MULTI-MODAL INTERSECTIONS: RESOLVING CONFLICTS BETWEEN TRAINS, MOTOR VEHICLES, BICYCLISTS AND PEDESTRIANS

Final Report

SPR 794

RESEARCH

Oregon Department of Transportation

MULTI-MODAL INTERSECTIONS: RESOLVING CONFLICTS BETWEEN TRAINS, MOTOR VEHICLES, BICYCLISTS AND PEDESTRIANS

Final Report

SPR 794

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16. Abstract

This research report investigates the relationship between pedestrians and bicyclists on paths parallel to railroad tracks and with a road perpendicular to the path. The possible conflicts at intersections within these design parameters are of concern to ODOT, and therefore, has been recognized as an opportunity to conduct research that improves this type of intersection. The goal of this research project is to create a Guidebook that suggests appropriate path or road treatments for crossings, while also acknowledging and complimenting the unique site conditions present at the intersection. The report contains an extensive literature review, including existing railroad treatment options, and a description of the conducted field surveys and pedestrian, bicycle, vehicle, and train counts from the video. The report could help future work, such as developing more design solutions for paths parallel to tracks and the road perpendicular to the path. A preliminary guidebook is exemplified in the conducted case studies. It is intended to be a user friendly tool for city planners and engineers to assess a crossing and identify appropriate treatment options to improve the path and road user environment, and overall safety for all users.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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LIST OF ACRONYMS

AGENCIES AND ORGANIZATIONS	
AREMA	American Railway Engineering and Maintenance-of-Way Association
ITE	Institute of Transportation Engineers
NACTO	National Association of City Transportation Officials
ODOT	Oregon Department of Transportation
FHWA	The Federal Highway Administration
FRA	The Federal Railroad Administration
TriMet	Tri-County Metropolitan Transportation District of Oregon
PUBLICATIONS	
MUTCD	Manual on Uniform Traffic Control Devices
OAR	Oregon Administrative Rules
ORS	Oregon Revised Statutes
OTHER	
AADR	Average Annual Daily Railway Movement
AADT	Average Annual Daily Traffic
ADT	Average Daily Traffic
LRT	Light Rail Transit
SAP	State (Grade Crossing) Action Plans

1.0 INTRODUCTION

The safety of all users including pedestrians, and bicyclists on paths parallel to and in close proximity to railroad tracks with a road and the vehicles traversing through a crossing perpendicular to the path and railroad is a safety concern for the Oregon Department of Transportation (ODOT). Current observations indicate that vehicles are unprepared to stop at a safe distance from the path and instead, have been observed stopping on railroad tracks as pedestrians and cyclists cross the path. This puts the vehicle in a high-risk position as it dwells on railroad tracks with the threat of oncoming trains. The safety of pedestrians and cyclists is also compromised as vehicles come to a sudden stop near the path in order to allow pedestrians and cyclists to pass. Furthermore both stopping on tracks and not stopping for pedestrians is undesired in Oregon, which is why it is important that intersection design dissuades these two behaviors.

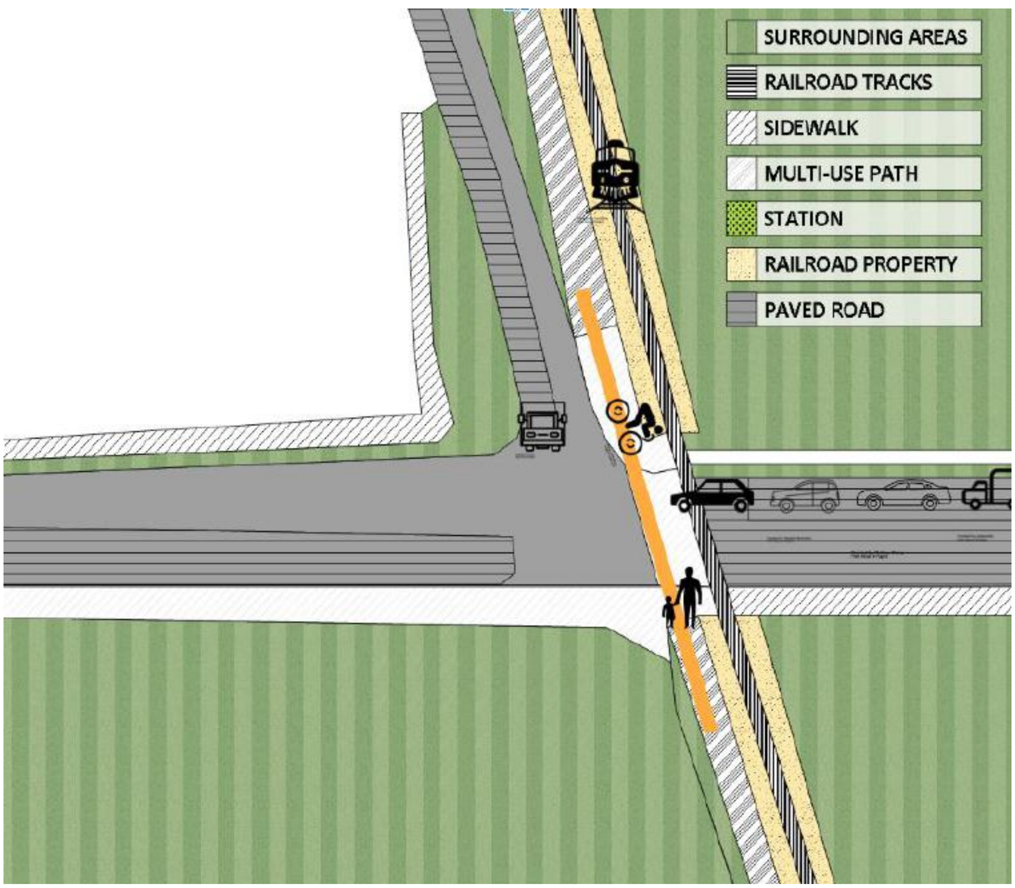


Figure 1.1: The illustration above depicts the issue with multimodal intersections discussed in this report

Currently, the minimum highway treatment for crossing train tracks is a crossbucks sign with either a ‘STOP’ sign (R1-1) or ‘YIELD’ sign (R1-2), which prompts all road users to yield at the railroad crossing. There are no other requirements to improve path user and road user safety at this type of crossing, and major resources such as the Manual on Uniform Traffic Control Devices (MUTCD), American Association of State Highway and Transportation Officials (AASHTO), and street design guidebooks do not adequately address the concerns outlined in this scenario.

The objective of this research is to produce a reliable document that is to serve as a concise and thorough guidebook to effectively address safety concerns at sites where there is a path in parallel with and in close proximity to railroad tracks and has a roadway running perpendicular to both the path and the railroad tracks. This research is based off a limited number of case studies and the guidebook is a starting point for public agencies, however additional research is needed to integrate additional knowledge, if found. Challenges in this research include isolating the concerns and behavior of path and road users and recognizing the limits of treatment options. There can be many treatments used to guide human behavior, but little can be done to force compliance.

It is important to recognize that the conditions of the built environment at such crossings emphasize the different priorities of various stakeholders involved in this scenario. These stakeholders include railroad companies, municipalities, counties, and federal agencies. There are currently many sites with paths parallel to and in close proximity to railroad tracks with perpendicular roads. This document is designed to serve as an informative document for the stakeholders.

The research report summarizes the findings, methods, and guidebook into the following chapters. Chapter 1 outlines the issues presented in the document. In Chapter 2 national and international literature is reviewed, including policy documents, legal statues. Familiar as well as non-conventional treatment options are also described in this section. Chapter 3 documents the field surveys that were completed at seven case study sites in Oregon, including photos, diagrams and descriptions of conditions at the particular sites. Criteria to evaluate the performance of treatments at railroad crossings are described in detail in Chapter 4, which also includes the methodology for completing these evaluations.

Chapter 5 contains a detailed list of treatments for both highways and trails and includes evaluation of their performance, cost and concerns. It also presents the primary concerns that can be observed at this type of crossing. This information is brought into the Guidebook which is presented in Chapter 6. The Guidebook is shown here, but is also published as a separate document, that makes it easy for users who need to address safety concerns at pathways that are parallel to and adjacent to a highway rail grade crossing. The Guidebook is shown in use in Appendix D, where it is applied to the seven different project study sites visited as described in Chapter 3.

Chapter 7 presents the conclusions, recommendations and the further research that can potentially supplement the knowledge from this report. Chapter 8 contains references.

2.0 LITERATURE REVIEW

The Federal Railroad Administration (FRA) keeps yearly statistics on the number of railroad accidents on heavy rail systems, and the individual states have jurisdiction over the light rail systems. Though the number of accidents is not high, compared to e.g. automobile accidents, they often have severe consequences. One factor that contributes to these accidents is that fact that road user compliance can be low, even when the crossing of tracks is heavily regulated. However, train incidents in Oregon, and nationally, are down significantly over the past 30 years. A 1989 study found that 62% of road users complied with closed gates (Meeker and Barr 1989), whereas another study found the compliance to be 86% (Witte and Donohue 2000). At this level of non-compliance, the risk of accidents and potentially fatal outcomes are high. In 2016 the FRA published a report summarizing an analysis of grade crossing accidents that resulted in injuries and fatalities and explored trends and factors in these accidents (FRA 2016).

2.1 OREGON LEGAL STATUTES

- There is conflicts between laws, when it comes to stopping on tracks and stopping for pedestrians
- All at-grade crossing should be eliminated wherever possible

The interaction between bikes, pedestrians, automobiles and rail is described in the 2013 Oregon Revised Statutes (ORS), and consists of several different sections, of which an overview is given in a 2016 publication (ODOT, 2016). ORS 811.455 requires vehicles to stop at the line, or, if there is no line, not less than 15 feet from the rail and not more than 50 feet, at any of the following circumstances; A mechanical or electrical warning device is in use; upon lowering of a gate or other barrier; if the train is clearly visible, or; if an audible signal is being made by the train (Oregon Laws, 2013). Furthermore, under 811.462, a person operating a commercial motor vehicle is required to slow down and look for trains before crossing any rails, no matter the crossings configuration, unless it is governed by a signal (Oregon Laws, 2013). There are other requirements for other types of high-risk vehicles, mainly school busses, which are required to make a full stop at all rail crossings (Oregon Laws, 2013).

A series of additional parameters, which are set in administrative rules and statutes, furthermore helps guide decisions in the railroad area. ORS 824.018 describes the establishment and guiding principles of the Grade Crossing Protection Account, which funds are used for *"the elimination of hazardous railroad-highway crossings"*, as well as *"to enhance safety at railroad-highway crossings"* (Oregon Laws, 2013). ORS 824.204 describes the authority to construct new at-grade crossings, while ORS 824.206 describes the elimination, relocation or alternation of at-grade crossings. Under ORS 824.202, all at-grade crossings are required to be eliminated wherever possible. In a similar fashion, ORS 824.210 describes the construction and alteration of separated crossings (Oregon Laws, 2013). The Oregon Administration Rules Compilation offers interpretation and descriptions of the applicable laws and general practice. In relation to this topic, OAR 741-200-0050 describes the use of plans, while OAR 741-120-0020 describes the guiding principles for construction and maintenance of at-grade crossings.

2.2 POLICY DOCUMENTS

- A wide variety of publications are available regarding at-grade crossings, here under both planning documents and technical reports.

- Policy documents are published by three types of organizations; federal organizations, such as the FHWA and FRA; state agencies, such as ODOT, and; independent organizations such as AREMA and ITE.

The following table contains publications that describes standards, rules, regulations and guidelines for railroad crossing, light rail transit crossings and crossings with bikes and pedestrians.

Table 2.1: Policy Documents Regarding At-Grade Rail Crossings

PUBLICATION	DESCRIPTION
Manual on Uniform Traffic Control Devices Part 8 (MUTCD) and the Oregon Supplement to the MUTCD	This manual describes traffic control devices, including all signs, signals, markings or other warning devices, that are used for safety and efficiency at railroad and light rail transit (LRT) crossings. (FHWA, 2009)
Railroad-Highway Grade Crossing Handbook	This handbook describes best practices and adopted standards at highway-rail grade crossings, including a chapter on LRT and pedestrians and bicycles. (FHWA, 2007)
AREMA Communications and Signals Manual	This manual contains a technical description of railroad signal systems and grade crossing warning systems, including descriptions of the electrical components. It is geared towards technicians and engineers within the industry. (AREMA, 2016)
AREMA 2016 Manual for Railway Engineering	This manual gives a more general overview of railway engineering, but does contain chapters on signaling and warning systems both at highway grade crossings and for transit, intercity and commuter rail. (AREMA, 2016)
Traffic Control Devices Handbook	This handbook provides information and guidance for implementing the provisions of the MUTCD, including a chapter on human factors. (ITE, 2013)
Transit Street Design Guide	This guide provides knowledge on how to design streets that includes transit, including light rail transit. It has an in-depth chapter on intersections, along with various case-studies describing issues that was previously solved. (NACTO, 2016)
Preemption of Traffic Signals Near Railroad Crossings	This publication contains a synthesis of experience of knowledge regarding signals near rails. It discusses current issues and technological advances in the field. It is the predecessor of their above-mentioned handbook. (ITE, 2006)
Oregon At-Grade Rail Crossings	This document provides information on procedure in Oregon in relation to requesting new crossings, modifying an existing crossing or closing a crossing (ODOT, Seen 2016)
Oregon State Rail Plan	This document is the guiding planning document in the State of Oregon. Along with other documents, it *“defines and implements goals, policies and strategies for managing, developing and investing in Oregon’s transportation system”* (ODOT, 2014)

2.3 ACADEMIC PUBLICATIONS

- Public education can play an important role in increasing safe behavior at crossings.
- Pedestrians in large groups are more likely to violate crossings with passive control devices (Khattak & Luo, 2011).
- Active warning devices generally lead to less violations at railroad crossings.

In 2002 one of the earliest reports on the experience gained from “Rails-with-Trails”, which are multi-use paths directly adjacent to railroads, was published. It included a detailed literature review of at the time current practices, city plans and international experience and knowledge. It also contains case studies and a detailed guide to the development and construction of new trails adjacent to rails, including national legislation and crash trends (Birk, et al., 2002). It mentions the safety issue of at-grade railroad crossings, but points out that most crossings in the US at the time have passive warning devices (Birk, et al., 2002). In one study, two active devices were compared, and it was found that the addition of automated gates to blinking flashers, had the potential to reduce the percentage of drivers violating the warning signs from 67% down to 38% (Meeker, Fox, & Weber, A Comparison of Driver Behavior at Railroad Grade Crossings with two Different Protection Systems, 1997).

A detailed report published in 2013 investigated warning devices and signs for pedestrians and bicyclists. They compared stated and actual behavior by pedestrians and bikes, and found that: many participants were involved with other activities while crossing, which interfered with their awareness of the tracks. Active signs were noticed more than passive signs, and the use of gates lowered violation. People who crossed tracks more often generally displayed more safe behavior, than people who seldom crossed tracks. Pedestrian violate relatively more in urban areas than in rural areas. Larger groups were more likely to violate than one or two people (Metaxatos & Sriraj, Pedestrian/Bicyclist Warning Devices and Signs at Highway-Rail and Pathway-Rail Grade Crossings, 2013). This was confirmed by another study, that also found that children under the age of eight had more risky behavior and induced risky behavior amongst others (Khattak & Luo, 2011)

In 1997 a report was published on grade crossing treatments for high speed rail in Oregon, which set five different treatment categories, based on the type of rail and the speeds:

1. Special minimum, private, AADT <1, rail speed <110
   - A. None
2. Basic minimum, AADT private <200, AADT public <20, rail speed <110 mph
   - B. Normally closed, locked gates, remotely controlled
3. Basic low volume public crossing, AADT <=200, rail speed <110 mph
   - A. Four quadrants, fully blocking the road on each side of crossing

B. Gate activation based on a fully stopped or non-present train

C. Variable message signs

4. Higher-speed, basic crossings, AADT private <=200, AADT public <20, rail speed <125 mph

    A. As category 1, but with crash-rated vehicle arresting barriers

5. Higher-speed low volume public crossings, AADT <200, rail speed <125 mph

    A. Standard approach warning gates +crash-rated vehicle arresting barriers

    B. Based on automatic intrusion detection

    C. Variable message signs (Bell & Zaworski, 1997)

The report by (Metaxatos & Sriraj, Pedestrian/Bicyclist Warning Devices and Signs at Highway-Rail and Pathway-Rail Grade Crossings, 2013) contained a video analysis of pedestrian behavior. The following database sheet was used to extract the information from the videos.

Table 2.2: Database Attributes from Video Observations (Metaxatos & Sriraj, 2013).

FIELD	EXPLANATION	FORMAT	POSSIBLE VALUES
Crossing Number	Crossing ID	Text	NA
Crossing name		Text	NA
Crossing distance	Rail to rail distance	Number	NA
Part of platoon	Solo crosser or platoon	Text	Yes, No
# in Platoon		Number	Integers
Direction	Direction (N, S, E, W) from which the pedestrian approached the crossing	Text	N, S, E, W
Side of street		Text	N, S, E, W
Pedestrian path		Text	Straight, Diagonal
Pedestrian enter crossing time (min)	# of minutes elapsed since start of video to pedestrian entering crossing	Number	Integers
Pedestrian enter crossing time (sec)		Number	Integers
Pedestrian exit crossing time (min)	# of minutes elapsed since start of video to pedestrian exiting crossing	Number	Integers
Pedestrian exit crossing time (sec)		Number	Integers
Gate Activity	Whether the pedestrian was at the crossing	Text	Yes, No

	during a gate activation		
Violation type	1: (Lights flashing only); 2: (Gate in motion), 3: (Gate in down position)	Text	1, 2, 3
Train Coming or Gone	For pedestrians with gate activity, whether they entered the crossing when a train was coming towards the crossing or all trains had already gone through)	Text	C, G
Crossing activation time (min)	# of minutes elapsed since start of video to flashing lights activating	Number	Integers
Crossing activation time (sec)		Number	Integers
Crossing de-activation time (min)	# of minutes elapsed since start of video to flashing lights deactivating	Number	Integers
Crossing de-activation time (sec)		Number	Integers
PedEnterCross	Time (24-hour format) when pedestrian entered crossing	Time (24)	NA
PedExitCross	Time (24-hour format) when pedestrian exited crossing	Time (24)	NA
Time to cross	Duration of rail-to-rail crossing time for pedestrians	Time (24)	NA
CrossAct	Time (24-hour format) when flashing lights activated	Time (24)	NA
CrossDeact	Time (24-hour format) when flashing lights deactivated	Time (24)	NA
TimeActive	Duration of gate activation	Time (24)	NA
Pedestrians present at crossing?	If pedestrians were present in the gate or crossing area during gate activation	Text	Yes, No
Violations (#)	Number of pedestrian violations	Number	Integers
Train presence	Whether a train entered the crossing during a gate activation (if not: false alarm/gate malfunction)	Text	Yes, No
Train arrival time (min)	# of minutes elapsed since start of video to train entering crossing	Number	Integers
Train arrival time (sec)		Number	Integers
Train departure time (min)	# of minutes elapsed since start of video to train exiting crossing	Number	Integers
Train departure time (sec)		Number	Integers
Type of train		Text	Freight,

			Passenger, Track Maintenance
Direction from which the train approached the crossing		Text	N, S, E, W
Second train event	Whether a second (or third) train was present during the gate activation	Text	Yes, No, NA
Train Arrive	Time (24-hour format) when train entered crossing	Time (24)	NA
Train Depart	Time (24-hour format) when train exited crossing	Time (24)	NA
Train In Crossing	Time elapsed while train was present in crossing	Time (24)	NA

With regards to pedestrians and light rail traffic, a report described safe crossing as being comprised of four factors:

- Awareness of a crossing;
- Pedestrian path across a trackway;
- Awareness of and ability to see an approaching light rail train
- Understanding of potential hazards at grade crossings

(Siques, 2001)

The paper provides a list of possible treatments, which will be included in the treatments section of this literature review.

The author subsequently published a paper evaluating the effect of different treatments on risky pedestrian behavior, and found that pedestrian automatic gates lowered the risky behavior the most (Siques, 2002).

2.4 INTERNATIONAL POLICY DOCUMENTS AND RECOMMENDATIONS

- Higher levels of compliance were found when active warning devices are used.
- An important challenge is avoiding unintentional non-compliance, by ensuring that warning systems are easy to understand, and in the case where they are not understood, still doesn’t lead to an incident.
- Males and school children are the most exposed groups.

- Pedestrians deliberately violate crossing regulations.
- Crossings can be assessed without accident data, using a variety of methods.

Not much literature is available regarding trails running adjacent to railroad tracks. For that reason, this section is concerning information that in the literature has been applied to crossing the tracks, but that also has implications for paths adjacent to the tracks. A 2010 study analyzed the effectiveness of controlling at-grade railroad crossings with a standard traffic light versus gates ("boom barriers" in Australia) with flashing lights. They found that around 55% of the surveyed violated at the stop sign, 28% violated when presented with flashing lights and gates, and 20% violated at traffic lights, but that most people preferred gates and flashing lights: they felt it was safer, though their behavior wasn't safer. However, the study concluded, that there isn't necessarily a benefit to traffic lights over gates (Rudin-Brown, Lenne, Edquist, & Navarro, 2010). This is relevant for adjacent paths, as part of ensuring that the different modes coexist is ensuring that there is compliance of the treatments for all users. If 55% of motorists do not make a stop before crossing tracks and a path, this may mean that they end up stopping and dwelling on the tracks, when they later realize that a pedestrian is about to cross. The study suggests that installing flashing lights could help decrease the number of people dwelling on tracks. A Dutch study also found high compliance with red lights, until the train has passed, where drivers would run the red signal, which can put them at risk, in situations where a second train was coming (Tenkink & Horst, 1990). This is especially problematic, if drivers respond to the train have passed, as opposed to the change of the traffic light, as there may still be pedestrians or bikes crossing adjacent to the tracks. Another 2010 paper reviewed low-cost warning devices, and found that the use of these could have unwanted legal implications for the authority, and will need a more detailed cost-benefit analysis, as well as an assessment of reliability issues (Wullems, 2010). This does not only apply to the highway/rail crossing, but also to the highway/path crossing adjacent to it.

