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16. Abstract

A short storage space railroad crossing has insufficient distance between the crossing and the highway intersection stop line to safely store a design vehicle. The current Michigan Department of Transportation (MDOT) project (OR 19-032), led by Texas A&M Transportation Institute (TTI), aimed to provide guidance on these crossing types. This study examined the crash data, surroundings of the crossing, and driver behavioral patterns using naturalistic driving and simulation data to identify suitable countermeasures and build communication between MDOT Traffic & Safety and Office of Rail to refine the guidelines. This project conducted four major tasks: 1) a comprehensive review on short-storage crossing related studies, 2) data preparation and development of safety indices for short-storage crossing locations, 3) development of driver behavior related safety scoring for different passive treatments using data from SHRP-2 naturalistic driving study (NDS) and simulation, and 4) development of a guidance document and final report on short-storage crossings in Michigan. The findings of literature review show that little research has been conducted to empirically evaluate the effectiveness of different treatments for grade crossings with short storage, outside of traffic signal preemption strategies. The results also revealed that the highest number of crashes occurred in southeast Michigan (Detroit area), and the lowest number occurred in the sparsely populated northern part of the state. The findings also show that short storage locations are mostly on local undivided roadways. Both NDS and simulation study results indicate that drivers face difficulties in following signs and markings near the short storage locations. This study can help authorities in identifying the issues of driver-related distraction and sign following patterns and can aid in improving short storage crossing safety. In addition, this project provided recommendations for modifications to the language in six relevant MDOT publications.

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Short-Storage-Space Railroad Crossings, Naturalistic Driving Study, Natural Driving Simulation, MUTCD, Behavioral Score, Passive Control Devices	No restrictions. This document is also available to the public through the Michigan Department of Transportation.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

A short storage space railroad crossing has an insufficient distance between the crossing and the highway intersection stop line to safely store a design vehicle. This project aimed to provide guidance on these crossing types. This study examined the crash data, the surroundings of the crossing, and driver behavioral patterns using naturalistic driving and simulation data to identify suitable countermeasures and build communication between MDOT Traffic & Safety and the Office of Rail to refine the guidelines.

This project conducted four major tasks: 1) a comprehensive review of short-storage crossing-related studies, 2) data preparation and development of safety indices for short-storage crossing locations, 3) development of driver behavior-related safety scoring for different passive treatments using data from the SHRP 2 naturalistic driving study (NDS) and simulation, and 4) development of a guidance document and final report on short-storage crossings in Michigan.

At the beginning of this project, the research team conducted a comprehensive literature review on short storage crossings. The literature review focuses on treatments identified for short storage locations, including a mix of passive and active treatments, Manual on Uniform Traffic Control Devices (MUTCD) guidance, and other issues affecting the safety of these locations. This synthesis task also summarized existing state-specific information on passive rail-crossing treatments, especially at short-storage locations. The research team collected crash data for five years (2015-2019) on different types of rail grade crossings. During 2015-2019, 90 crashes occurred on short storage crossings. Generally, the crash frequency was closely related to population centers within the state. This study developed safety indices for all railroad crossings in Michigan using both New Hampshire Index (NHI) and NCHRP Report 50 formulas.

To explore the issues associated with driver behavior at the short storage crossing locations, the research team used the Second Strategic Highway Research Program (SHRP 2) naturalistic driving study (NDS) data and simulation data. To perform analysis, five passive control devices (crossbuck only, crossbuck and yield, crossbuck and stop, DEM, and near-side stop line) were selected. For behavioral scores, five major factors were considered: 1) acceleration, 2) speed before, 3) speed after, 4) head rotation, and 5) sign and marking following. The scores were calculated based on percentile value.

MDOT hosted a workshop on this project at the Horatio S. Earle Learning Center in suburban Lansing. Approximately eight people attended in person, with a further approximate virtual attendance of 25 individuals via Microsoft Teams. Two members of the research team from Wayne State University attended in person while one member of the research team from Texas A&M Transportation Institute attended virtually.

The findings of the literature review show that there is a poor level of consistency in the selection of treatments for different grade-crossing scenarios. The development of a data-driven decision process based on local traffic conditions, existing geometry, and other site factors would be of significant value to ensure that systemic treatments have their intended effect. In addition, little research has been conducted to empirically evaluate the effectiveness of different treatments for grade crossings with short storage, outside of traffic signals, preemption strategies. The unique situation of short storage at a passive grade crossing places a significant burden on the driver. In addition to the extra visual and cognitive tasks associated with decision making at an ordinary passive grade crossing, the driver may also need to consider the intersection ahead of the grade crossing and make a quick judgment about which side of the grade crossing to stop on.

The highest number of crashes occurred in southeast Michigan (the Detroit area), and the lowest number occurred in the sparsely populated northern part of the state. This study showed that short storage locations are associated with a higher proportion of crashes than non-short storage locations. Also, failure to yield is one of the major driving-related violations for short storage crossings. The findings also show that short storage locations are mostly on local undivided roadways. Crossing angles (60–90 degrees) are disproportionately high in short-storage-crossing-related crossing angles.

Both NDS and simulation study results indicate that drivers face difficulties in following signs and markings near the short storage locations. Effectiveness measures of five passive countermeasures indicate that dynamic envelop markings and crossbucks with stops are more effective than other passive countermeasures such as crossbuck only, crossbuck and yield, and near-side stop line.

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND AND PROBLEM STATEMENT

The safety of a railroad-highway grade crossing is of paramount importance. It should be measured and improved by modifying the potential causal factors– such as types of warning devices, train and traffic flows, and crash history– that are associated with crashes. Rail grade crossing sites have the greatest potential for train-vehicle crashes, and they also have much higher injury and fatality rates in comparison to highway intersections. Although there are various signals, such as warning signs, pavement markings, flashing lights, or gates, that are meant to alert drivers of these crossings, the different characteristics of the drivers have a significant effect on how they process the information of these approaches. It is generally anticipated that drivers comprehend that they are approaching a crossing grade when they observe one of the following signals: crossbuck, advance warning signs, pavement markings, flashing light signals, or automatic gates.

A short storage crossing is when the clear storage distance between the crossing and the highway intersection stop line is not sufficient to safely store a design vehicle (typically measured by the longest legal truck combination). Pre-signals are a common countermeasure for the short storage railroad crossings in Michigan. The current project investigated crossings that do not have sufficient space for traffic to queue at nearby roadway intersections without backing over the crossing. The findings of this study can be useful for MDOT to establish suitable countermeasures.

1.2 OBJECTIVES

The objectives of this study are to:

- Identify countermeasures suitable for crossings with short storage space.
- Compare driver behavior at different crossing types.
- Identify suitable countermeasures for MDOT.
- Conduct risk analysis of roadway intersections associated with the different approaches.
- Build communication between MDOT Traffic & Safety and the Office of Rail to refine the guidelines.

1.3 RESEARCH TASKS

This project mainly concentrated on the six research tasks listed below.

- Task 1: Project Management
- Task 2: Identify Current Knowledge
- Task 3: Site Selection and Data Integration
- Task 4. Second Strategic Highway Research Program (SHRP 2) naturalistic driving study (NDS) and Simulation Study
- Task 5. Guideline Development and In-Person Meeting

- Task 6. Final Report

1.4 REPORT ORGANIZATION

The organization of the report is listed below:

- In Task 2, the project team conducted two major tasks: 1) Literature Review and 2) Selection of an Effective Countermeasure. Chapter 2 provides details on the current state of knowledge.
- In Task 3, the project team collected data from rail crossings in Michigan. The project team performed data integration to develop a dataset with different crossing scenarios. In addition, the project team conducted a feasibility assessment on whether the research project would be able to determine multiple scenarios of interest. Chapter 3 documents the data integration work conducted in this task.
- In Task 4, the project team compared driver behavior at different crossing types. To perform this task, the project team used SHRP 2 NDS data and simulation data. Chapter 4 provides details on both SHRP-2 NDS and simulation data analysis.
- The project team prepared stand–alone guidance supporting the implementation of the research findings and materials developed in Tasks 3–4. The project team incorporated references to the research report and additional relevant resources throughout the guide to ensure that practitioners can access further information as needed. The project team developed a preliminary peer exchange workshop plan to build the communication between MDOT Traffic & Safety and the Office of Rail and refine the guidelines. The workshop began with a brief session describing the purpose of the project, the different tasks involved, and an introduction to the project team and panel members that are associated with this project. This introduction was followed by sessions that provided a brief overview of the draft products for discussion at the workshop. Chapter 5 provides details on Task 5.

CHAPTER 2. IDENTIFICATION OF CURRENT KNOWLEDGE

2.1 INTRODUCTION

This chapter provides a brief overview of the state of the practice of safety treatments at short-storage-space railway crossings.

The issue of highway-rail grade crossing (HRGC) safety has been studied extensively over the past several decades, with significant reductions in HRGC fatalities occurring since the passage of the Federal Aid Highway Act of 1973, which authorized the Federal-Aid Highway Crossing Program. One of the most significant issues affecting the safety of HRGCs is the provision of sufficient distance at the crossing for the storage of queuing vehicles, both upstream and downstream of the crossing. Of specific interest is the downstream queuing space, known as the clear storage distance (CSD), defined as (Federal Highway Administration [FHWA], 2019):

> *The distance available for vehicle storage measured between six (6) feet from the rail nearest the intersection to the intersection stop line or the normal stopping point on the highway.*

Safety issues within and approaching the CSD become evident when a roadway intersection is located close to the HRGC in the downstream direction. These locations can prove especially risky for drivers and problematic to manage for transportation engineers due to the competing areas of driver attention, the CSD for vehicles in between the intersection, and the HRGC itself.

Compounding the issue of insufficient CSD in these locations is the general lack of compliance with passive HRGC traffic control devices (TCDs). Over the past several decades, a large body of research has been compiled to examine different types of TCDs and their effectiveness at passive HRGCs (Lerner et al., 2002), although the most recent decade has seen a comparable dearth of study in this area. Nonetheless, the message from this research is clear: passive TCDs nearly always suffer from poor rates of compliance, in at least some situations, especially compared to HRGCs equipped with active TCDs (such as gate arms and traffic signals). Furthermore, interviews conducted as part of these research projects strongly suggest the existence of a risk-reward perception associated with passive HRGC safety; that is, there is only so much that can be done to warn the driver about the risks of a passing train, and beyond this, the drivers bear the responsibility for their actions. While presumably based on the notion of a limited available resource pool to ensure HRGC safety, this ethos conflicts with recent safety conversations around Vision Zero and Toward Zero Deaths initiatives, which aim to dispel the notion that most traffic fatalities and serious injuries—more than 90 percent, by some estimates—are attributable primarily to driver error. Consequently, the review of the literature found that the perceived difficulty of systemically treating passive HRGCs has resulted in little innovation in this space over the past 15–20 years.

This literature review is organized into several sections:

- The first section provides a formal definition of short storage locations and passive HRGCs to clearly delineate the scope of interest for this study.
- The second section focuses on treatments identified for short storage locations, including a mix of passive and active treatments, Manual on Uniform Traffic Control Devices (MUTCD) guidance, and other issues affecting the safety of these locations.

- The third section focuses on summarizing existing state-specific information on passive HRGC treatments, especially at locations with insufficient CSD and other locations. This section also includes limited guidance on prioritizing passive grade crossings for enhanced treatment.
- The final section synthesizes the findings from the previous sections and lays out specific criteria for designing and operating HRGCs and adjacent intersections with insufficient CSD.

2.2 IDENTIFICATION OF SHORT STORAGE LOCATIONS

There is a lack of definitive guidance on what constitutes an HRGC with inadequate CSD, especially for grade crossings that lack active warning devices. Chapter 8 of the MUTCD provides some guidance that is suggestive of environments in which the storage of queued vehicles is an issue (FHWA, 2009):

> *If a highway-rail grade crossing is equipped with a flashing-light signal system and is located within 200 feet of an intersection or midblock location controlled by a traffic control signal, the traffic control signal should be provided with preemption in accordance with Section 4D.27.*

However, this language is largely prescriptive to the issue of improving traffic operations at HRGCs adjacent to signalized intersections and does not address the matter of short storage issues at crossings that lack traffic control signals or other active warning devices. Nonetheless, it identifies a key characteristic associated with many short storage locations: the proximity of the HRGC to an adjacent intersection, usually with some type of TCD that could put vehicles at risk of queuing back into the crossing itself.

The Code of Federal Regulations (CFR) provides some additional guidance on identifying short storage locations, focusing on commercial vehicles to ensure that a design vehicle for a given roadway has a sufficient distance to proceed safely and completely through a highway-rail crossing. Per 49 CFR 392.12:

> *No driver of a commercial motor vehicle shall drive onto a highway-rail grade crossing without having sufficient space to drive completely through the crossing without stopping.*

Based on this language, an agency may wish to consider any grade crossing where a design vehicle is unable to completely traverse the crossing and safely come to a complete stop at an intersection downstream of the crossing as a short storage location.

