	$2,819
					$9.6 M	$6,014
	5,000→5,387	0.06687	3.4007	$1,129	$4.5 M	$3,231
					$9.6 M	$6,893
5	1,000→1,077	0.03320	8.4452	$484	$4.5 M	$1,320
					$9.6 M	$2,817
	2,500→2,694	0.05909	6.0097	$862	$4.5 M	$2,350
					$9.6 M	$5,014
	5,000→5,387	0.06773	3.4446	$988	$4.5 M	$2,694
					$9.6 M	$5,747

The AADT values shown in the table correspond to the construction and mid-life values. As noted previously, these alternatives are defined as follows:

- Alternative 1 – Mast located 6 feet from edge of traveled way
- Alternative 2 – Mast located 10 feet from edge of traveled way
- Alternative 3 – Breakaway mast located 6 feet from edge of traveled way
- Alternative 4 – Mast located 6 feet from edge of traveled way with guardrail provided
- Alternative 5 – Mast located 10 feet from edge of traveled way with guardrail provided

In each alternative, the number of crashes increased with increased traffic volumes, but the rate of increase decreased as AADT increased. Thus, the crash rates decreased with higher traffic volumes. This can be visualized in Figure 28, where the crash frequencies are represented by solid lines and the crash rates are represented by dashed lines.

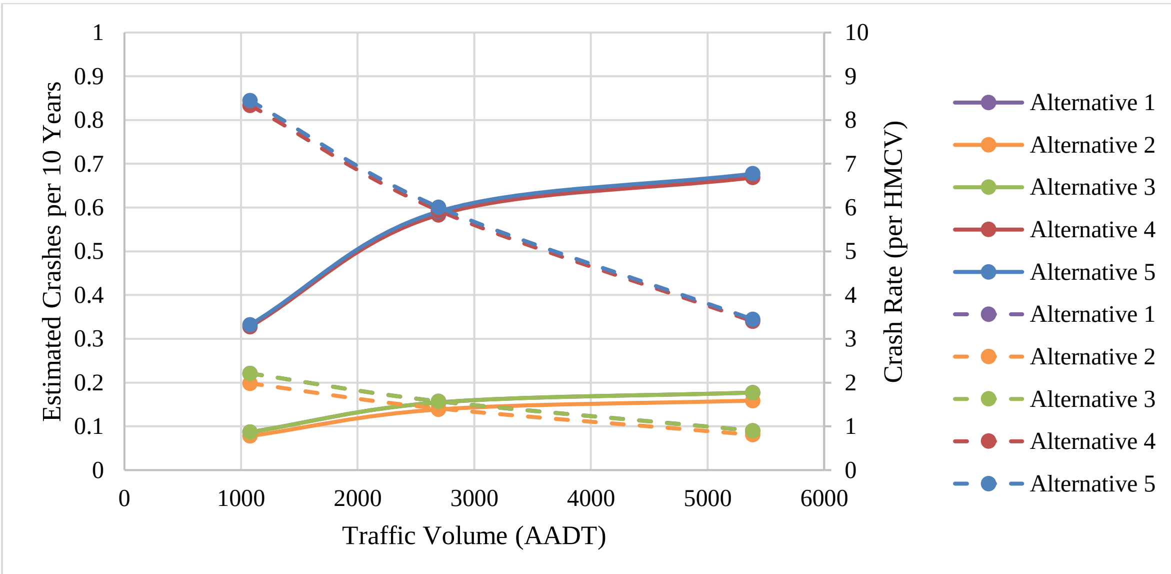

Figure 28. Estimated railroad-related crashes per 10 years and crash rates using RSAP

Alternatives 1 (mast with 6-foot offset) and 3 (breakaway mast with 6-foot offset) have the same estimated number of crashes and crash rate and, as such, are shown to overlap in this figure.

When looking at the annual repair costs, all of the alternatives appear to be relatively similar except Alternative 3 (see Figure 29).

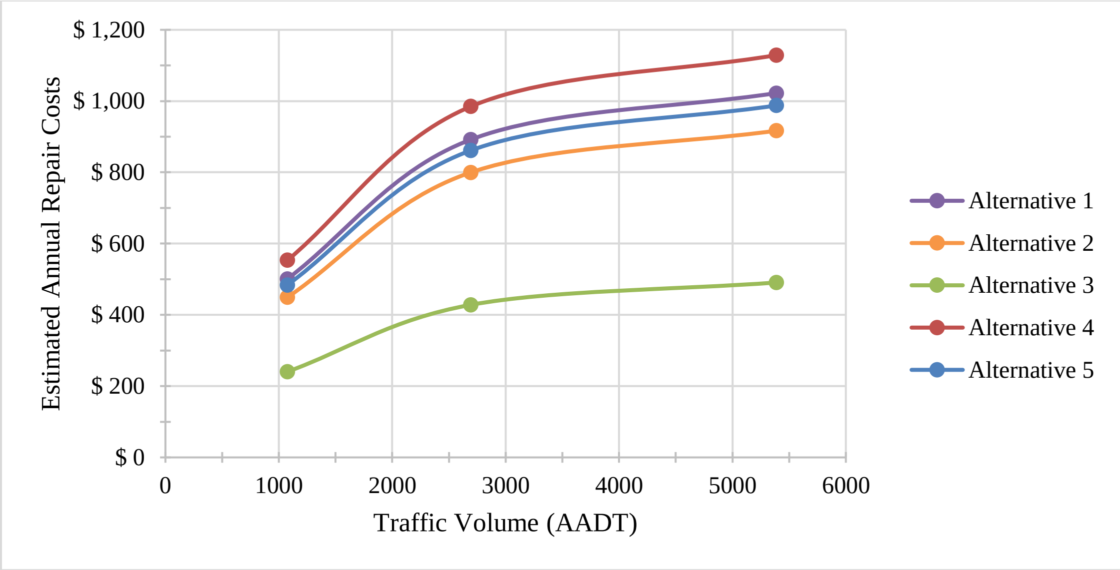

Figure 29. Estimated annual repair costs by traffic volumes using RSAP

Because existing railroad signal arms are generally not designed to be breakaway, the closest alternative in RSAP (breakaway traffic signal) was used for Alternative 3. As such, the predicted repair costs for this alternative may be underestimated.

The assumed VSL is critical to the benefit-cost analysis. The calculated annual crash costs under the two different VSL values are plotted in Figure 30 and Figure 31 for assumed values of $4.5 million and $9.6 million, respectively.

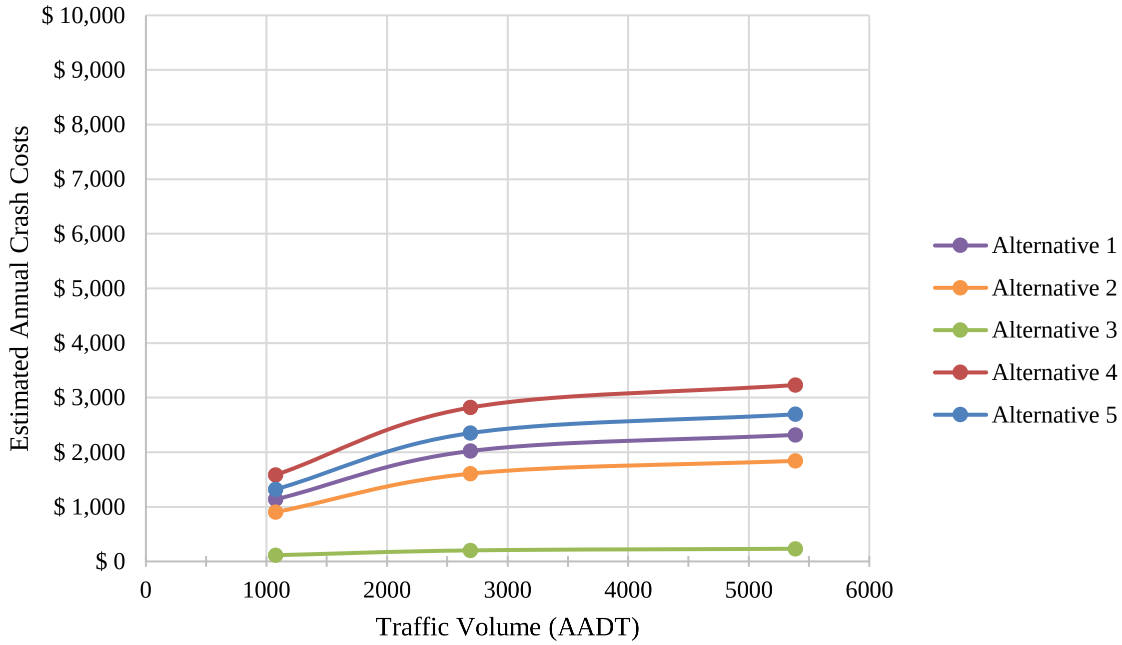

Figure 30. Estimated annual crash costs using a VSL of $4.5 million

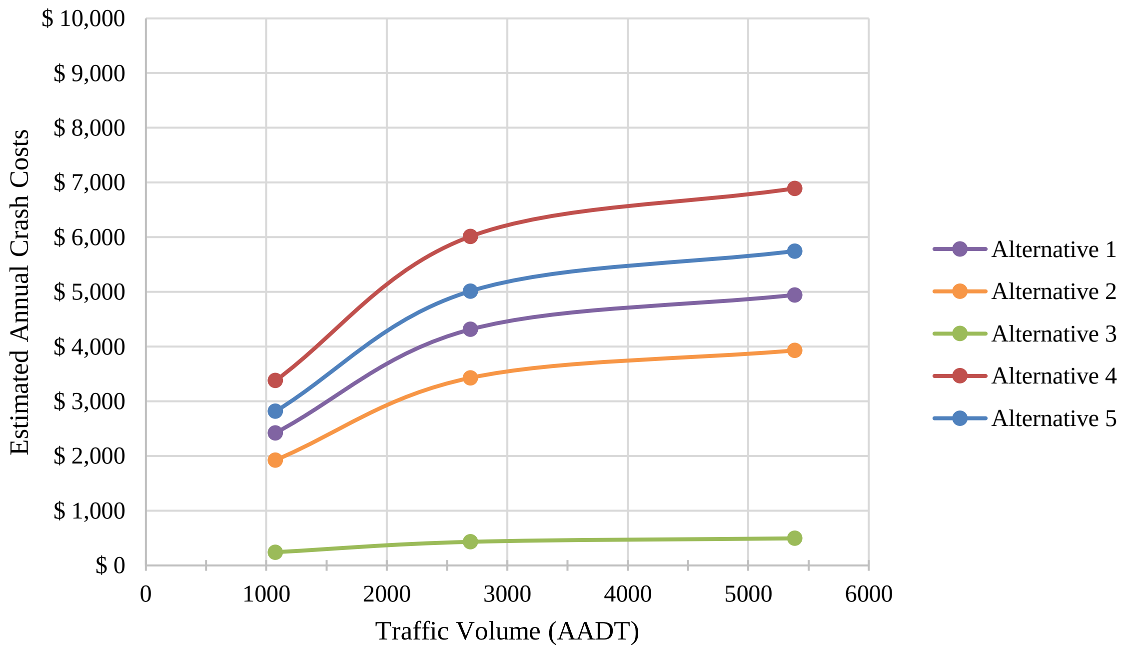

Figure 31. Estimated annual crash costs using a VSL of $9.6 million

Although the two alternatives that provided guardrail protection to the signal mast had higher repair and crash costs, when the average cost per crash was considered these alternatives had much lower costs than the two alternatives without guardrails (see Figure 32).