As previously mentioned, non-compliance is higher at grade crossings (62-86%, as noted previously). Though human factors play an important role in compliance, effective warning signs are an important part of securing compliance as well. An Australian study investigated systemic and psychological factors that led to unintentional non-compliance at a crossing, defined as instances where road users *"fail to detect warnings, fail to comprehend their meaning, or misjudge the speed of an oncoming train"* (Salmon, Read, Stanton, & Lenne, 2013). The study was built on an accident that happened in Kerang, Northern Victoria, Australia in 2007 and concluded that almost half of all rail crossing crashes in Australia, are due to unintentional non-compliance (Salmon, Read, Stanton, & Lenne, 2013). The fact that more non-compliance is seen also applies to paths adjacent to tracks, in situations where pedestrians or bikes fail to detect warning signs, or motorists do and end up displaying undesired behavior. The study also found that driver and pedestrian behavior around railroad crossings found to be the largest contributor to accidents in Australia. A study found that the driver's approach speed was lowest at stop-signs, but that it was also the crossing type where the surveyed participants displayed the most reckless behavior (Lenne, et al., 2010). An Australian government-sponsored report, surveyed pedestrian behavior at railroad crossings, through a focus group, a quantitative study and in-depth interviews, and identified the following main areas of interest regarding pedestrian behavior:

- Deliberate violations
    - Participants were aware that they were breaking the rules, to save time or walking distance etc.
- Mistakes
    - Participants were preoccupied, using their phone, talking or similar and committed a violation
- Risk-taking behavior
    - All participants of all ages displayed risky behavior, such as crossing after warnings signs had started.
- Time (bus connections, impatience, appointments)
    - Participants would cross in an undesired manner to make bus connections or an appointment, or simply to just avoid waiting.
- Rules (knowing the rules, obeying the rules, rule breaking, rules over time, maturity, comparing self to others, pedestrian walkers)
    - Most participants did not talk about rules regarding railroads and crossings.
- Deterrents (barriers, fines, shame factor)
    - Fines were reported to be most effective in deterring participants from violating. Barriers did not make a change.
- Surveillance (police and qr staff, cameras)
    - Participants said they'd be more respectful of crossings if police were present, and so would they if a camera was surveilling them.
- Setting an example
    - Most participants would not violate if someone they knew were watching.
- Interventions (education)
    - Education was said to make a difference, as participants felt like it would make them more knowledgeable and aware of train speeds and dangers.

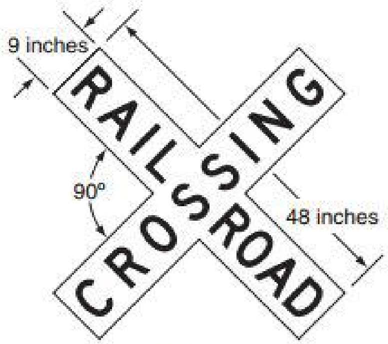
(McMaster, et al., 2014)

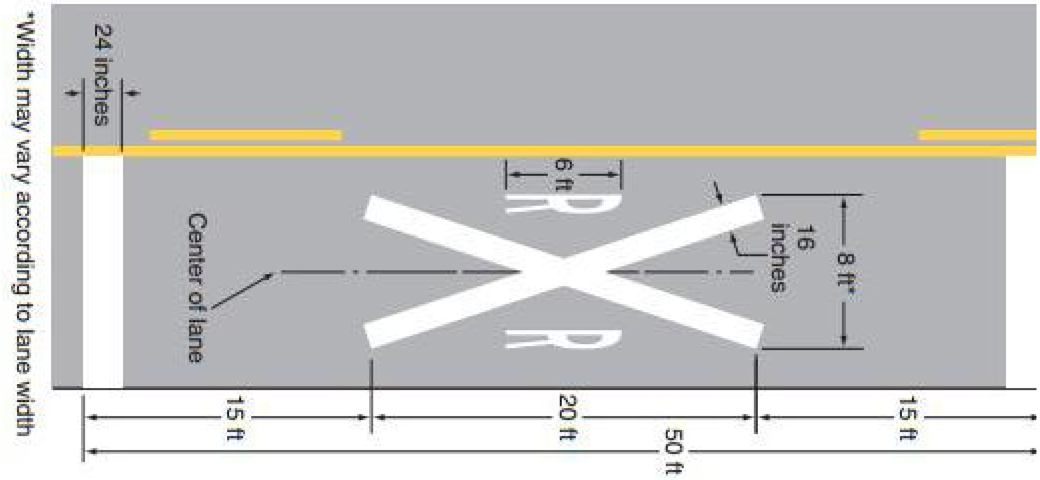
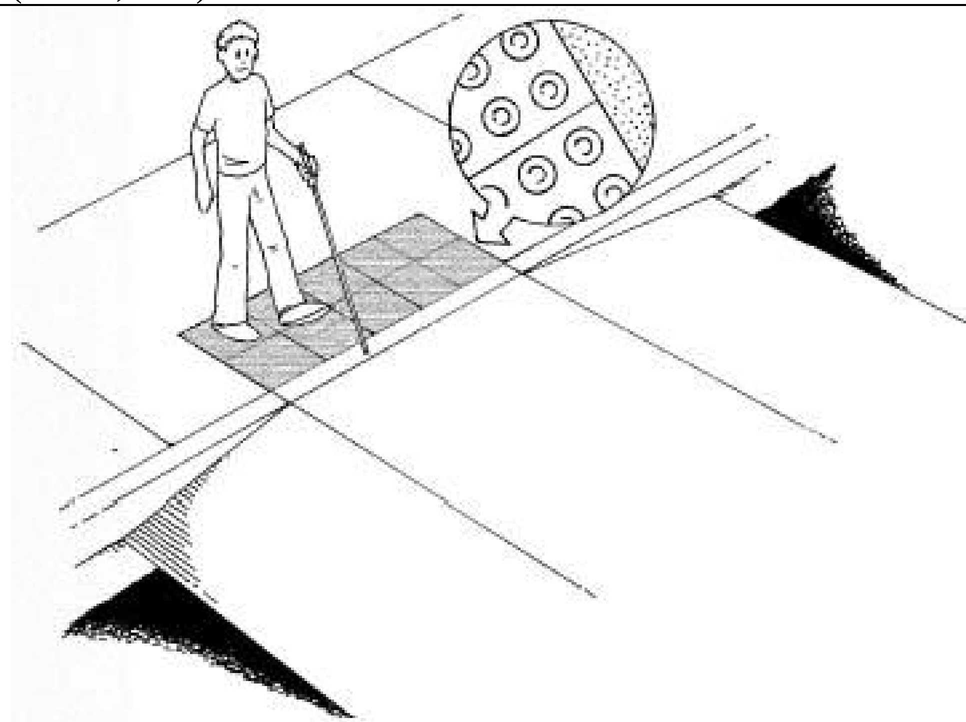
The study also found that males and school children were the most exposed groups (McMaster, et al., 2014). These findings also apply to paths running adjacent to tracks.

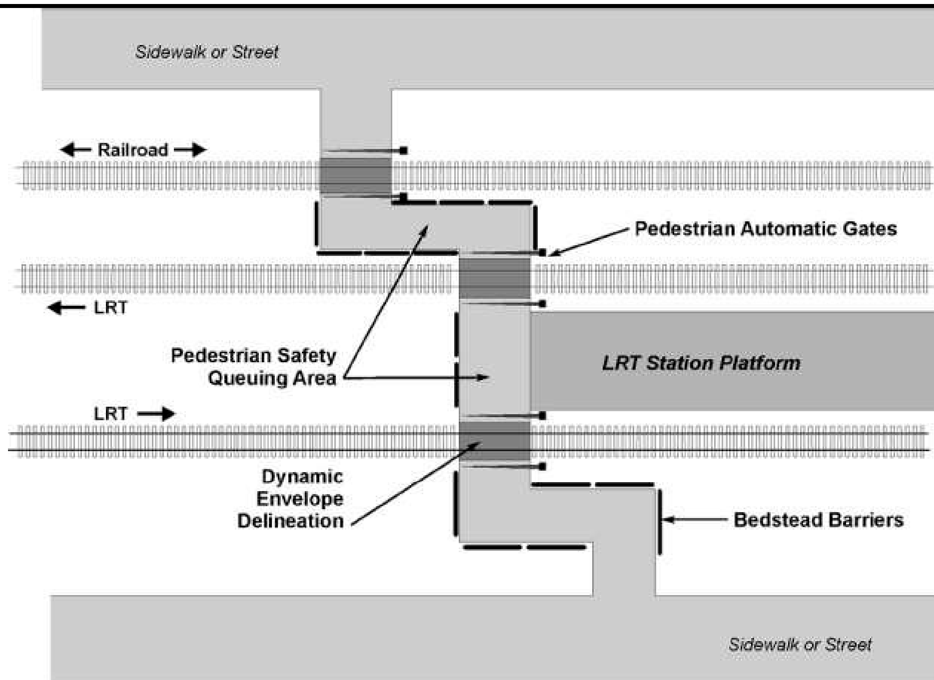
2.5 TREATMENTS AND PROCESSES

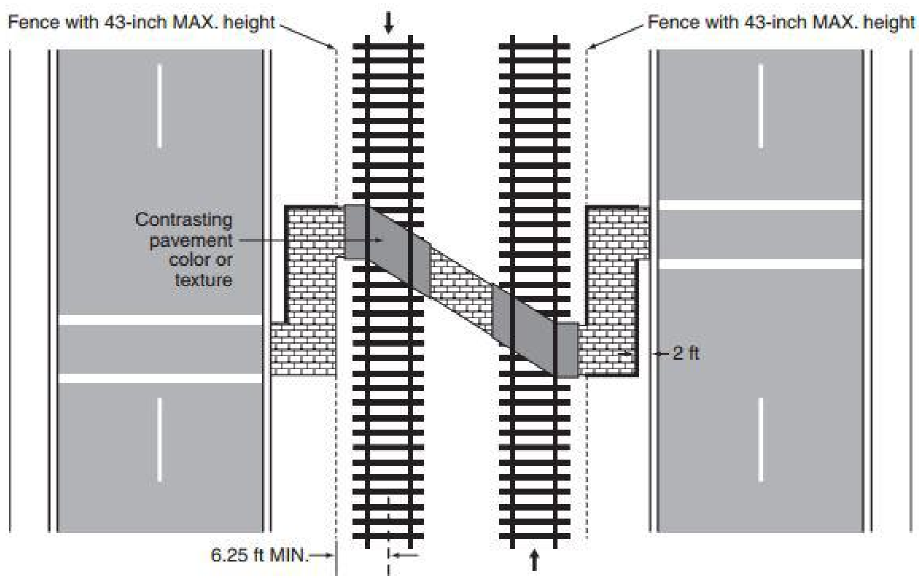
Based on the reviewed literature, the following two tables contain treatments that are used both domestically and internationally to improve safety for pedestrians and bicyclists.

Table 2.3: Passive Railroad Crossing Treatments

TREATMENT	DESCRIPTION
Warning signs *Note: Most commonly used signs showed, other signs can be found in Part 8 of the MUTCD*	 R15-1 (FHWA, 2009)  R1-1 (FHWA, 2009)  W10-1 (FHWA, 2009)

Pavement markings	 (FHWA, 2009)
Tactile Warning	 (FHWA, 2001)

<table>
<tr>
<td>Pedestrian Channelization (Z-Crossing)</td>
<td>


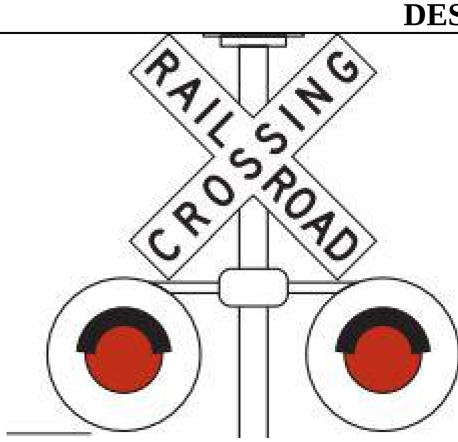
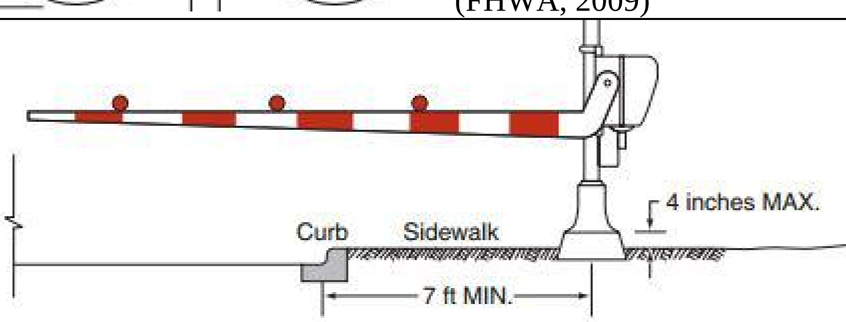
(Primarily used for LRT) (FHWA, 2007)


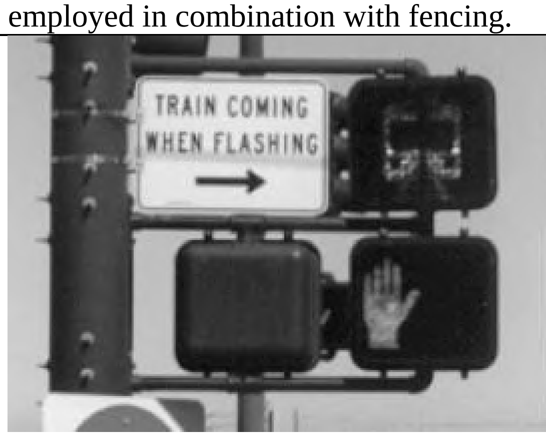
(FHWA, 2009)
Can also be active (Maricopa Association of Governments, 2014)
</td>
</tr>
</table>

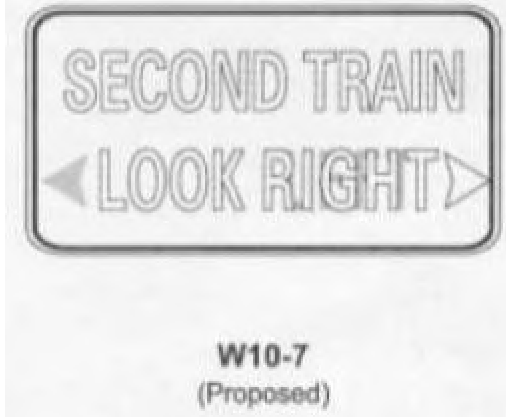
Manual Swing Gates	  (Primarily used for LRT) (FHWA, 2007)
Pedestrian Refuge	  (FHWA, 2013)

Fencing	 (Pardue, 2010)

Table 2.4: Active Railroad Crossing Treatments

TREATMENT	DESCRIPTION
Flashing lights	 (FHWA, 2009)
Automatic Gates	 (FHWA, 2009)

Traffic lights	 (FHWA, 2007)
Vehicle-Activated Strobe Light	A strong light that is activated by an oncoming vehicle. Intended for use at passive highway-railroad grade crossings, with the purpose of gaining the driver’s attention and directing their attention to the warning signs (Fambro & Noyce, 1997). Positive experience in rural Texas. Cost $5,000 per light (1997-$s), maintenance is higher than passive signs (Fambro & Noyce, 1997).
Automatic Swing Gates	As manual swing gates, but operated as standard automatic gates. Usually employed in combination with fencing.
Train Coming Icon	 (Siques, 2001)

“Second Train Coming” Icons	 *“An LRV-activated, internally illuminated matrix sign displaying the pedestrian crossing configuration with one or two (or three or four, etc.) LRVs passing may be used to alert pedestrians to the direction from which one or multiple LRVs are approaching the crossing, especially at locations where pedestrian traffic is heavy (such as LRT stations)”* (FHWA, 2007)
Audible device	 (FHWA, 2009)
Variable message signs	 (Signal Tech, 2016)

Warning devices are installed and maintained by either the railroad or by the agency who has the authority over the public road at the railroad crossing. The decision to implement a new form of warning device, is generally made by evaluating four criteria: vehicle traffic count at the crossing; types of vehicles using the crossing; number of daily trains each way, and; collision history at the crossing. In 2008 the Rail Safety Improvement Act of 2008 which required the 10 states with the most railroad crossings to develop State Grade Crossing Action Plans (SAP). The FHWA and the FRA furthermore developed a model grade crossing action plan, which guides the development of the plan (FHWA, 2016). The steps to develop such a plan are described in the following table.

Table 2.5: Steps to Develop a State Grade Crossing Action Plan (FRA, 2015)

STEP	ACTIVITIES
Pre-planning	Develop sap team Review current strategic sap Generate and review crossing and accident reporting data for high-risk crossings Review previous saps (including from other states) Identify goal(s) and objective(s) Identify a plan scope Brainstorm new sap ideas
Planning	Establish goal(s) and objective(s) Define and establish a plan scope Generate additional data metrics Inventory resources for sap update Review past efforts Assess future programmatic needs Decide on next steps, options, and contingencies Determine implementation strategy Review and modify plan Prioritize and schedule actions
Post-planning	Regular review and modification Evaluate and measure success Communication Prepare for next iteration of the sap
Implementation	Manage action items as planned Implement contingency plans as needed Review action item product to determine effectiveness
Action review	Modify sap as needed due to potential changes in the strategic plan Disseminate modified sap to sap team for review and comment

The full description of all activities can be found in the published document (FRA, 2015).

PennDOT does not have a set process for the installation of crossing, but generally will survey the following points, in deciding the appropriate type of crossing, when trails are present:

- Type of trail users;
- Average daily traffic (ADT) of roadway and trail;
- Mix of vehicular traffic (commercial, agricultural, etc.);
- Type of roadway to be crossed (limited access, arterial, etc.);

- Number of lanes to be crossed;
- Speed of the roadway;
- Sight distance;
- Percent grade; and
- Drainage (Gittings, Torbic, & Zangwill, 1996)

On the topic of light rail, the former director of TriMet, Don Irwin, published an article on safety criteria for light rail crossings in 2003. The article includes a list and graphics of possible treatments, and the combination they should be used applied in Portland, OR. The focus of the report, however, is the development of safety criteria and standards and how they are applied. The criteria include, but are not limited to: LRT design speed, line-of-sight between persons and trains, and other conditions, such as school zone proximity, geometry and likelihood of pedestrian inattention (Irwin, 2003).

As noted before, the Canadian government imposed new rules on at-grade rail crossings. The road authorities and railroad companies are now required to report the following technical data to each other, to help identify the most high-risk crossings:

Table 2.6: Grade Crossing Information Requirements (Weelderen, 2014)

TECHNICAL PARAMETER	METHOD FOR COLLECTING DATA	PARTY RESPONSIBLE FOR DATA COLLECTION
# of tracks	Measure	Railway Company
Average annual daily railway movements (AADR) PASSENGER TRAIN AADR FREIGHT TRAIN AADR	Request	
Maximum Rail Operating Speed (mph) PASSENGER TRAIN FREIGHT TRAIN	Request	
Crossing angle (degrees)	Measure	
Warning system (RCS, SRCS, FLB, FLBG)	Observe	
STOP sign installed on the same post as the RAILWAY CROSSING sign (yes/no)	Observe	
# of traffic lanes over crossing surface	Measure	Road Authority
Average annual daily traffic	Measure	
Road design speed	Observe	
Road classification	Record	
Width of each traffic lane on the road approach (m)	Measure	
Design vehicle (include special vehicles)	Record	
Stopping sight distance (m)	Calculate	
Average gradient of the road approach	Measure	
Departure time (s)	Calculate	
Advance activation time (s)	Calculate	
Warning system is interconnected with highway traffic control signals (yes/no)	Observe	
Traffic control signals are pre-empted in advance of the warning system flashing light (yes/no)	Observe	
Pre-emption time of traffic control signals (s)	Calculate	
Sidewalk, path or trail (yes/no)	Observe	
Crossing regularly used by persons using assistive devices (yes/no)	Observe	

It was estimated that this work would cost $900 CAD per crossing location (Weelderen, 2014).

The Arizona-based regional planning organization Maricopa Association of Governments published a report in 2014 with recommendations for improving safety for pedestrians and bikes at crossings. With the report, they developed a flowchart to decide which treatments should be used at an at-grade crossing. The flowchart is shown in full below.