2.3 TREATMENTS FOR SHORT STORAGE LOCATIONS

The *Highway-Rail Crossing Handbook* and the MUTCD maintain several provisions to handle short storage crossing locations, including but not limited to (Field & Field, 2013; FHWA, 2009, 2019):

- Restriction of certain vehicle types
- Additional signage to alert drivers of the unique geometrics of the crossing
- Relocation of the stop line to upstream of the adjacent intersection

- Installation of a traffic control signal upstream of the highway rail crossing (i.e., pre-signal) with or without preemption/coordination to the adjacent signalized intersection
- Restriction of turns from adjacent roadways
- Road realignment
- Grade separation
- Closure of the crossing

These options include a mix of active warning treatments, passive treatments, and alterations to the geometric alignment of the roadway. Depending on the HRFC context, these treatments may or may not be feasible in certain scenarios. For example, many agencies, particularly smaller agencies or those dealing with short-storage-space issues for lower-volume rural grade crossings, lack the resources to install and maintain additional traffic signals in these situations or to pursue costly geometric realignments of the roadway. Other active warning systems, which can decrease the likelihood of vehicles being caught in a grade crossing, are equally costly to manage (Abraham et al., 1998; Noyce & Fambro, 1998; Rys et al., 2012).

2.3.1 MUTCD Signage Treatments

The MUTCD specifically includes several signage treatments that may be relevant for short storage locations, as shown in Figure 1. Only W10-11 is specifically mentioned in the *Highway-Rail Crossing Handbook* as a solution to notifying drivers about short storage issues. However, the MUTCD also states that W10-11 can be modified as needed for different geometrics, and the *Highway-Rail Crossing Handbook* lists W10-2, W10-3, and W10-4 as "required on parallel roadways where there is an intersection within 100 feet of a crossing." Nonetheless, because the four signs are all geometric permutations of the same basic design, it can be surmised that all four are equally applicable to notifying drivers about short storage crossings depending on the specific geometrics.

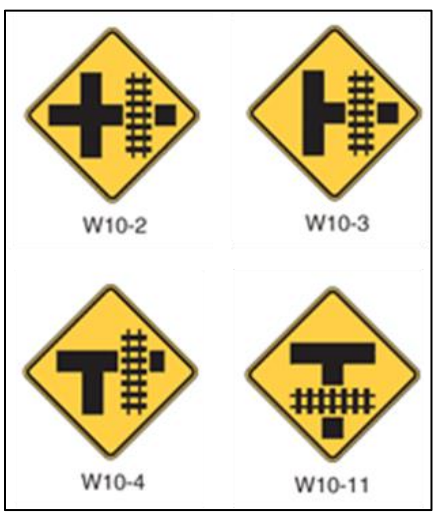


Figure 1. Examples of MUTCD Warning Signs for Short Storage HRGCs.

The MUTCD also contains two supplemental signs, W10-11a, and W10-11b, which give the driver more specific information about the actual storage space available. These signs, shown in

Figure 2, can be used upstream and downstream of the grade crossing, respectively, when CSD is insufficient to handle the design vehicle for the roadway.

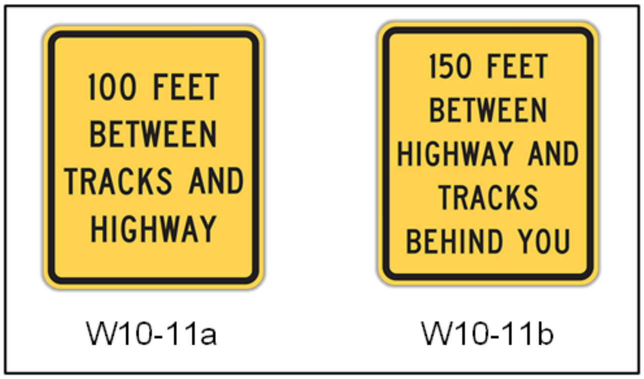


Figure 2. MUTCD Supplemental Storage Space Signs.

Despite the prominent placement of this signage in the MUTCD, there does not appear to have been substantive research, to date, into the effectiveness of this signage on communicating CSD issues to drivers or how this signage may be used in combination with other passive or active grade crossing treatments. According to the National Committee on Uniform Traffic Control Devices (NCUTCD), the W10-2, W10-3, and W10-4 signs have been used in the MUTCD since 1978, and the W10-11 signage first appeared in 2000. However, according to Rick Campbell (Co-Chair of the IACP sub-committee within NCUTCD; https://ncutcd.org/), he is "not aware of specific incidents that brought these signs into being."

2.3.2 Relationship between HRGC and Adjacent Intersections

One of the primary complicating factors for addressing safety concerns at HRGCs with inadequate CSD is the matter of the jurisdictional domain of the HRGC itself and the adjacent intersection. Often, different agencies are responsible for maintaining the roadway at the HRGC and the adjacent intersection. An example might be a county road HRGC that intersects a state highway shortly downstream. The challenge in this scenario is to what extent the agency responsible for the intersection can coordinate traffic control with the agency responsible for the HRGC roadway. A mismatch in expectations or desired treatment can result in most or all CSD warnings and traffic control taking place in the storage area itself, rather than upstream of the HRGC.

The MUTCD does provide some basic guidance about the extent to which an HRGC and an adjacent intersection should be operated as a single entity. For example, the W10-11 sign, which warns drivers of an approaching HRGC with short storage, can be placed up to 650 feet in advance of an HRGC, depending on the speed limit or 85th percentile speed of the HRGC roadway; see Table 1 for the full range of placement options. The implication here is that HRGCs that occur within the distance interval of a downstream intersection for the W10-11 sign placement should be considered a single functional entity for said intersection, at least in the context of ensuring safety and continuity of operations at both locations (see Table 1).

Table 1. Guidance for Advance Placement of W10-11 Warning Sign (Adapted from MUTCD, Table 2C-4).

Posted/85th Percentile Speed (mph)	Advance Placement Distance for Potential Stop Situation (Feet)
20	100
25	100
30	100
35	100
40	125
45	175
50	250
55	325
60	400
65	475
70	550
75	650

Unfortunately, study on the real-world department of transportation (DOT) practice in this area is extremely sparse. Much of the guidance around whether to treat intersections with adjacent HRGCs as two separate entities or as one larger intersection comes from literature associated with traffic signal preemption at HRGCs. It may be assumed that in the case of traffic signal preemption at HRGCs, the HRGC itself is functionally being treated as a component of the adjacent intersection, either through a single agency controlling both locations or through thorough coordination of operations across multiple agencies. In 2017, a comprehensive study of state DOT treatments for signalized intersections near HRGCs was completed, which included a direct survey of DOT practices (Stanos, 2017). While the question of the jurisdictional domain was not asked directly of DOTs in terms of how they handle intersections and adjacent HRGCs, some sense of the intersection and HRGC integration can be inferred from other responses. For example, at least one DOT incorporates advanced HRGC treatments, such as blank-out signs and turn restrictions, at the signalized intersection when the distance is 100 feet or less between the two. Multiple agencies—at least 12, based on a survey for the National Cooperative Highway Research Program (NCHRP) discussed in *NCHRP Report 507*—take a queuing-based approach to incorporate intersection and grade crossing controls as a single entity, with HRGCs further than 200 feet from the intersection being considered if queues routinely exceed the CSD. This scenario may be less common at passive HRGCs in low-traffic locations.

2.3.3 Roadway Conditions and Driver Characteristics

A large body of research has been conducted to assess risk factors for HRGC safety that pertain to driver behavior or operational characteristics of the roadway. Higher traffic volumes, higher train speeds, and a greater percentage of large trucks at the crossing have all been found to be associated with higher rates of fatal and serious injury crashes (Abraham et al., 1998; Lee et al., 2019; Millegan et al., 2009; Raub, 2009). Another characteristic found to be associated with higher serious injury crash rates includes driver age (Abraham et al., 1998; Raub, 2009).

Several studies have found the speed of the vehicle approaching the grade crossing to be significantly associated with crash risk; that is, higher levels of travel speed are found to be associated with an increased risk of a crash or greater crash severity (Lee et al., 2019). This may be due to the inability of the driver to accurately gauge safe stopping distances at higher speeds, along with the heightened difficulty of processing multiple external stimuli for correct decision-making.

Lerner (2012) went a step further, identifying four distinct zones in advance of a passive HRGC in which driver behavior must be considered. Figure 3 shows these zones. The zones are based on a combination of stopping sight distance and reaction times, with the exception of the hazard zone, which is spatially set at 15 feet on either side of the tracks.

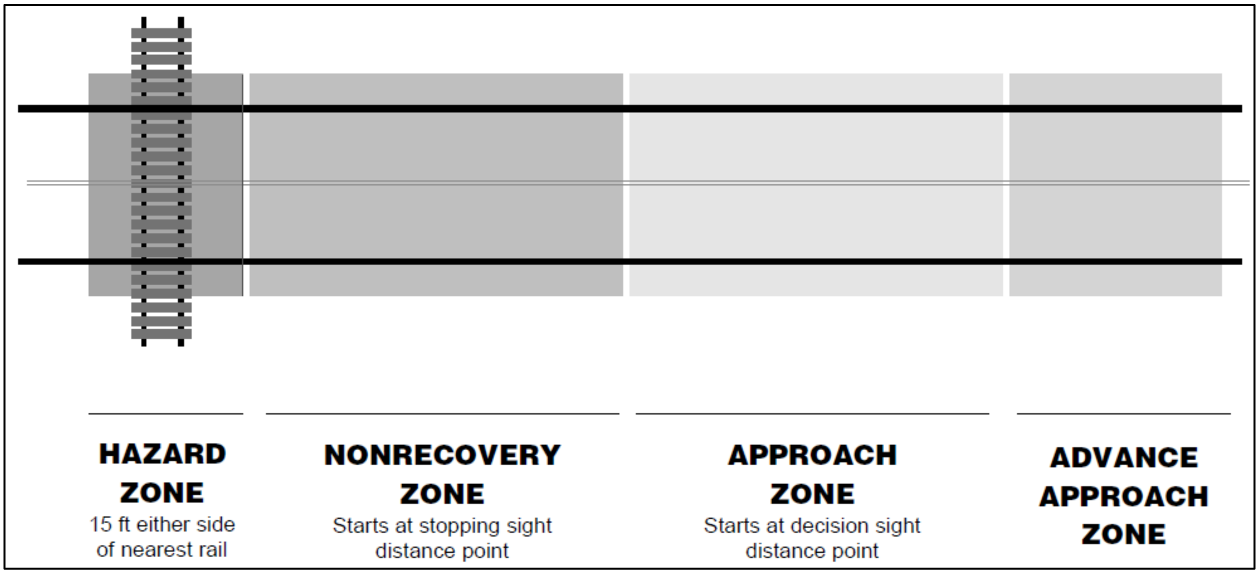


Figure 3. Grade Crossing Approach Zones (Source: Lerner (2002)).

Other studies have identified drivers' unawareness of oncoming trains as one of the leading problems for crashes on HRGCs. Many of these practices consist of various experiments around TCD modifications to address driver deficiencies explored in previous sections. For example, the Idaho DOT developed the IdaShield sign, which consists of red and white diamond grade strips mounted by a crossbuck. This sign was designed to reflect the lights from the oncoming train onto the drivers to make them more aware of the oncoming train (Dixon et al., 2014). The Massachusetts DOT achieved some success in addressing distracted driving by installing dynamic pavement markings ahead of the HRGCs (Knodler and Fisher, 2017). There is some evidence of the use of web-mapping applications as a cost-effective way to resolve visibility restrictions at HRGCs (Liu and Edwards, 2010).

Besides the presence of the HRGC itself, other issues can arise as drivers approach these locations. Research in Florida has identified wrong turns onto HRGCs as one of the major factors for crashes and found success in the use of advance direction signage and striping, dynamic envelope pavement markings, and other TCDs to reduce crashes (Lin et al., 2013). Some studies have also investigated a warning system for preventing such crashes. Shah (2005) used computer vision (CV) techniques for alarming vehicles and pedestrians if they were in the danger zone. Bien-Aime (2009) also deployed several such systems in an effort to increase train speeds in

North Carolina. Some studies have found that passive crossing treatments alone are of limited effectiveness in reducing HRGC crashes (Cooper et al., 2007; Cooper et al., 2012; Wilbur Smith Associates, 2001; Bien-Aime, 2009; Hellman and Ngamdung, 2010; Liu and Khattak, 2017). Most of these treatments are not specifically focused on short storage crossings.

2.3.4 Use of Naturalistic Driving Data

A promising area of current and future research in HRGC safety is the use of naturalistic driving study (NDS) data to ascertain more nuanced information about how drivers react to different grade-crossing treatments, including at locations with insufficient CSD. Several studies have laid a framework for best practices with respect to the selection of representative grade crossings and driver performance measures in this space (Dean et al., 2017; Muhire et al., 2017).

In particular, one set of studies from Michigan Tech University used a three-point scoring system to evaluate driver behavior in the NDS dataset as drivers approached a grade crossing (Salim et al., 2018). This scoring methodology uses a combination of head rotation and vehicle speed changes to assess whether drivers have adequately looked for a train and positioned their vehicle in such a way that it would be able to come to a stop if necessary. The points are awarded as follows:

- +1 point if the driver visually scans to the right
- +1 point if the driver visually scans to the left
- +1 point if the driver slows the vehicle down to an appropriate speed in preparation for a stop

The speed reduction must be performed in such a manner that would allow for adequate stopping time/distance prior to the crossing. The specific window of analysis for the NDS data was determined as twice the reaction time immediately preceding the “point of no return” for the crossing. Figure 4 provides a conceptual overview of this analysis window.