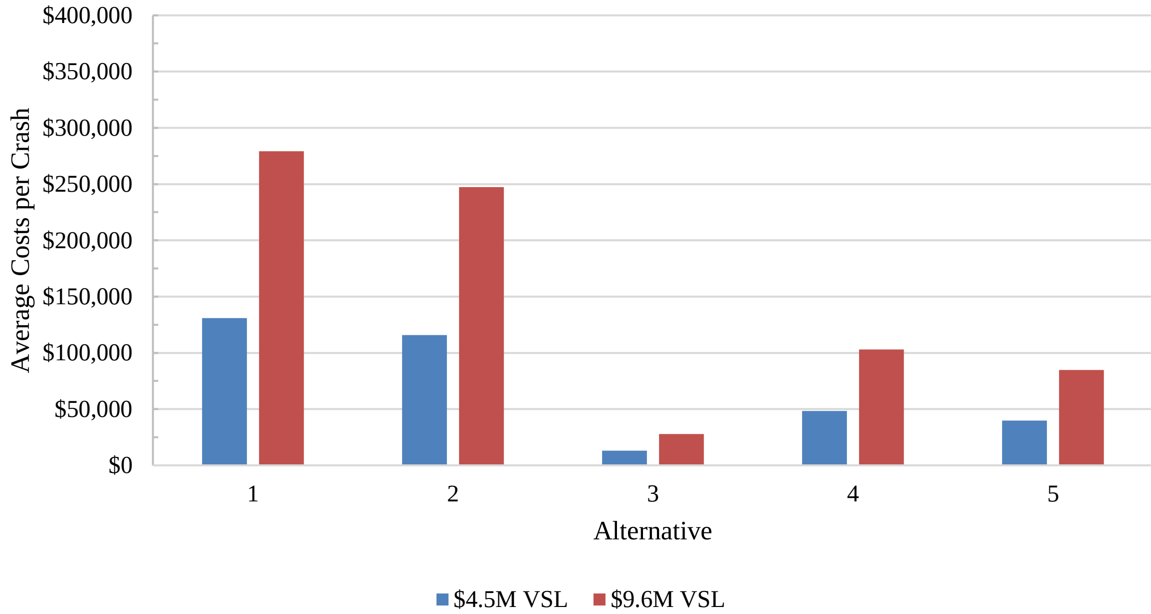

Figure 32. Average costs per crash at each alternative with different VSLs

With proper cost, crash, and injury information, in-service evaluations can result in reliable benefit-cost analyses (Alluri et al. 2012). The output BCR that RSAP generates is calculated by dividing the reduction in crash costs by the cost of the improvement (equation [4]).

$$BCR_{ji} = \frac{CC_i - CC_j}{(I_j + M_j + RE_j) - (I_i + M_i + RE_i)} \tag{4}$$

The reduction in crash costs (CC) takes into consideration the number of crashes that occur and the severity of each, while the cost of the improvement considers the associated installation (I), maintenance (M), and repair (RE) costs. The indices (*i* and *j*) represent the different alternatives; for example, BCR_{21} is the benefit-cost ratio of Alternative 2 compared to Alternative 1.

RSAP is designed to provide a BCR to compare the relative safety performance of various devices at a given location. In contrast, this study evaluates the impacts of guardrails (versus no guardrails) at an offset distance of 6 feet, as well as the differences in safety performance (both with and without guardrails) at an offset distance of 10 feet. For example, Alternatives 1 and 2 have the same installation and maintenance costs because they only differ in their offsets from the roadway. Because of this, Alternative 2 has reduced crashes, crash costs, and repair costs. This would result in a negative BCR using equation (4), when the alternative should be preferred.

To address this issue, equation (5) was used, which takes the absolute value of the denominator, providing the appropriate result of interest in comparing alternatives.

$$BCR_{ji} = \frac{CC_i - CC_j}{|(I_j + M_j + RE_j) - (I_i + M_i + RE_i)|} \quad (5)$$

The results can be seen in Table 14 and Table 15 for VSL values of $4.5 million and $9.6 million, respectively.

Table 14. Benefit-cost ratios with VSL of $4.5 million

	Alt. 1	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**
1,000 AADT					
Alt. 1	0.00	4.50	0.22	-0.18	-0.08
Alt. 2		0.00	0.16	-0.27	-0.17
Alt. 3			0.00	-0.65	-0.52
Alt. 4				0.00	3.80
Alt. 5					0.00
2,500 AADT					
Alt. 1	0.00	4.50	0.40	-0.31	-0.14
Alt. 2		0.00	0.30	-0.46	-0.30
Alt. 3			0.00	-1.31	-1.01
Alt. 4				0.00	3.80
Alt. 5					0.00
5,000 AADT					
Alt. 1	0.00	4.51	0.47	-0.36	-0.16
Alt. 2		0.00	0.35	-0.52	-0.34
Alt. 3			0.00	-1.56	-1.19
Alt. 4				0.00	3.80
Alt. 5					0.00

Table 15. Benefit-cost ratios with VSL of $9.6 million

	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
1,000 AADT					
Alt. 1	0.00	9.61	0.46	-0.38	-0.16
Alt. 2		0.00	0.35	-0.57	-0.36
Alt. 3			0.00	-1.39	-1.11
Alt. 4				0.00	8.10
Alt. 5					0.00
2,500 AADT					
Alt. 1	0.00	9.61	0.86	-0.67	-0.29
Alt. 2		0.00	0.65	-0.98	-0.63
Alt. 3			0.00	-2.79	-2.15
Alt. 4				0.00	8.10
Alt. 5					0.00
5,000 AADT					
Alt. 1	0.00	9.61	1.00	-0.77	-0.33
Alt. 2		0.00	0.75	-1.12	-0.72
Alt. 3			0.00	-3.33	-2.54
Alt. 4				0.00	8.10
Alt. 5					0.00

To understand the two BCR tables, begin in the upper left corner (Alternative 1 versus Alternative 1). These cells show a BCR equal to 0.00 since they are comparing the same alternative. When comparing alternatives, read across the row to the right until a BCR is found that is greater than 2.00 (the decision point BCR). If an alternative satisfies this condition, travel down the column and see if any of the remaining alternatives have a BCR greater than 2.0. Repeat this process until there is no alternative that meets this condition. A decision point BCR of 2.00 was used instead of 1.00 because this allowed for variance in uncertainty with the values used in the analysis.

In each of the BCRs calculated in this analysis, the alternative with the highest BCR was Alternative 2, which was the base condition (no guardrail) with a 10-foot offset from the edge of the traveled way. The breakaway signal had a positive BCR but did not exceed the decision point BCR. Even under the extreme case where the AADT was set at 31,000 (the highest value at a railroad-highway crossing in the state) and a VSL of $9.6 million was used, the estimated BCR did not exceed the decision point compared to Alternative 2.

Neither of the guardrail alternatives (4 and 5) was found to be cost-effective when compared to the other three alternatives. This suggests that the provision of guardrails does not appear to provide sufficient reductions in injury severity given the associated installation costs. This also reinforces the findings from the crash severity analysis presented previously, which did not show a substantial difference in injury outcomes between crashes that occurred with and without barrier present.

As under base conditions with only the signal mast present, the guardrail alternative with a 10-foot offset was shown to outperform its counterpart alternative with a 6-foot offset. Although Alternative 5 (10-foot offset) was estimated to experience more crashes than Alternative 4 (6-foot offset) despite the extended lateral clearance from the guardrail, it also showed lower crash costs on average. This suggests that the guardrail performs better when sufficient lateral clearance is provided, but the signal mast also becomes exposed to motorists leaving the roadway to the left under this scenario.

7. CONCLUSIONS AND RECOMMEDATIONS

7.1 Summary

The installation of active warning devices (crossing signals and gates) remains an important aspect of state and federal railroad crossing safety programs. The effectiveness of these devices in preventing crashes between motor vehicles and trains is well documented, but their presence introduces a risk of crashes where an errant motor vehicle may strike the signal mast or other related infrastructure. While most active crossings are occupied by trains for only a few minutes each day, signal masts and related items such as crossing gate mechanisms, cantilever supports, and signal controller boxes are present continuously. Currently, these items are not designed to be crashworthy.

The Iowa DOT developed a longitudinal guardrail system to protect errant motorists from striking non-frangible crossing signal hardware. (This design differs substantially from the ring-style barrier occasionally used to protect signal masts from low-speed knockdowns by turning tractor-trailers.) The Iowa design has been implemented at numerous crossings, most notably on rural highways that are under state jurisdiction. The MUTCD, RDG, and FHWA *Railroad-Highway Grade Crossing Handbook* suggest not to protect railroad crossing signals unless they are located in low-speed, industrial areas where they may become vulnerable to turning trucks. The three guides suggest that a crash cushion could be used, if deemed necessary. However, it is unclear whether any agencies currently use this system and, if it is installed, its effectiveness versus guardrails.

The main objective of this study was to examine how the presence of guardrails affects the prevalence and severity of motor vehicle strikes involving crossing signal masts and related infrastructure. To address this question, 10 years of police-reported crash data were reviewed for more than 1,800 active crossings in Iowa, along with supplemental data from the Iowa DOT and the FRA.

The review indicates that 156 crashes involving signal masts or related hardware occurred between 2007 and 2016, an average of 15.6 crashes per year. Crashes involving signal masts were the most prevalent, followed by vehicles striking the guardrail. Although rare, there were also complex cases such as a vehicle initially striking a train and then becoming wedged between the train and a signal mast. It was found that crash rates were highest at crossings with flashing lights and gates only and lowest at crossings with flashing lights and a cantilever beam only. Crossings that had a guardrail or barrier present showed higher crash rates than those that did not, although these differences were not found to be statistically significant.