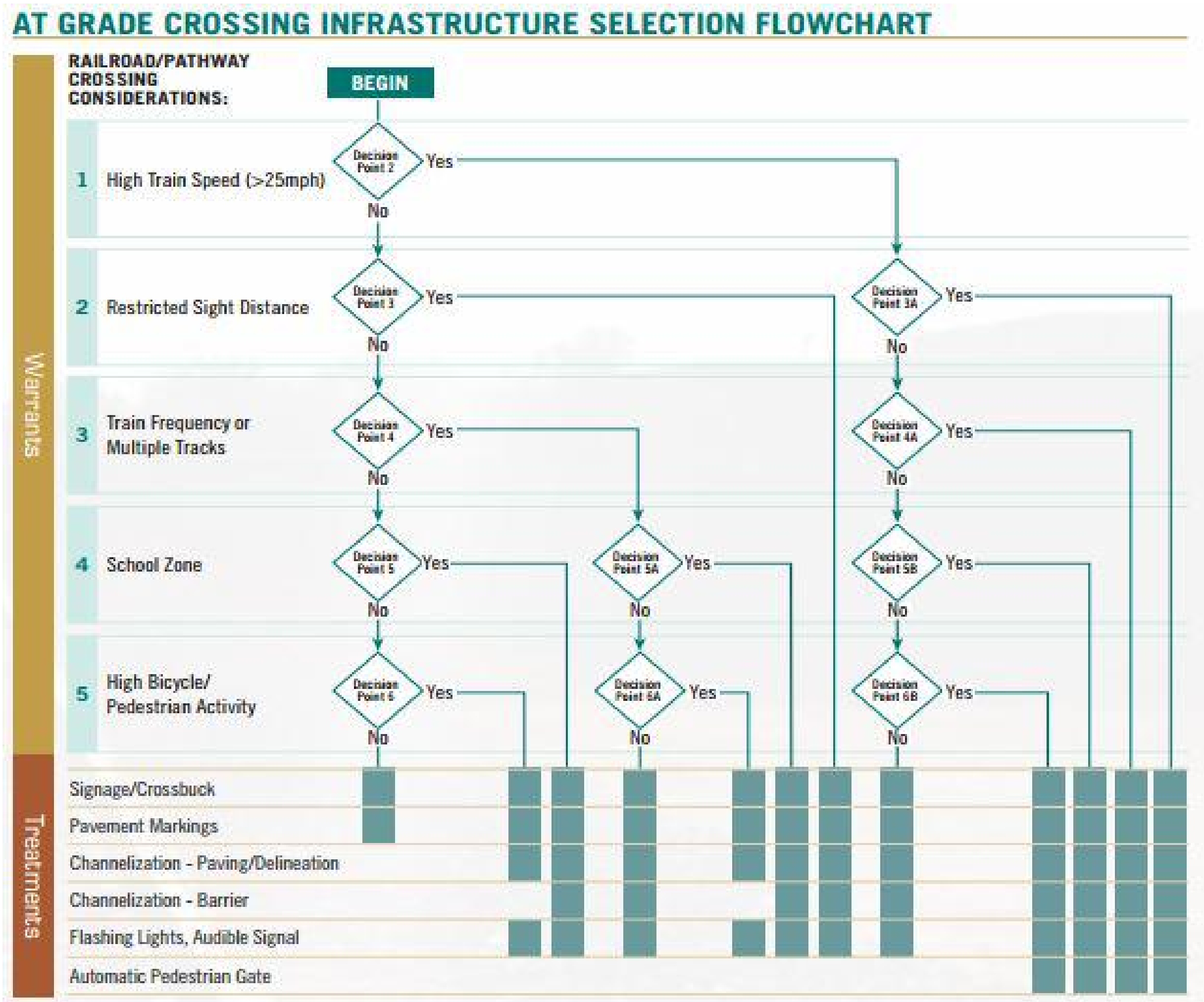


Figure 2.1: At-grade crossing infrastructure selection flowchart (MAG, 2014)

A similar approach was completed previously, where a thorough study from Minnesota resulted in the decision tree in figure 2.3, which is used to determine which type of treatment should be utilized

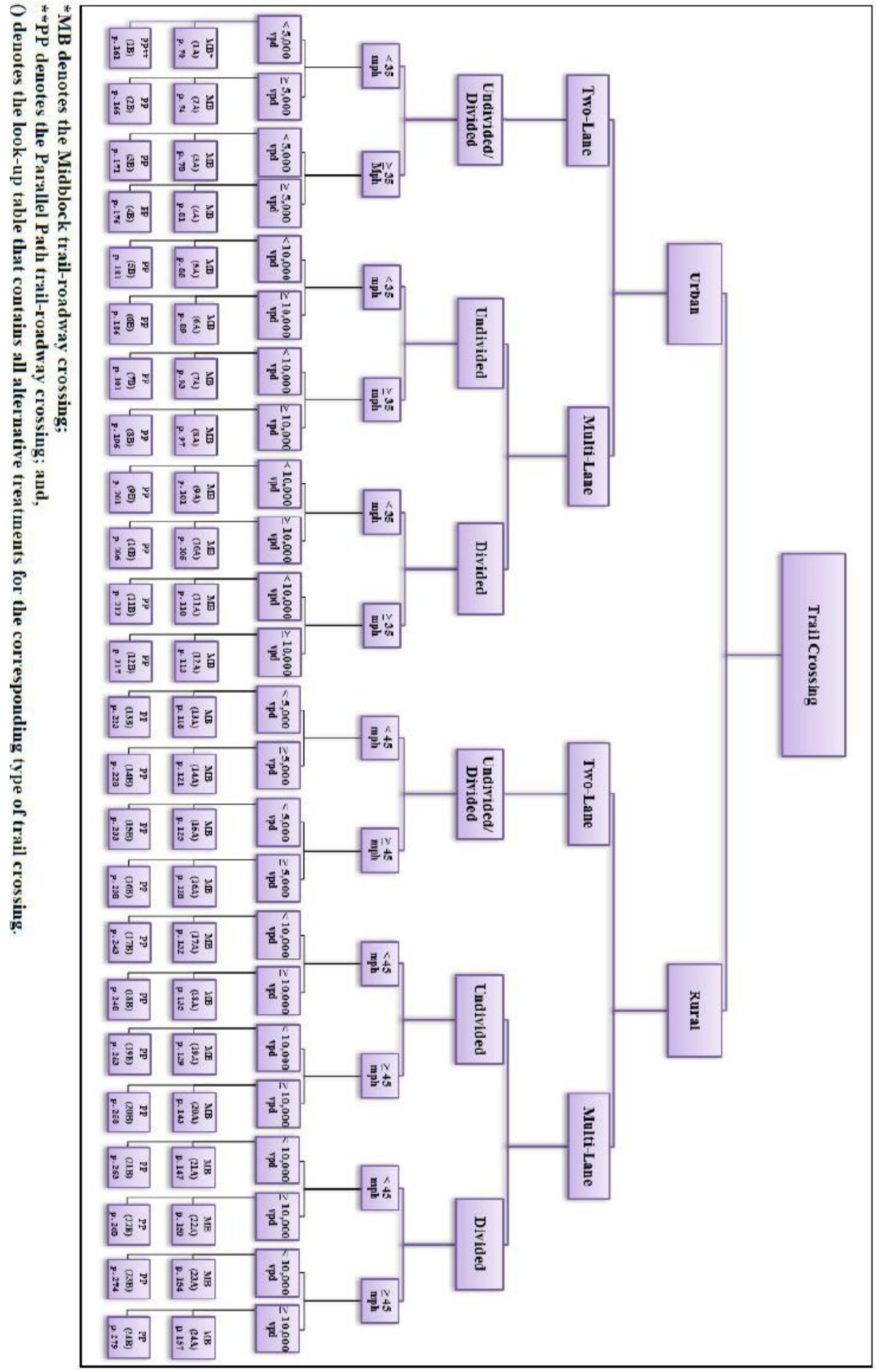


Figure 2.2: Decision tree for rail/trail crossings in Minnesota (Noyce, 2013)

3.0 FIELD STUDIES

This chapter documents the field surveys that were completed at seven case study sites in Oregon, including photos, diagrams and descriptions of conditions at the sites.

3.1 NW CIVIC DR, GRESHAM

3.1.1 Current Conditions

ODOT Crossing No. 43A 13.80 is a light rail crossing located in the Portland suburb of Gresham, OR. It consists of two tracks crossing NW Civic Dr. This crossing is owned by the light rail authority TriMet and has approximately 155 trains coming through per day. The average car size is two cars and the timetable speed is up to 55 mph, though operating speed is typically around 25 mph approaching the crossing, according to ODOT RPTD.

The road is a two-lane road and is marked as a 25-mph zone. The AADT is reported at 6172 cars.

The crossing and adjacent street is lighted with three street lamps, as well as lighting coming from the nearby light rail station. There have been no recorded incidents at this crossing. Facilities that can be found near this location includes the light rail station, a charter school, a community college, residential areas, parking as well as a large mall area nearby.

Figure 3.1: Satellite photo of the NW Civic Dr crossing in Gresham, OR (Trail is marked in orange)

3.1.1.1 Highway/Rail Crossing Treatments

The current treatments at this site includes a variety of active and passive equipment. The crossing is fitted with active gates, lights and bells. Signage includes a 2-tracks cross buck, a sign telling pedestrians to look both ways, and signs pointing out the sites of the pedestrian crosswalk field. Underneath the pedestrian crosswalk sign, which can be illuminated with the help of a push button (Rectangular Rapid Flash Beacon), a sign telling drivers to not stop on tracks is installed. Where the tracks can be crossed, channelization has been installed to make pedestrians look both ways. The Z crossing enables the pedestrian and the train operator to be in nearly constant eye contact during the crossing movement. The use of a median refuge island separates the crossing into two movements. These are accompanied by an active mini pedestrian light and bell between the two sets of tracks, and a sign telling pedestrians to look both ways. There is a stop line for road users and no median. The pedestrian crosswalk zone is furthermore marked using a different type of surfacing.

Figure 3.2: Active and passive treatments, and the adjacent light rail station.

Figure 3.3: Active and passive treatments at the NW Civic Dr crossing

3.1.1.2 Highway/Path Crossing Treatments

This location allows pedestrians to cross adjacent to the tracks on both sides. As one side is equipped with a trail, which is where most of the crossing take place, though there's also quite a few crossings made adjacent to the tracks, by people walking to and from the station. Both crosswalks are marked with tactile surfaces, different crossing surface, and pedestrian-activated push buttons (RRFBs) that can be enabled by users wishing to cross adjacent to the tracks. The crosswalk fields are marked by signage as seen in Figure 3.4.

Figure 3.4: Pedestrian facilities found at both sides of the crossing

3.1.1.3 Bike and Pedestrian Facilities

This location has several different forms of facilities for bike and pedestrian traffic. There is a multi-use trail running adjacent to the light rail tracks, called the Max Rail Trail. Though there is a trail running across the road, it did not appear that the two trails were connected or used for their connection, and few users were seen moving from one side of the trail to the other. Both sides of the road are equipped with sidewalks and the road and tracks can be crossed four ways. There is passive pedestrian management across the tracks, and pedestrian-activated push buttons to cross the road next to the track. Both sides of the road are equipped with bike lanes.

Figure 3.5: Multiuse trail

Figure 3.6: Pedestrian facilities and trailhead

3.1.2 Observed Movements

A simplified diagram of NW Civic Dr. is included below to exemplify the dynamic movements of road and path users at this crossing.

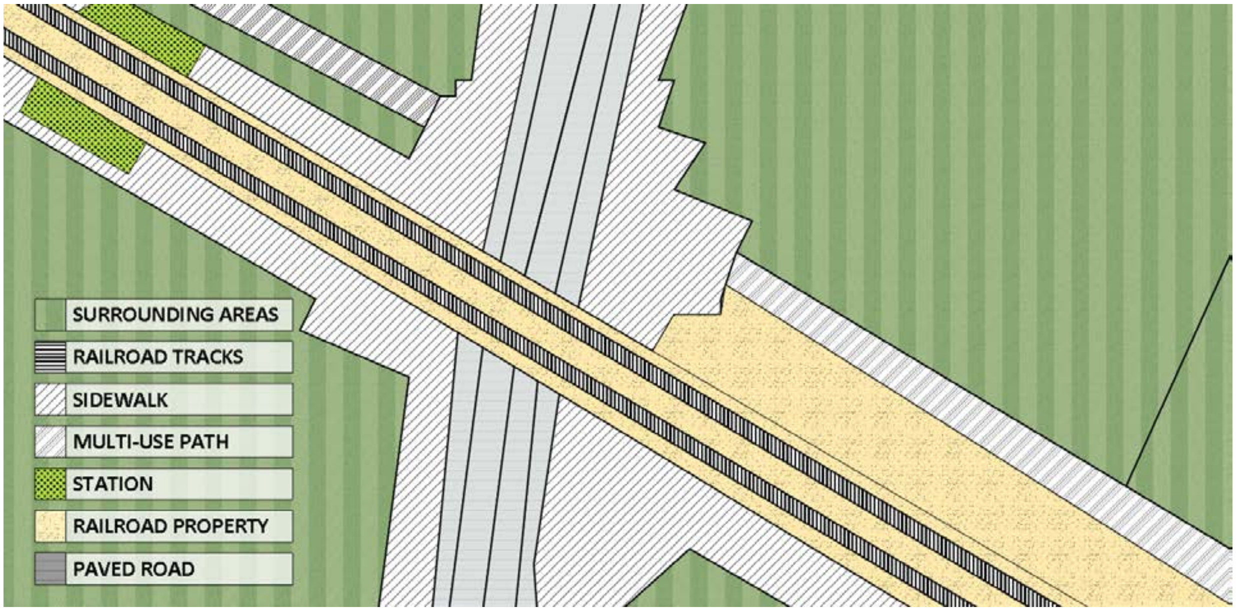


Figure 3.7: Diagram of NW Civic Dr.

3.1.2.1 Vehicles and Trains

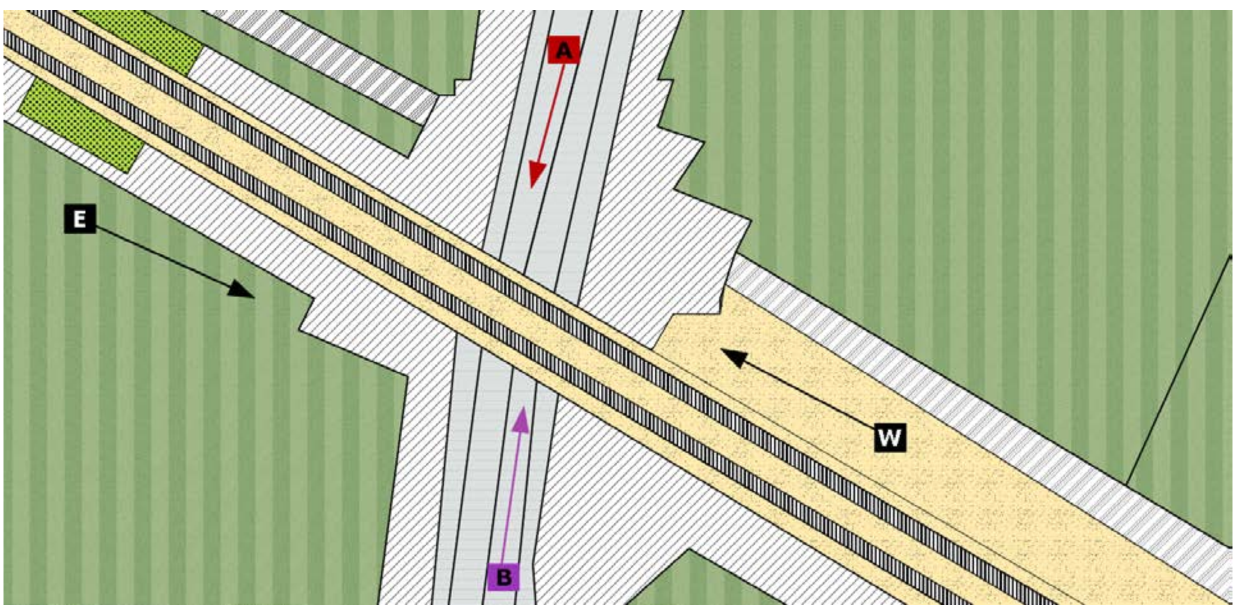


Figure 3.8: Diagram depicting observed vehicle and train movements

Table 3.1: Vehicle and Train Video Counts - Counts Correspond with Diagram Above.	
VIDEO COUNTS	
	2016/05/23 5pm-6pm
Vehicles, total	438
Movement A (NB)	221
Movement B (SB)	217
Trains, total	9
Movement W (WB)	4
Movement E (EB)	5

3.1.2.2 Pedestrians and Bikes

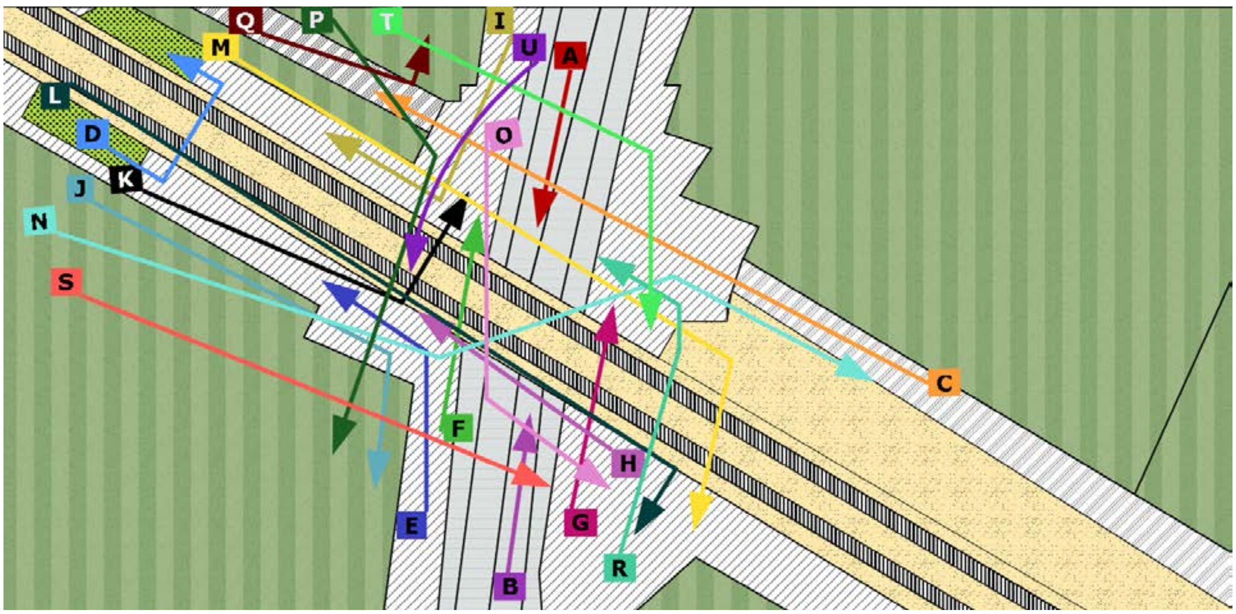


Figure 3.9: Diagram depicting observed pedestrian and bike movements

Most frequently observed pedestrian movements, Movements I & J involve keeping to the sidewalk.

Table 3.2: Pedestrian and Bike Video Counts - Counts Correspond with Diagram Above

VIDEO COUNTS	
	5pm-6pm
Pedestrians, total	76
Movement A	0
Movement B	0
Movement C	1
Movement D	2

Movement E	3
Movement F	1
Movement G	7
Movement H	2
Movement I	12
Movement J	16
Movement K	10
Movement L	2
Movement M	2
Movement N	0
Movement O	1
Movement P	2
Movement Q	2
Movement R	4
Movement S	1
Movement T	3
Movement U	5
Bikes, total	8
Movement A	2
Movement B	1
Movement C	1
Movement D	0
Movement E	0
Movement F	0
Movement G	1
Movement H	0
Movement I	0
Movement J	1
Movement K	0
Movement L	0
Movement M	0
Movement N	1
Movement O	1
Movement P	0
Movement Q	0
Movement R	0
Movement S	0
Movement T	0
Movement U	0

3.1.2.3 Field Counts

Table 3.3: Pedestrian and Bike Counts from Field Visit

FIELD COUNTS		
	Pedestrians	Bikes
Trail, WB	34.0	8
Trail, SB	13	2
Crossings	98.0	1
Total	145	11

3.2 NE CENTURY BLVD (FORMERLY NW 231ST AVE), HILLSBORO

3.2.1 Current Conditions

ODOT Crossing No. TMW 13.60 is a light rail crossing located in the Portland suburb of Hillsboro, OR. It consists of two tracks crossing NE Century Blvd. This crossing is owned by the transit authority TriMet with approximately 200 trains using the crossing each day. The average train size is two cars and the timetable speed is up to 55 mph, though the usually operating speed through this crossing is observed to be around 10 mph.

The road is a two-lane road in what constitutes the center of Hillsboro and is marked as a 35-mph zone. The AADT is around 10,600 cars per day, however the traffic was lower during the field observations, due to roadwork in progress.

The crossing and adjacent street is illuminated lighted with four street lamps, and there have been no recorded incidents at this crossing. As this is the city center, many different facilities can be found in the area including: TriMet Bike and Ride, the light rail station, several residences and apartment complexes, senior housing, bus stop, Orenco Station Plaza, which is a small outdoor shopping center and Orenco Elementary School.

Figure 3.10: Satellite photo of the NE Century Blvd crossing in Hillsboro (Google, 2016) (Trail is marked in orange)

3.2.1.1 Highway/Rail Crossing Treatments

This crossing has the most treatments of all the surveyed crossings. First, the crossing is controlled with a traffic signal. While the southbound light is only used to stop cars when pedestrians are present and when a train is crossing, the northbound light is different. Upstream another light is found, and when that is red, the northbound light is too. This leads to some confusion. The crossing is also equipped with active gates, flashing lights and bells, activated by an oncoming train and active TriMet Style Pedestrian Flashers (TMPF’s), which are placed at both pedestrian track crossings between each set of tracks. There is standard signage such as cross bucks, railroad ahead, etc. In addition to that there is a TriMet “LOOK BOTH WAYS” black on yellow warning sign, which are utilized by TriMet exclusively and are permitted to be installed. Other passive treatments at this location includes pedestrian gates and pedestrian fencing, along with tactile surfaces and painted road marks.

Figure 3.11: Tactile surface and painted stop signs for pedestrians

Figure 3.12: Active TriMet Style Pedestrian Flashers (TMPF's) and pedestrian fencing

Figure 3.13: This crossing has many different types of treatments

Figure 3.14: Passive gates close off both sides of the crossing closets to the light rail

3.2.1.2 Highway/Path Crossing Treatments

The adjacent path is primarily used by pedestrians, though a few bikes were also observed. The trailhead is marked by bollards on one side, the one leading from the station and the plaza, but not on the other side. There are pedestrian crossings on both sides of the street and they are both marked with stripes and yellow tactile warning plates.

Both crosswalks have refuge islands in the middle, and are signalized with a button activated light signal.

Figure 3.15: Highway/Path Crossing (Google, 2016)

3.2.1.3 Bike and Pedestrian Facilities

This crossing has several infrastructure installations designed for bikes and pedestrians. Both sides of the road are equipped with both sidewalks of varying width and with on-road bike lanes. The sidewalks enable users to cross the railroad tracks on both sides, through passive fences as previously described. There is not a continuous trail running adjacent to the road at this location, but there is some activity stemming from the plaza and the light rail station, using a pedestrian walkway that leads into a residential complex.