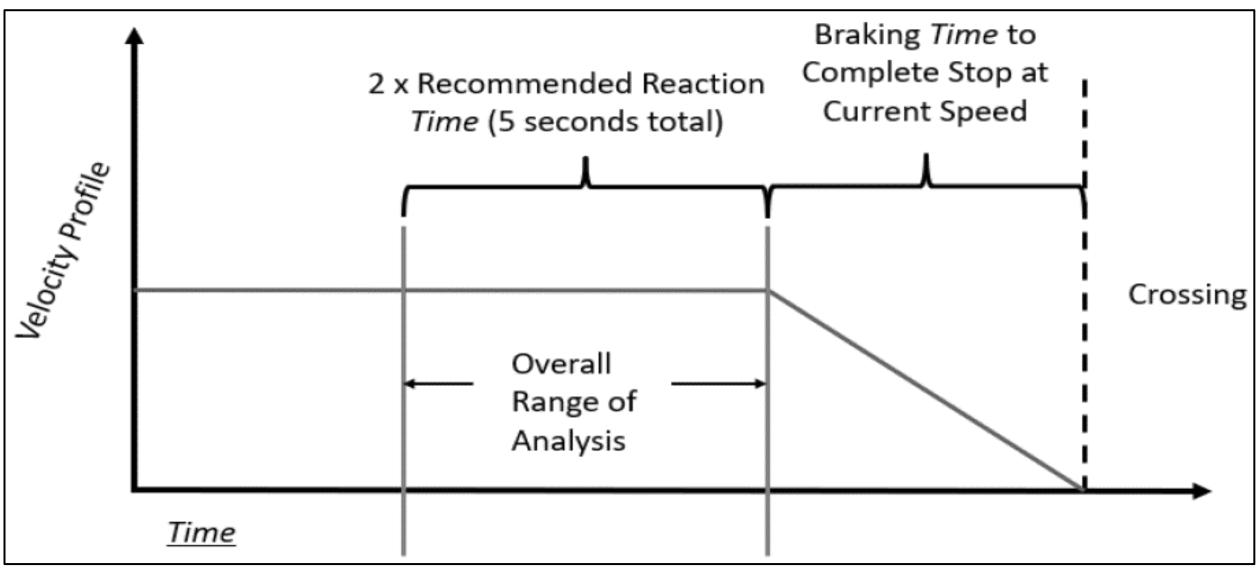


Figure 4. Concept of Michigan Tech University Analysis Window for NDS Scoring (Source: Salim et al., 2018).

2.4 SUMMARY OF INDIVIDUAL STATE PRACTICES

Table 2 shows various current state practices and proposed changes for improving the safety of HRGCs. These practices and supporting research are described in greater depth throughout the remainder of this chapter. Unfortunately, the available research on state practices associated with short storage HRGC locations is extremely limited, and even policies associated with passive crossing treatments do not appear to be as well codified as the active crossing treatments.

Table 2. Findings from State Practices.

State	Publication	Treatment	Major Findings
Arizona	Roberts et al. (2005)	Improve the efficiency of the early warning system (EWS). Potential treatments include: • Embedded EWS algorithm in traffic controller • Dynamic message sign • EWS sensors	• The current EWS is inefficient. The authors have provided guidelines for improving the EWS.
California	Cooper et al. (2012); Metrolink (2021)	Channelization devices, long-arm gates, and median separators. Photo enforcement if these treatments are not available.	• If the clear storage distance is more than 50 feet, and if it is possible to locate a pre-signal between the HRGC and the intersection, the pre-signal faces should be located such that the stop line of the pre-signal is at the same location as the railroad warning gate stop line. • Where the clear storage distance is inadequate to store the design vehicle clear of the minimum track clearance distance, consideration should be given to the installation of vehicle detection loops within the clear storage distance. This could prevent vehicles from being trapped within the minimum track clearance distance by extending the track clearance green time. Pre-signals shall display a red signal indication during the transition into the preemption control portion of a signal preemption sequence. This shall prohibit additional vehicles from crossing the railroad tracks.
Florida	Shah (2005)	Visual monitoring system	• CV techniques were deployed for alarming vehicles and pedestrians if they were in the danger zone.
Florida	Lin et al. (2013)	• Upstream: advance direction signage and striping • Downstream: guide signs and striping	• Incorrect turns onto railroad tracks are mainly caused by: • Confusing signs and pavement markings • Poor illumination • Global positioning system (GPS) device instruction to turn onto railroad tracks • HRGC skewness

State	Publication	Treatment	Major Findings
		• Critical zone: pavement gate markings, striping, or dynamic envelope pavement markings, bollards, and illumination • Night: illumination	• Distracted driving
Florida	Lin et al. (2019)	• Eliminate misleading pavement markings and signs • Replace continuous right-turn arrows with straight arrows plus guidance information on pavements • Straight arrow pavement markings with guidance information • Qwick Kurb installation	• The authors have identified several reasons for vehicles making incorrect turns into railroad tracks. • Straight arrows plus guidance information pavement markings are more effective in nighttime than daytime. • Reduced hesitation rates by 97% in night and 85% in daytime with a confidence level of 99.9%. • Qwick Kurb device installation resulted in complete elimination of incorrect U-turn observations.
Idaho	Dixon et al. (2014)	IdaShield (a reflective sign consisting of red and white diamond grade strips mounted by a crossbuck) sign	• The visibility and safety of the railway crossings increased by installing the pair of IdaShield and Yield signs. • Stop sign paired with IdaShield resulted in no significant result. • Recommended to include IdaShield signs in the national standards for nationwide implementation.
Illinois	Hellman and Ngamdung (2010)	Four-quadrant gate with inductive loop vehicle detection	• The proposed treatment increased the safety of the crossings but resulted in a delay of an estimated 38.5 minutes, or approximately 4 minutes per train. • The proposed treatment did not have a significant impact on the HRGC malfunctions duration or frequency.
Iowa	Iowa Department of Transportation (2007)		• Statistics and causes for derailment, HRGC crashes, and trespasser casualties were presented.
Iowa	Goepel et al. (2018)	Current Texas model	• Evaluated variables and approaches used by other states for determining HRGC safety improvement project priority.
Iowa	Cyr (2018)	Guardrail	• The authors recommended the use of guardrail despite an increase in the number of crashes because it resulted in a direct reduction in injury severity.

State	Publication	Treatment	Major Findings
Iowa, Illinois, Wisconsin, and Minnesota	Liu and Khattak (2017)	Four-quadrant gates	• Four-quadrant gates were observed to have fewer gate-violation crashes than two-quadrant gates.
Massachusetts (New England)	Knodler and Fisher (2017)	Dynamic envelope pavement markings on driver glance pattern	• Drivers may be in danger because of obstructions in the visibility triangle. • Crossings on curves or multi-lane roads may be difficult for driver to navigate. • The authors recommended an extra layer of safety that can be provided by the dynamic envelope pavement markings. This can prevent crashes particularly when the driver is distracted.
Minnesota	Preston et al. (2016)	Closed crossing	• About 91% of the HRGCs had no observed crashes in the 10-year study period. • Fatal-plus-injury crash density was very low—0.004 per HRGC per year. • The Federal Railroad Administration crash prediction model and the Texas hazard index performed poorly with the Minnesota accident data. • Multiple features like volume, speed, and design were frequently represented while analyzing crashes. Crash density increased drastically with the presence of many of these factors.
Nebraska	Khattak et al. (2007)	Flexible rubber and plastic barriers	• Installation of the barrier resulted in a decrease in the number of U-turns and number of gate rushes. • However, after installation of the barrier, the number of vehicles backing up or driving on the wrong side increased. • The need for maintenance of the centerline barriers decreased. Maintenance was done mainly because of abuse from roadway vehicles. • Pedestrian and bicyclist safety investigation is recommended for future research.
Nevada	Ryan et al. (2017)	HRGC hazard index model	• Strengths and weaknesses of the Nevada DOT's current HRGC safety prioritization procedures were reviewed. A revised hazard index model was proposed by evaluating similar indexes from other states.
New Jersey	Jeng et al. (2005)	Proposed a draft railroad section that educated driver about different signs, markings, lights, and gates and provided safety tips to the drivers	• Differences in driving behavior on active and passive crossings were observed. • Driver confusion should be prevented by carefully designing the TCDs used in the vicinity of HRGCs, such as traffic signal lights and Stop signs.

State	Publication	Treatment	Major Findings
			• Driver manuals should include instructions concerning operating a vehicle at light-rail crossings. • Driver perception and decision making in driving should be investigated using human factors approaches.
New Jersey	Liu and Edwards (2010)	Identification of potential problem locations using web-mapping applications, and then use of conventional survey procedures for identification of vegetation blockage and delineate trimming boundaries	• Concerns of driver visibility blockage on HRGCs are addressed using Google Earth/Bing Map.
New Jersey	New Jersey Department of Transportation and New Jersey Transit Corporation (2012)	Public awareness activities and police enforcement on high-risk crossings	• An extension of New Jersey Transit's Rail School Safety Program and revision of the New Jersey driver's education manual are recommended for including information on pedestrian and vehicular safety at HRGCs. • Identified high-risk crossings for deploying New Jersey Transit police.
North Carolina	Bien-Aime (2009)	Warning device, closing HRGCs, traffic channelization and four-quadrant gates, special signage, and video ticketing system	• At least 19 lives were estimated to be saved by the study. • Train speed increased to 79 mph. • Approximately 52% of the risk would be eliminated. • The North Carolina Sealed Corridor Program aims at improving or consolidating every HRGC, public and private, along the section of the designated Southeast High Speed Rail Corridor that runs through North Carolina between Raleigh, Greensboro, and Charlotte.
Ohio	Ludlow et al. (2020)	Implement temporary traffic control	• Devised and implemented an operation plan in suspended traffic at HRGCs due to temporary traffic control operations.
South Carolina	Wilbur Smith Associates (2001)	Adding gates, lights, signals, and barriers	• Several TCDs were implemented on two routes in several traffic scenarios. • With the implemented improvements, the train speed could be increased to 79 mph, which could be further increased by realigning the railroad.
Texas	Weissmann et al. (2012)		• Warrants were developed for active warning devices at low-volume HRGCs. • The authors recommend prioritizing active and passive crossings separately for generation of a more useful priority list.

2.4.1 Passive Grade Crossing Treatments

At passive HRGCs in general, including those with insufficient CSD for the downstream intersection, there is an issue of driver compliance with proper crossing procedures. This is especially problematic in crossing locations without active warning devices, traffic control signals, or gate arms because there is less opportunity to provide drivers with relevant information about the safety of the crossing before they find themselves in harm's way. Crossings with so-called "passive" treatments also rely primarily on the driver's respect for the warning devices, as opposed to crossings with gate arms and other active treatments, which physically prevent drivers from entering the crossing during unsafe periods. To this end, researchers explored the effectiveness of passive warning devices and treatments to improve driver awareness of general crossing conditions.

A comprehensive, national-level review of treatments at passive grade crossings was conducted as part of *NCHRP Report 470*; this study focused specifically on TCDs suitable for passive grade crossings and, in addition to conducting an original literature search, incorporated findings of previous NCHRP studies in the analysis, such as Schoppert and Hoyt (1968). While the original *NCHRP Report 470* study was completed in 2002, there does not appear to have been significant innovation since then with respect to passive grade crossing treatments.

A number of different types of passive treatment devices have been studied for safety effectiveness at HRGCs. Stop signs are a commonly used treatment, and one comprehensive national study by Millegan et al. (2009) found significantly lower crash rates at HRGCs treated only with Stop signs when compared to crossings treated only with crossbucks. Other studies have found similar benefits of Stop sign installation in addition to or instead of crossbucks (Yan et al., 2010). However, as *NCHRP Report 470* concluded in 2002, the use of Stop signs as a systematic treatment remains controversial due to the overall mixed findings in historical literature, a litany of methodological shortcomings that have plagued past research, and the concern that if drivers ignore stop signs at passive grade crossings, they will begin to lose respect for these TCDs at other locations (Lerner et al., 2002).

Yield signs are another passive treatment that has been extensively researched, although with a greater mix of results on effectiveness. Some studies have found rates of compliance with Yield signs to be especially low, like compliance rates with crossbucks (Liu et al., 2015), while others have found rates of compliance with Yield signs to be more in line with Stop signs in certain environments (Rys et al., 2012).

One relatively recent innovation in passive treatments has been dynamic envelope pavement markings. The FHWA study of dynamic envelope pavement markings found a statistically significant decrease in vehicles stopping on the tracks at grade crossings with the markings, but the markings did not significantly change driver behavior once a stopping decision was made. Drivers already stopped on the tracks were no more likely to try and quickly exit their position at grade crossings with the markings (Gabree et al., 2014). An additional limitation of this study is that it only included a single crossing, which contained several active warning devices. The extent to which these devices complement or enhance the dynamic envelope pavement markings is unclear currently. Despite the deficiency in research and field study around the use of dynamic envelope pavement markings, there is a strong logical case to be made for their effectiveness. Consequently, the Michigan Department of Transportation (MDOT) is currently moving forward with several test deployments of these markings, one of which is illustrated in Figure 5 and Figure 6. Table 3 lists the locations with exclusive zone pavement markings in Michigan.

Figure 5. Dynamic Envelop Crosshatching at M96 and 28th Street (Source: MDOT).

Figure 6. Dynamic Envelop Crosshatching at M96 and 30th Street (Source: MDOT).

Table 3. Exclusion Zone Pavement Markings in Michigan (Source: MDOT).

Intersection	Signalized	Railroad Pre-signal	Distance from Rail line to Railroad Stop Bar (Feet)	Dynamic Envelope Pavement Markings	Notes
M-96 at 28th Street	No	N/A	25	Yes	T intersection
M-96 at 30th Street	No	N/A	25	Yes	
M-96 at 33rd Street	Yes	Yes	21	Yes	T intersection
M-96 at 35th Street	Yes	Yes	91	No	
M-96 at Burgess	No	N/A	32 NB, 27 SB	No	Skewed crossing
M-96 at McCollum Drive	No	N/A	19.5	Yes	T intersection. Skewed crossing. New Kalamazoo River Trail crossing at this intersection.