One fatal crash and four major injury crashes involving signal masts were found during the 10-year period. Most of the remaining crashes involving crossing signal hardware or barriers installed at crossings were of moderate to low severity. Overall, the severity of crashes was slightly lower when the vehicle struck a guardrail versus a railroad signal mast, but this result was not statistically significant due to the small number of guardrail-involved crashes.

Simulation analyses were conducted using RSAP to compare five different alternative scenarios: (1) mast located 6 feet from edge of traveled way, (2) mast located 10 feet from edge of traveled way, (3) breakaway mast located 6 feet from edge of traveled way, (4) mast located 6 feet from edge of traveled way with guardrail provided, and (5) mast located 10 feet from edge of traveled way with guardrail provided.

The results of these analyses provided two primary insights. First, the provision of guardrail systems appears to provide a marginal benefit from an economic standpoint. While guardrails tend to reduce the crash severity and cost per crash, the frequency of crashes with railroad signal arms is generally low, and the minimum deflection distance available when the barrier is struck tends to limit its effectiveness. The optimal scenario was found to be locating the mast 10 feet from the edge of the traveled way without a guardrail.

Second, the results suggest that providing more lateral space between the signal support and the edge of the traveled way would reduce the probability of a vehicular strike. Providing an additional 4 feet of clearance (from a 6-foot offset to a 10-foot offset) was found to provide the most economically viable solution in the RSAP analyses, yielding a BCR of around 4.5. Allowing this offset would eliminate the need for installing guardrail systems, thereby reducing costs. However, it should be noted that this change may require changes in the size and placement of the associated signs and lights, which could lead to higher installation costs due to the need for larger gates and cantilever beams.

7.2 Limitations

A limitation of the dataset is that the crash information provided for this study only includes reported crashes within the state of Iowa. Because of this limitation, the number of unreported crashes at the locations of interest is unknown. Underreporting may exist; however, it is believed that this would be more prevalent for lower severity and property damage-only crashes because it is expected that all fatal and serious injury crashes would be reported.

Another potential limitation is the robustness of the RSAP software. The encroachment data used in the software is based on 1978 field collections (RoadSafe LLC 2012b), and the accuracy of these data for current roadway conditions is uncertain. The RSAP Engineer’s Manual addresses these concerns, and future NCHRP research aims to reevaluate these models. The installation, maintenance, and repair costs used in the analysis can also vary depending upon site location.

7.3 Future Research

Additional studies to compare these results with those of other crossing signal protection barrier designs would be valuable. Other locations in the United States known to use some type of barrier include Idaho and Washington State, and other countries include Australia, Finland, Germany, and Japan. Alternatively, crash dynamics could be explored using finite element analysis to confirm the effects of barrier use on crash severity and to explore which barrier designs are the most effective in minimizing the effects of signal mast crashes on vehicle occupants. Two journal articles presented in this report used this methodology to explore the effects of guardrails on crashes involving luminaire poles (Pajouh et al. 2017a, Pajouh et al. 2017b). This method could be transferred to railroad signal masts to find the optimal placement of these devices from a crash analysis perspective.

Although the use of the longitudinal guardrail system did not appear to have a strong effect on crash rates at active at-grade crossings in Iowa, other methods for reducing crash prevalence and severity could be explored in future research. For example, crashworthy signal assemblies can possibly be developed for flashing signal-only crossings. Such a design would eliminate the need for a guardrail to protect the signal. The development of more crashworthy railroad crossing signal hardware would require collaboration between transportation agencies, railroads, and railroad equipment suppliers. Other possibilities for reducing crash prevalence and severity could include improving communication between the different transportation agencies involved to ensure the use of properly designed signaling devices and appropriate clearances from the roadway and safety barriers. Future RSAP models could also be developed to study the likelihood of encroachments under different scenarios (e.g., urban non-primary highways or locations with ring-style guardrails) and at various offsets to test for the sensitivity of these factors on crash rate and severity. A sensitivity analysis could also be conducted on other variables in the model, such as the design life or the discount rate.

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APPENDIX A: STANDARD DRAWINGS

LIST OF FIGURES

Figure A1. ArDOT Standard Drawing RRX-3 Revision 10..........**Error! Bookmark not defined.**
Figure A2. ITD Standard Drawing G-1-J Revision 6....................**Error! Bookmark not defined.**
Figure A3. Iowa DOT Standard Road Plan RE-63 Revision 11....**Error! Bookmark not defined.**
Figure A4. Iowa DOT Standard Road Plan BA-253 (new)...........**Error! Bookmark not defined.**
Figure A5. Iowa DOT Standard Road Plan BA-253 Revision 1...**Error! Bookmark not defined.**
Figure A6. Iowa DOT Standard Road Plan BA-253 Revision 2...**Error! Bookmark not defined.**
Figure A7. Iowa DOT Standard Road Plan BA-253 Revision 3...**Error! Bookmark not defined.**
Figure A8. Iowa DOT Standard Road Plan LS-633 (new)............**Error! Bookmark not defined.**
Figure A9. Mississippi DOT Standard Plan RRS-1.......................**Error! Bookmark not defined.**
Figure A10. Nevada DOT Standard Plan T-35.3.1........................**Error! Bookmark not defined.**
Figure A11. Oregon DOT Standard Drawing RD445...................**Error! Bookmark not defined.**
Figure A12. Oregon DOT Standard Drawing RD445...................**Error! Bookmark not defined.**
Figure A13. WSDOT Standard Plan C-20.14-03..........................**Error! Bookmark not defined.**