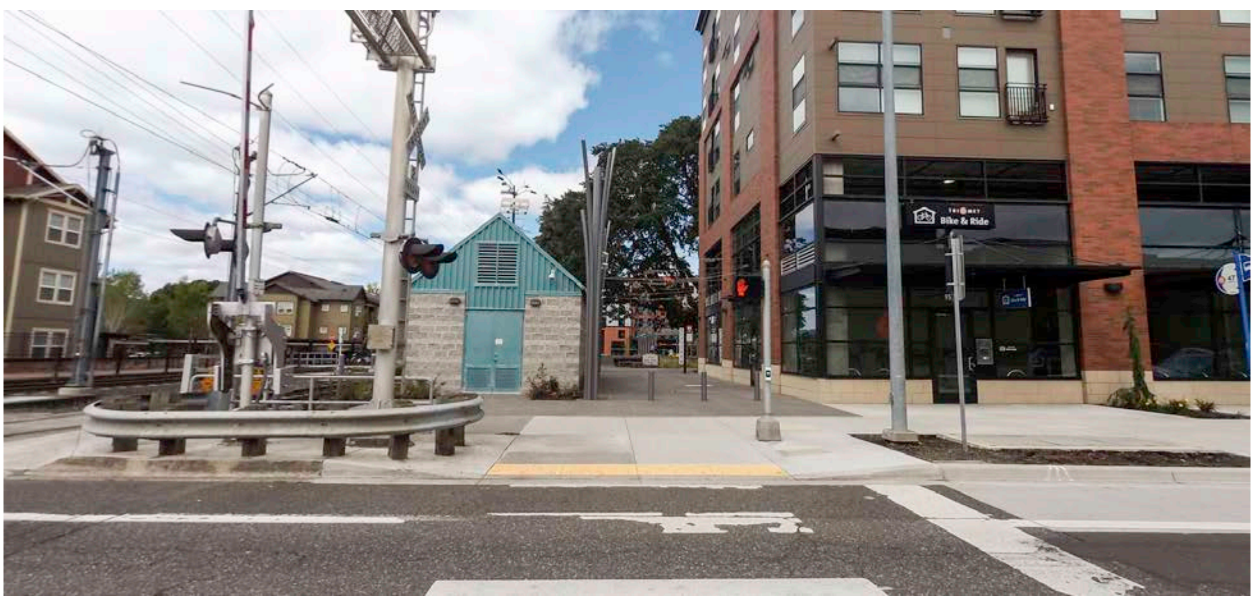


Figure 3.16: Pedestrian facilities, the light rail station and the Orenco Plaza entrance

3.2.2 Observed Movements

A simplified diagram of NE Century Blvd is included below to exemplify the dynamic movements of road and path users at this crossing.

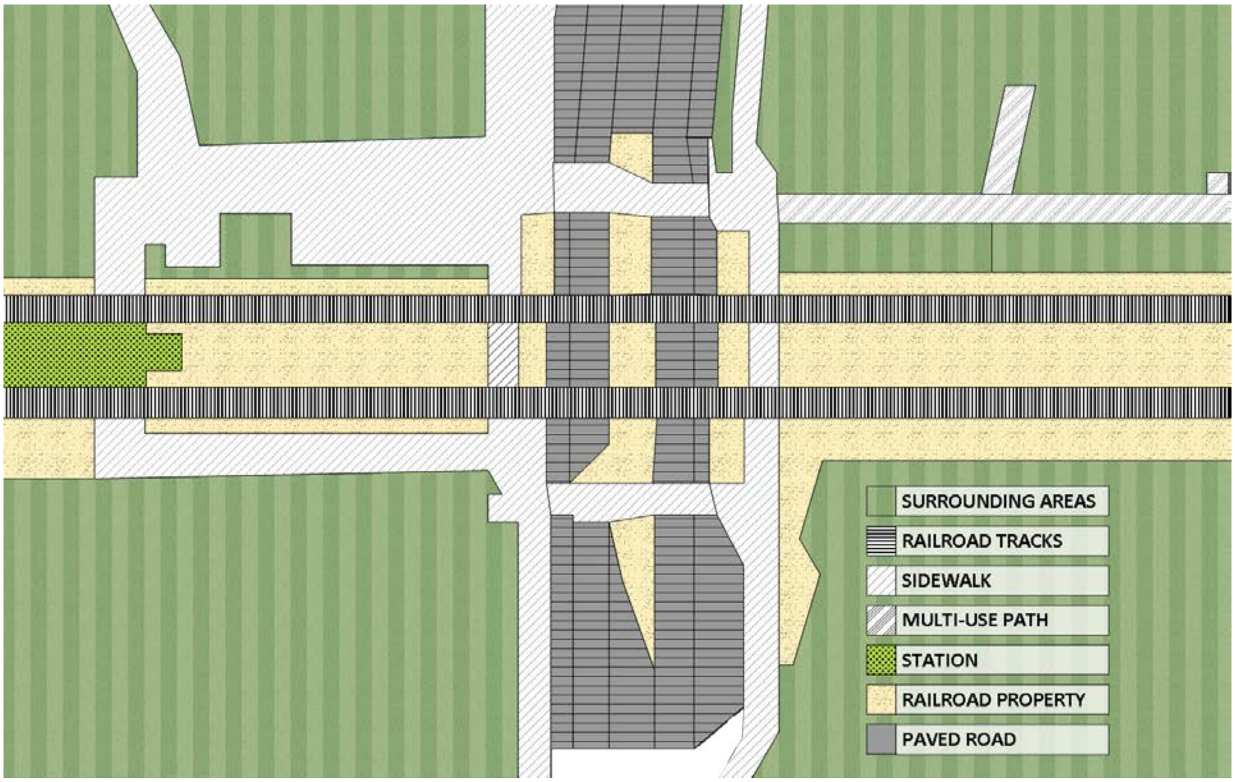


Figure 3.17: Diagram of NW231 St.

3.2.2.1 Vehicles and Trains

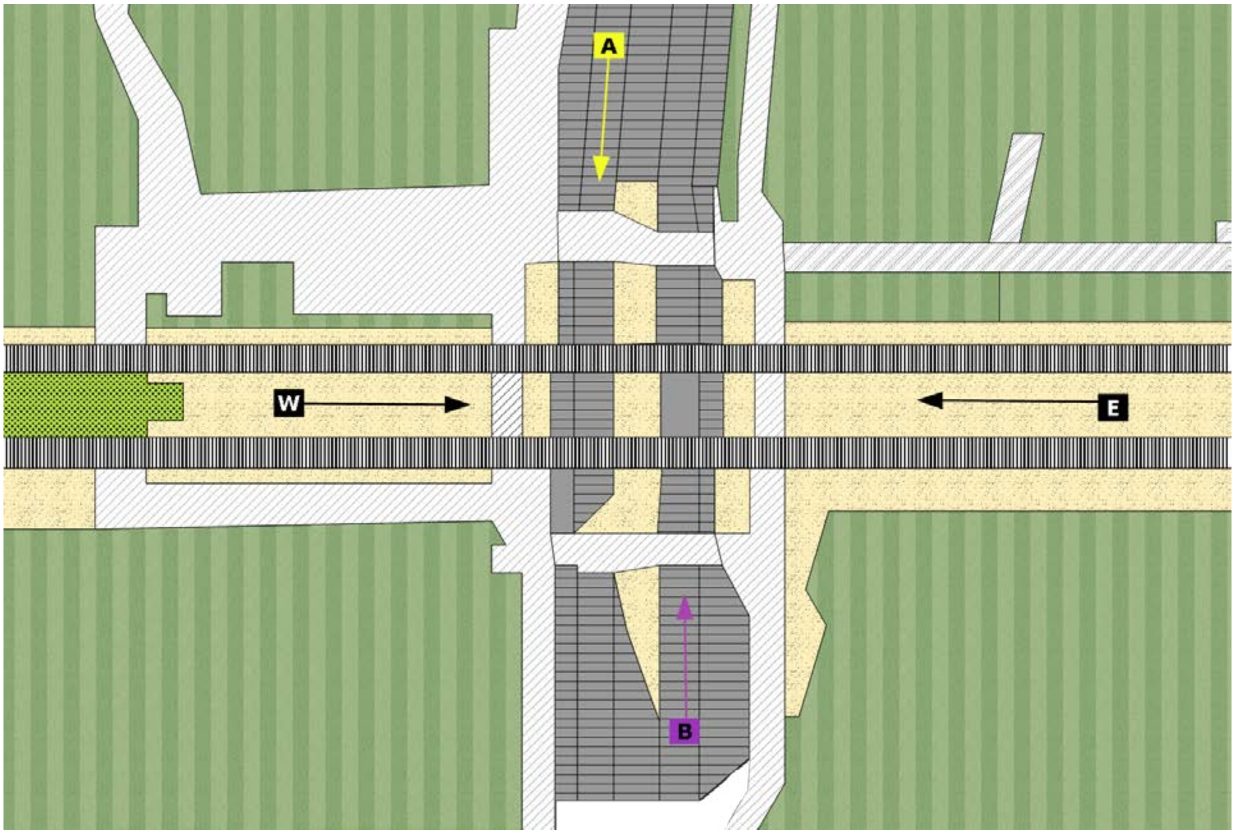


Figure 3.18: Diagram depicting observed vehicle and train movements

Vehicles speed through the crossing while the light rail warning lights are flashing red.

Table 3.4: Vehicle and Train Video Counts - Counts Correspond with Diagram Above

VIDEO COUNTS			
	2016/07/06 8am-9am	2016/07/05 5pm-6pm	Average
Vehicles	647	823	735
Movement A (SB)	201	512	356.5
Movement B (NB)	446	311	378.5
Trains	11	12	11.5
Movement W (WB)	6	7	6.5
Movement E (EB)	5	5	5

3.2.2.2 Pedestrians and Bikes

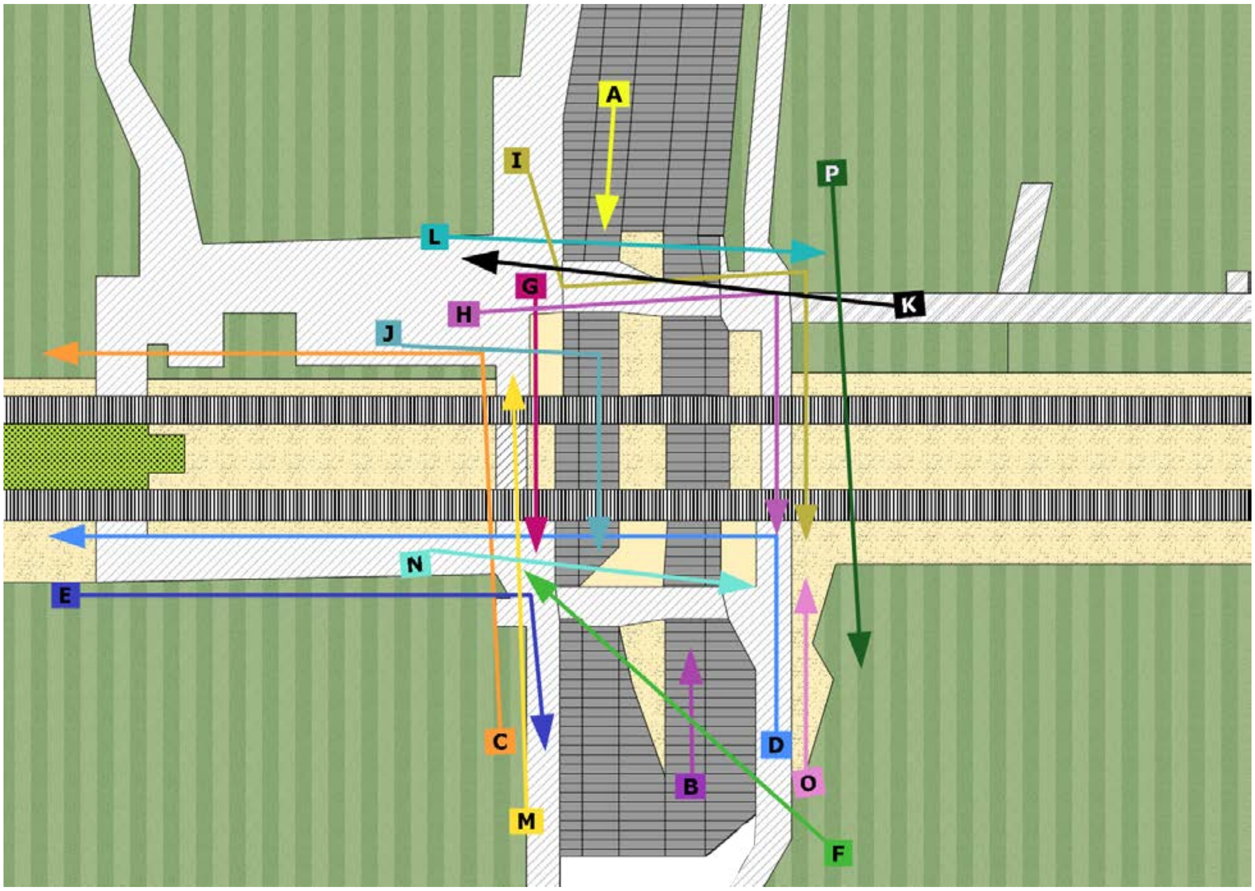


Figure 3.19: Diagram depicting observed pedestrian and bike movements

Four of the most frequently observed movements during morning rush hour; Movements C, D, K & L involve entering and exiting the path.

Undesired observed pedestrian movements include Movement F.

Most observed bicyclists utilized the road's bike path. This is indicated by Movement B during morning rush hour and Movement A during evening rush hour.

Table 3.5: Pedestrian and Bike Video Counts - Counts Correspond with Diagram Above

VIDEO COUNTS			
	2016/07/06 8am-9am	2016/07/05 5pm-6pm	Average
Pedestrians	68	51	59.5
Movement A	0	0	0
Movement B	0	0	0
Movement C	12	2	7

Movement D	11	0	5.5
Movement E	2	0	1
Movement F	1	0	0.5
Movement G	2	5	3.5
Movement H	0	0	0
Movement I	0	4	2
Movement J	0	0	0
Movement K	19	9	14
Movement L	12	18	15
Movement M	1	4	2.5
Movement N	6	5	5.5
Movement O	1	2	1.5
Movement P	1	2	1.5
Bikes	20	27	23.5
Movement A	2	10	6
Movement B	11	5	8
Movement C	1	0	0.5
Movement D	0	0	0
Movement E	0	1	0.5
Movement F	0	1	0.5
Movement G	0	2	1
Movement H	0	1	0.5
Movement I	0	0	0
Movement J	0	1	0.5
Movement K	2	4	3
Movement L	4	1	2.5
Movement M	0	1	0.5
Movement N	0	0	0
Movement O	0	0	0
Movement P	0	0	0

3.2.2.3 Field Counts

Table 3.6: Pedestrian and Bike Counts from Field Visit

FIELD COUNTS		
	Pedestrians	Bikes
Trail	30	2
Track Crossings	14	9
Total	44	11

3.3 SE SPOKANE ST, PORTLAND

3.3.1 Current Conditions

USDOT Crossing No. 862961L / ODOT Crossing No. 46A 3.58 is a railroad crossing located in Portland, OR. It consists of one track crossing SE Spokane St at a slight angle. This crossing is owned by Oregon Pacific Railroad (OPR) and has two trains coming through per day. The trains are both passenger and freight trains with around five cars and runs at a maximum timetable speed of 10 mph.

The road is a two-lane road in a residential neighborhood and is marked as a 25-mph zone. In 1993 the AADT was 3,644. During the observations, a count of 86 cars per 15 minutes or 344 cars per hour was made.

The crossing and adjacent street is lighted with two street posts, and there have been no recorded incidents at this crossing. Nearby facilities include residences, a public park and a large amusement park.

Figure 3.20: Satellite photo of the SE Spokane St crossing in Portland (Google, 2016) (Trail is marked in orange)

3.3.1.1 Highway/Rail Crossing Treatments

This crossing has no active treatments. The crossing is equipped with crossbucks, stop signs and railroad road pavement markings.

3.3.1.2 Highway/Path Crossing Treatments

The multi-use trailheads are both equipped with stop signs of a design specified for use on trails which are placed lower and are smaller than a standard sign, and designed according to MUTCD Section 8D and Part 9. Both trailheads are equipped with a stop line and both have one bollard, which is placed to show the two-way nature of the multi-use path. The crossing is marked.

Figure 3.21: There are stop signs installed at all approaches and for all road users

3.3.1.3 Bike and Pedestrian Facilities

The railroad track lies adjacent to the Springwater Corridor. The section of the trail around the crossing is known as Springwater on the Willamette, and is a 3-mile section that opened in 2005. The corridor is used by considerable multi-modal commuter traffic and is important for connecting parts of Portland. The multiuse trail is separated from the rail line by a fence, and from other road users by fencing and vegetation. The trail crossing the road is marked with a continental crosswalk and the trail head is marked with mini stop-signs placed in bike height. There is also a stop line marked on both sides of the trailhead. The railroad tracks can be crossed on either side of the road on the sidewalks, but pedestrians are not directed to cross the road on the non-trail side of the railroad. The road is also marked with shared lane markings for bike traffic.

3.3.2 Observed Movements

A simplified diagram of SE Spokane St. is included below to exemplify the dynamic movements of road and path users at this crossing.

Figure 3.22: Diagram of SE Spokane St.

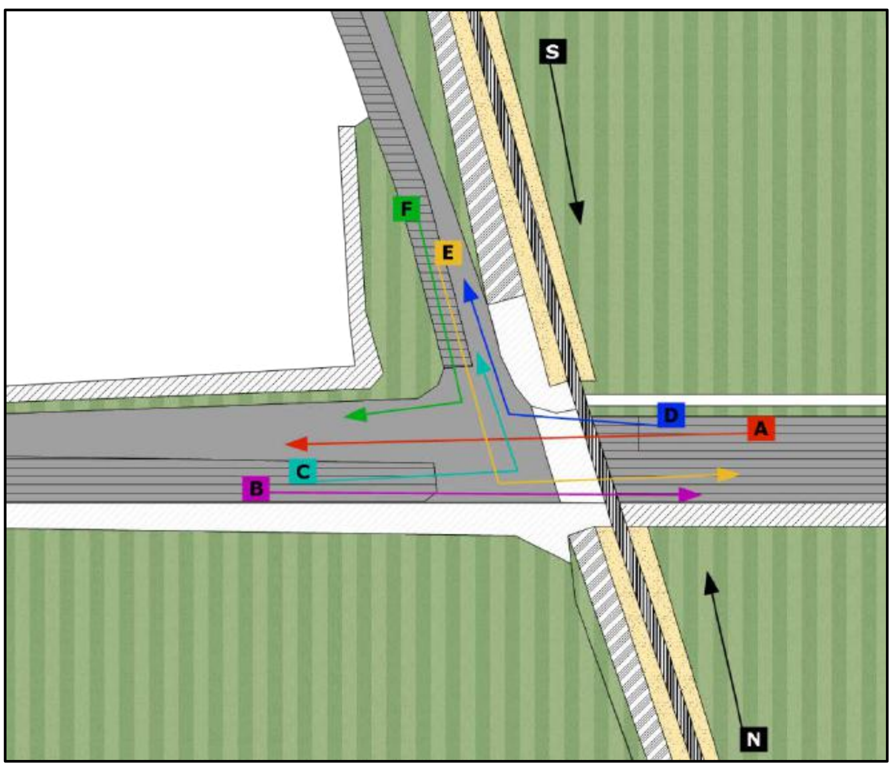


Figure 3.23: Diagram depicting observed vehicle and train movements

Movement D is on average the most frequently observed vehicle movement. Video observations reveal that there is a conflict between vehicles and path users during this movement because turning vehicles often drive on the pavement or path after turning, before readjusting to being fully on the road. This is because the path is at-grade with the roadway. This issue is addressed in the case studies of the location.

Movement D also demands more dwell time on the railroad tracks while high pedestrian and bike traffic volume utilize the path.

Movement E is also a frequently observed movement. Vehicles making this turning must share the turning radius with cyclists who perform the same movement on the road.

Table 3.7: Vehicle and Train Video Counts - Counts Correspond with Diagram Above

VIDEO COUNTS				FIELD COUNTS
	2016/07/07 8am-9am	2016/07/06 5.15pm-6.15pm	Average	3.23pm-4.38pm
Vehicles	136	281	208.5	439
Movement A (WB)	27	12	19.5	41
Movement B (EB)	14	29	21.5	53
Movement C	1	1	1	N/A
Movement D	54	102	78	150
Movement E	18	137	77.5	191
Movement F	1	0	0.5	N/A
Other Movements	21	0	10.5	4
Trains	0	0	0	
Movement A (SB)	0	0	0	
Movement B (NB)	0	0	0	

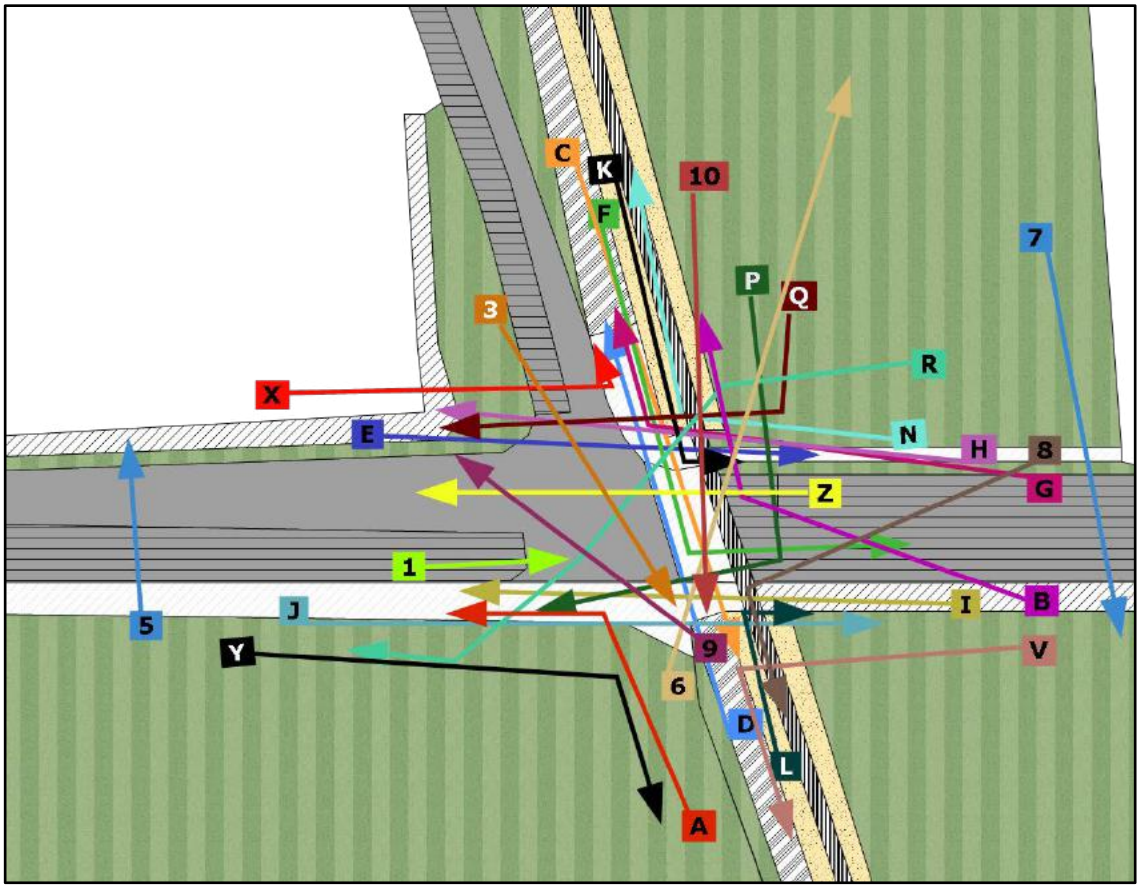


Figure 3.24: Diagram depicting observed pedestrian movements

The two most frequently observed pedestrian movements per hour during rush hour is Movement E & H. Neither one of these movements involve utilizing the path, simply crossing the path.