The addition of flashing strobes to existing signage has also seen limited usage in past studies (Noyce & Fambro, 1998). Certain extensions of the passive grade crossing treatment concept, such as including a separate in-vehicle audible alert, have shown some promising results in enhancing driver compliance (Landry et al., 2016). A summary of the main types of TCDs considered in previous literature has been adapted from *NCHRP Report 470* and is shown in Table 4 (Lerner et al., 2002).

Table 4. Summary of TCD Research Findings from *NCHRP Report 470*.

Traffic Control Device	Expected Outcomes	Summary of Findings
Enhanced crossbuck design	• Increased conspicuity of crossing • Enhanced comprehension of driver responsibilities • Slower approach speeds • Improved driver search	• Drivers generally understand the crossbuck meaning, but enhancements to the standard format do not improve an understanding of responsibility • Nearly all previous research has shown that these designs may improve the level of visual information for the driver but do not significantly improve compliance
Improved reflectivity of existing TCDs	• Increased conspicuity during adverse conditions • Improve visibility of skewed-angle approaches • Better judgment of crossing distance and sign placement • Better detection of trains (via flicker effect for opposite-side TCDs)	• Some improved awareness of trains via flicker effect • Full-length reflectivity improves conspicuity and relative distance assessments • Some long-term improvements in driver behaviors • Roadside delineators can improve awareness of the approach
Addition of intersection TCDs at crossing	• Better comprehension of responsibility • Slower speeds and greater search	• Stop signs reduce speeds but suffer from high rates of non-compliance • Yield signs improve driver comprehension; mixed results on compliance

Traffic Control Device	Expected Outcomes	Summary of Findings
Addition of crossing information	• Convey additional items of information about the crossing that are relevant • Improve conspicuity of the crossing	• Limited findings that additional information signs should be placed in advance of the crossing
Advance information about active versus passive crossing type	• Inform driver of different responsibilities at each crossing • Slower speeds and greater search • Counteract beliefs that all crossings are active	• Little to no empirical work on effectiveness
Addition of advance information signs	• Alert drivers to the crossing • Guide driver information processing • Earlier alert for potential hazards	• Little empirical evidence to support systematic implementation • Existing studies suffer from limited sites or other methodological flaws • More commonly used in European countries
Vehicle-activated signals	• Increase conspicuity of signage in adverse conditions	• Signage may increase driver attention but add confusion about the meaning • Mixed results on long-term effectiveness or potential adverse reactions
Pavement markings	• Redundant visual cues for crossing location • Indication of hazard zone	• Limited empirical research
Surface treatments	• Indication of hazard zone	• Limited empirical research

A variety of different passive grade crossing treatments were evaluated by the *NCHRP Report 470* research team. Table 5 and Table 6 provide a replication of these results for warning signs in advance of the crossing, and Table 7 and Table 8 are for warning signs at the crossing itself. Details on active grade crossings can be found in the MDOT *Guidelines for Highway–Railroad Grade Crossings* (MDOT, 2017). Figure 7 depicts different advance warning signs for passive crossings both at the crossing and in advance of the crossing.

Table 5. Effectiveness of Different Advance Warning Signs for Passive Crossings, Mean Comprehension Scores (Source: Lerner, 2002).

Variable	Category	Sign 1	Sign 2	Sign 3	Sign 4	Sign 5	Sign 6	Sign 7	Sign 8	Sign 9	Sign 10	Sign 11	Sign 12
Overall	--	(3.42*)	3.64	3.02	4.11	3.17	4.23	3.97	3.86	3.33	3.29	3.77	3.50
Age	Young	--	3.41	4.12	4.06	2.59	4.24	3.76	3.70	3.47	3.24	3.41	3.29
Age	Middle	--	3.77	3.04	4.19	3.65	4.42	4.27	4.00	4.38	3.62	4.04	3.96
Age	Old	--	3.60	2.30	4.00	3.30	3.95	3.70	3.76	1.95	3.20	3.65	3.00
Gender	Male	--	3.70	3.07	3.96	3.26	4.19	3.89	3.75	3.52	3.37	3.89	3.41
Gender	Female	--	3.56	3.11	4.19	3.25	4.25	4.00	3.93	3.25	3.39	3.64	3.53
Location	Columbus, Georgia	--	4.10	3.50	4.90	3.20	4.90	4.50	4.30	4.50	3.60	4.00	4.00
Location	Hagerstown, Maryland	--	3.74	2.74	4.00	3.53	4.05	3.89	3.83	3.21	3.47	4.00	3.58
Location	Rockville, Maryland	--	3.42	2.63	3.95	3.00	3.95	3.84	3.64	2.95	3.53	3.42	3.11
Location	Madison, Wisconsin	--	3.40	3.87	3.87	3.27	4.33	3.80	3.67	3.33	2.93	3.67	3.47
Percent Dangerous Confusion	--	--	0.0	20.6	3.2	7.9	0.0	6.3	0.0	12.7	3.2	3.2	1.6

*Note: For list of signs, see Figure 7; * indicates mean comprehension scores.*

Table 6. Effectiveness of Different Advance Warning Signs for Passive Crossings, Percent Indicating That Sign Meant (Source: Lerner, 2002).

Countermeasure	Sign 1	Sign 2	Sign 3	Sign 4	Sign 5	Sign 6	Sign 7	Sign 8	Sign 9	Sign 10	Sign 11	Sign 12
Active warning	--	3.0*	7.6	9.1	10.6	3.0	4.5	3.0	6.1	3.0	6.1	3.0
No warning	--	15.2	68.2	84.8	10.6	83.3	84.8	19.7	78.8	7.6	9.1	6.1
Some behavior req.	--	93.9	69.7	95.5	86.4	93.9	89.4	78.8	78.8	81.8	86.4	89.4
Yield	--	80.3	7.6	10.6	4.5	10.6	7.6	10.6	9.1	78.8	6.1	83.3
Stop for tracks	--	16.7	22.7	27.3	6.1	37.9	27.3	15.2	10.6	12.1	84.8	15.2
Stop if train	--	27.3	10.6	19.7	24.2	19.7	12.1	15.2	19.7	27.3	7.6	18.2
Stop if signal/gate	--	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*Note: For list of signs, see Figure 7; * indicates percent representing that sign meant.*

Table 7. Effectiveness of Different Warning Signs for Passive Crossings at the Crossing Itself, Mean Comprehension Scores (Source: Lerner, 2002).

Variable	Category	At Crossing (A) (Sign 13)	At Crossing (B) (Sign 14)	At crossing (C) (Sign 15)	At Crossing (D) (Sign 16)	At Crossing (E) (Sign 17)	At Crossing (F) (Sign 18)	At Crossing (G) (Sign 19)	At Crossing (H) (Sign 20)	At Crossing (I) (Sign 21)	At Crossing (J) (Sign 22)
Overall	--	4.21*	3.97	3.83	3.91	4.00	3.06	3.86	3.94	3.85	2.91
Age	Young	4.12	3.88	3.76	3.65	4.00	2.94	3.65	3.47	3.53	3.06
Age	Middle	4.35	4.12	4.12	4.04	4.12	3.42	3.88	4.15	4.00	2.92
Age	Old	4.15	3.85	3.50	3.95	3.85	2.75	4.00	4.05	3.90	2.79
Gender	Male	4.22	4.00	3.70	3.88	3.81	3.19	3.85	3.93	3.85	2.81
Gender	Female	4.22	3.94	3.92	3.92	4.14	3.00	3.86	3.94	3.83	3.00
Location	Columbus, Georgia	4.00	4.00	4.00	4.00	4.00	2.80	4.00	4.10	3.90	2.70
Location	Hagerstown, Maryland	4.37	3.89	3.74	3.89	4.05	3.16	4.05	4.26	4.05	2.72
Location	Rockville, Maryland	4.16	3.89	3.79	3.89	3.74	3.26	3.58	3.68	3.68	3.11
Location	Madison, Wisconsin	4.27	4.13	3.87	3.87	4.27	2.93	3.87	3.73	3.73	3.07
Percent Dangerous Confusion	--	1.6	4.8	3.2	1.6	0.0	11.1	1.6	3.2	1.6	12.9

*Note: For list of signs, see Figure 7; * indicates mean comprehension scores.*

Table 8. Effectiveness of Different Warning Signs for Passive Crossings at the Crossing Itself, Percent Indicating That Sign Meant (Source: Lerner, 2002).

Countermeasure	At Crossing (A) (Sign 13)	At Crossing (B) (Sign 14)	At crossing (C) (Sign 15)	At Crossing (D) (Sign 16)	At Crossing (E) (Sign 17)	At Crossing (F) (Sign 18)	At Crossing (G) (Sign 19)	At Crossing (H) (Sign 20)	At Crossing (I) (Sign 21)	At Crossing (J) (Sign 22)
Active Warning	4.5*	3.0	1.5	1.5	0.0	4.5	0.0	4.5	4.5	0.0
No Warning	25.8	24.2	9.1	18.2	18.2	10.6	12.1	16.7	10.6	4.5
Some Behavior Req.	97.0	92.4	93.9	86.4	86.4	77.3	87.9	88.9	89.4	74.2
Yield	15.2	71.2	77.3	7.6	78.8	74.2	74.2	72.7	7.6	1.5
Stop for tracks	31.8	21.2	17.9	98.5	16.7	6.1	13.6	25.8	100.0	100.0
Stop if train	21.2	36.4	31.3	1.5	31.8	22.7	37.9	31.8	0.0	0.0
Stop if signal/gate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*Note: For list of signs, see Figure 7; * indicates percent representing that sign meant.*

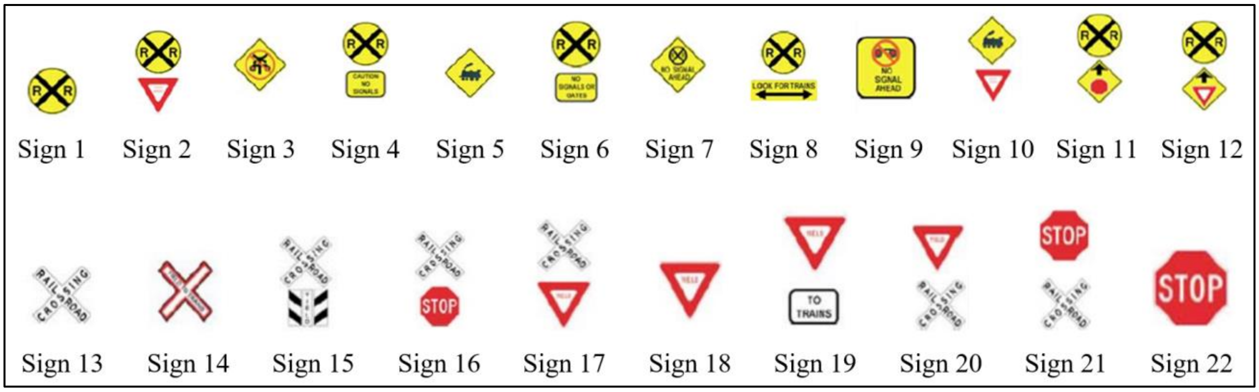


Figure 7. Different Advance Warning Signs for Passive Crossings

2.4.2 Selection of HRGCs for Treatment

Implementation of some of the previously mentioned TCDs for HRGCs can be very costly. In particular, systemic passive treatments can potentially include thousands of HRGCs, and more complex passive or hybrid passive-active treatments face additional issues of ongoing maintenance and repair, along with the need for public-facing and defensible processes to justify their installation. Therefore, a few papers have devised a strategy for determining the priority list for HRGCs for fund allocation by transportation agencies. However, Gibson et al. (2015) established an HRGC reconstruction and/or rehabilitation priority mechanism. Weissmann et al. (2012) also developed warrants for active warning devices at low-volume HRGCs and recommended prioritizing active and passive crossings separately.

Additionally, some studies have recommended an equal focus on driver and agency education associated with highlighting dangerous HRGC locations. For this purpose, either manuals are created or changes in the existing models are proposed. For example, the New Jersey Department of Transportation and the New Jersey Transit Corporation (2012) recommended a manual for driver awareness on such crossings and recommended deploying New Jersey Transit police on high-risk crossings. Malloy et al. (2014) developed a manual for instructing users to execute the three main HRGC rehabilitation phases:

- Pre-project administration
- Rehabilitation activities
- Post-project administration

Ryan et al. (2017) analyzed the strengths and weaknesses of Nevada's current HRGC safety prioritization procedures and proposed a revised hazard index model. Jeng et al. (2005) proposed a draft railroad section that educated drivers about different signs, markings, lights, and gates and provided safety tips to drivers. In a similar study by Goepel et al. (2018), variables and approaches used by other states were inspected to determine HRGC safety improvement project priority. The authors selected the current Texas model for implementation in their state. However, Preston et al. (2016) indicated that the Texas hazard index performed poorly with the Minnesota accident data. This indicates that no one model can be used in all states because conditions in different states vary vastly.