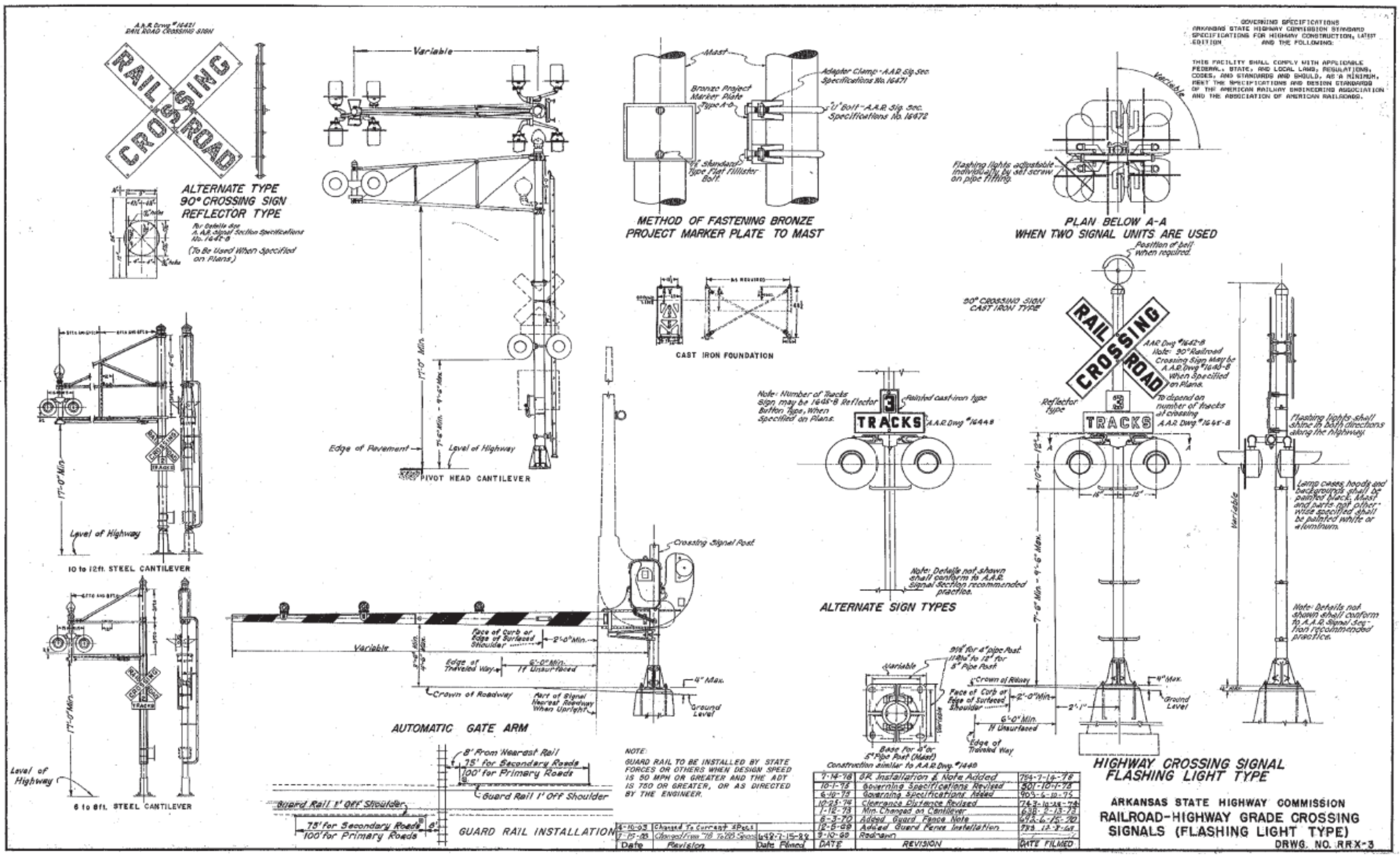


Figure A1. ArDOT Standard Drawing RRX-3 Revision 10

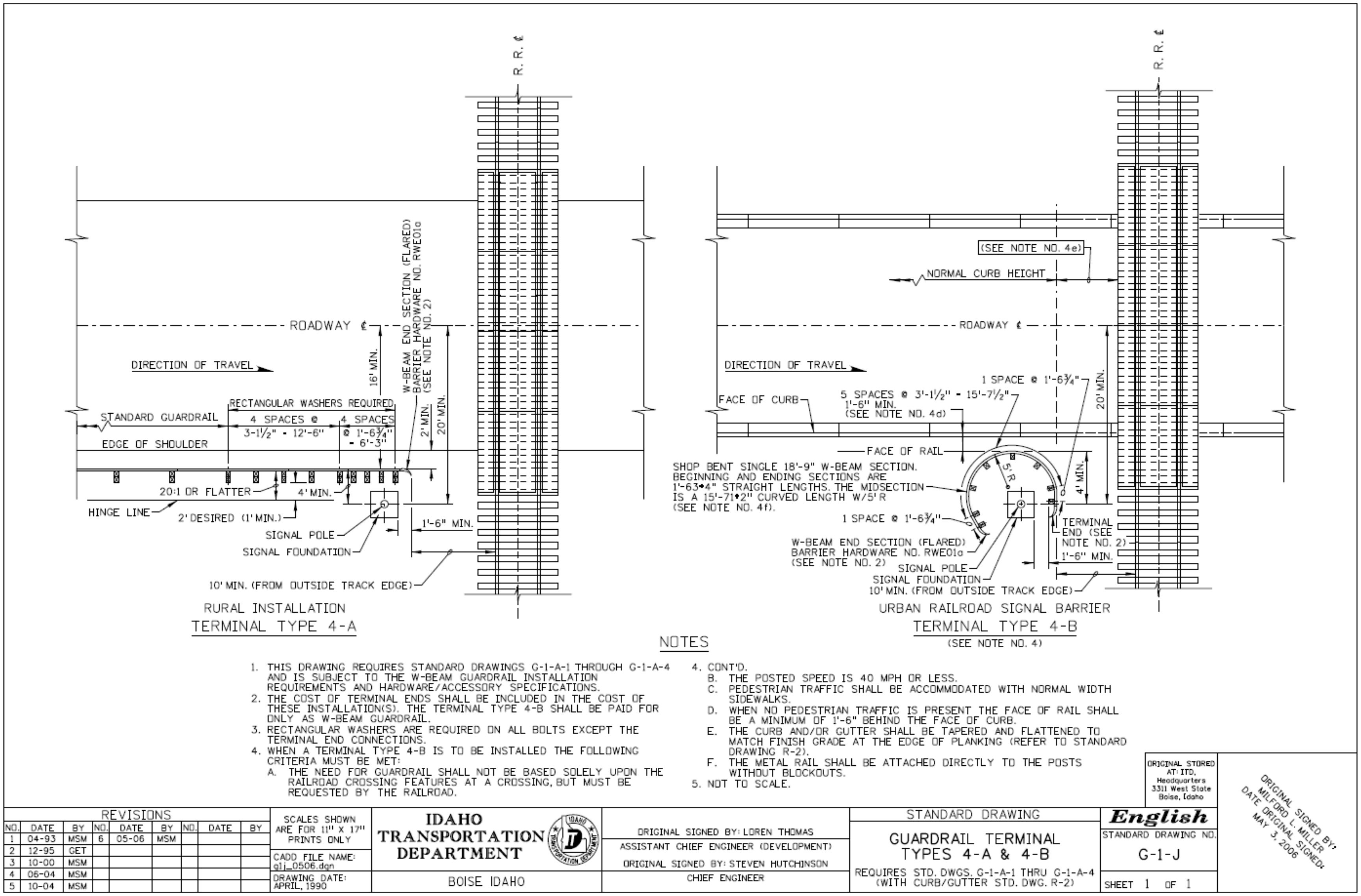
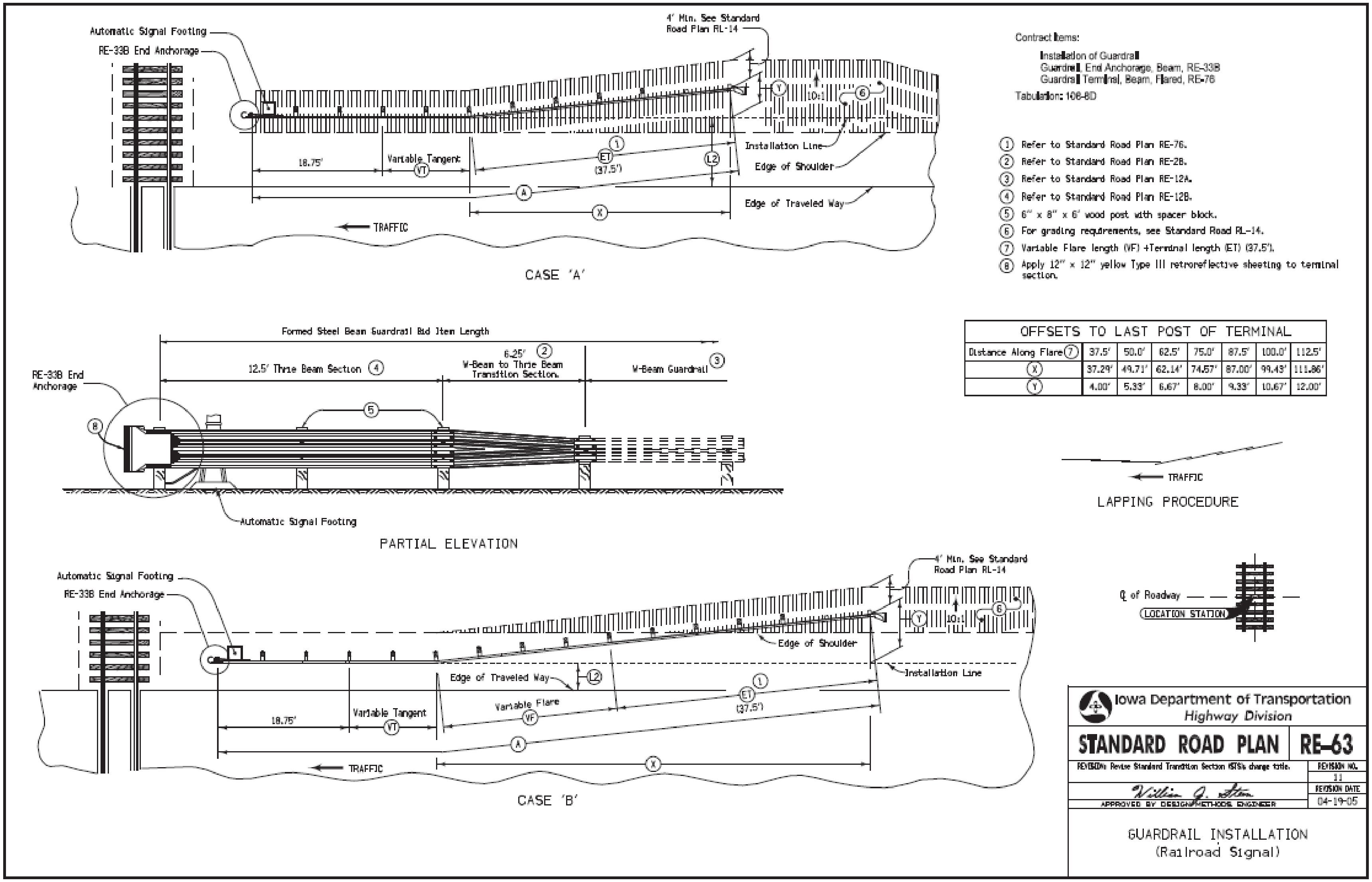


Figure A2. ITD Standard Drawing G-1-J Revision 6



OFFSETS TO LAST POST OF TERMINAL