Movement 6, 10, P, Q, & B indicate trespassing railroad property.

Undesired crosswalk crossing of the road is prevalent at this crossing. Pedestrians are choosing shortest routes to their destination over utilizing designated crosswalks. Movement B, F, P, R, 3, 5, 6, 7, 8, & 9 exemplify observed undesired pedestrian crossing.

The most frequently observed movement during rush hour is Movement F where pedestrians coming from the trail continue up the street, either on or off the sidewalk.

Pedestrian right-of-way creates unpredictability and uncertainty for drivers.

There are numerous ad-hoc movement possibilities for pedestrians at this crossing, which creates an uncertain crossing environment for the path users and the vehicles at this intersection.

Table 3.8: Pedestrian Video Counts - Counts Correspond with Diagram Above

VIDEO COUNTS			
	2016/07/07 8am-9am	2016/07/06 5.15pm-6.15pm	Average
Pedestrians, total	55	68	61.5
Movement A	2	2	2
Movement B	2	4	3
Movement C	4	3	3.5
Movement D	2	3	2.5
Movement E	6	7	6.5
Movement F	11	0	5.5
Movement G	1	0	0.5
Movement H	7	6	6.5
Movement I	3	3	3
Movement J	1	3	2
Movement K	2	2	2
Movement L	1	0	0.5
Movement N	3	2	2.5
Movement P	5	3	4
Movement Q	2	1	1.5
Movement R	1	1	1
Movement V	1	4	2.5
Movement X	1	5	3
Movement Y	0	1	0.5
Movement Z	0	0	1
Movement 1	0	0	1
Movement 3	0	2	1
Movement 5	0	3	1.5
Movement 6	0	4	2
Movement 7	0	2	1
Movement 8	0	3	1.5
Movement 9	0	2	1
Movement 10	0	2	1

3.3.2.1 Bikes

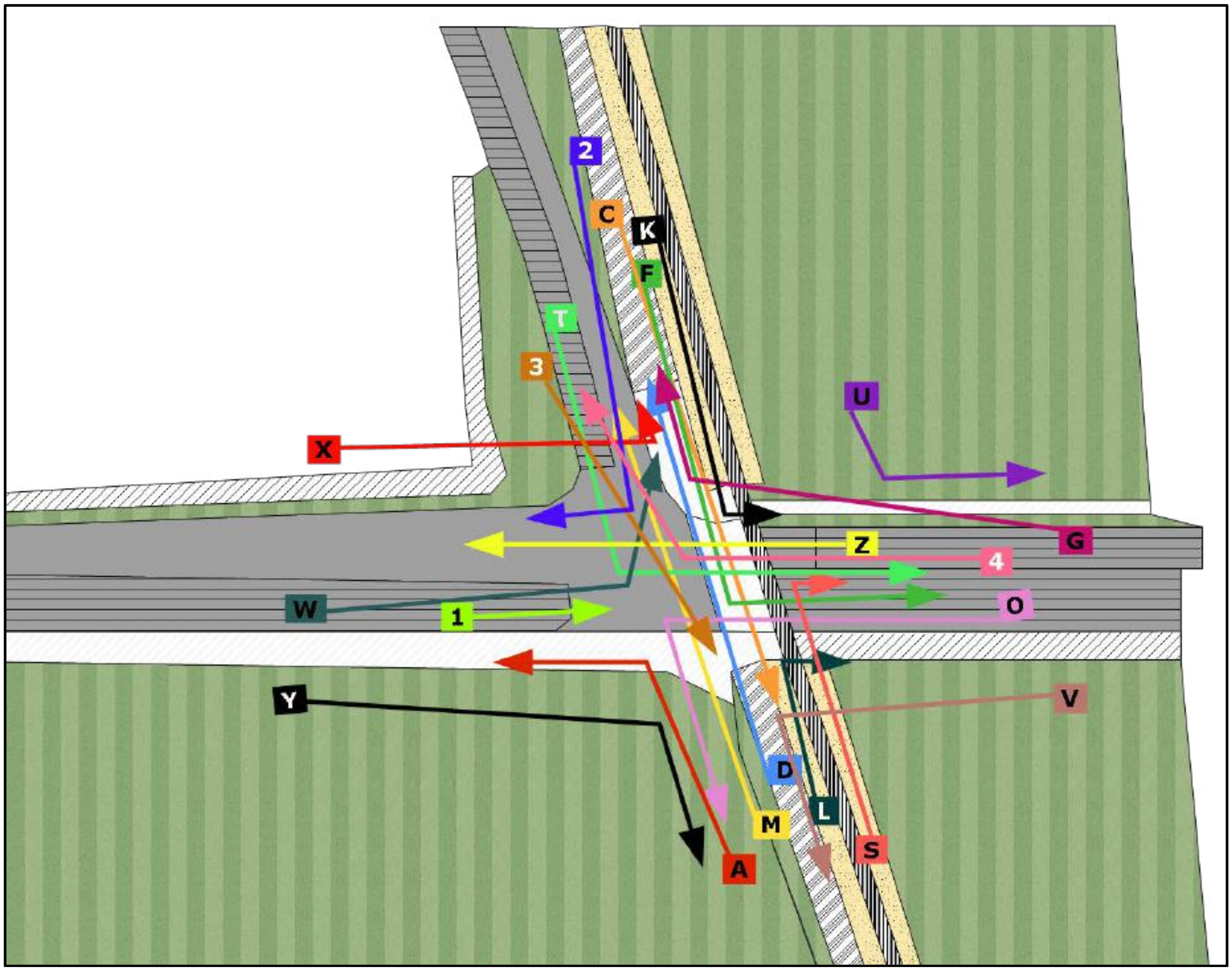


Figure 3.25: Diagram depicting observed bike movements

The most frequently observed bicycle movement is staying on path, Movement C. Cyclists are required to come to a full stop before crossing the road; however, the observations indicate a high non-compliance rate for stopping before crossing. The issue is addressed in the case studies.

Together, Movement 1, F, S, & T utilize the eastbound roadway on average of 44 bikes/hour. This is the same roadway bicyclists are sharing with vehicle drivers performing Movement E.

Bicyclists performing Movement 1, F, L, S, & T are unlikely to come to a full stop due to the incline they are anticipating.

Bicyclists are entitled to utilize the road, path, or sidewalk. This right in conjunction with the high speeds of cyclists and vehicle presence creates confusion and unpredictability for both bicyclists and vehicle drivers at the crossing.

Table 3.9: Bike Video Counts - Counts Correspond with Diagram Above

VIDEO COUNTS			
	2016/07/07 8am-9am	2016/07/06 5.15pm-6.15pm	Average
Bikes, total	154	305	229.5
Movement A	0	1	0.5
Movement C	15	114	64.5
Movement D	74	44	59
Movement F	0	80	40
Movement G	47	25	36
Movement K	1	13	7
Movement L	3	7	5
Movement M	1	0	0.5
Movement O	4	3	3.5
Movement S	1	0	0.5
Movement T	4	1	2.5
Movement U	1	0	0.5
Movement V	1	0	0.5
Movement W	1	5	3
Movement X	1	1	1
Movement Y	0	2	1
Movement Z	0	2	1
Movement 1	0	2	1
Movement 2	0	1	0.5
Movement 3	0	2	1
Movement 4	0	2	1

3.3.2.2 Field Counts

Table 3.10: Pedestrian and Bike Counts from Field Visit

FIELD COUNTS		
	Pedestrians	Bikes
Trail, SB	54.0	250
Crossings	53	87
Total	107.0	337

3.4 SE MILL ST, SALEM

3.4.1 Current Conditions

USDOT Crossing No. 759677P / ODOT Crossing No. C 718.30 is a railroad crossing located in Salem, OR. It consists of one track crossing SE Mill St. This crossing is owned by Union Pacific Railroad (UP) and has around 20 trains coming through per day. The trains are both passenger and freight with up to 100 cars and with a timetable speed of 35 mph. ODOT reports that the trains generally run at 45 mph, and the FRA inventory reports general speeds between 17 mph and 35 mph.

The road is a two-lane road and is marked as a 25-mph zone. According to the FRA inventory, the AADT is 2,890.

Three incidents have been reported at this crossing, all prior to 1980. Nearby facilities include an international school, Willamette University, the Willamette Heritage Center, playfields and recreational area, a Greyhound bus terminal and an Amtrak train station, that is serviced by the trains on the line.

Figure 3.26 Satellite photo of the SE Mill St crossing in Salem, OR (Google, 2016) (Trail is marked in orange)

3.4.1.1 Highway/Rail Crossing Treatments

This crossing is equipped with active treatments in the form of gates, lights and bells. It also has several other treatments including cross bucks, pavement markings and a stop lines. For pedestrians, there are only passive treatments, except for the audible device. These include tactile markings, a painted warning mark on the sidewalk and a sign "NO TRAIN HORN" reminding pedestrians that the train at this location does not use its horn and that it can be coming from both sides. This is due to the crossing being in a Quiet Zone. The road is equipped with a median, potentially to discourage road users to drive around the gates.

Figure 3.27: Active and passive treatments at the SE Mill St Crossing

3.4.1.2 Highway/Path Crossing Treatments

The crossing at SE Mill St is equipped with a variety of pedestrian and bike facilities. First, it has a trail coming from one side, which seems to be more geared towards pedestrians, though it is categorized as a Promenade, where motor vehicles are legally permitted to share with bicyclists and pedestrians. The trail does not continue onto the other side. There is nothing facilitating crossing the road adjacent to the railroad tracks, but instead it is designed so that people continue down the sidewalk to the next intersection, cross there, before walking back up on the other side.

Figure 3.28: The sight from the pedestrian stop line at the end of the trail

3.4.1.3 Bike and Pedestrian Facilities

The trail is equipped with benches. During the observations, a few bikes were seen, though the trail was mostly occupied by people sitting on the trail and on the benches, drinking, eating and talking for long periods of time. As previously mentioned, this Promenade is open to motor vehicles along with bicyclists and pedestrians. There are constraints to vehicles in this area on the promenade due to the park benches, there is no restriction for motor vehicles to utilize the portion of the promenade. Both sides of the road are equipped with sidewalks, which also have tactile markings as described in the previous section. Both roads are marked with sharrows. There is also an overpass, which connects the Willamette University to the Tokyo International School.

3.4.2 Observed Movements

A simplified diagram of SE Mill St is included below to exemplify the dynamic movements of road and path users at this crossing.

Figure 3.29: Diagram of SE Mill St

3.4.2.1 Vehicles and Trains

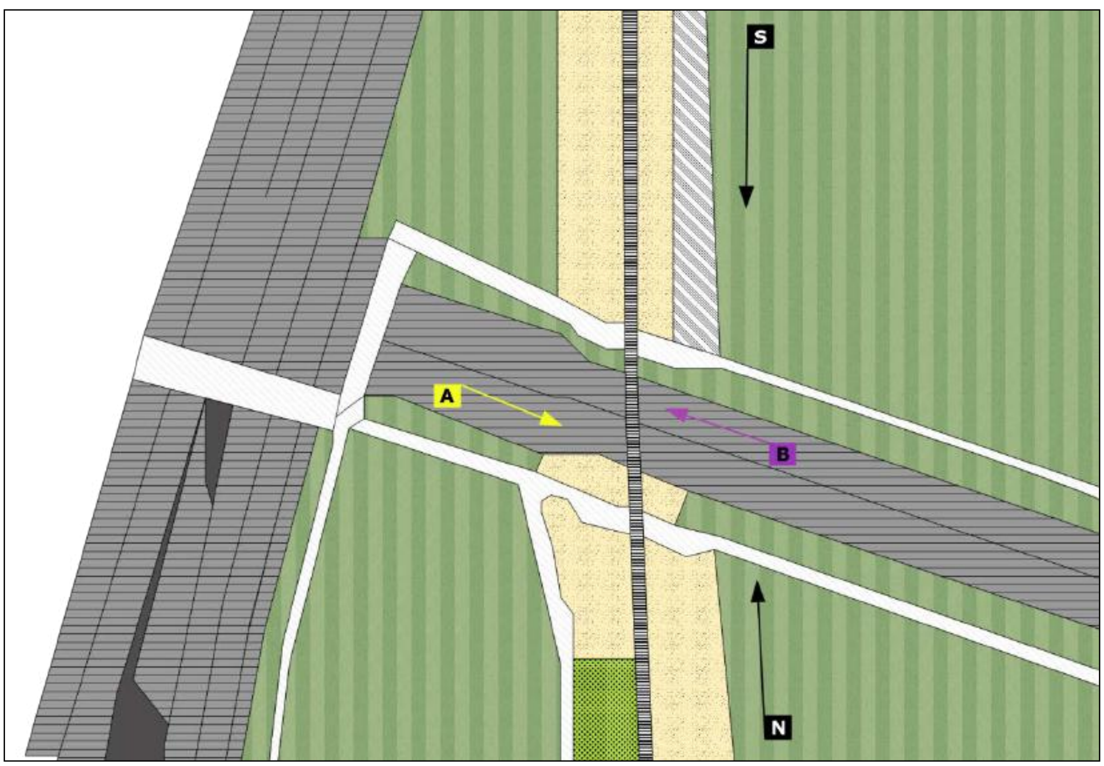


Figure 3.30: Diagram depicting observed vehicle and train movements

Table 3.11: Vehicle and Train Video Counts - Counts Correspond with Diagram Above

VIDEO COUNTS			
	2016/06/02 7.40am-8.40am	2016/06/01 4.40pm-5.40 pm	Average
Vehicles	274	247	260.5
Movement A (EB)	112	139	125.5
Movement B (WB)	49	108	78.5
Trains	1	2	1.5
Movement N (NB)	1	1	1
Movement S (SB)	0	1	0.5

3.4.2.2 Pedestrians and Bikes

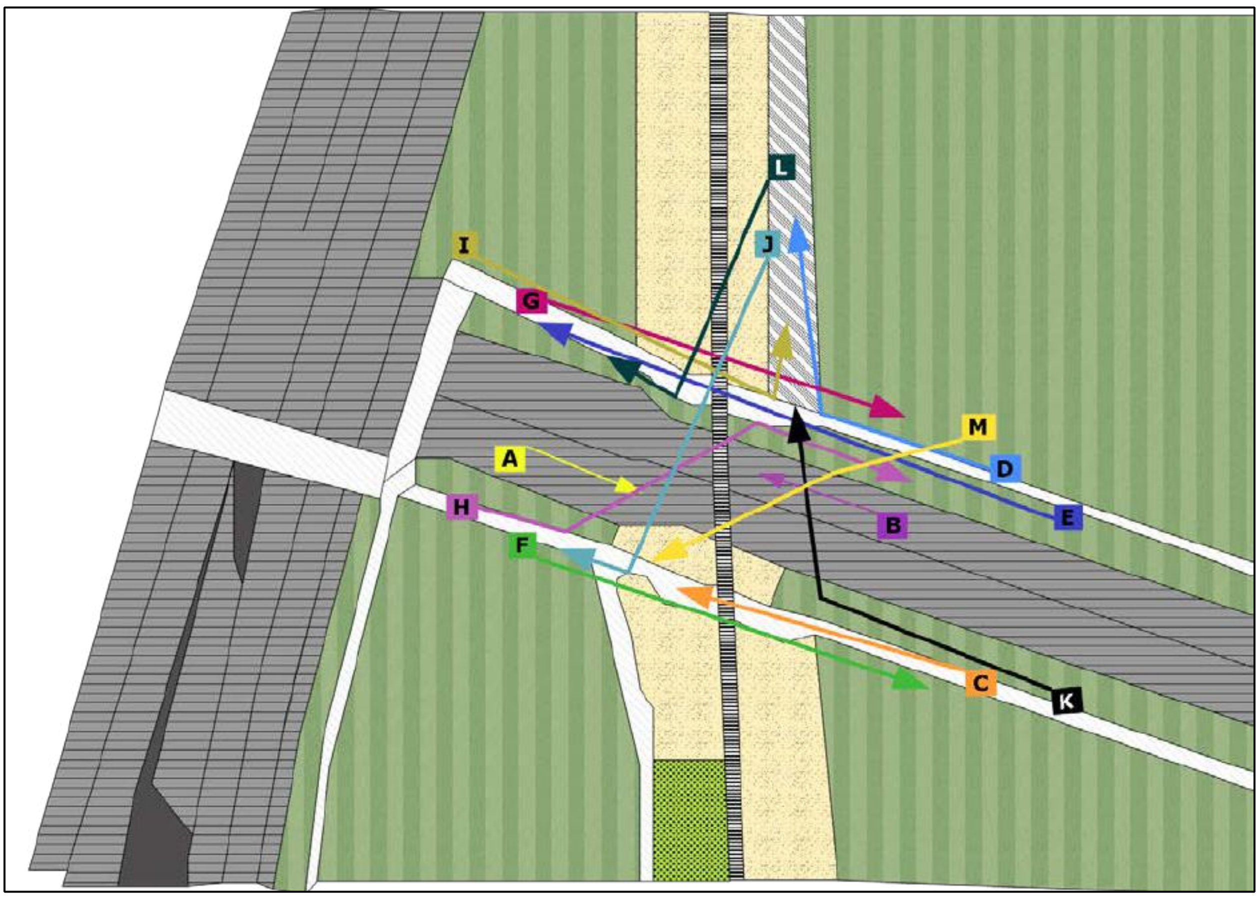


Figure 3.31: Diagram depicting observed pedestrian and bike movements

Majority of pedestrian movements include staying on a sidewalk. For example, Movement C & F.

Undesired pedestrian movements observed are Movement H, K, & M.

A small fraction of observed pedestrians and bicyclists utilize the path.

Prior video surveillance and observations has noted much more activity on movement J, that was seen during these counts.

Table 3.12: Pedestrian and Bike Video Counts - Counts Correspond with Diagram Above

VIDEO COUNTS

	2016/06/02 7.40am-8.40am	2016/06/01 4.40pm-5.40 pm	Average
Pedestrians	57	42	49.5
Movement A	0	0	0
Movement B	0	0	0
Movement C	26	17	21.5
Movement D	8	2	5
Movement E	0	2	1
Movement F	19	10	14.5
Movement G	0	1	0.5
Movement H	1	0	0.5
Movement I	0	9	4.5
Movement J	0	0	0
Movement K	0	1	0.5
Movement L	1	0	0.5
Movement M	2	0	1
Movement N	0	0	0
Bikes	10	16	13
Movement A	0	3	1.5
Movement B	0	4	2
Movement C	0	2	1
Movement D	3	1	2
Movement E	1	1	1
Movement F	0	2	1
Movement G	0	0	0
Movement H	0	3	1.5
Movement I	2	0	1
Movement J	3	0	1.5
Movement K	0	0	0
Movement L	0	0	0
Movement M	1	0	0.5
Movement N	0	0	0

3.4.2.3 Field Counts

Table 3.13: Pedestrian and Bike Counts from Field Visit

FIELD COUNTS		
	Pedestrians	Bikes
Trail	22.0	10
Crossings	54	27
Total	76.0	37

3.5 NE CONIFER BLVD, CORVALLIS

3.5.1 Current Conditions

USDOT Crossing No. 759203E/ODOT Crossing No. CK 700.20 is a railroad crossing located in Corvallis, OR. It consists of one track crossing NE Conifer Blvd. The crossing is owned by Union Pacific Railroad and leased and operated upon by PNWR and has 4-6 trains coming through per day. The trains are freight trains up to 30 cars, with a timetable speed of 35 mph, and a general speed of 20 mph.

The road is a two-lane road leading into the city of Corvallis and is marked as a 25-mph zone. Right after the crossing is a school zone, marked as 20 mph during certain times and when children are present. The AADT is 3,813. During the observations, a count of 61 cars per 15 minutes or 244 cars per hour was made.

The crossing and adjacent street is illuminated with two large street lamps. There is one recorded incident, prior to 1980 at this location. Nearby facilities include Cheldelin Middle School, large playfields, recreational areas, such as Village Green City Park, residences and a bus stop.

Figure 3.32: Satellite photo of the NE Conifer Blvd crossing in Corvallis, OR (Google, 2016) (Trail is marked in orange)

3.5.1.1 Highway/Rail Crossing Treatments

This location is equipped with both active and passive treatments. This include active gates, lights and bells and a railroad warning sign, W10-1 cross bucks and a stop line for vehicular users.

Figure 3.33: The active treatments at NE Conifer Blvd (School marked in yellow)

3.5.1.2 Highway/Path Crossing Treatments

At the end of both trailheads, a "No pedestrian crossing"-sign facing people who are approaching the crossing from the path, is placed as seen in Figure 3.34. Under ORS 810.080 the authority can: "(…) prohibit [] pedestrians from crossing a roadway where a crosswalk has been closed by placing and maintaining signs giving notice of closure. prohibit [] pedestrians from crossing a highway at any place other than within a marked or unmarked crosswalk", why crossing the road at such a location is considered prohibited.