2.5 SUMMARY AND CONCLUSIONS

From the current review of the literature, several key findings and recommendations for MDOT come to light:

- There is a poor level of consistency in the selection of treatments for different grade-crossing scenarios. The development of a data-driven decision process based on local traffic conditions, existing geometry, and other site factors would be of significant value to ensure that systemic treatments have their intended effect.
- While the number of alternatives available for improving grade crossing safety is vast, much of the research over the past 10 years has focused on improving safety using active warning devices. There has been limited work on developing a deeper understanding of passive grade-crossing treatments or risks.
- Little research has been conducted to empirically evaluate the effectiveness of different treatments for grade crossings with insufficient CSD, outside of traffic signal preemption strategies. The use of dynamic envelop pavement markings shows some early promise, but the initial findings are limited in scope. MDOT would be well served by developing a formal evaluation process for this treatment in a variety of contexts.
- The unique situation of insufficient CSD at a passive grade crossing places a significant burden on the driver. In addition to the extra visual and cognitive tasks associated with decision making at an ordinary passive grade crossing, the driver may also need to consider the intersection ahead of the grade crossing and make a quick judgment about which side of the grade crossing to stop on.
- There is little documented practice from state DOTs on when to consider a passive HRGC and a downstream intersection as a single versus separate entities. The MUTCD and some anecdotal practitioner evidence provide limited guidance based on spacing, but the extent to which this is enforced in practice is unknown.

Based on these findings, some general principles that should be adhered to when installing TCDs at HRGCs with insufficient CSD include:

- Provide drivers with early notice of the unique hazards at the crossing.
- Consider relying more heavily on existing MUTCD guidance when attempting to treat the passive HRGC and adjacent intersection as a single entity. All agencies with jurisdiction at these locations should work to ensure consistent and continuous traffic control, especially in advance of the HRGC.
- Make it clear to drivers that the responsibility lies with them to ensure their own safety.
- Make it clear what decision(s) needs to be made on the part of the drivers. For example, does the driver always need to wait upstream of the HRGC before proceeding through the intersection, or is the CSD sufficient to accommodate only specific vehicle types?
- Reduce the consequence of driver error.

Additionally, quasi-active treatments, such as solar-activated warning devices, or in-vehicle communications may be considered for effectiveness evaluation. There is some research that shows that over time drivers may become desensitized to even the most effective passive treatments unless there is some way to provide context to the driver about the relative risks of each crossing event.

CHAPTER 3. SITE SELECTION, DATA COLLECTION, AND ANALYSIS

The chapter describes the process of data collection and exploratory data analysis. In addition, safety evaluation analysis using the New Hampshire index and *NCHRP Report 50* formula is also discussed in this chapter.

3.1 SHORT STORAGE LOCATIONS

Table 9 lists the number of crossings, count of crashes, and average exposure by different crossing types. Although short storage crossings (CT3 and CT4) are 32 percent of all crossing types, these crossings represent 39 percent of all crashes.

Table 9. Crossing-Related Data.

Type	Crossing Type	Count of Crossings	Sum of Crashes (2015–2019)	Average Exposure (2015–2019)
Long storage locations	High-volume roadway intersection more than 500 feet away with a stop condition that is known to cause traffic backups with or without interconnection (Crossing Type 1 [CT1])	22	1	4,685
Long storage locations	More than 500 feet away without traffic-backup issues or just do not apply (CT2)	3,124	139	2,793
Short storage locations	Less than 500 feet to a roadway intersection and that roadway intersection has a stop condition but does not have traffic control signals (CT3)	1,129	48	1,173
Short storage locations	Less than 500 feet to a roadway intersection and that roadway intersection has traffic-control signals (CT4)	335	42	6,619
	Total	4,610	230	2,684

Table 10 lists the distance from the crossing by different crossing types. With the available distance information, around 84 percent of the short storage crossings have a 300-foot distance, and 28 percent of these crossings have a 50-foot distance.

Table 10. Distance by Crossing Types.

Distance (Feet)	CT3 Crossing	CT3 Crash	CT4 Crossing	CT4 Crash	CT2 Crossing	CT2 Crash	CT1 Crossing	CT1 Crash
50	94	1	5	0	-	-	-	-
100	81	2	3	0	-	-	-	-
150	41	-	2	-	-	-	-	-
200	29	1	3	0	-	-	-	-
250	23	1	2	0	-	-	-	-
300	30	0	6	0	-	-	-	-
310	1	1	-	0	-	-	-	-

Distance (Feet)	CT3 Crossing	CT3 Crash	CT4 Crossing	CT4 Crash	CT2 Crossing	CT2 Crash	CT1 Crossing	CT1 Crash
350	16	0	-	-	-	-	-	-
400	21	0	2	-	-	-	-	-
450	13	0	3	0	-	-	-	-
500	4	3	1	1	-	-	-	-
600	-	0	-	0	-	-	1	-
1,000	-	-	-	-	-	-	1	0
NA	776	39	308	41	3,124	139	20	1
Total	1,129	48	335	42	3,124	139	22	1

The highway speed near the crossing is a significant contributor to crossing-related crashes. Based on the available information, CT3 crossings are associated with 25-mph or 44-mph roadways. For CT4, 25-mph and 30-mph roadways are higher in counts (see Table 11).

Table 11. Highway Speed by Crossing Types.

Highway Speed (mph)	CT3	CT4	CT2	CT1
25	21	17	0	23
30	2	9	0	15
35	4	5	0	19
40	0	4	0	2
45	0	3	1	18
50	0	1	0	5
55	21	3	0	57

Figure 8 shows the spatial distribution of the crashes across Michigan, also by injury severity. Generally, the crash frequency was closely related to population centers within the state. The highest number of crashes occurred in southeast Michigan (the Detroit area), and the lowest number occurred in the sparsely populated northern part of the state. A notable exception is Monroe County, south of Detroit, in the far southeast corner of the state. Despite being the 16th-largest county in Michigan by population, Monroe County experienced the second-highest number of “no injury” HRGC crashes. This may be partly explained by the high level of industry and train traffic in this county relative to the rest of the state; Monroe County is positioned on the western edge of Lake Erie—a key freight shipping corridor—and sits squarely between the industrial centers of Detroit and Toledo, Ohio.

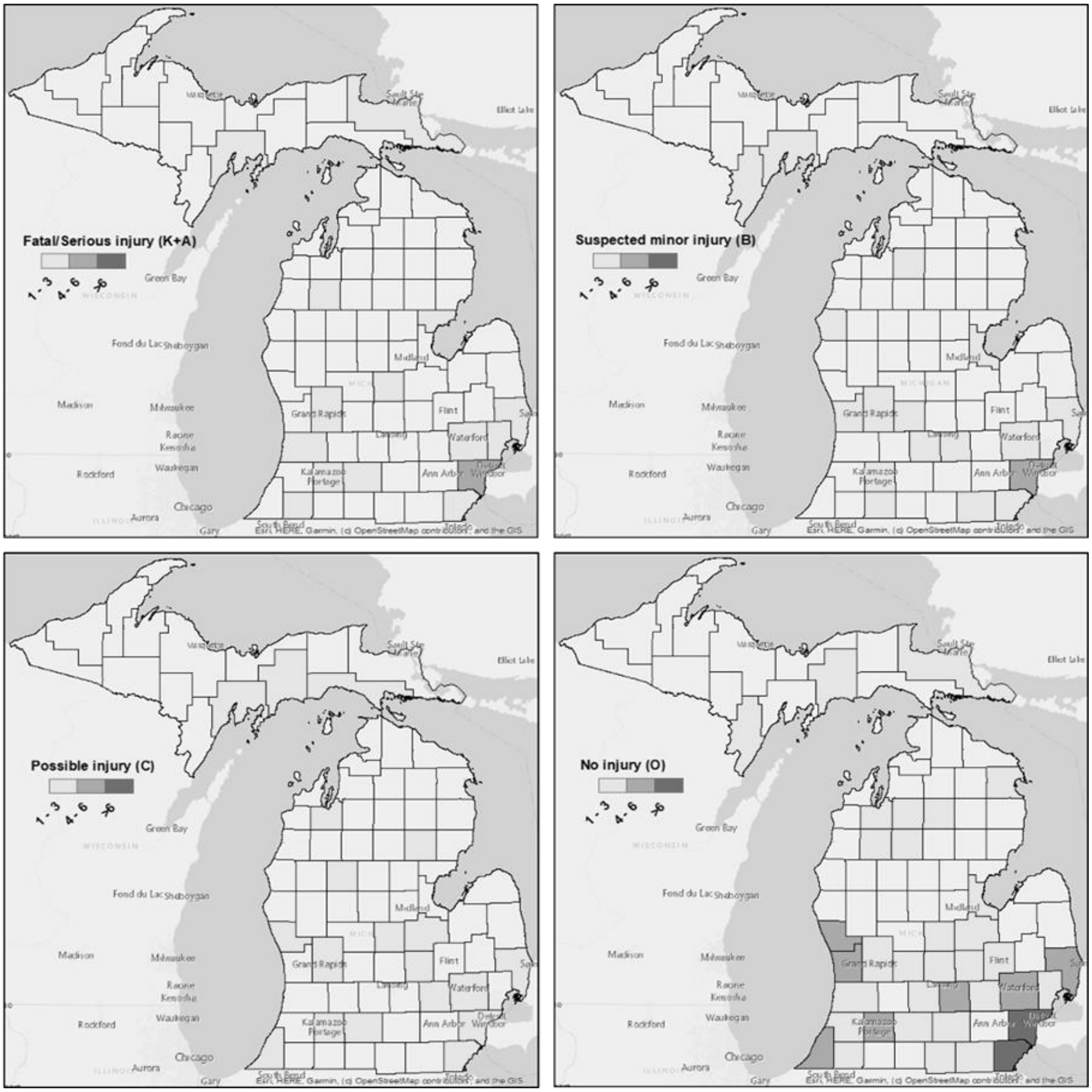


Figure 8. Train-Involved Crashes of Different Injury Severity within 500 Feet of HRGC by Counties in Michigan.

To understand the crash patterns, it is important to perform descriptive statistics on crash data. The variables used for the analysis include a wide range of information related to human, vehicular, environmental, and roadway/crossing design factors that could influence the likelihood of a crash. Table 12 shows the descriptive statistics of all variables and the percentage of total crashes of different levels of injury severity. The injury severity of crashes is classified into four levels:

- Fatal and incapacitating injury (K+A)
- Non-incapacitating injury (B)
- Minor or possible injury (C)
- No injury

Table 12. Descriptive Statistics of Short Storage Crossing Crashes.

Variable	Category	K+A	B	C	O	Total
VTYPE (Vehicle Type)	Passenger car/SUV	77.2	57.1	65.4	75	71.7
VTYPE (Vehicle Type)	Pickup truck	18.2	19.1	26.9	8.7	13.9
VTYPE (Vehicle Type)	Truck/bus	0	9.5	3.8	10.5	8.1
VTYPE (Vehicle Type)	Other	4.6	14.3	3.9	5.8	6.3
DV (Driver Violation)	Disregarded traffic control	27.3	38.1	23.1	20.2	23.7
DV (Driver Violation)	Failure to yield/stop	45.5	38.1	53.9	47.1	46.8
DV (Driver Violation)	Speeding/reckless driving	22.7	9.5	11.5	13.5	13.8
DV (Driver Violation)	None	4.5	9.5	7.7	5.7	6.4
DV (Driver Violation)	Other	0	4.8	3.8	13.5	9.3
VNUM (Number of Lanes)	Two	72.7	95.2	84.6	78.8	80.9
VNUM (Number of Lanes)	Three	0	0	0	7.7	4.6
VNUM (Number of Lanes)	Four or more	27.3	4.8	15.4	13.5	14.5
PSL (Posted Speed Limit)	< 35 mph	18.2	38.1	30.8	38.5	34.7
PSL (Posted Speed Limit)	35–55 mph	45.4	28.6	26.9	31.7	32.4
PSL (Posted Speed Limit)	55+ mph	36.4	33.3	42.3	29.8	32.9
WEATHER (Weather Condition)	Clear	40.9	71.4	53.8	60.6	58.4
WEATHER (Weather Condition)	Cloudy	36.4	19.1	23.1	15.4	19.7
WEATHER (Weather Condition)	Inclement	22.7	9.5	23.1	24	21.9
LGT (Lighting Condition)	Dark lighted	31.8	19.1	7.7	18.3	18.5
LGT (Lighting Condition)	Dark unlighted	9.1	9.5	19.2	18.3	16.2
LGT (Lighting Condition)	Daylight	59.1	71.4	73.1	63.4	65.3
ALCDRG (Alcohol or Drug Use by Driver)	No	59.1	76.2	88.5	93.3	86.1
ALCDRG (Alcohol or Drug Use by Driver)	Yes	40.9	23.8	11.5	6.7	13.9
VTRAFWAY (Roadway Type)	Divided	0	4.8	3.9	7.7	5.8
VTRAFWAY (Roadway Type)	Not divided	100	95.2	96.1	92.3	94.2
XANGLE (Crossing Angle)	0–29 degree	0	0	0	5.8	3.5
XANGLE (Crossing Angle)	30–59 degree	18.2	23.8	15.4	22.1	20.8
XANGLE (Crossing Angle)	60–90 degree	81.8	76.2	84.6	72.1	75.7
ROUTE (Route Type)	Local	95.5	95.2	96.2	80.8	86.7
ROUTE (Route Type)	State	4.5	4.8	3.8	19.2	13.3
AGE (Age of Driver)	Young	27.3	23.8	26.9	18.3	21.4
AGE (Age of Driver)	Adults	54.5	57.1	53.9	56.7	56.1
AGE (Age of Driver)	Senior	18.2	19.1	19.2	25	22.5
PSLPOST (Posted Speed Limit)	Not posted	36.4	23.8	50	34.6	35.8
PSLPOST (Posted Speed Limit)	Posted	63.6	76.2	50	65.4	64.2
TRFCNTRL (Traffic Control)	Signal	45.5	38.1	34.6	37.5	38.2
TRFCNTRL (Traffic Control)	Stop sign	13.6	19.1	19.2	14.4	15.5