Distance Along Flare (7)	37.5'	50.0'	62.5'	75.0'	87.5'	100.0'	112.5'
(X)	37.29'	49.71'	62.14'	74.57'	87.00'	99.43'	111.86'
(Y)	4.00'	5.33'	6.67'	8.00'	9.33'	10.67'	12.00'

Figure A3. Iowa DOT Standard Road Plan RE-63 Revision 11

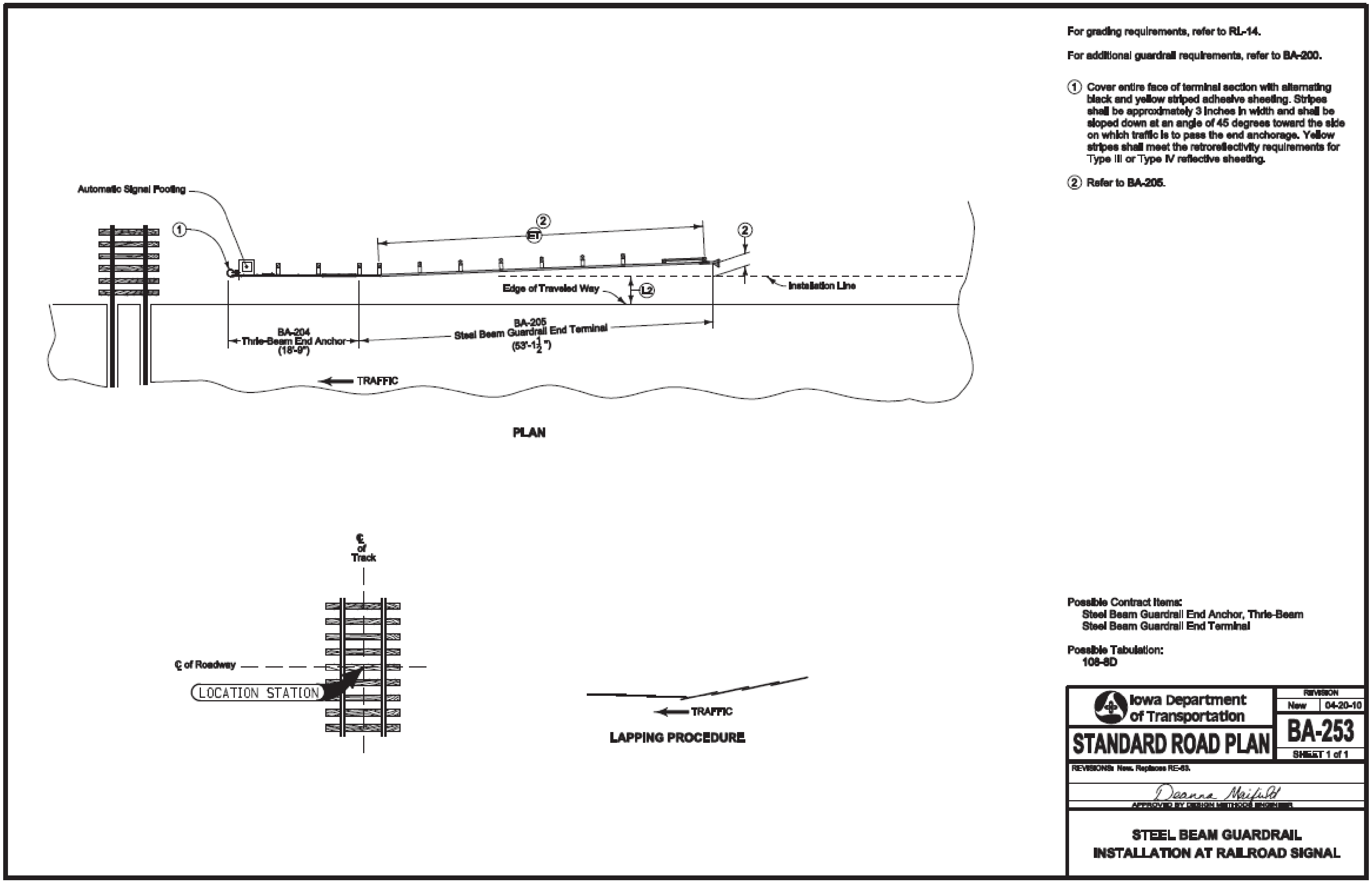


Figure A4. Iowa DOT Standard Road Plan BA-253 (new)