Figure 3.34: The" No Pedestrian Crossing"-sign placed at both trailheads.

3.5.1.3 Bike and Pedestrian Facilities

The trail at this location is part of a long section of trail that is primarily intended for commuters, but also used by locals walking dogs or exercising, school children from the nearby school etc. This location is equipped with sidewalks on both sides of the street, through one of them ends before entering the NE quadrant, following the road and crossing the tracks on one side. On the other side, the sidewalk stops suddenly, as seen in Figure 3.35 and it is not possible to cross at the location of the path. Pedestrians can either step over the rails or walk down the street where crossing is not prohibited. Adjacent to the railroad tracks run a multiuse trail, which is unnamed. Previously it was possible to cross the road to continue the trail, according to ODOT RPTD, but at some point, the curb was reinstalled and the two "No pedestrian crossing"-signs were put up. There is nowhere nearby where it makes sense to cross, except for in the middle of the road further down. Both sides have dedicated bike lanes.

Figure 3.35: The sidewalk suddenly stops at the tracks

3.5.2 Observed Movements

A simplified diagram of NE Conifer Blvd. is included below to exemplify the dynamic movements of road and path users at this crossing.

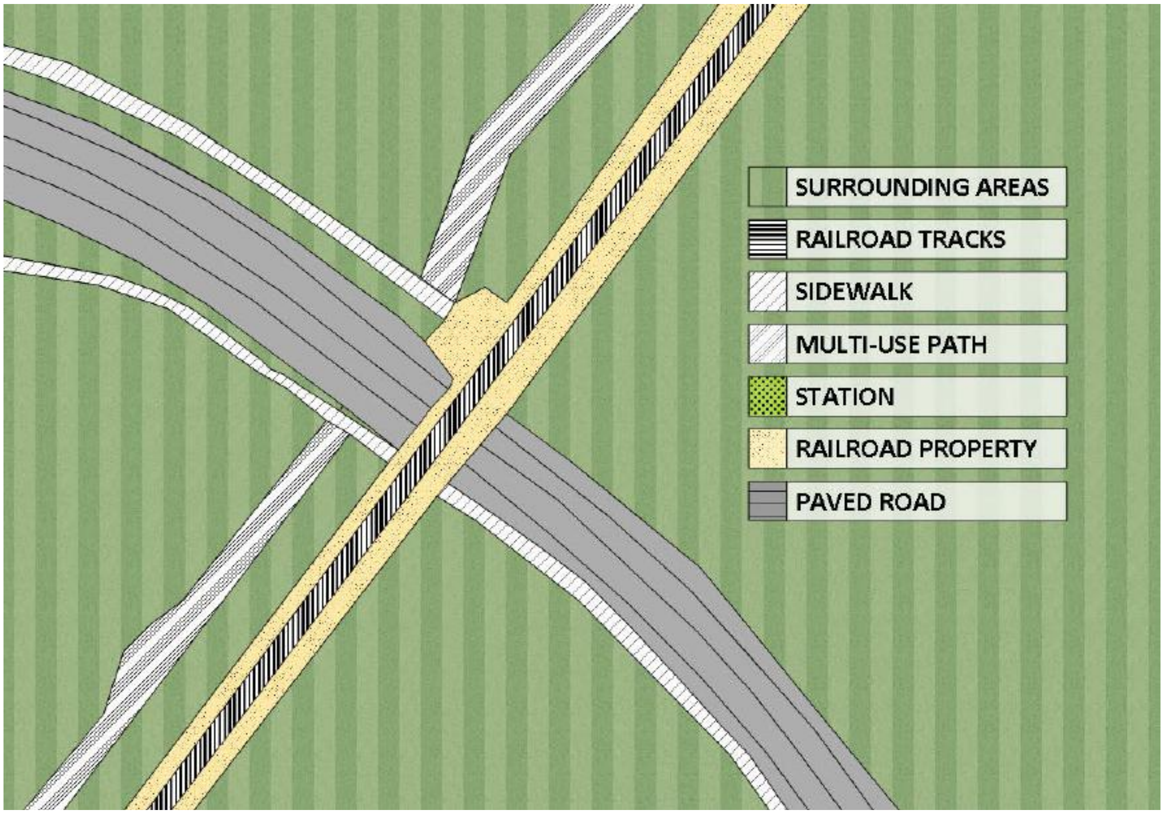


Figure 3.36: Diagram of NE Conifer Blvd.

3.5.2.1 Vehicles and Trains

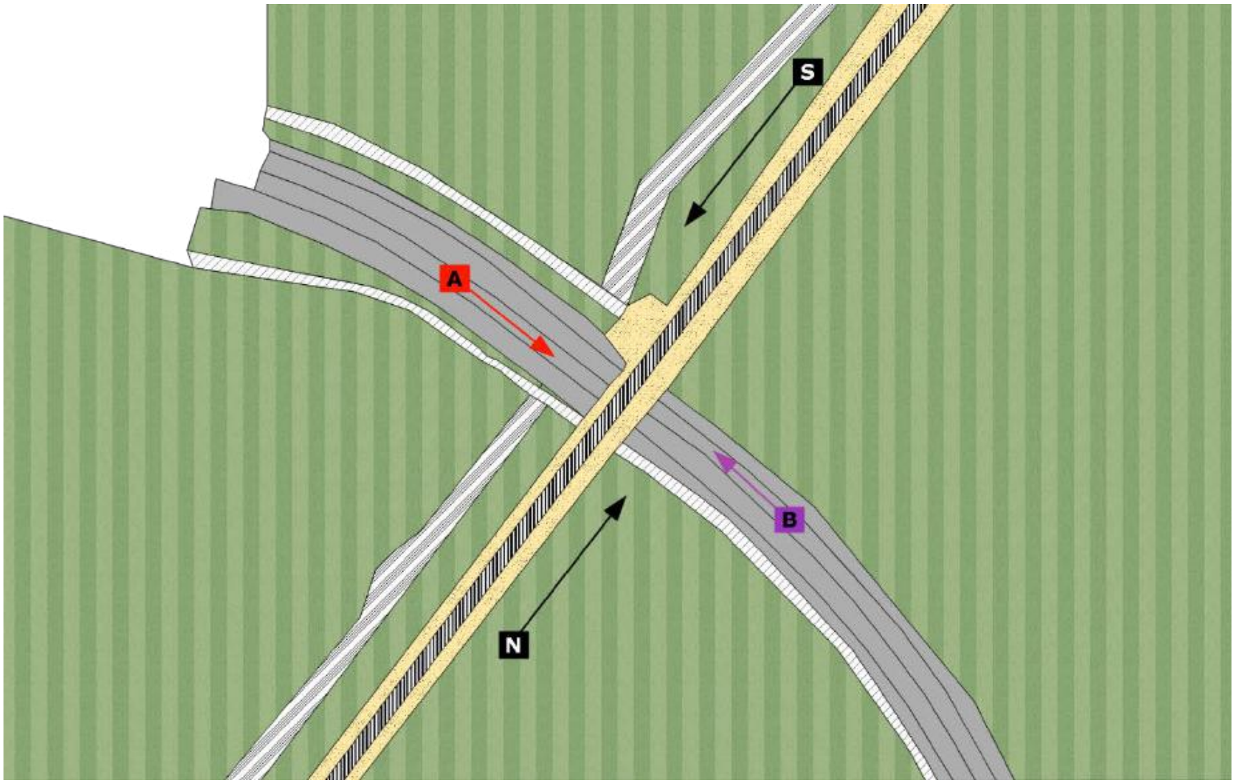


Figure 3.37: Diagram depicting observed vehicle and train movements

Table 3.14: Vehicle and Train Video Counts - Counts Correspond with Diagram Above

	VIDEO COUNTS			**FIELD COUNTS**
	2016/06/02 8.30am-9.30am	2016/06/01 5.30pm-6.30pm	**Average**	10.40am-11.40am
Vehicles	**240**	**377**	**308.5**	**257**
Movement A (EB)	115	211	163	160
Movement B (WB)	125	166	145.5	97
Trains	**0**	**0**	**0**	**3**
Movement S (SB)	0	0	0	2
Movement N (NB)	0	0	0	1

3.5.2.2 Pedestrians and Bikes

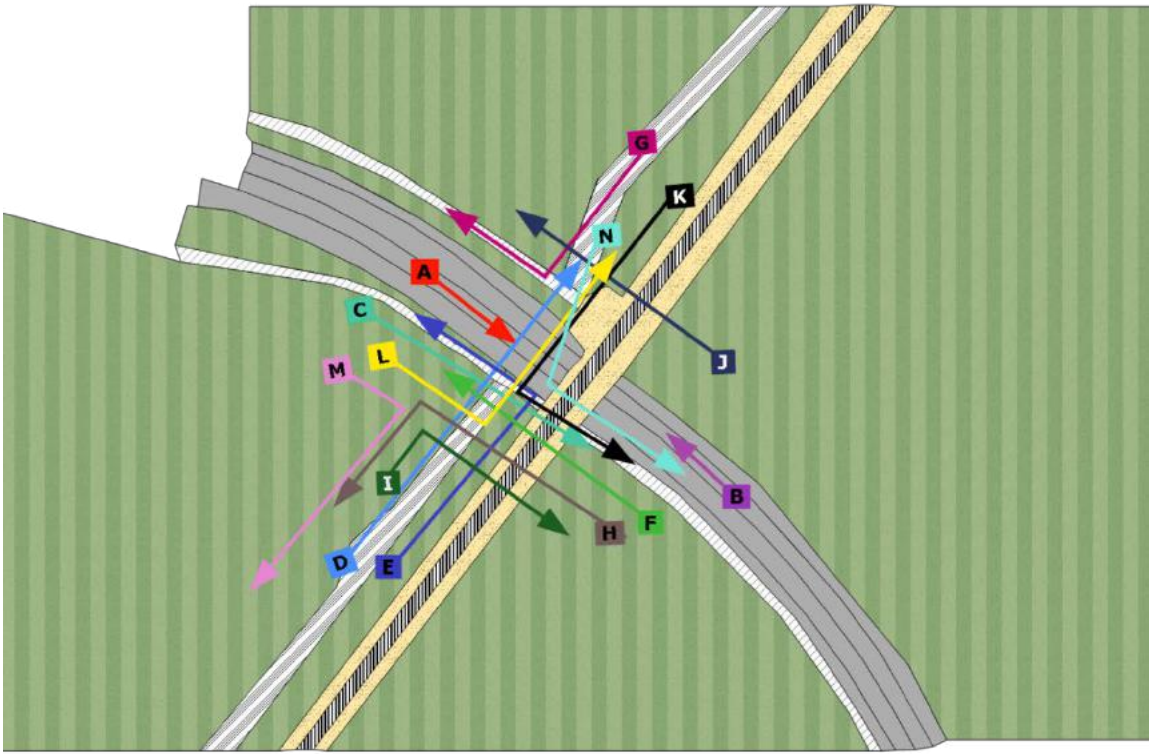


Figure 3.38: Diagram depicting observed pedestrian and bike movements

The most frequently observed pedestrian movement, Movement D, involves staying on the path and crossing parallel to the railroad tracks. This also becomes a prohibited movement while crossing the road to continue onto the path. It is considered prohibited because of the sign indicating on both sides that pedestrians are not allowed to cross, as mentioned in the previous section.

Prohibited pedestrian movements observed: Movement D, K, L, & N.

Majority of pedestrian movements are concerned with entering or exiting from path as exhibited by Movement D & E and cross the road in the process.

Table 3.15: Pedestrian and Bike Video Counts - Counts Correspond with Diagram Above

VIDEO COUNTS			
	2016/06/02 8.30am-9.30am	2016/06/01 5.30pm-6.30pm	Average
Pedestrians	9	23	16
Movement A	0	0	0
Movement B	0	0	0
Movement C	0	0	0
Movement D	2	6	4
Movement E	2	3	2.5
Movement F	3	2	2.5
Movement G	0	1	0.5
Movement H	0	1	0.5
Movement I	0	0	0
Movement J	0	1	0.5
Movement K	0	5	2.5
Movement L	2	2	2
Movement M	0	2	1
Movement N	0	0	0
Bikes	1	7	4
Movement A	0	1	0.5
Movement B	1	1	1
Movement C	0	0	0
Movement D	0	0	0
Movement E	0	0	0
Movement F	0	0	0
Movement G	0	0	0
Movement H	0	1	0.5
Movement I	0	1	0.5
Movement J	0	0	0
Movement K	0	0	0
Movement L	0	2	1
Movement M	0	0	0
Movement N	0	1	0.5

3.5.2.3 Field Counts

Table 3.16: Pedestrian and Bike Counts from Field Visit

FIELD COUNTS		
	Pedestrians	Bikes
Trail, NB	5	0
Trail, SB	5	1
Crossing Tracks	7	5
Total	17	6

3.6 NE WALNUT BLVD, CORVALLIS

3.6.1 Current Conditions

USDOT Crossing No. 916556A /ODOT Crossing No. CK 700.90 is a railroad crossing located in Corvallis, OR. It consists of one track crossing NE Walnut Blvd. The crossing is owned by UPRR and leased by PNWR and has 4-6 trains coming through per day. The trains are freight trains up to 30 cars, with a timetable speed of 25 mph, and a general speed between 10 and 20 mph.

The road is a two-lane road leading into the city of Corvallis and is marked as a 35-mph zone. In 2001 the AADT was 3236. During the observations, a count of 61 cars per 15 minutes or 244 cars per hour was made.

The crossing is not illuminated, though one street lamp is near the location. There have been no recorded incidents at this crossing. Nearby facilities include a several apartment complexes with new construction underway, along with recreational areas.

Figure 3.39: Satellite photo of the Walnut Blvd crossing in Corvallis, OR (Google, 2016) (Trail is marked in orange)

3.6.1.1 Highway/Rail Crossing Treatments

The treatments at this location are very like the treatments found at the NE Conifer Blvd crossing. There are active treatments, including gates, lights and bells. The crossing is signaled with cross bucks, railroad road markings and a stop line.

Figure 3.40: Active treatments at the NE Walnut Blvd crossing

3.6.1.2 Highway/Path Crossing Treatments

The purpose of the trail at this location is primarily to connect residents of the area to other residential areas and provide a through cut for users. It is possible to cross the tracks on both sides of the road. East of the tracks, and south of Walnut Blvd, a road named NE Seavy Ave functions as a trail. However, at the crossing, it is designed just as NE Conifer Rd, as seen in Figure 3.41, and is marked with the use of a "No Pedestrian Crossing'-sign that is placed at both entrances to the trail. Under ORS 810.080 the authority can: "(…) prohibit [] pedestrians from crossing a roadway where a crosswalk has been closed by placing and maintaining signs giving notice of closure.

(c) Prohibiting pedestrians from crossing a highway at any place other than within a marked or unmarked crosswalk", why crossing the road at such a location is considered prohibited.

3.6.1.3 Bike and Pedestrian Facilities

The NE Walnut Blvd crossing is equipped with sidewalks on both sides of the road. The vegetation of these sidewalks is unmaintained. When these sidewalks are inaccessible it leads to more people crossing, walking in the street etc. to avoid walking through the vegetation. Both sides of the road are equipped with separated bike lanes, which are well kept.

Figure 3.41: At NE Walnut Blvd it is prohibited under ORS 810.080 to cross the road between the two trailheads

3.6.2 Observed Movements

A simplified diagram of NE Walnut Blvd. is included below to exemplify the dynamic movements of road and path users at this crossing.

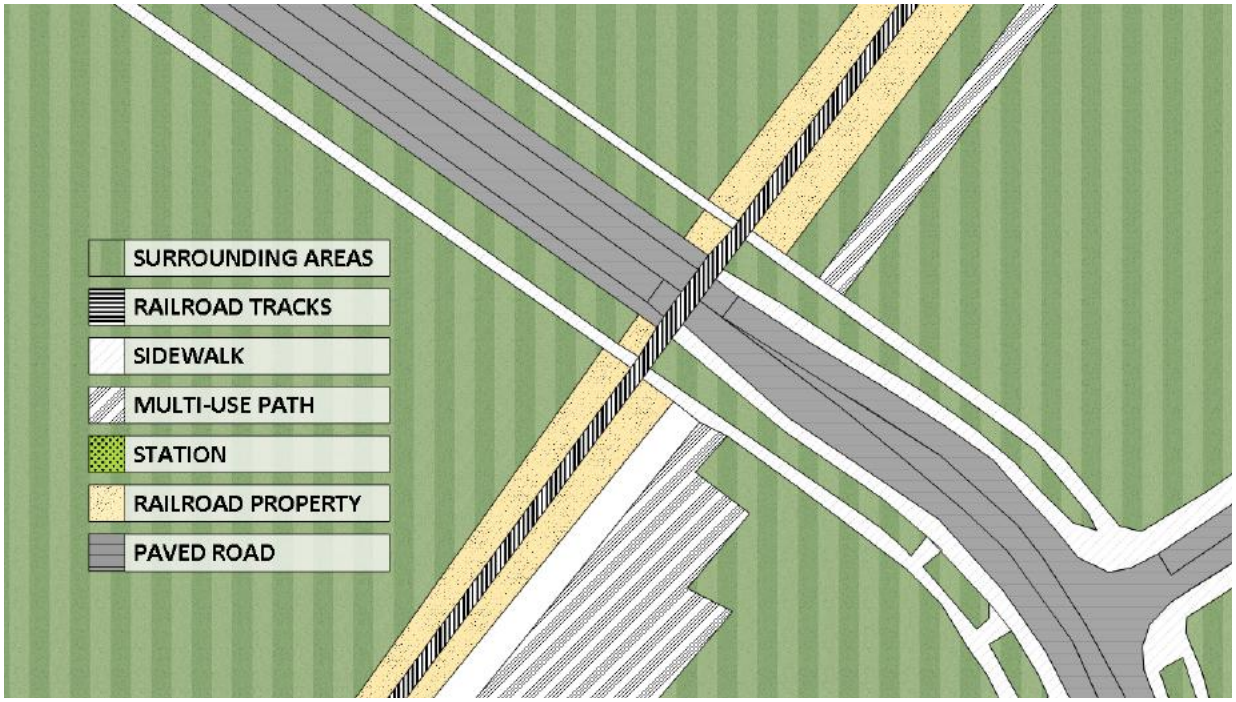


Figure 3.42: Diagram of NE Walnut Blvd

3.6.2.1 Vehicles and Trains

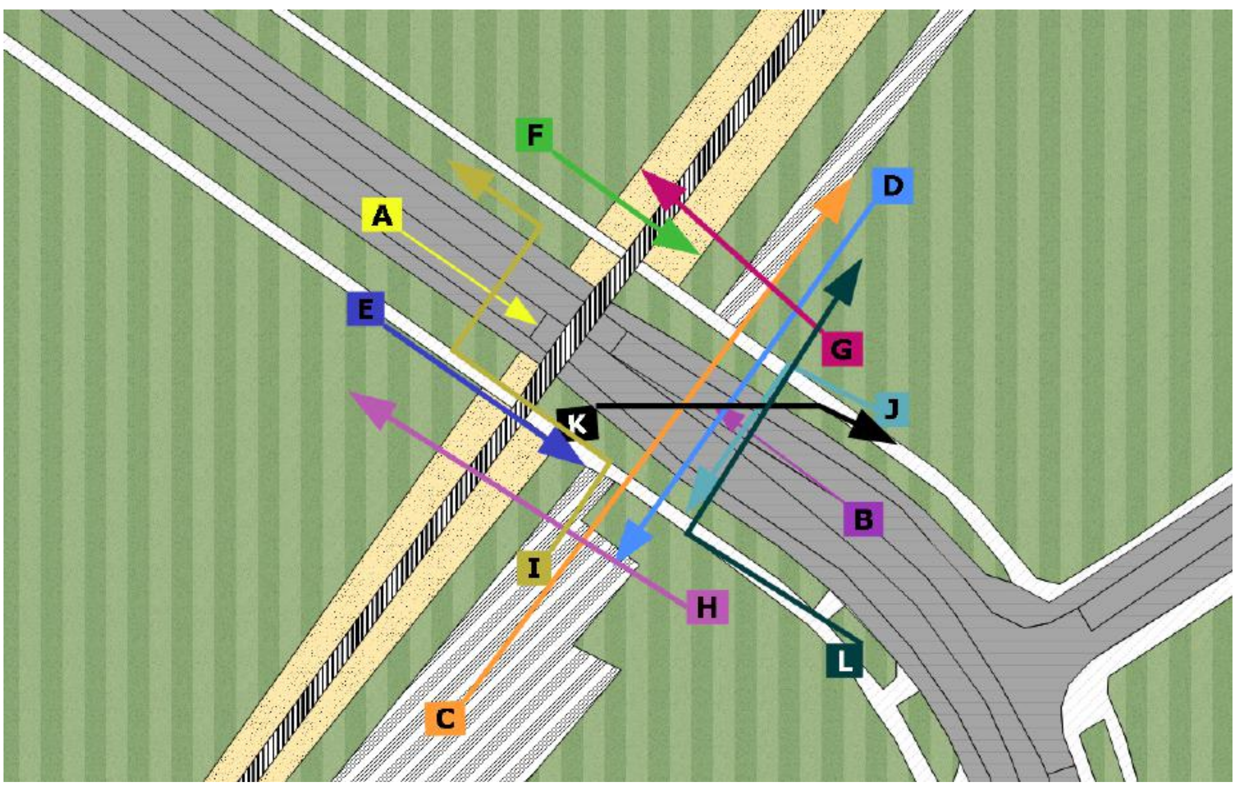


Figure 3.43: Diagram depicting observed vehicle and train movements

Table 3.17: Vehicle and Train Video Counts - Counts Correspond with Diagram Above

	VIDEO COUNTS			**FIELD COUNTS**	
	2016/07/07 8am-9am	2016/07/07 5.30pm-6.30pm	**Average**	2016/07/07 12.40pm-1.40pm	2016/07/07 1.40pm-2.40 pm
Vehicles	**279**	**303**	**291**	**261**	**266**
Movement A (EB)	194	137	165.5	134	131
Movement B (WB)	85	166	125.5	127	135
Trains	**0**	**0**	**0**	**1**	**2**
Movement N (NB)	0	0	0	-	-
Movement S (SB)	0	0	0	-	-