Variable	Category	K+A	B	C	O	Total
TRFCNTRL (Traffic Control)	Stop with flashing beacon	4.6	9.5	11.5	8.7	8.7
TRFCNTRL (Traffic Control)	Yield sign	13.6	9.5	15.5	7.7	9.8
TRFCNTRL (Traffic Control)	None	22.7	23.8	19.2	31.7	27.8
RDCNDT (Road Condition)	Dry	63.6	76.2	46.1	60.6	60.7
RDCNDT (Road Condition)	Not dry	36.4	23.8	53.9	39.4	39.3
SEASON (Seasonal Factor)	Autumn	27.3	28.6	42.3	23.1	27.2
SEASON (Seasonal Factor)	Spring	13.6	28.6	19.2	19.2	19.7
SEASON (Seasonal Factor)	Summer	18.2	33.3	11.5	24	22.5
SEASON (Seasonal Factor)	Winter	40.9	9.5	26.9	33.7	30.6
WKD (Crash Day)	Weekdays	72.7	71.4	80.8	75	75.1
WKD (Crash Day)	Weekends	27.3	28.6	19.2	25	24.9
LNDUSE (Land Use Type)	Commercial	9.1	28.6	26.9	26.9	24.9
LNDUSE (Land Use Type)	Farm/open	40.9	57.1	38.5	29.8	35.8
LNDUSE (Land Use Type)	Industrial	36.4	0	11.5	18.3	17.3
LNDUSE (Land Use Type)	Residential	13.6	14.3	23.1	24.1	21.4
LNDUSE (Land Use Type)	Unknown	0	0	0	0.9	0.6
ADT (Average Daily Traffic)	High	36.4	28.6	19.2	28.9	28.3
ADT (Average Daily Traffic)	Low	22.7	38.1	50	25.9	30.6
ADT (Average Daily Traffic)	Medium	40.9	33.3	30.8	45.2	41

Note: K = fatal, A = incapacitating injury, B = non-incapacitating injury, C = minor injury, O = no injury or property damage only

Most of the crashes (71.68 percent) involved passenger vehicle type (VTYPE). Failure to yield or stop (46.82 percent) and disregarding traffic control signals (23.70 percent) were common driver violations (DV). More than 80 percent of crashes occurred on two-lane roadways. The proportion of crashes that occurred on roadways with a posted speed limit (PSL) less than 35 mph, 35–55 mph, and greater than 55 mph were almost equal. However, most of the fatal/serious injury crashes (K+A) occurred on roadways with a speed limit of 35–55 mph (45.45 percent). About 42 percent of crashes occurred in cloudy and inclement weather conditions combined. About 40 percent of K+A crashes were drug or alcohol related, while this category makes up about 13 percent of total crashes. The percentage of crashes at crossings with the smallest crossing angle (XANGLE) greater than 60 degrees was 75 percent. Most crashes occurred during winter (30.6 percent) and autumn (27.2 percent) seasons. Also, 38.2 percent of crashes occurred at signal-controlled crossings. The frequency distribution of crashes at different injury severity levels shows that weather, speeding, and drug or alcohol use (ALCDRG) could influence fatal and serious injury (K+A) crashes.

3.2 SAFETY EVALUATION OF SHORT STORAGE CROSSINGS

Although there are many safety indices, they can largely be broken down into two categories. The first category is for relative hazard indices, which compute a hazard or safety score based on a variety of geometric and operational factors. The computed hazard score does not convey an absolute sense of hazard or risk; it is only by comparing the hazard score of two or more HRGCs that a risk assessment can be made.

The second category of safety indices is indices derived using the collision prediction method, which predicts the number of collisions expected to occur at an HRGC based on similar variables as those used for the relative hazard computations. Unlike the relative hazard method, however, the collision prediction method is able to qualify the safety performance of an HRGC in terms of absolute risk, that is, the number of expected crashes.

The most common relative hazard index is the New Hampshire index, while the most common collision prediction method is the crash prediction model developed in *NCHRP Report 50*.

3.2.1 New Hampshire Index

This index can be written as:

$$\text{New Hampshire Index} = V \times T \times P_f \quad (1)$$

Where:

V = annual average daily traffic (AADT)

T = average daily train traffic

P_f = protection factor (see Table 13)

MDOT adjusted the National Highway Institute (NHI) factors by adding new categories to account for 12-inch lenses.

Table 13. Protection Factors for Different Treatments (Source: MDOT, 2017).

Type	**Treatments**	P_f
Passive devices	Crossbuck sign with or without a Yield sign	1.00
Passive devices	Crossbuck sign with a Stop sign	0.80
Passive devices	Stop and flag procedures	0.75
Active devices	Flashing-light signals with all 8-inch lenses	0.33
Active devices	Flashing-light signals with all 12-inch lenses	0.30
Active devices	Flashing-light signals with cantilever arms and all 8-inch lenses	0.27
Active devices	Flashing-light signals with cantilever arms and all 12-inch lenses	0.24
Active devices	Flashing-light signals with roadway gates and all 8-inch lenses	0.11
Active devices	Flashing-light signals with roadway gates and all 12-inch lenses	0.10
Active devices	Flashing-light signals with cantilever arms, roadway gates, and all 8-inch lenses	0.09
Active devices	Flashing-light signals with cantilever arms, roadway gates, and all 12-inch lenses	0.08
Traffic signal interconnections	Any passive warning device with a traffic signal interconnection	0.10
Traffic signal interconnections	Any passive warning device with a traffic signal interconnection	0.05

3.2.2 NCHRP Report 50 Crash Prediction Model

The crash prediction model can be written as:

Expected crash frequency = $A \times B \times T$ (2)

Where:

A = factor for AADT (see Table 14)

B = factor for existing warning devices (see Table 10)

T = current trains per day

Future AADT can be calculated as:

Future AADT value = $Current\ AADT \times (1 + i)^n$ (3)

Where:

i = expected growth factor

n = number of years

Table 14. Factors for AADT and Warning Devices (Source: MDOT, 2017).

Factor	AADT/Treatments	Values
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	250	0.000347
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	500	0.000694
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	1000	0.001377
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	2000	0.002627
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	3000	0.003981
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	4000	0.005208
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	5000	0.006516
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	6000	0.007720
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	7000	0.009005
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	8000	0.010278
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	9000	0.011435
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	10000	0.012674
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	12000	0.015012
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	14000	0.017315
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	16000	0.019549
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	18000	0.021736
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	20000	0.023877
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	25000	0.029051
Factors for 10-year AADT in vehicle per day (vpd) (Factor A)	30000	0.034757
Factor for existing warning devices (Factor B)	Crossbucks, highway volume < 500 vpd	3.89
Factor for existing warning devices (Factor B)	Crossbucks, urban	3.06
Factor for existing warning devices (Factor B)	Crossbucks, rural	3.08

Factor	AADT/Treatments	Values
Factor for existing warning devices (Factor B)	Stop signs, highway volume < 500 vpd	4.51
Factor for existing warning devices (Factor B)	Stop signs	1.15
Factor for existing warning devices (Factor B)	Flashing lights, urban	0.23
Factor for existing warning devices (Factor B)	Flashing lights, rural	0.93
Factor for existing warning devices (Factor B)	Gates, urban	0.08
Factor for existing warning devices (Factor B)	Gates, rural	0.19

Table 15 lists the combined safety evaluations by the crossing types using both NHI and NCHRP report formulas.

Table 15. Safety Evaluation of Michigan Rail Crossings.

Type	Crossing Type	Average of NHI	Sum of Expected Crash Frequency
Long Storage Crossings	High-volume roadway intersection more than 500 feet away with a stop condition that is known to cause traffic backups with or without interconnection (Crossing Type 1 [CT1])	60,030	0.33
Long Storage Crossings	More than 500 feet away without traffic-backup issues or just do not apply (CT2)	20,935	28.68
Short Storage Crossings	Less than 500 feet to a roadway intersection and that roadway intersection has a stop condition but does not have traffic-control signals (CT3)	5,701	6.50
Short Storage Crossings	Less than 500 feet to a roadway intersection and that roadway intersection has traffic-control signals (CT4)	62,200	8.81
	Total	4,610	230

3.3 SUMMARY AND CONCLUSIONS

Some of the key findings of this chapter are as follows:

- Short storage locations are associated with a higher proportion of crashes than non-short storage locations.
- Failure to yield is one of the major driving-related violations for short storage crossings.
- These locations are mostly on local undivided roadways. The crossing angle (60–90 degrees) is disproportionately high in short-storage-crossing-related crossing angles.
- Both NHI and NCHRP Report 50 formulas are based on the available traffic control devices and historical crashes. There is a need for a Michigan-specific safety performance function, which will require additional efforts.

CHAPTER 4. SHRP 2 NATURALISTIC DRIVING STUDY AND SIMULATION STUDY

This chapter presents the detailed description and procedure of Task 4 of this study. Note that the objective of Task 4 is to compare driver behavior at different crossing types. To perform this task, the project team used the Second Strategic Highway Research Program (SHRP 2) naturalistic driving study (NDS) data and simulator data.

4.1 SHRP 2 NATURALISTIC DRIVING STUDY

The goal of the SHRP 2 NDS is to address the role of driver behavior in highway safety. NDS offers two key advantages:

- Detailed and accurate precrash information, including objective information about driving behavior
- Exposure information, including the frequency of behaviors in normal driving, and the larger context of contributing factors.

NDS data are collected by voluntary participants over an extended period of time. The participants complete a consent form and take several tests and questionnaires. The participants' vehicles are then taken to a specific field for installing the data acquisition systems, including radar units, cameras covering various fields of view, eye-forward monitors, accelerometers, GPS units, incident push buttons, and so on. The project team will use the data collected from two studies.

The NDS data are supplemented by the companion Roadway Information Database (RID) that captures detailed roadway data for around 12,500 centerline miles in the study states. Linked NDS and RID data provide a wealth of information that can help to address research questions concerning various areas of highway safety, design, and operations research. One of the RID layers is event data that can be used to obtain the work zone information.

To obtain the SHRP 2 naturalistic data, the project team used the data query tool available from the Insight website (https://insight.shrp2nds.us) to determine different scenarios. It is anticipated that driver workload is higher at the railroad crossings. The project team identified several scenarios with sufficient sample sizes to determine the contributing factors in understanding the workload of the drivers.

4.1.1 Data Collection and Analysis

The RID provides roadway and route information on trips of the NDS routes. The researchers used similar weather conditions and chose Indiana and Pennsylvania for the crossing selection. These two states have 163 rail-grade crossings. Table 16 shows the number of crossings in each state.

Table 16. Number of Rail Grade Crossings in SHRP 2 RID.

State	Number of Rail Grade Crossings
Indiana	104
Pennsylvania	59

Table 17 lists the facility information, countermeasure type, and short-storage distance measures for both the NDS and the simulation study. Figure 9 illustrates the schematic of the study design.

Table 17. Design of NDS and Simulation Study.

Name	NDS Study	Simulator Study
Facility information	Rural two-lane; 45-mph posted speed limit; 5-mile segment	Rural two-lane; 45-mph posted speed limit; 5-mile segment
Number of drivers	5	50
Countermeasure type	Crossbuck Crossbuck and yield Crossbuck and stop Dynamic envelop marking Near-side stop line	Crossbuck Crossbuck and yield Crossbuck and stop Dynamic envelop marking Near-side stop line
Short storage distance	100 feet or less	100 feet or less

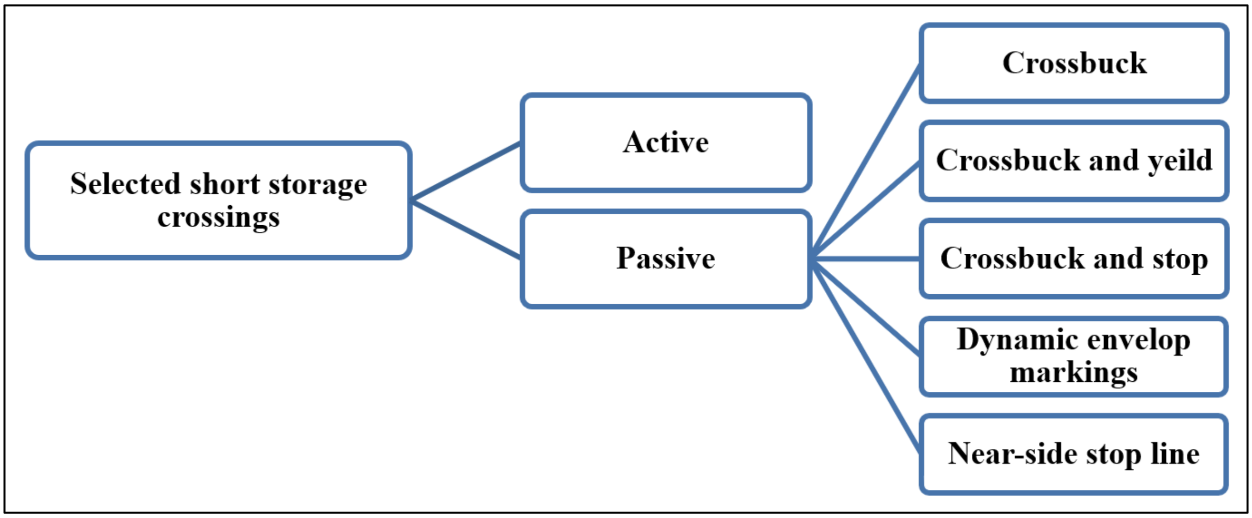


Figure 9. Scenario Selection.