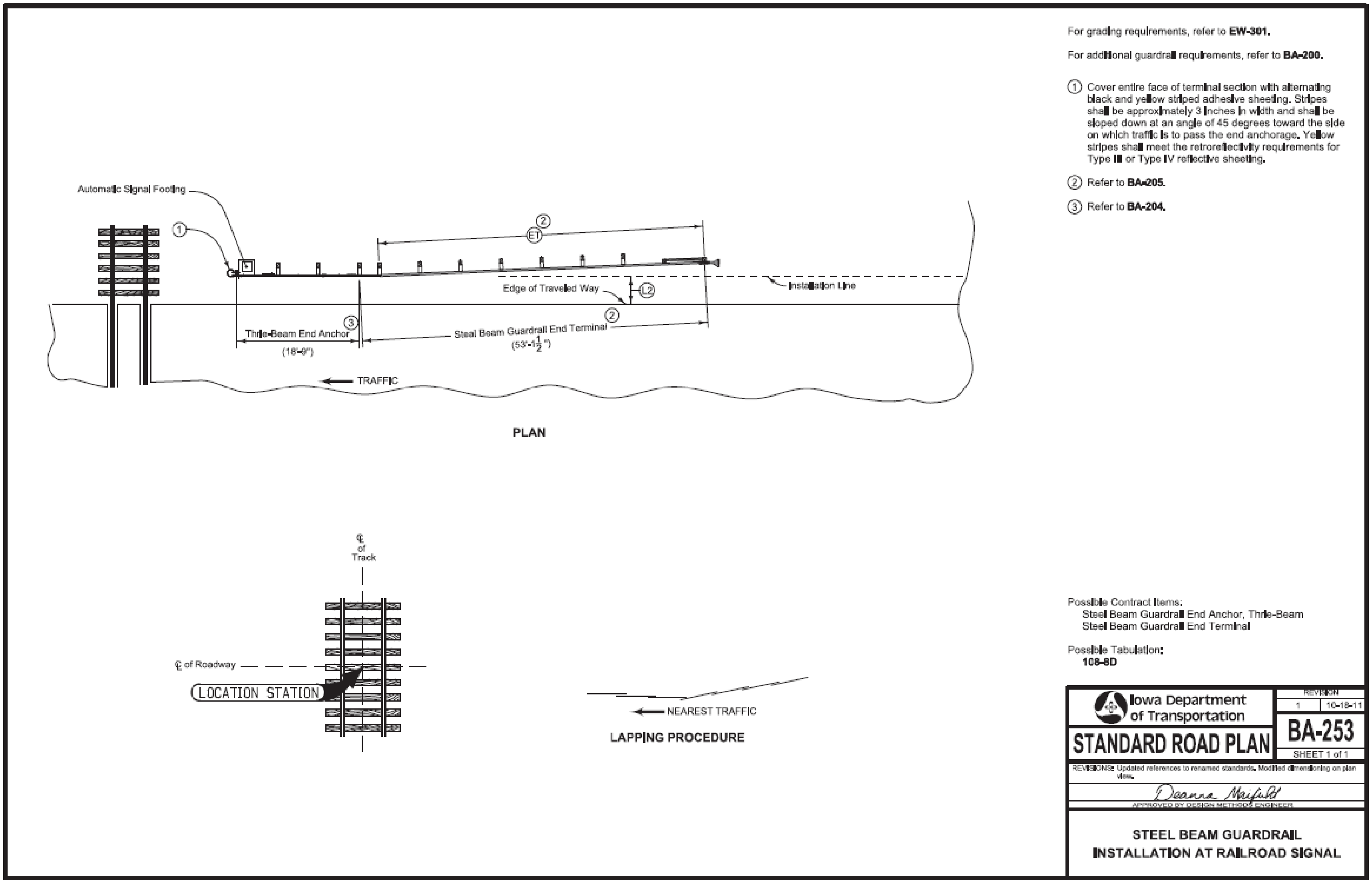


Figure A5. Iowa DOT Standard Road Plan BA-253 Revision 1

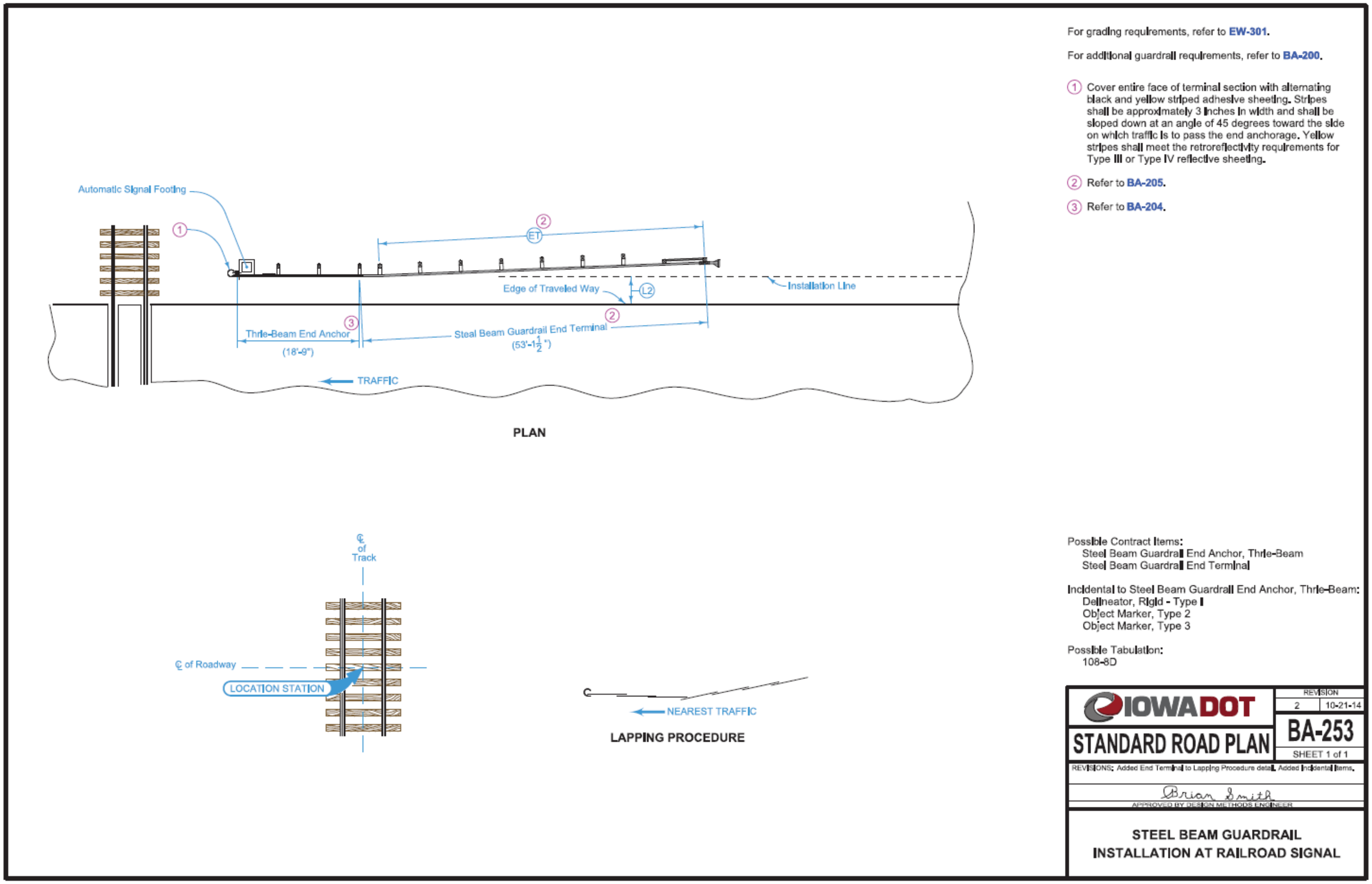


Figure A6. Iowa DOT Standard Road Plan BA-253 Revision 2

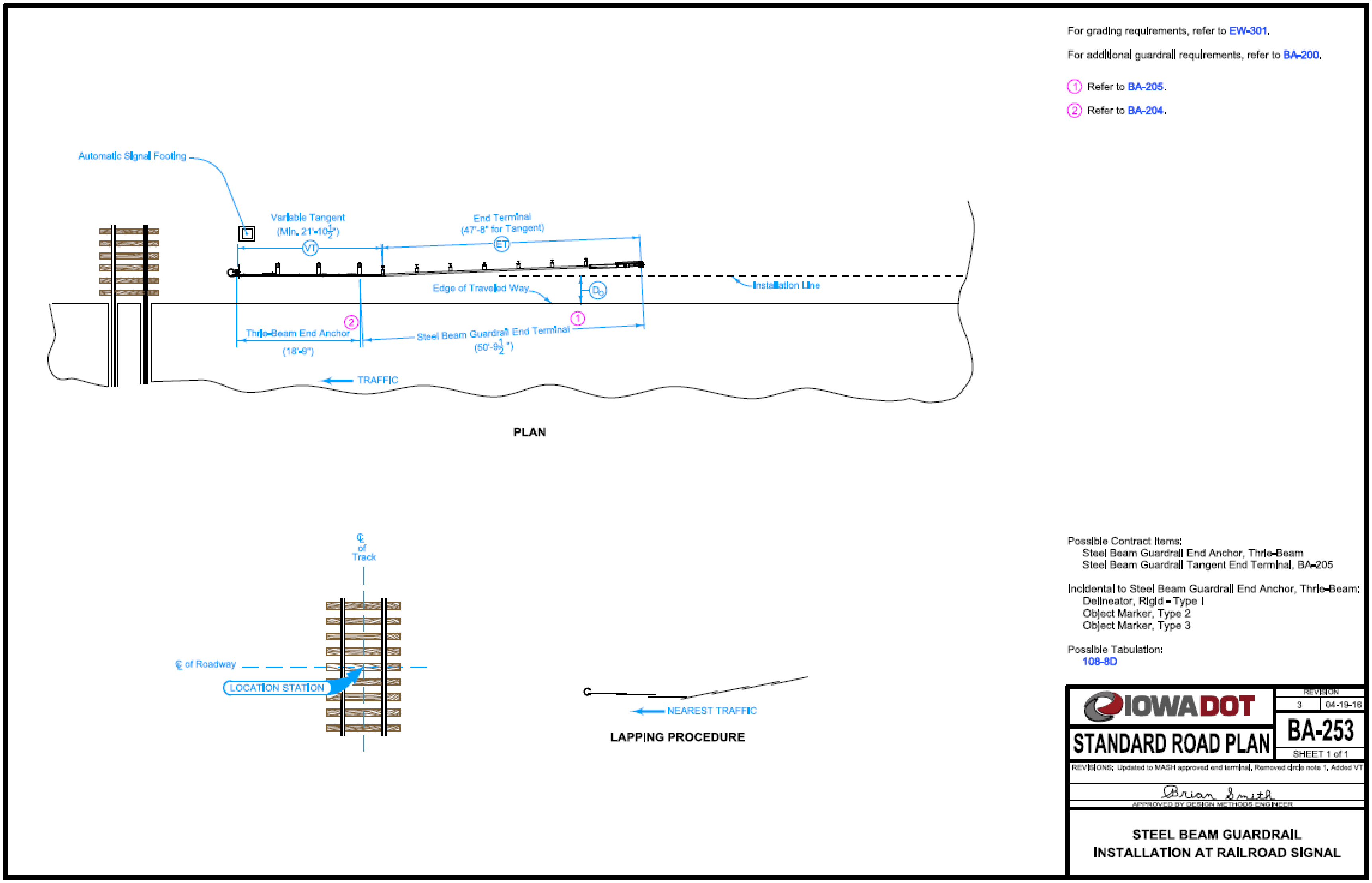


Figure A7. Iowa DOT Standard Road Plan BA-253 Revision 3

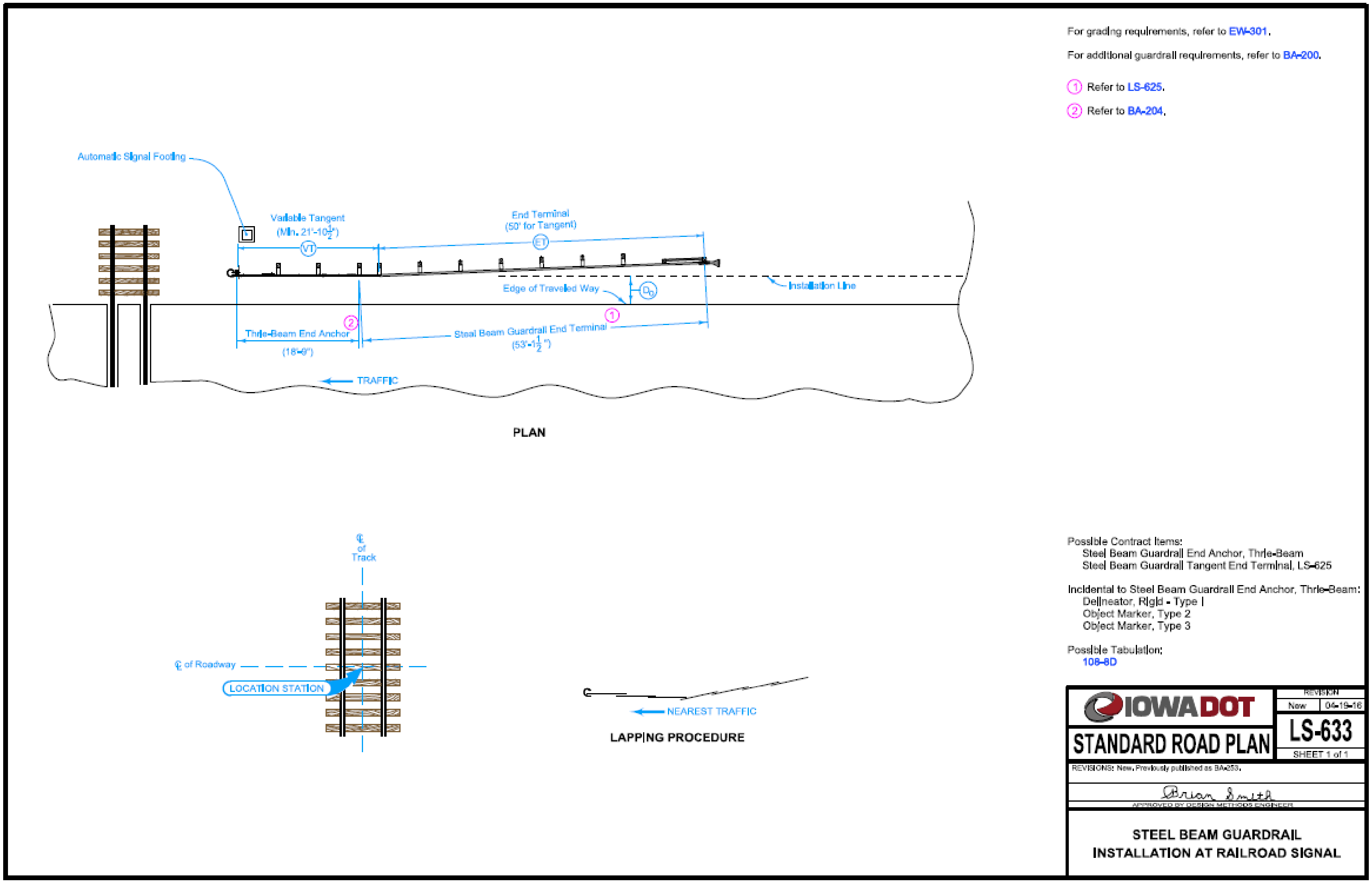


Figure A8. Iowa DOT Standard Road Plan LS-633 (new)