3.6.2.2 Pedestrians and Bikes

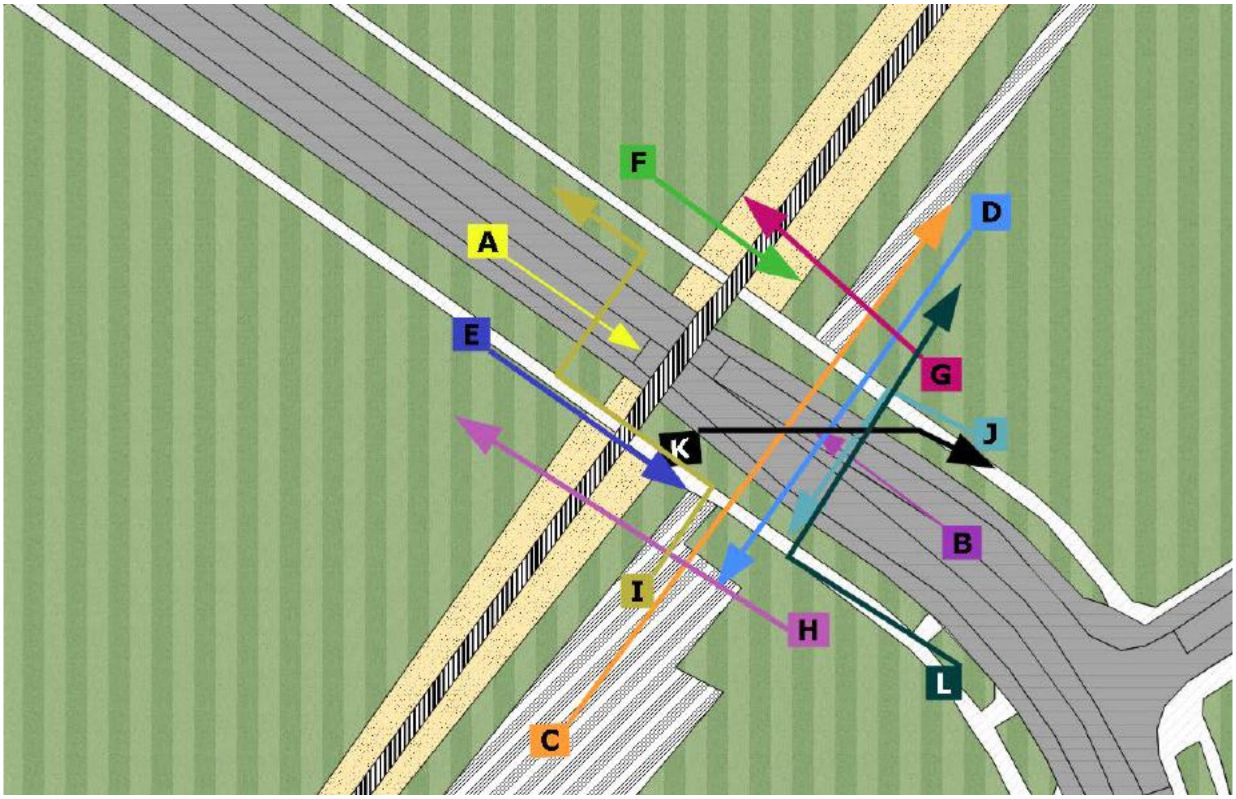


Figure 3.44: Diagram depicting observed pedestrian and bike movements

Most frequently observed pedestrian movement is Movement C, which also becomes a prohibited movement once pedestrians proceed to cross the street to continue onto the path.

Observed prohibited pedestrian movements include Movement C, D, I, J, & K.

Table 3.18: Pedestrian and Bike Video Counts - Counts Correspond with Diagram Above

VIDEO COUNTS			
	2016/07/07 8am-9am	2016/07/07 5.30pm-6.30pm	Average
Pedestrians, total	9	9	9
Movement A	0	0	0
Movement B	0	0	0
Movement C	1	3	2
Movement D	2	0	1
Movement E	1	0	0.5
Movement F	2	1	1.5
Movement G	0	2	1
Movement H	1	1	1
Movement I	0	1	0.5
Movement J	0	1	0.5
Movement K	2	0	1
Movement L	0	0	0
Bikes, total	6	5	5.5
Movement A	4	0	2
Movement B	1	2	1.5
Movement C	0	1	0.5
Movement D	1	0	0.5
Movement E	0	0	0
Movement F	0	0	0
Movement G	0	0	0
Movement H	0	0	0
Movement I	0	0	0
Movement J	0	0	0
Movement K	0	1	0.5
Movement L	0	1	0.5

3.6.2.3 Field Counts

Table 3.19: Pedestrian and Bike Counts from Field Visit

FIELD COUNTS		
	Pedestrians	Bikes
Trail, SB	5	1
Trail, NB	2	1
Track Crossings	8	4
Total	15	6

3.7 N MOUNTAIN AVE, ASHLAND

3.7.1 Current Conditions

USDOT Crossing No. 756418T/ ODOT Crossing No. C 428.70 is a railroad crossing located in Ashland, OR. It consists of two tracks crossing N Mountain Ave at an angle. This crossing is owned by Central Oregon & Pacific Railroad (CORP) and has between two and four trains coming through per day. The trains are freight trains of an average size of 10 cars, with a timetable speed of 20 mph.

The road is a two-lane road leading into the city of Ashland and is marked as a 25-mph zone. The AADT is around 5000. During the observations, a count of 82 cars per 15 minutes or 330 cars per hour was made.

The crossing and adjacent street is lighted with two street lamps, and there have been no recorded incidents at this crossing. Nearby facilities include a church and industrial facilities.

Figure 3.45: Satellite photo of the Mountain Ave crossing in Ashland, OR (Google, 2016) (Trail is marked in orange)

3.7.1.1 Highway/Rail Crossing Treatments

The treatment at this site are primarily active and included active lights and active gates, along with bells. The site was also equipped with cross bucks. Stop lines were used to indicate where bikes and cars should stop for trail users and trains.

Figure 3.46: The active treatments and the trailhead at the N Mountain Ave crossing

3.7.1.2 Highway/Path Crossing Treatments

The path at this location is primarily used for commuters, as it connects a university, residential areas and other areas of interest. The path in this location does not have any treatments. The crossing itself is marked with transverse pavement markings but not marked with a continental crosswalk. The crossing is equipped with stop-signs on both sides.

3.7.1.3 Bike and Pedestrian Facilities

Adjacent to the railroad tracks are a multiuse trail called the Central Bike Path, that was observed to be primarily used by pedestrians and a very few bikes. The trail is 1.8 miles long and connects residential areas with business areas and with Southern Oregon University. The users of the trail at the time of the observations were recreational in nature. Around half of the pedestrians continued across the crossing and onto the trail, whereas the other half crossed the railroad tracks.

Except for the NE quadrant, the road is equipped with sidewalks, which were designed to cross the railroad tracks at a 90° angle to meet ADA requirements. The curve furthermore encourages users to look down the tracks before crossing. There were no facilities for crossing the tracks at the other side of the street, though many users did so anyways. A few crossings on the diagonal was also observed.

In this location, separate bike lanes are found on both sides of the street. They were however not commonly used by bikes, and many cars etc. were seen driving in them or even parking. As paint is the only thing used to separate, it is not always clear what is bike facilities and what is parking or something else.

Figure 3.47: Curving the foot path enables pedestrians and bikes to cross at a 90° angle, to meet ADA access and encourages pedestrians to look to the sides before crossing

Figure 3.48: Bike facilities at the N Mountain Ave crossing

Figure 3.49: The trail, known as The Central Bike Path continues on the other side of the crossing

3.7.2 Observed Movements

A simplified diagram of N Mountain Ave. is included below to exemplify the dynamic movements of road and path users at this crossing.

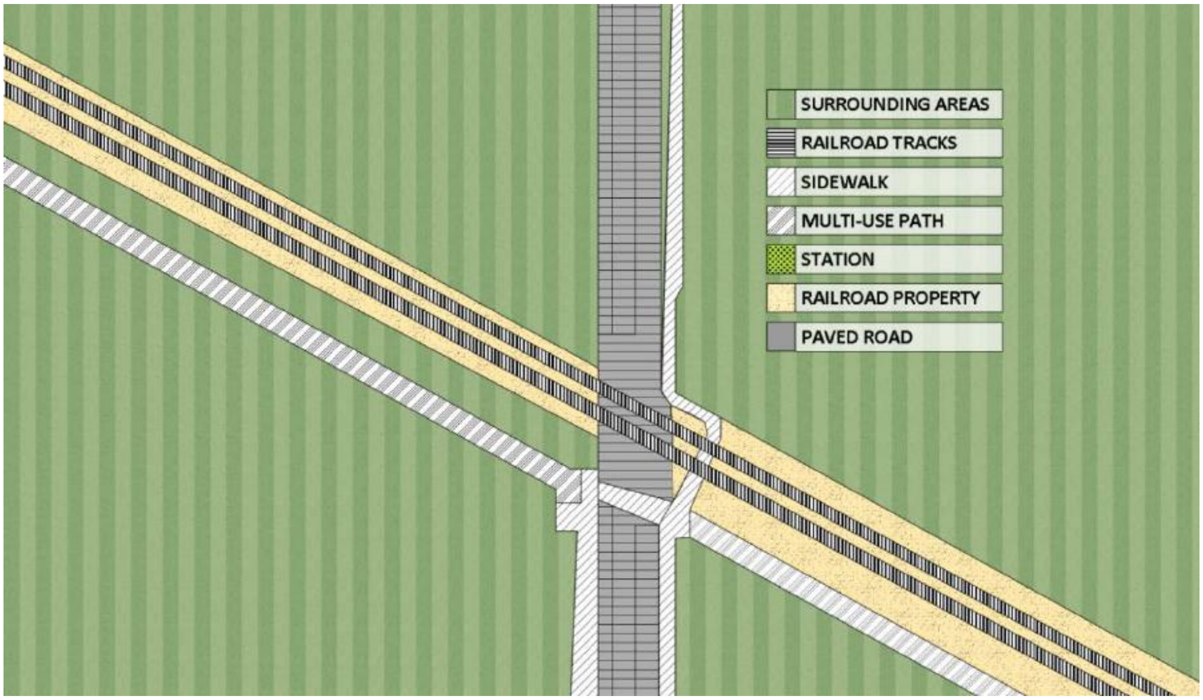


Figure 3.50: N Mountain Ave.

3.7.2.1 Vehicles and Trains

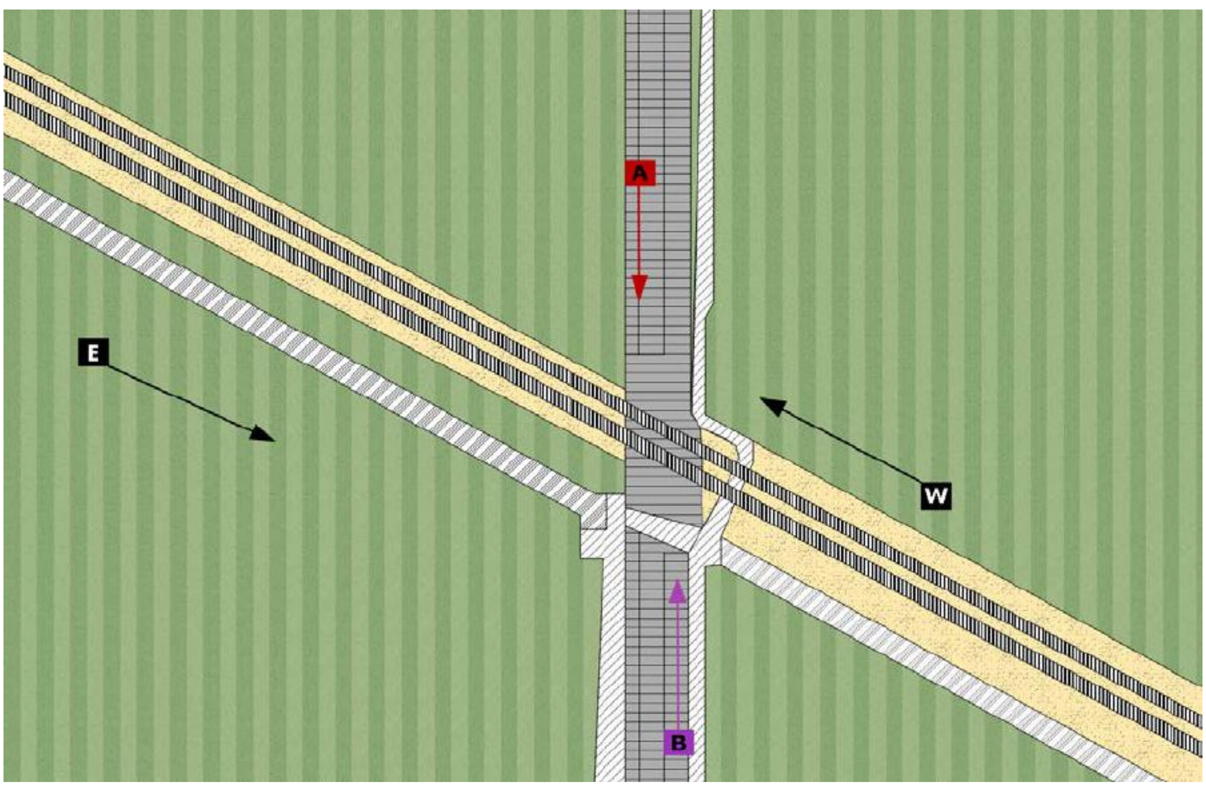


Figure 3.51: Diagram depicting observed vehicle and train movements

Table 3.20: Vehicle and Train Video Counts - Counts Correspond with Diagram Above

	VIDEO COUNTS			FIELD COUNTS
	2016/07/09 8.30am-9.30am	2016/07/08 5.30pm-6.30pm	**Average**	2016/07/08 10.10-10.55
Vehicles	**180**	**389**	**284.5**	**308**
Movement A (SB)	119	205	**162**	169
Movement B (NB)	61	184	**122.5**	139
Trains	**0**	**0**	**0**	**0**
Movement E (EB)	0	0	**0**	0
Movement W (EB)	0	0	**0**	0

3.7.2.2 Pedestrians and Bikes

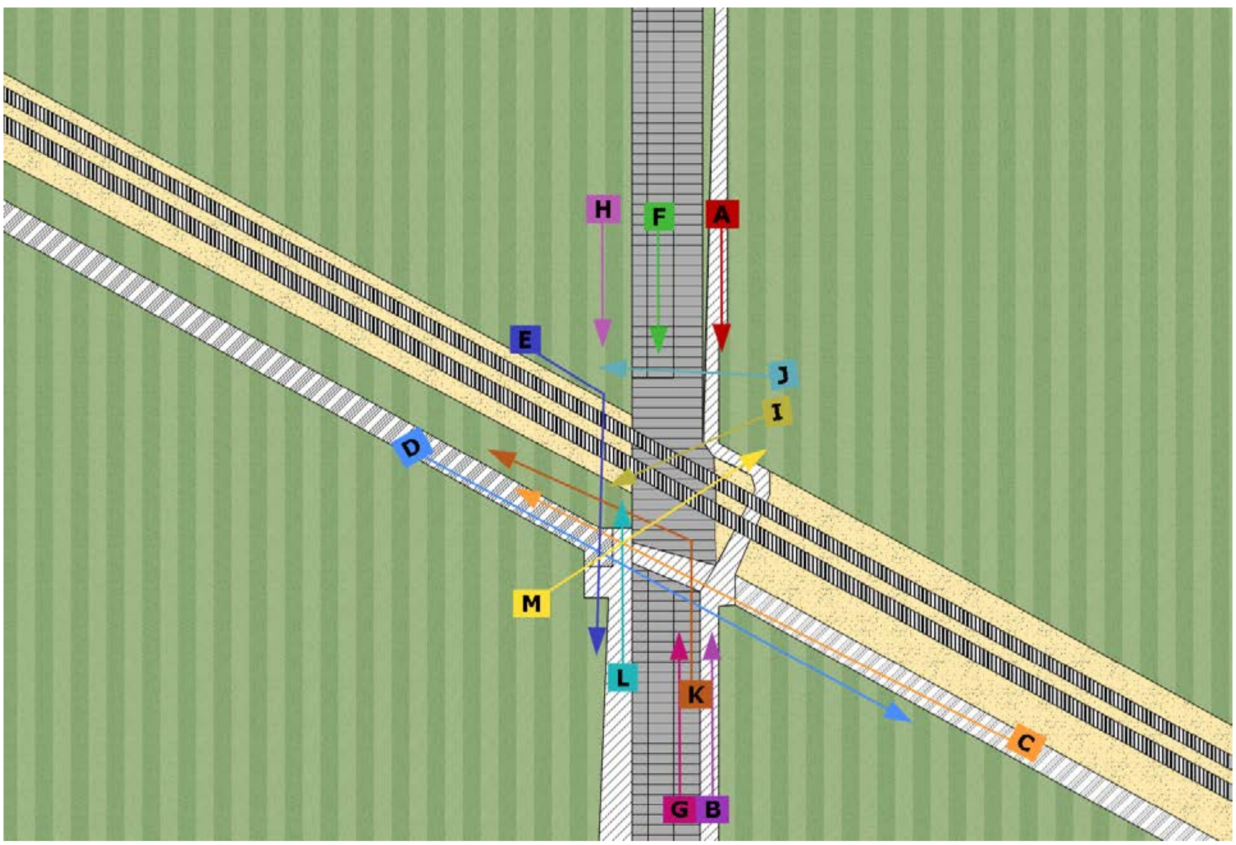


Figure 3.52: Diagram depicting observed pedestrian and bike movements

Two of the most frequently observed pedestrian movements are staying along the path which is exhibited by Movement C & D.

No pedestrian infrastructure to facilitate Movement E.

Observed undesired pedestrian movements include: Movement E, I, J, L, & M.

Bike observations exhibit high path use: Movement C, D, & K.

Table 3.21: Pedestrian and Bike Video Counts - Counts Correspond with Diagram Above

VIDEO COUNTS			
	2016/07/09 8.30am-9.30am	2016/07/08 5.30pm-6.30pm	Average
Pedestrians	42	11	26.5
Movement A	0	0	0
Movement B	2	0	1
Movement C	12	3	7.5
Movement D	10	2	6
Movement E	0	2	1
Movement F	0	0	0
Movement G	0	0	0
Movement H	3	0	1.5
Movement I	2	0	1
Movement J	2	0	1
Movement K	0	0	0
Movement L	1	0	0.5
Movement M	1	0	0.5
Movement N	0	0	0
Bikes	9	4	6.5
Movement A	3	0	1.5
Movement B	0	0	0
Movement C	2	2	2
Movement D	3	2	2.5
Movement F	0	0	0
Movement G	0	0	0
Movement F	0	0	0
Movement G	0	0	0
Movement H	0	0	0
Movement I	0	0	0
Movement J	0	0	0

Movement K	1	0	0.5
Movement L	0	0	0
Movement M	0	0	0
Movement N	0	0	0

3.7.2.3 Field Counts

Table 3.22: Pedestrian and Bike Counts from Field Visit

FIELD COUNTS		
	Pedestrians	Bikes
Trail, WB	17	3
Trail, EB	11	1
Track Crossings	17	3
Total	45	7

4.0 EVALUATION CRITERIA

The following is a list of suggested criteria that can be used to evaluate the efficacy of the implemented treatments. It seeks to evaluate the level of safety improvement at a crossing that is treated with the options suggested in the previous documents. The evaluation criteria represent a measurement of a level of safety improvement. As railroad incidents fortunately are somewhat rare, it is not feasible to compare short-term impacts on number of incidents before and after the installation of a treatment. Instead, these criteria function as proxies as they are directly correlated with improved safety conditions at a given site and this makes it easier to do a direct short-term comparison to the condition prior to installing treatments, and to immediately quantify and qualify the expected safety improvement obtained. In many of these situations, the undesired behavior exhibited is not intentional, but is a case of unintentional non-compliance.

4.1 UNINTENTION NON-COMPLIANCE

Unintentional non-compliance generally stems from either a lack of understanding of the rules of the path and road and/or from a lack of enough information to make an informed decision. Crossings explored in this research include two major participants – path users and road users – and both users have been observed participating in unintentional non-compliance. It is desired to decrease unintentional non-compliance for all participants at a crossing so that the crossing is low-risk and predictable.

Observing unintentional non-compliance can be complicated to identify, which is why this section instead focuses on whether the crossing provides adequate information and data for the user to make the correct decision. If an improvement is implement at a crossing, it should follow that the amount of unintentional non-compliance decreases.

Unintentional non-compliance generally stems from various issues: failing to detect the crossing; failing to adhere to or understand path and road treatments, failing to notice an approaching train, and; misjudging the risk of approaching trains. If these issues can be mitigated using better treatments, it is likely that the amount of high-risk behavior would decrease as well.

4.2 COST

Cost is a pragmatic quantitative evaluation criterion that is appropriate because the treatment possibilities may be limited depending on the budget. Therefore, using cost as an evaluation criterion automatically filters treatment options. Treatments should be evaluated in terms of cost of installing and maintaining them, as that may influence the decisions on which treatments to install and what may be the most cost-beneficial treatment for a given site.

4.3 AVERAGE PEDESTRIAN DELAY

Pedestrian delay is an important evaluation criterion because it serves as a strong indicator of path user compliance of various treatments. Results in this field of study indicate that pedestrians have a limit to the amount of time that they are willing to spend adhering to treatments before engaging in high-risk behavior. Therefore, using ‘Average Pedestrian Delay’ as an evaluation criterion can help cities understand the positives and negatives associated with various treatments in more depth. If pedestrians must wait for too long, they may not comply, cross, and ultimately create an unpredictable environment in which vehicles are forced to wait on the railroad tracks until they cross.

Research indicates that there are models to calculate and evaluate pedestrian crossing characteristics and delay. This is important, as this is a way to measure and better understand pedestrian compliance or non-compliance at a crossing.