For the site selection for analysis, passive control devices were selected (see Figure 9). A total of 10 sites were selected for the final analysis. For each treatment, five sites were selected. A data request was made for 20 individuals for each site.

For behavioral scores, five major factors were considered:

- Acceleration
- Speed before
- Speed after
- Head rotation
- Sign and marking following

The scores were calculated based on percentile value. Table 18 shows the mean values for each factor.

Table 18. Behavioral Scores of NDS Sample Data.

Name	Behavioral Score
Acceleration	Percentile based (mean = 2.13)
Speed before	Percentile based (mean = 2.56)
Speed after	Percentile based (mean = 2.12)
Head rotation	Percentile based (mean = 1.92)
Sign/marking following	Percentile based (mean = 1.23)

Note: Scores are calculated based on the percentage of observations:
1: < 21%, 2: 21–40%, 3: 41–60%, 4: 61–80%, and 5: > 81%

Figure 10 shows the statistical significance test for each of the treatments using NDS sample data. Each individual score can range from 1 to 25. Higher values indicate that drivers have difficulties in passing the rail grade crossing with the available treatment. The crossbuck treatment shows the highest mean value of 18.77, and the dynamic envelop markings show the lowest mean of 11.92. The statistical significance test shows that the driver behavioral scores at each of the treatments significantly differ.

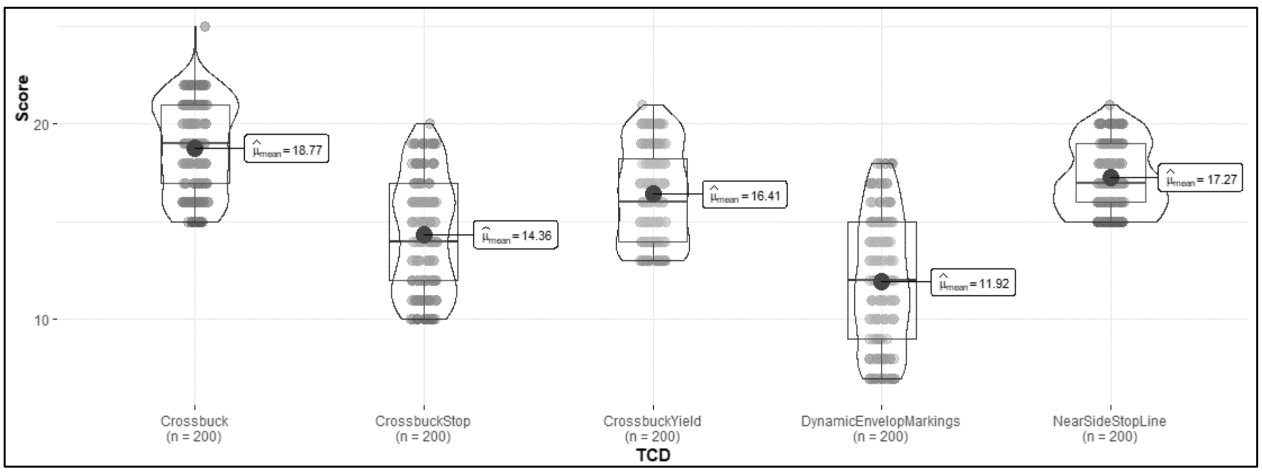


Figure 10. Statistical Significance Test on NDS Data.

4.1.2 Simulation Study

In the simulation study, the driver counts were considered as 50 (in NDS study, this count was 5). Table 19 shows the percentile-based scores. In behavioral scores, "speed after" shows a higher mean compared to NDS sample data. In both studies (NDS and simulation), "sign following" has the lowest value, which indicates the difficulties of following signs and markings at the short storage locations.

Table 19. Behavioral Scores of Simulation Data.

Name	Behavioral Score
Acceleration	Percentile based (mean = 2.47)
Speed before	Percentile based (mean = 2.22)

Name	Behavioral Score
Speed after	Percentile based (mean = 2.86)
Head rotation	Percentile based (mean = 2.13)
Sign/marking following	Percentile based (mean = 1.89)

Note: Scores are calculated based on the percentage of observations:
1: < 21%, 2: 21–40%, 3: 41–60%, 4: 61–80%, and 5: > 81

Like in the NDS study, each individual score can range from 1 to 25. Higher values indicate that drivers have difficulties in passing the rail grade crossing with the available treatment. The crossbuck treatment shows the highest mean value of 19.79, and dynamic envelop markings show the lowest mean of 12.39 (see Figure 11). The statistical significance test shows that driver behavioral scores at each of the treatments significantly differ. The patterns of effectiveness in both the NDS and simulation study are similar.

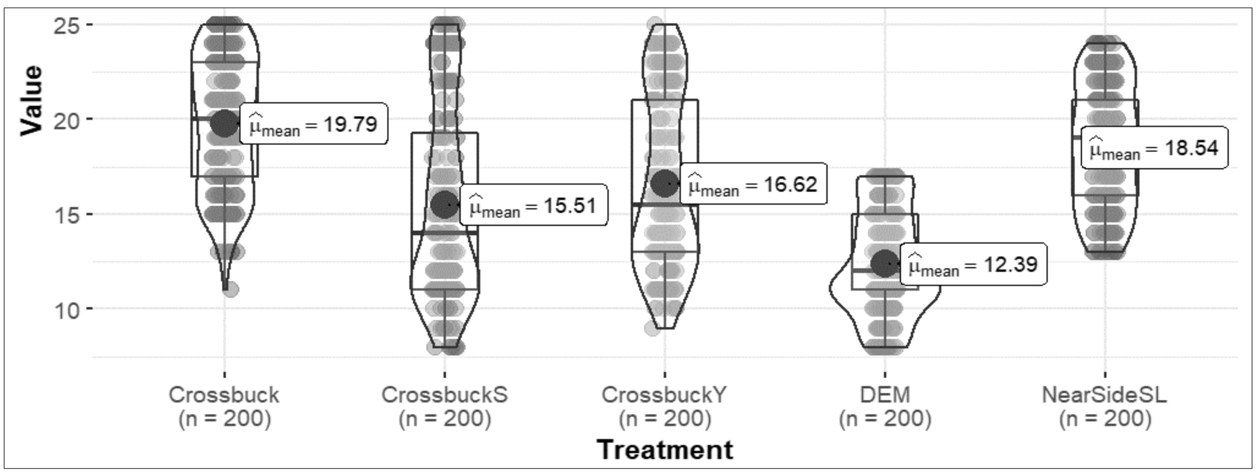


Figure 11. Statistical significance Test on Simulation Data.

4.2 SUMMARY AND CONCLUSIONS

Both NDS and simulation study results indicate that drivers face difficulties in following signs and markings near the short storage locations. Effectiveness measures of five passive countermeasures indicate that dynamic envelop markings and crossbucks with stops are more effective than other passive countermeasures such as crossbuck only, crossbuck and yield, and near-side stop line.

CHAPTER 5. GUIDANCE AND RECOMMENDATIONS

5.1 MDOT WORKSHOP

On September 15th, MDOT hosted a workshop for the OR 19-032 project at the Horatio S. Earle Learning Center in suburban Lansing. Approximately eight people attended in person, with a further approximate virtual attendance of 25 individuals via Microsoft Teams. Two members of the research team from Wayne State University attended in person while one member of the research team from Texas A&M Transportation Institute attended virtually.

The workshop was held in the afternoon and broken into two parts. In Part 1, the research team, led by Dr. Subasish Das, provided an overview of the completed research work to date, including the literature review findings, review and analysis of existing Michigan crash data, and the results of the Naturalistic Driving Study and additional simulation-based evaluation of a limited number of countermeasures. There was some discussion and questions raised during this period, primarily around the availability of detailed simulation results and presentation of the Michigan crash data, but the group expressed a general consensus around the project findings thus far.

In the second part of the workshop, Dr. Steven Lavrenz facilitated a roundtable discussion on specific ideas for language changes and modifications to existing MDOT publications based on the preliminary findings of the project. A photo of this discussion is shown in Figure 12. During this session, Dr. Lavrenz presented five MDOT publications and technical guides that had been identified during an earlier round of literature search and weighed feedback from the group on specific language modifications to be made with respect to passive, short storage HRGC safety and countermeasures. A summary of these findings is shown in Figure 13. The group further identified a sixth publication, PAVE-66 (Standard plan for exclusion zone markings), that had been missed during the earlier literature search; the details of this publication are included in the final report.

Figure 12. Dr. Steven Lavrenz from the research team (Wayne State University) facilitating a discussion during the September 15th project workshop (credit: Bedan Khanal, Wayne State University)

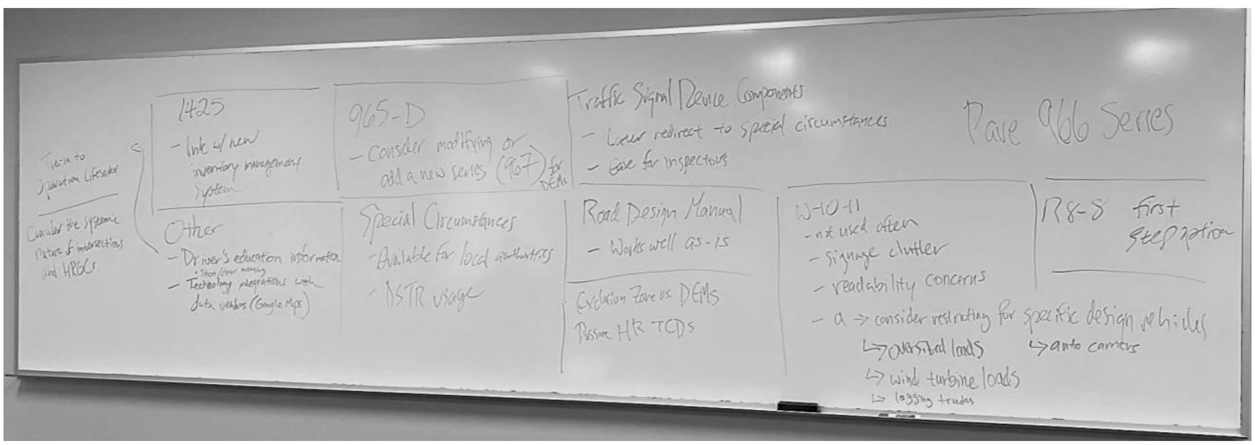


Figure 13. Whiteboard summary of lessons and feedback from part 2 of the September 15th workshop (credit: Bedan Khanal, Wayne State University).

General feedback from Parts 1 and 2 of the workshop was incorporated throughout the final report, while specific items from Part 2 are discussed in the proposed language modifications below.

5.2 PROPOSED MODIFICATIONS FOR MDOT TECHNICAL GUIDANCE

One of the later tasks of this project involved a review of current MDOT HRGC literature, with the goal of identifying opportunities to improve guiding language around the design and operation of short storage grade crossings. From this review process, six publications were identified that largely guide the development and design of Michigan HRGCs:

- Michigan MUTCD, Part 8: Traffic Controls for Railroad and Light Rail Transit Grade Crossings
- MDOT Road Design Manual
- MDOT Guidelines for Highway-Railroad Grade Crossings
- MDOT Standard Plan 965-D: Railroad Grade Crossing Pavement Markings
- MDOT Standard Plan 966: Exclusion Zone Pavement Markings
- MDOT Form 1425: Notification of Proposed Project Involving a Public Railroad Crossing

An initial set of recommendations for modifications to the language in these publications, based on the findings of the project, were developed and presented to the TAC and various MDOT stakeholders during the workshop on September 15th. Based on the feedback received, several of these modifications were added, eliminated, or otherwise revised. The updated set of proposed modifications is as follows:

5.2.1 Michigan MUTCD, Part 8: Traffic Controls for Railroad and Light Rail Transit Grade Crossings

Section 8B.09, DO NOT STOP ON TRACKS Sign (R8-8)

This section currently contains guidance from the national MUTCD on the use of R8-8 signs "whenever an engineering study determines that the potential for highway vehicles stopping on the tracks at a grade crossing is significant". However, MDOT should consider strengthening this guidance for passive HRGCs with CSD of 200 feet or less, by including specific language about the short storage locations in this same part of the document or in a support section. Feedback from the stakeholder group further indicated a preference to describe the use of R8-8 signage as a first step or "low hanging fruit" action, suggesting that this treatment could be included as a systemic option for HRGCs that meet the design and operational conditions of this study.

Section 8B.24, Storage Space Signs (W10-11, W10-11a, W10-11b)

This section currently contains guidance from the national MUTCD on the use of W10-11 signs "where there is a highway intersection in close proximity to the grade crossing and an engineering study determines that adequate space is not available to store a design vehicle(s) between the highway intersection and the train or LRT equipment dynamic envelope." Initially, the research team recommended that MDOT consider strengthening this guidance with language specific to passive HRGCs with insufficient CSD. However, multiple individuals at the September 15th workshop raised concerns about the potential increase in signage clutter, readability of the signs, and general unfamiliarity with the signage for the regional engineers. Consequently, it is recommended that instead of a broad statement encouraging greater use of the W10-11 series, MDOT focuses on expanding the deployment in areas with specific vehicle types that prove especially problematic at these grade crossings. This could include areas with significant wind turbine traffic, other types of oversized loads where the driver has reliable information about the size of their vehicle, or areas further north with substantial logging truck activity.