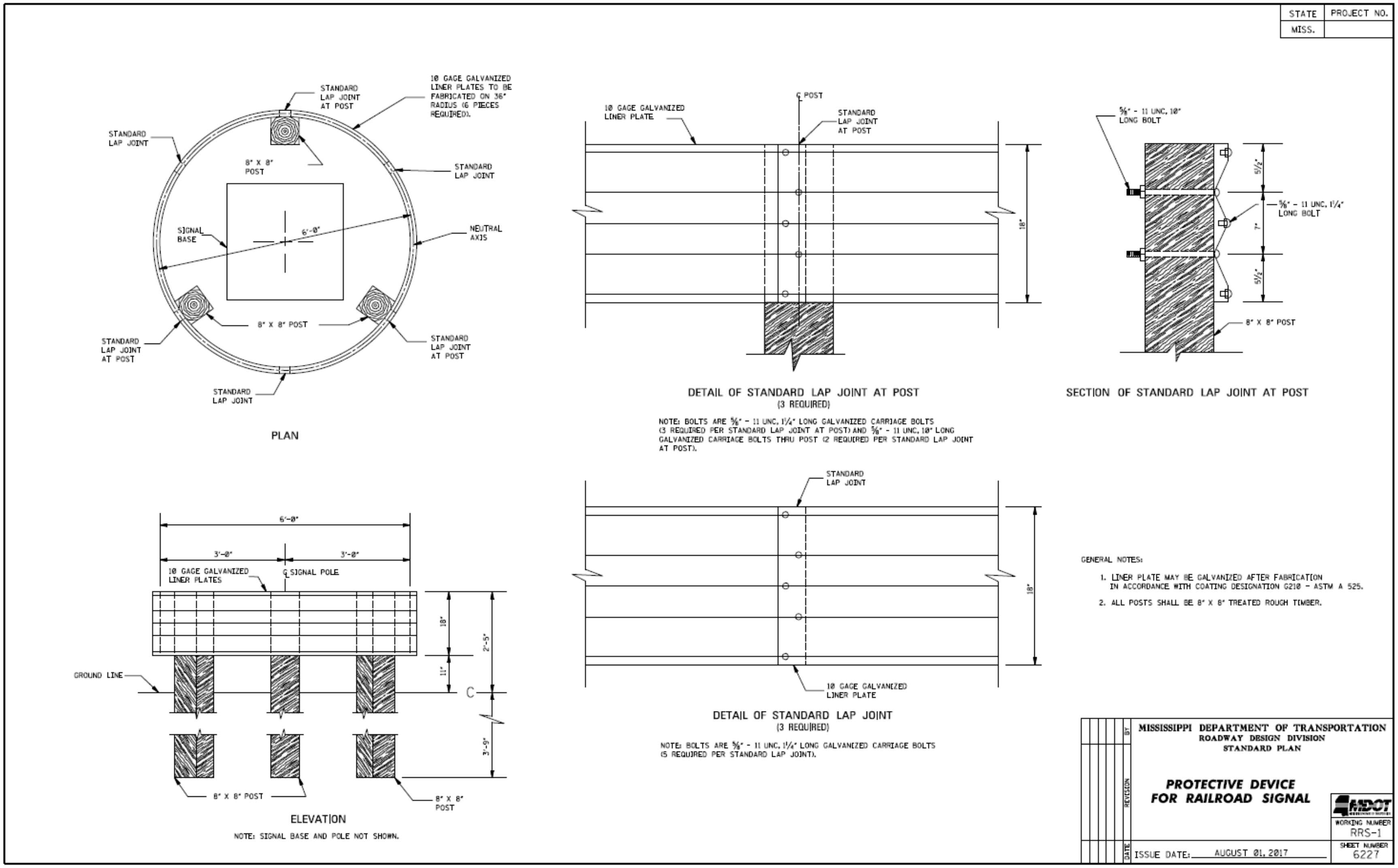


Figure A9. Mississippi DOT Standard Plan RRS-1

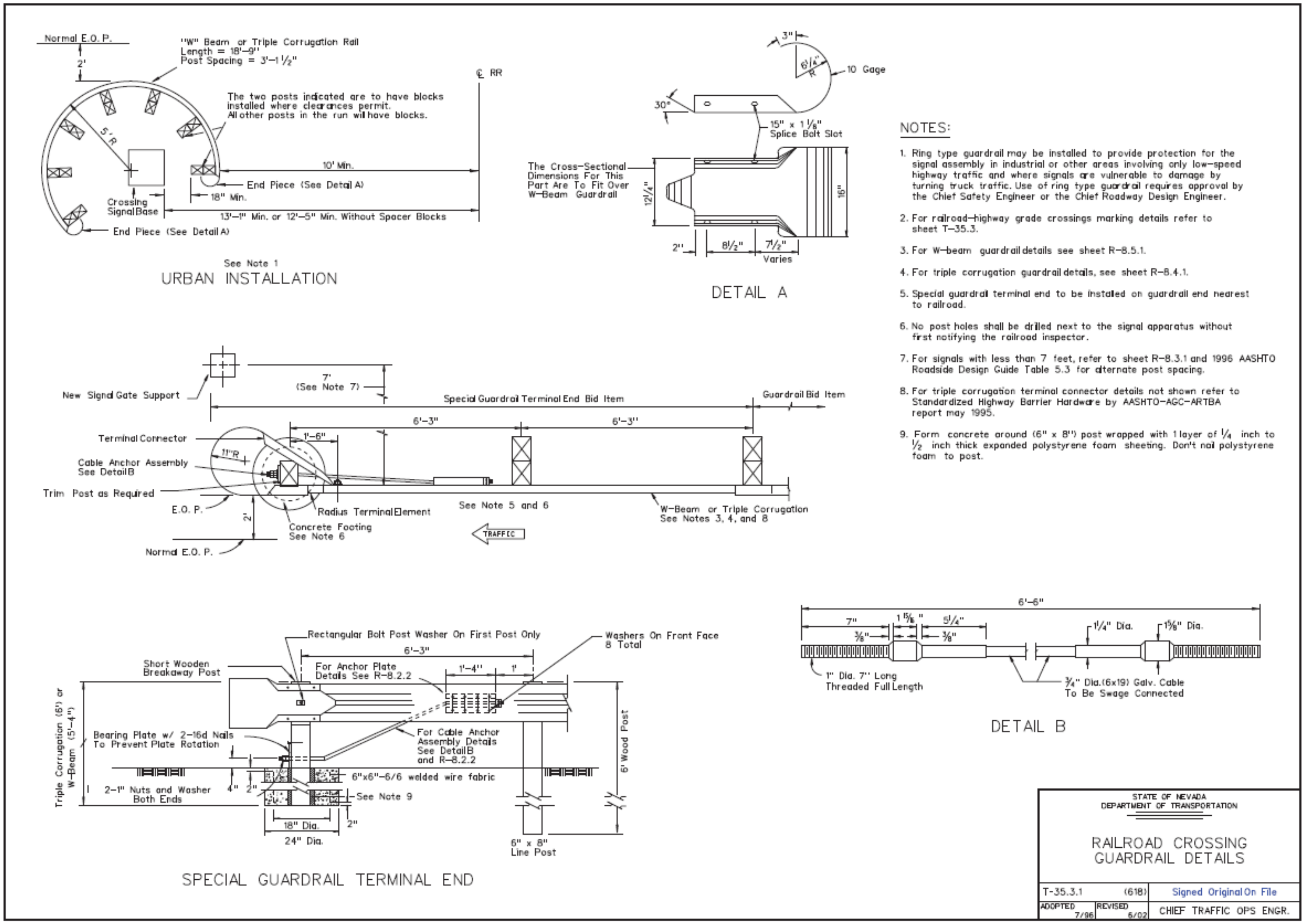


Figure A10. Nevada DOT Standard Plan T-35.3.1

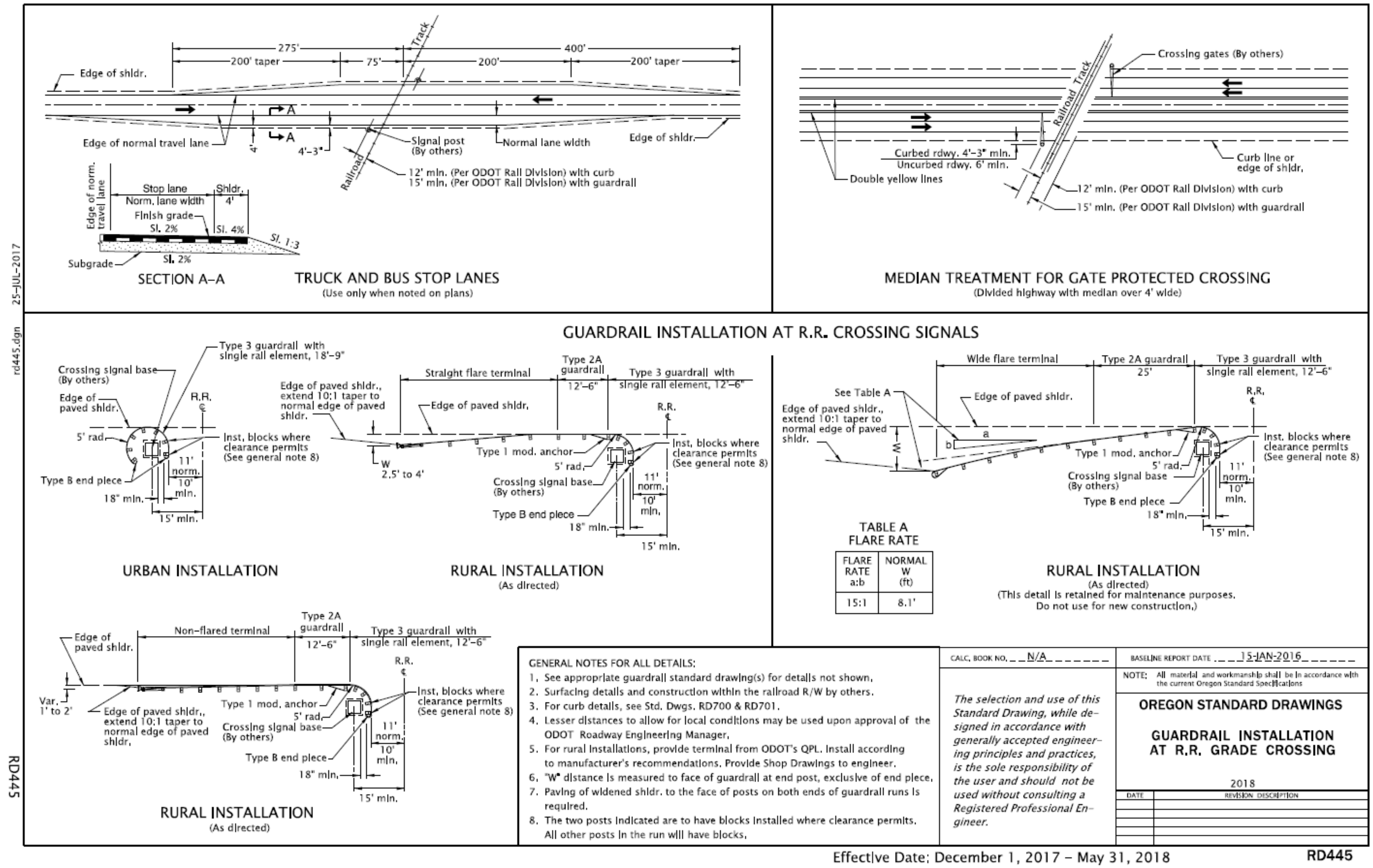


Figure A11. Oregon DOT Standard Drawing RD445

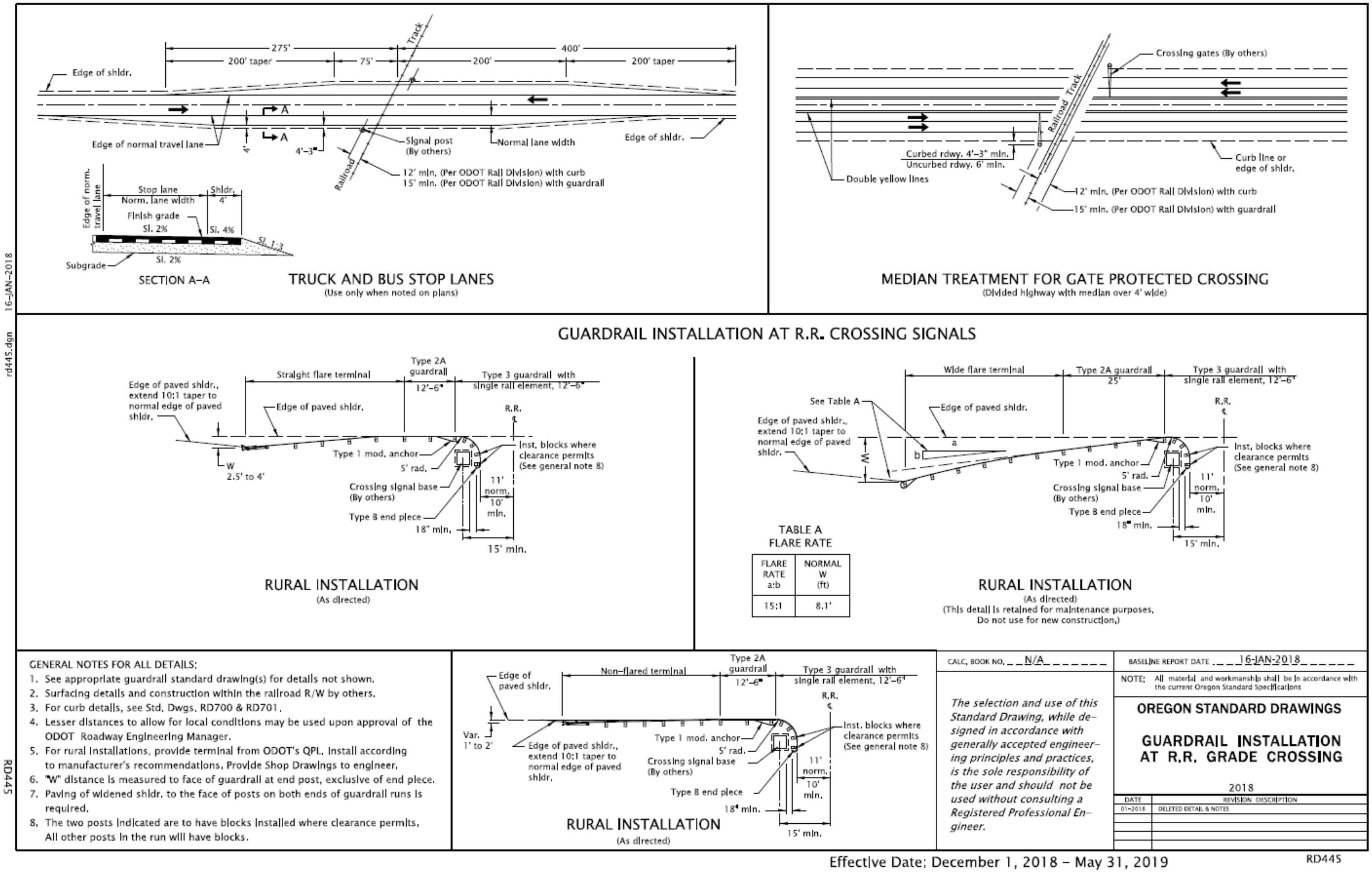
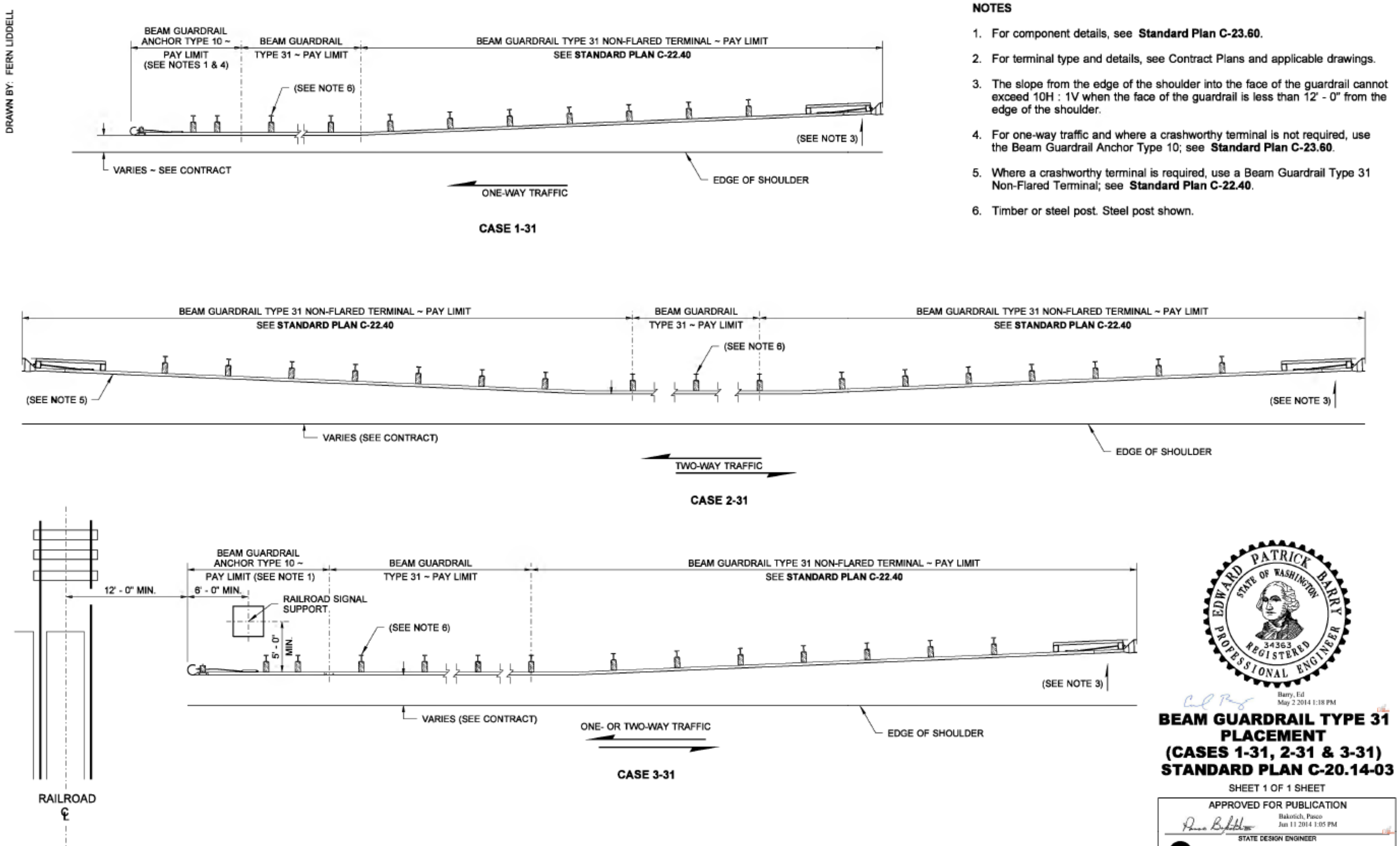


Figure A12. Oregon DOT Standard Drawing RD445



NOTES

1. For component details, see **Standard Plan C-23.60.**
2. For terminal type and details, see Contract Plans and applicable drawings.
3. The slope from the edge of the shoulder into the face of the guardrail cannot exceed 10H : 1V when the face of the guardrail is less than 12' - 0" from the edge of the shoulder.
4. For one-way traffic and where a crashworthy terminal is not required, use the Beam Guardrail Anchor Type 10; see **Standard Plan C-23.60**.
5. Where a crashworthy terminal is required, use a Beam Guardrail Type 31 Non-Flared Terminal; see **Standard Plan C-22.40**.
6. Timber or steel post. Steel post shown.

BEAM GUARDRAIL TYPE 31 PLACEMENT (CASES 1-31, 2-31 & 3-31) STANDARD PLAN C-20.14-03

SHEET 1 OF 1 SHEET

APPROVED FOR PUBLICATION

Bakotich, Pasco
Jun 11 2014 1:05 PM

STATE DESIGN ENGINEER

Washington State Department of Transportation

Figure A13. WSDOT Standard Plan C-20.14-03

APPENDIX B: SURVEY

Crashworthiness of Rail-Highway Crossing Signal Equipment

Crashworthiness of Rail-Highway Crossing Signal Equipment

Motor vehicle collision with railroad crossing signals near Danbury, CT (Aug 2016). Photo: Metropolitan Transportation Authority of NY

Iowa State University is conducting this survey on behalf of the Iowa Department of Transportation. We are reaching out to engineers, administrators, and law enforcement officials to explore the prevalence of crashes involving vehicles that strike signal poles or signal controller boxes at railroad crossings on public streets and highways. The questions in this survey refer specifically to crashes involving railroad signal hardware, not crashes where a motorist strikes a train. We also hope to gather information about the design standards that are currently being applied to warning systems at rail-highway crossings. (For the purposes of this survey, "railroad crossings" also include public grade crossings on light rail and heavy rail mass transit lines and commuter rail systems).

Your agency or company's participation in this survey is voluntary. The information gathered will help the research team identify and disseminate best practices for the design and management of railroad crossings. Questions about this survey can be directed to Dr. Peter

Savolainen, the Principal Investigator, at 515-294-3381. Thank you for participating!

Q1 Which best describes your agency or organization:

- ○ State (1)
- ○ County (2)
- ○ City, Village, Town, or Township (3)
- ○ Railroad (4)
- ○ Public Transit Agency (5)
- ○ Other (please specify) (6) ____________________

Q2 Which best describes your role in the agency or organization:

- ○ Administration / Management (1)
- ○ Engineering / Public Works / Maintenance of Way (2)
- ○ Operations (3)
- ○ Law Enforcement / Public Security (4)
- ○ Other (please specify) (5) ____________________

Q3 Approximately how many public at-grade railroad crossings are located in your area of responsibility?

	None (1)	1-9 (2)	10-49 (3)	50-99 (4)	100-499 (5)	500-999 (6)	1000-4999 (7)	Over 5000 (8)
Signalized with gates (1)	○	○	○	○	○	○	○	○
Signalized WITHOUT gates (2)	○	○	○	○	○	○	○	○
Unsignalized (crossbucks and signs only) (3)	○	○	○	○	○	○	○	○
Other (4)	○	○	○	○	○	○	○	○

Q4 Have you received reports of motorists colliding with railroad signal poles or signal control boxes in your area, or observed evidence of hit-and-run collisions involving this equipment?

○ Yes (please explain) (1) ____

○ No (2)

○ Unknown (3)

Display This Question:

If Have you received reports of motorists colliding with railroad signal poles or signal control box... = Yes (please explain)

Q5 Have any of these incidents resulted in casualties?

- ◯ Yes, including one or more fatalities (1)
- ◯ Yes, injuries but no fatalities (2)
- ◯ No (3)
- ◯ Unknown (4)

Display This Question:

If Have you received reports of motorists colliding with railroad signal poles or signal control box... = Yes (please explain)

Q6 Do you have information about how often signal equipment has been struck, or the cost of repairs? Can you share the information or suggest a person to contact?

____

____

____

____

____

Q7 If the signal equipment at a railroad crossing is struck by a motor vehicle, who would you expect to pay for repairs?

- ◯ The driver of the errant vehicle (or their insurance company) (1)
- ◯ Railroad (2)
- ◯ City, county, or state transportation department (3)
- ◯ Other (please explain) (4) ____
- ◯ Unknown (5)

Q8 If a hit-and-run collision damages railroad crossing signals, who pays for repairs?

- ○ Railroad (1)
- ○ City, county, or state transportation department (2)
- ○ Other (please explain) (3) ____
- ○ Unknown (4)

Q9 How is the design of railroad crossing signal hardware determined in your area? (Please mark all that apply).

- ☐ Discretion of the railroad (1)
- ☐ AREMA signal design standards or other vendor-supplied specifications (2)
- ☐ State DOT design standards or standard detail drawings (3)
- ☐ County or local design standards (4)
- ☐ Negotiated between public agency and railroad (5)
- ☐ Unknown / Installed long ago (6)
- ☐ Other (please explain) (7) ____

Q10 Do your railroad crossing signals (or signal controller boxes) include any of the following safety features? (Please mark all that apply).

☐ Guard rail or concrete barrier to prevent vehicles from striking the signal (rural areas) (1)

☐ Guard rail or concrete barrier to prevent vehicles from striking the signal (urban areas) (2)

☐ Bollards or posts to prevent vehicles from striking the signal (rural areas) (3)

☐ Bollards or posts to prevent vehicles from striking the signal (urban areas) (4)

☐ Crash cushions / impact attenuators (rural areas) (5)

☐ Crash cushions / impact attenuators (urban areas) (6)

☐ Break-away bases crash-tested to MASH or NCHRP 350 standards (7)

☐ Unknown / installed long ago (8)

☐ Other (please explain) (9) ____

☐ None of the above (10)

Q11 General comments / suggestions

____

____

____

____

____

Q12 Name of Agency

____

Q13 Name of Person Completing This Form

____

Q14 Job Title

____

Q15 Telephone Number

____

Q16 E-Mail Address

____

Q17 May we contact you with follow-up questions?

- ◯ Yes (1)
- ◯ No (2)

Thank you for participating in this survey.

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