Section 8C.12, Grade Crossings Within or In Close Proximity to Circular Intersections

This section of the MMUTCD is concerned with the general provision of safe vehicle storage at circular intersections, which do not typically accommodate traffic control signals. More specifically, the standard is written to ensure that intersections within 200 feet of the highway-rail grade crossing, regardless of ownership, receive special consideration via an engineering study to determine if additional countermeasures are needed to reduce the risk of HRGC crashes. The current language [reproduced in a substantially identical form below] is as follows:

> ***Section 8C.12 Grade Crossings Within or In Close Proximity to Circular Intersections***
>
> *Support:*
>
> *At circular intersections, such as roundabouts and traffic circles, that include or are within close proximity to a grade crossing, a queue of vehicular traffic could cause highway vehicles to stop on the grade crossing.*
>
> ***Standard:***
>
> ***Where circular intersections include or are within 200 feet of a grade crossing, an engineering study shall be made to determine if queuing could impact the grade crossing. If traffic queues impact the grade crossing, provisions shall be made to clear highway traffic from the grade crossing prior to the arrival of rail traffic.***
>
> *Support:*
>
> *Among the actions that can be taken to keep the grade crossing clear of traffic or to clear traffic from the grade crossing prior to the arrival of rail traffic are the following:*
>
> *A. Elimination of the circular intersection,*
> *B. Geometric design revisions,*
> *C. Grade crossing regulatory and warning devices,*
> *D. Highway traffic signals,*
> *E. Traffic metering devices,*
> *F. Activated signs, or*
> *G. A combination of these or other actions.*

This section of the MMUTCD currently uses language exclusively from the federal MUTCD and specifically identifies the need for special consideration at *circular* intersections. However, based on the findings of this research, we recommend that MDOT explore a revision of this Section to encompass all *unsignalized* intersections.

A change of the word ‘circular’ to ‘unsignalized’ should achieve the intended purpose of ensuring that intersections near HRGCs, but operated by local agencies, are not in conflict with the safety performance of a short-storage HRGC. This recommendation also preserves the legal requirements of 23 CFR 655.603(b), which stipulate that state adaptations of the MUTCD must remain in ‘substantial conformance’ with the federal MUTCD, by ensuring that the standards in the federal MUTCD are met ‘at a minimum’. Expanding Section 8C.12 to include all unsignalized intersections would, at a minimum, ensure that circular intersections – the target of this section in the federal MUTCD – are covered.

5.2.2 MDOT Road Design Manual

Section 12.11 of this publication is focused on the design details of HRGCs on Michigan roads. However, a careful review of this section finds that it primarily focuses on basic material selections and decisions about the approach grade of the HRGC itself; there is little to no current mention of details associated with traffic control devices, pavement markings, or CSDs- other than those, practitioners are to follow 'standard' design plans for these elements.

At this time, based on the perceived focus of this publication on fundamental roadway design, it is not recommended that additional direct language be added. This recommendation was affirmed by most of the attendees at the September 15th workshop, who generally felt that the Road Design Manual works well in its current form. However, MDOT may want to update this section to include references to other resources, such as the MDOT Guidelines for Highway-Railroad Grade Crossings publication.

5.2.3 MDOT Guidelines for Highway-Railroad Grade Crossings

This publication, for which the most recent version found is from 2017, provides a compendium of design resources, standards, and guidelines for transportation professionals and public officials seeking to achieve safe and efficient compliance in the design and operation of public HRGC. The five main sections of this publication are as follows:

- Passive Highway-Railroad Traffic Control Devices
- Active Highway-Railroad Traffic Control Devices
- Traffic Signal Device Components
- Special Circumstances at Highway-Railroad Grade Crossings
- Grade Crossing-Related Laws

There are multiple sections of this publication where it may be appropriate to add language for strengthening the consideration of safety at passive, short storage HRGCs (see Table 20).

Table 20. Recommendations on MDOT Guidelines for Highway-Railroad Grade Crossings.

Chapter	Section	Recommended Addition
Passive Highway-Railroad Traffic Control Devices	Advance Warning Signs (W10 Series)	The use of W10-11a and W10-11b signs, which give drivers information about the CSD present at the HRGC, are absent from this publication. Recommend adding for consideration
Passive Highway-Railroad Traffic Control Devices	Highway-Railroad Grade Crossing Pavement Markings	The pavement marking designs in this publication are inconsistent with those shown in MDOT Standard Plan 965-D, especially as they pertain to design details relevant to short storage HRGCs. For example, the designs shown here include optional dynamic envelope pavement markings, which are absent from 965-D. Recommend ensuring that all design details between this publication and 965-D are consistent. The same recommendation is made for publication 966, which deals with exclusion zone pavement markings.

Chapter	Section	Recommended Addition
Traffic Signal Device Components	Criteria for Crossings Adjacent to Signalized Intersections, Intersection Near a Grade Crossing	These two sections are the only ones that appear to consider the proximity of the HRGC from adjacent intersections, for the purpose of determining appropriate traffic control design and functionality. Recommend adding language here directing readers to the "Special Circumstances" chapter in the event that the intersection proximity conditions are met, but active grade crossing treatments are not warranted or desired.
Special Circumstances at Highway-Railroad Grade Crossings	N/A	This chapter is missing a section on short storage passive HRGCs. Recommend adding language in this chapter to underscore the risks associated with these locations, and the importance of combining multiple signage and pavement marking treatments to hold driver attention and ensure consistent compliance with stop and yielding requirements. It is also recommended to include language in this section that intersections located within 200 feet of an unsignalized HRGC should be potentially considered as a single system, and should be evaluated, at a minimum, using an engineering study to determine if safety risks exist if the intersection is not treated alongside the short storage HRGC as a holistic unit.

5.2.4 MDOT Standard Plan 965-D: Railroad Grade Crossing Pavement Markings

This publication does not currently contain design details for dynamic envelope pavement markings. Based on the literature review task and outcomes of the NDS and simulation studies demonstrating their effectiveness at holding driver attention and ensuring proper yielding behavior, it is recommended that MDOT update this document to include information on dynamic envelope pavement markings.

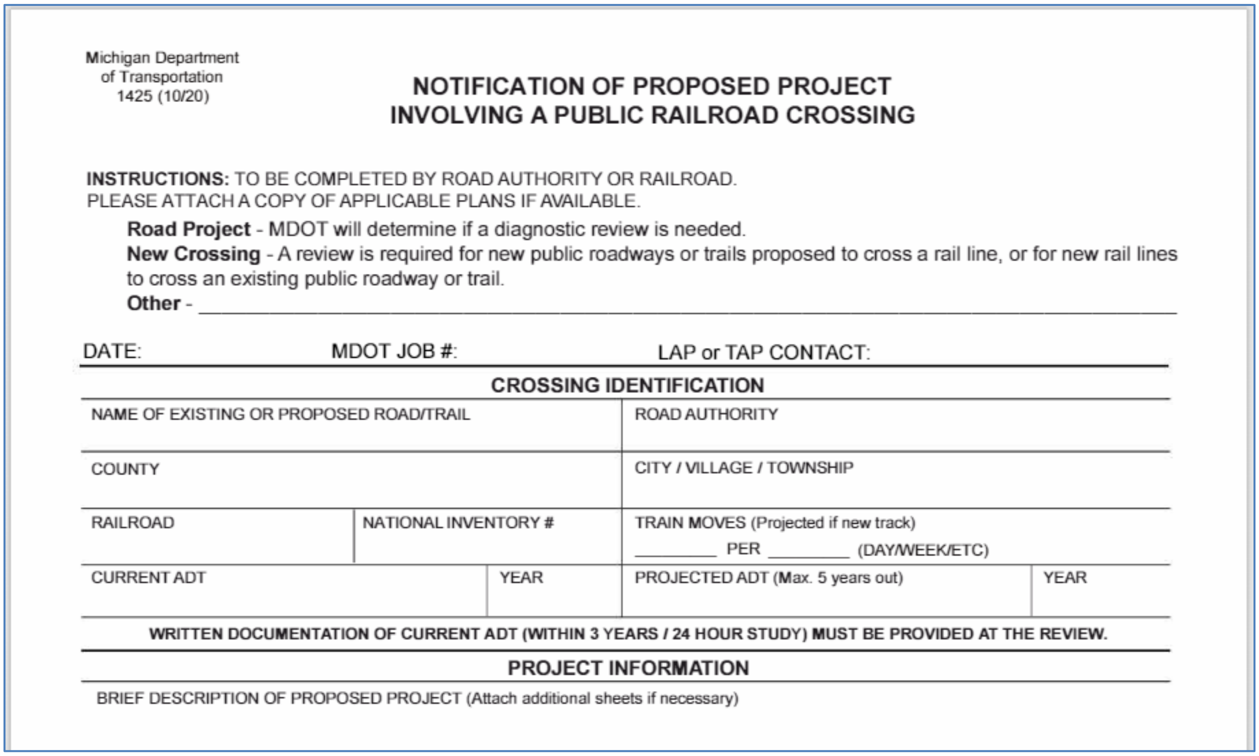
5.2.5 MDOT Standard Plan 966: Exclusion Zone Pavement Markings

This publication was missed in an initial search by the research team and was identified during the September 15th workshop. There was some confusion during the project as to the differentiation of the dynamic envelope concept versus the exclusion zone concept, where at various times the terminologies were used interchangeably. However, while dynamic envelope pavement markings are limited in their placement to an area a standard distance away from the outer edge of each rail (often 3 feet, to reflect the maximum width and overhang distance of railcar cargo), exclusion zones can be applied over any extended area. While no direct modifications are recommended for Standard Plan 966, it is recommended that MDOT clarify the distinct differences and use cases of exclusion zone pavement markings and dynamic envelope pavement markings in their technical literature.

5.2.6 MDOT Form 1425: Notification of Proposed Project Involving a Public Railroad Crossing

This form is directly available from the MDOT website and is required to be filled out whenever roadwork at or adjacent to an HRGC is to be performed, either by a local road agency or the railroad associated with the HRGC track. Once submitted, this form is reviewed by the MDOT Office of Rail, which determines if a Diagnostic Safety Team Review (DSTR) is warranted for the project, involving an in-depth review of traffic management plans, lane closures, and construction equipment staging associated with the project to ensure that it does not create safety deficiencies at the HRGC.

The current form consists of three main sections: (1) crossing identification, (2) project information, and (3) contact information. With respect to safety issues associated with short storage passive HRGCs, it is reasonable to expect that such crossings would be identified in section 1 of this form; however, no such identification currently exists, as shown in Figure 14.



Michigan Department
of Transportation
1425 (10/20)

NOTIFICATION OF PROPOSED PROJECT
INVOLVING A PUBLIC RAILROAD CROSSING

INSTRUCTIONS: TO BE COMPLETED BY ROAD AUTHORITY OR RAILROAD.
PLEASE ATTACH A COPY OF APPLICABLE PLANS IF AVAILABLE.

Road Project - MDOT will determine if a diagnostic review is needed.
New Crossing - A review is required for new public roadways or trails proposed to cross a rail line, or for new rail lines to cross an existing public roadway or trail.
Other - ________________________________

DATE: MDOT JOB #: LAP or TAP CONTACT:

CROSSING IDENTIFICATION

NAME OF EXISTING OR PROPOSED ROAD/TRAIL		ROAD AUTHORITY	
COUNTY		CITY / VILLAGE / TOWNSHIP	
RAILROAD	NATIONAL INVENTORY #	TRAIN MOVES (Projected if new track) ________ PER ________ (DAY/WEEK/ETC)	
CURRENT ADT	YEAR	PROJECTED ADT (Max. 5 years out)	YEAR

WRITTEN DOCUMENTATION OF CURRENT ADT (WITHIN 3 YEARS / 24 HOUR STUDY) MUST BE PROVIDED AT THE REVIEW.

PROJECT INFORMATION

BRIEF DESCRIPTION OF PROPOSED PROJECT (Attach additional sheets if necessary)

Figure 14. Section 1 of MDOT Form 1425, Crossing Identification

Therefore, it is recommended that MDOT consider adding language to this form that requires the agency performing work near the HRGC to identify two key pieces of additional information:

- Approximate distance from the HRGC to the nearest roadway intersection
- Type of traffic control present at the HRGC

These two pieces of information should be sufficient to identify potential short storage locations with passive traffic control and can be used to enhance the safety review process within MDOT. For example, the Office of Rail may choose to adopt a policy so that work occurring within potential short storage passive HRGC locations, based on this form, is automatically subject to a DSTR.

However, with respect to this final recommendation, the research team was made aware at the September 15th workshop that a new inventory management system is currently under development within MDOT, and that there is the potential to link this form with that system to auto-populate certain fields such as traffic control type. Depending on the extent to which this linkage is successful, and the specific types and reliability of data elements gathered for HRGCs, the recommended modifications to Form 1425 may not be necessary.

5.3 OTHER RECOMMENDATIONS

Finally, besides the recommended modifications to specific MDOT technical guidance, there was broad discussion at the September 15th workshop about additional and longer-term efforts to address safety concerns at short storage passive HRGCs. Examples of this include formally defining this type of crossing as a roadway element for which systemic safety solutions could be developed, much as how roadway features such as horizontal curves are categorically identified and treated with uniform signage.

A second recommendation included the potential development of additional educational and warning materials for drivers, either as part of a driver education curriculum or alongside the MDOT's Operation Lifesaver program, which focuses on several risks and recommended driving behaviors associated with active and passive HRGCs around the state. The details of these recommendations were not explored in depth by the research team and will thus require additional study and potential follow-up alongside some of the other treatments recommended in this section.

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