A constant value of 1.2m/second is the standard pedestrian walking speed. Note that the walking speed for various age groups and platoons influence walking speed. Older pedestrians have a walking speed of 1.0m/second. Research indicates that for both signalized and unsignalized crossings, pedestrian engage in high-risk behavior if they experience a 30 second delay or more

LOS	Pedestrian Delay (s/p)	Likelihood of Noncompliance
A	< 10	Low
B	≥ 10–20	
C	> 20–30	Moderate
D	> 30–40	
E	> 40–60	High
F	> 60	Very High

Figure 4.1: Level of Service Criteria for Pedestrians at Signalized Intersections (Transportation Research Board, 2000)

A study conducted by S. Marisamyanathan and P. Vedagiri as well as the Highway Capacity Manual indicate that that there are multiple approaches to most accurately calculate pedestrian delay depending on the crossing environment. In the following different methodologies are therefore presented and the most appropriate one should be selected on a case-by-case basis.

4.3.1 Pedestrian Delay in Signalized Intersections

To calculate the average delay per pedestrian at a signalized intersection:

$$d_p = \frac{0.5\,(C-g)^2}{C} \qquad (4\text{-}1)$$

Where:

d_p = average pedestrian delay

C = cycle length

g = effective green time

Table 4.1: LOS Criteria for Pedestrians at Signalized Intersections (TRB, 2000)

LEVEL OF SERVICE	PEDESTRIAN DELAY (s/p)	LIKELIHOOD OF NONCOMPLIANCE
A	<10	Low
B	>10-20	
C	>20-30	Moderate
D	>30-40	
E	>40-60	High
F	>60	Very High

4.3.1.1 Pedestrian Delay in Unsignalized Intersections

This methodology applies to "an unsignalized intersection with a pedestrian crossing against a free-flowing traffic stream or an approach not controlled by a stop sign. (…) If there are zebra-striped crossings at an unsignalized intersection, this procedure does not apply" (TRB, 2000). This procedure is shown for a single pedestrian, but can also be calculated for a group of pedestrians.

First, calculate the critical gap for a single pedestrian, tc:

$$\boldsymbol{t_c = \frac{L}{S_p} + t_s} \qquad (4\text{-}2)$$

Where:

t_c = critical gap for a single pedestrian (s)

S_p = average pedestrian walking speed (m/s)

L = crosswalk length (m)

t_s = pedestrian start-up time and clearance time (s)

Np = spatial distribution of pedestrians

Then the average pedestrian delay, dp, can be calculated:

$$\mathbf{D_p = \frac{1}{v}\left(e^{vt_c} - vt_c - 1\right)} \qquad (4\text{-}3)$$

Where:

d_p = average pedestrian delay

v = vehicular flow rate

t_c = single pedestrian critical gap

The following table can then be used to determine the LOS:

Table 4.2: LOS Criteria for Pedestrians at Unsignalized Intersections (TRB, 2000)

LEVEL OF SERVICE	PEDESTRIAN DELAY (s/p)	LIKELIHOOD OF NONCOMPLIANCE
A	<5	Low
B	>5-10	
C	>10-20	Moderate
D	>20-30	
E	>30-45	High
F	>45	Very High

4.4 AVERAGE BICYCLE DELAY

Understanding the average bicycle delay before and after a treatment is implemented serves as a proxy for how likely a cyclist is to comply with a treatment. This allows for a more informed decision-making process by considering the needs and optimum level of service for cyclists as equal to the needs of pedestrians and vehicles.

4.4.1 Bicycle Delay in Signalized Intersections

The average delay for bikes in signalized intersections is calculated as follows:

$$\boldsymbol{d_b = \frac{0.5C(1-\frac{g}{c})^2}{1-\left[\frac{g}{c}min(\frac{v_b}{c_b},1.0)\right]}} \quad (4\text{-}4)$$

Where

d_b = control delay (s/bicycle)

v_b = flow rate of bicycles in one-direction bicycle lane (bicycles/h)

The LOS can then be determined from the following table:

Table 4.3: LOS Criteria for Bicyclists at Intersections (TRB, 2000)

LEVEL OF SERVICE	PEDESTRIAN DELAY (s/p)	LIKELIHOOD OF NONCOMPLIANCE
A	<10	Low
B	>10-20	
C	>20-30	Moderate
D	>30-40	
E	>40-60	High
F	>60	Very High

4.4.1.1 Bicycle Delay in Unsignalized Intersections

The Highway Capacity Manual includes equations and methods to calculate bicycle level of service depending on various bicycle facilities. “An unsignalized intersection covered by these procedures is one in which there is a designated on-street bicycle lane on at least one of the minor approaches, control by a stop sign" (Transportation Research Board, 2010).

The HCM suggests that Average Vehicle Delay should be used to calculate the control delay for bicycles, and determined using the following table same table as used for signalized intersections.

4.5 AVERAGE VEHICLE DELAY

Understanding how the 'Average Vehicle Delay' is affected by various treatment options is important because the crossing type examined in this research is inherently multi-modal. Understanding how treatments impact vehicle delay and possibly encourage non-compliance is important when aiming to improve and lower risky behavior at a crossing.

The average vehicle delay measurement is based on a methodology presented by the Surface Transportation Board's Office of Environmental Analysis (OEA).

The methodology defines average vehicle delay at an at-grade railroad crossing in Level of Service categories, as signalized intersections in the Highway Capacity Manual:

Table 4.4: Level of Service Designations (Transportation Research Board, 2010)

LEVEL OF SERVICE	AVERAGE DELAY FOR ALL VEHICLES (SECONDS/VEHICLE)
A	<=10
B	>10 and <=20
C	>20 and <=35
D	>35 and <=55
E	>55 and <=80
F	>80

The calculated traffic delay includes the train's passing time, along with the time required to engage and disengage the warning devices. It is assumed that both the rail and road traffic is uniform throughout the day.

Step 1: Calculate gate-down time per train event (T)

The gate-down time per train event is calculated using the following equation:

$$\boldsymbol{T = T_W + \frac{L}{V}} \quad (4\text{-}5)$$

Where:

T_W = Gate warning time

L = Average train length

V = Average train speed

Step 2: Calculate number of stopped vehicles delayed per day (N_V)

The number of stopped vehicles delayed per day is calculated using the following equation:

$$N_V = \frac{T}{24} \times N \times AADT \qquad (4\text{-}6)$$

Where:

T = Gate-down time per train event

N = Number of trains per day

AADT = Annual Average Daily Traffic

24 = Hours per day

Step 3: Calculate the average delay per vehicle in a 24-hour period (D_V)

The average delay per vehicle over a 24-hour period is calculated using the following equation:

$$D_V = \frac{N_V}{AADT} \times \frac{T \times \frac{R_D}{R_D - R_A}}{2} \qquad (4\text{-}7)$$

Where:

N_V = Number of stopped vehicles delayed per day

R_D = Departure rate (vehicles/lane/hour) *Note: Based on the Highway Capacity Manual* (TRB, 2010)*, departure rates (in vehicles/lane/hour) are the following: highways (1,800), arterials (1,400), collectors (900), and local roads (700).*

R_A = Arrival rate, average daily traffic converted to vehicles/lane/hour

T = Gate-down time per train event

AADT = Annual Average Daily Traffic

2 = Denominator to reflect that vehicles do not experience the entire time the train is blocking the grade crossing. They are assumed to arrive on average at the midpoint of the train crossing period (Office of Environmental Analysis, 2015).

Step 4: Calculate total vehicle delay (D)

The total vehicle delay is calculated as a product of the average delay per vehicle (D_V) and the average daily traffic (AADT):

$$D = D_V \times AADT \qquad (4\text{-}8)$$

4.6 SIGHT DISTANCE

Sight distance is an important evaluation criterion because having clear visibility of all other participants at the crossing type examined in this study increases predictability and response times for all at the crossing. Having clear sight distance from the path user, road user, and even conductor's perspective improves behavior and reaction time for all.

Sight distance should be evaluated based on current best practices to make this a low-risk crossing. It is important for vehicles to have ample time to see and react to an approaching train to make this a more desired crossing. A multimodal crossing such as the one explored in this paper requires coordination between path users, road users, and light/heavy rail. Therefore, optimal sight distance for road users of approaching light/heavy rail is important.

This section is based on The American Association of State High and Transportation Official's (AASHTO) guide A Policy on Geometric Design of Highways and Streets, the "Green Book". Note that AASHTO points out that sight distance is a primary consideration at crossings without active warning devices, and not necessarily at crossings that are treated with automated gates. The following standard should be used to determine the adequacy of the sight distance:

Table 4.5: Design Sight Distance for Combination of Highway and Train Vehicle Speeds; 73.5 ft. Truck Crossing a Single Set of Tracks at 90 Degrees - U.S. Customary (AASHTO, 2012)

Train speed (mph)	**Departure from stop line**	**Moving vehicle**							
	Vehicle speed (mph)								
	0	10	20	30	40	50	60	70	80
Distance along railroad from crossing (ft.)									
10	255	155	110	102	102	106	112	119	127
20	509	310	220	203	205	213	225	239	254
30	794	465	331	305	307	319	337	358	381
40	1019	619	441	407	409	426	450	478	508
50	1273	774	551	509	511	532	562	597	635
60	1528	929	661	610	614	639	675	717	763
70	1783	1084	771	712	716	745	787	836	890
80	2037	1239	882	814	818	852	899	956	1017
90	2292	1394	992	915	920	958	1012	1075	1144
Distance along Highway from Crossing (ft.)									
		69	135	220	324	447	589	751	931

As can be seen in the table, the required sight distance is calculated for two cases; one where the vehicle is already moving at a certain speed, and one where the vehicle is parked at the stop line. For the case of the vehicle being in movement and deciding to either stop before the line or to continue across the crossing in front of the approaching train. The triangle of sight shown in Figure 4.2 consists of two legs that together decides the sight distance; the sight distance along the highway dH and the sight distance along the railroad tracks dT. The sight distances for various speeds is developed from the following equations:

$$d_H = AV_v t + \frac{BV_v^2}{a} + D + d_e \qquad (4\text{-}9)$$

$$d_T = \frac{V_T}{V_V}\left[(A)V_v t + \frac{BV_v^2}{a} + 2D + L + W\right] \qquad (4\text{-}10)$$

Where:

A = Constant = 1.47

B = Constant = 1.075

d_H = Sight-distance leg along the highway allows a vehicle proceeding to speed V_v to cross tracks even though a train is observed at a distance d_T from the crossing or to stop the vehicle without encroachment of the crossing area (ft.)

d_T = Sight-distance leg along the railroad tracks to permit the maneuvers de-scribed as for d_H (ft.)

V_v = Speed of the vehicle (mph)

VT = Speed of the train (mph)

t = Perception/reaction time, which is assumed to be 2.5 s (This is the same value used in Section 3.1 to determine the stopping sight distance.)

a = Driver deceleration, which is assumed to be 11.2 ft./s2

D = Distance from the stop line or front of the vehicle to the nearest rail, which is assumed to be 15ft

d_e = Distance from the driver to the front of the vehicle, which is assumed to be 8ft

L = Length of vehicle, which is assumed to be 73.5ft

W = Distance between outer rails (for a single track, this value is 5ft)

All values are U.S. Customary. Adjustments should be made for skewed crossings and highway grades other than flat (AASHTO, 2012).

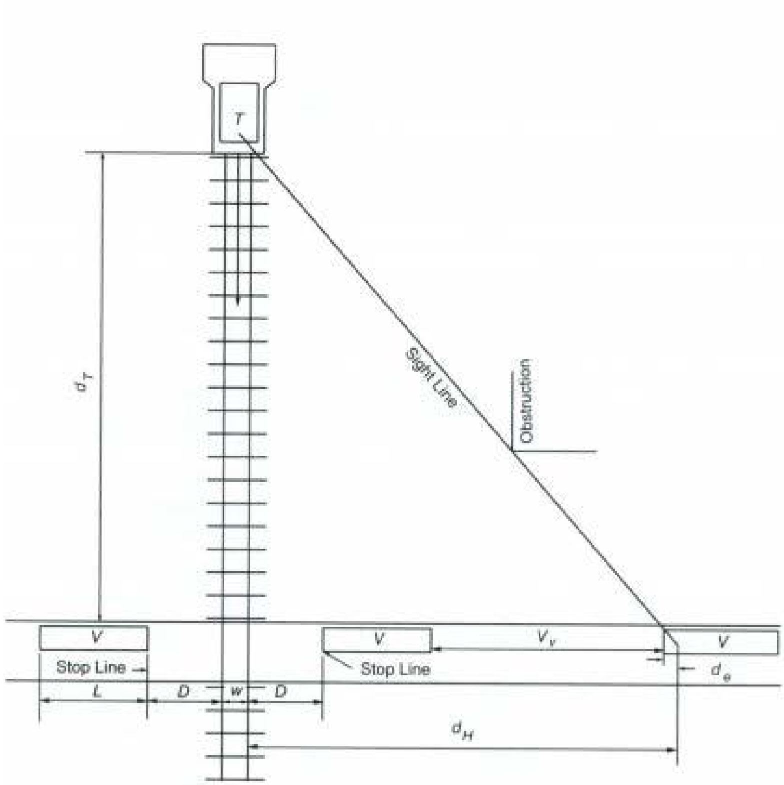


Figure 4.2: Moving vehicle to safely cross or stop at railroad crossing (AASHTO, 2012)

In the second case, the vehicle has stopped at a crossing, and the next maneuver is to start from the stop line and cross the tracks. This is shown in Figure 4.2. The operator should have sufficient sight distance to safely start and cross the tracks, even if the train comes into view, just as he starts. The sight distance is found using the following equation:

$$\boldsymbol{d_T = AV_T\left[\frac{V_G}{a_1} + \frac{L+2D+W-d_a}{V_G} + J\right]} \qquad (4\text{-}11)$$

Where:

d_T = Sight distance leg along the railroad tracks for the departure maneuver (ft)

A = Constant = 1.47

d_T = Sight distance leg along railroad tracks to permit the maneuvers described as for dH (ft)

V_T = Speed of train (mph)

V_G = Maximum speed of vehicle in first gear, which is assumed to be 8.8 ft/s

a_1 = Acceleration of vehicle in first gear, which is assumed to be 1.47 ft/s^2

L = Length of vehicle, which is assumed to be 73.5 ft

D = Distance from stop line to nearest rail, which is assumed to be 15ft

J = Sum of perception and time to activate clutch or automatic shift, which is assumed to be 2.0 s

W = Distance between outer rails for a single track, this value is 5 ft

$d_a = \frac{V_G^2}{2a_1} = \frac{(8.8)^2}{(2)(1.47)} = 26.3\ ft$ = Distance vehicle travels while accelerating to maximum speed in first gear (ft)

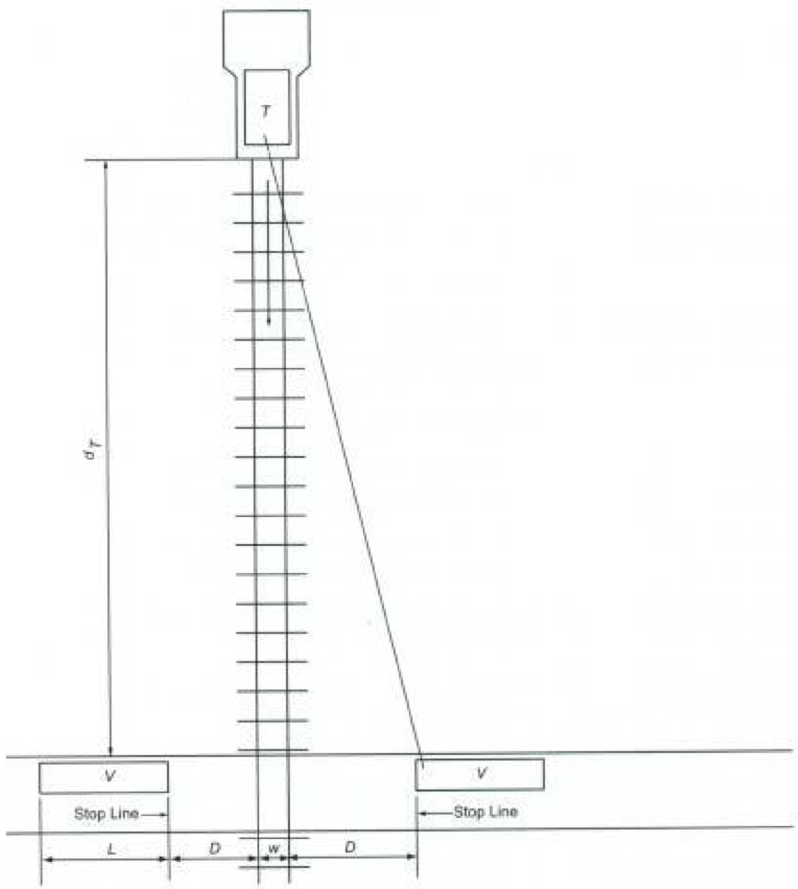


Figure 4.3: Sight line for stopped vehicles (AASHTO, 2012)

AASHTO recommends using speed control signals to lower speeds in non-flat grade crossings, and to always install active warning devices in locations with sight obstructions. The evaluation criteria for this section is improvement of sight distance, as that is linked to increase in the safety of a crossing (AASHTO, 2012).

4.6.1 Alternate Method

If it is not desired to measure sight distance at the crossing in question, using the formulas previously described, the sight distance can be estimated and described upon a site visit. A decision is then made as to whether the sight distance can be categorized as unrestricted, semi blind or blind. Please refer to the previous section for justification of using sight distance.

4.7 VEHICLES STOPPING ON TRACKS

'Vehicles Stopping on Tracks' is another evaluation criteria that has been included because vehicles have been observed stopping on tracks due to lack of clear road user information or poorly allotted reaction time. Therefore, there is an opportunity to better communicate to road users using treatments and measuring a treatment's efficacy by the number of vehicles stopping on tracks before and after a treatment is implemented. Decreasing the number of vehicles stopping on the tracks reduces the risk at the crossing.

This criterion is decided by counting the total number of cars from approaching from each direction within a designated time-frame. First the percentage of vehicles stopped on tracks is counted before and after the installation of treatments, using the following equations:

$$\boldsymbol{S_B = \frac{V_{S_B}}{V_{T_B}} \times 100} \qquad (4\text{-}12)$$

$$\boldsymbol{S_A = \frac{V_{S_A}}{V_{T_A}} \times 100} \qquad (4\text{-}13)$$

Where:

S_B= Percentage of vehicles stopping on tracks before treatment

V_{T_B}=Total number of vehicles counted before treatment

V_{S_B}= Total number of stopped vehicles counted before treatment

S_A= Percentage of vehicles stopping on tracks after treatment

V_{T_A} = Total number of vehicles counted after treatment

V_{S_A} = Total number of stopped vehicles counted after treatment

Then the percentage difference between the two numbers is found:

$$\boldsymbol{\frac{S_A - S_B}{S_B} \times 100} \qquad (4\text{-}14)$$

A negative result means that the treatments have resulted in a reduction in the number of vehicles stopping on the railroad tracks.

4.7.1 Alternate Method

The evaluation criteria in the following section can be used to do before and after comparisons of the observed behavior. It is meant to supplement the quantitative criteria, or in some situations stand alone as a cost-efficient method for evaluating treatments, heavily relying on engineering judgment and general observations. When vehicles fail to realize that a pedestrian or bike is entering in front of them, and are not able to stop at an appropriate point, this can result in the vehicle being stopped on the tracks or not yielding to pedestrians as they are supposed to do. In cases where it is not desired to perform calculations, the alternate method of qualitatively estimating changes can be utilized.

4.8 VEHICLES RUNNING RED LIGHTS

This criterion serves as another proxy to measure the efficacy of a new treatment, as some crossings have been observed to be high-risk due to vehicles running red lights. Vehicles have been observed to run red lights more so when there is difficulty negotiating multiple treatments in tandem. For example, vehicles may unintentionally run a red light if an automatic gate rises and they perceive this as a signal to proceed without registering that the traffic signal is still red. Implementing treatments to mitigate unintentional non-compliance can be an effective way to improve the crossing for all road users and path users. Therefore, vehicles running red lights before and after a new treatment is implemented can serve as a reliable evaluation criterion that reflects the efficacy of a new treatment.

This criterion is decided by counting the total number of cars from approaching from each direction within a designated time-frame. First the percentage of vehicles who runs red lights before and after the installation of the treatments is calculated, using the following equations:

$$R_B = \frac{V_{R_B}}{V_{T_B}} \times 100 \qquad (4\text{-}15)$$

$$R_A = \frac{V_{R_A}}{V_{T_A}} \times 100 \qquad (4\text{-}16)$$

Where:

R_B= Percentage of vehicles running red lights before treatment

V_(T_B)=Total number of vehicles counted before treatment

V_(R_B)= Total number of vehicles running red lights before treatments

R_A= Percentage of vehicles running red lights after treatment

V_(T_A) = Total number of vehicles counted after treatment

V_(R_A) = Total number of vehicles running red lights after treatment

Then the percentage difference between the two numbers is found:

$$\frac{R_A - R_B}{R_B} \times 100 \qquad (4\text{-}17)$$

A negative result means that the treatments have resulted in a reduction in the number of vehicles that runs red lights.

4.8.1 Alternate Method

See Section 4.7.1 Alternate Method.

4.9 UNDESIRED BEHAVIOR: PEDESTRIANS, BIKES AND OTHER

“Undesired Behavior” is when pedestrians, bikes, and others engage in high-risk behavior which can be mitigated using various treatment options. This is an evaluation criterion because a treatment’s impact can be measured by comparing behavior before and after a treatment is implemented. For example, if bikes are observed crossing the road at high-speeds, it can serve as the benchmark for comparison after a treatment (curve or hill) is implemented. If after a treatment is implemented and the average bike speed has decreased, the treatment may be evaluated and concluded as a success.

This criterion is decided by counting the total number of pedestrians, bikes and other non-vehicular users approaching from each direction within a designated time-frame. First the percentage of undesired behavior is counted before and after the installation of treatments, using the following equations:

$$\boldsymbol{I_B = \frac{U_{I_B}}{U_{T_B}} \times 100} \quad (4\text{-}18)$$

$$\boldsymbol{I_A = \frac{U_{I_A}}{U_{T_A}} \times 100} \quad (4\text{-}19)$$

Where:

I_B= Percentage of users exhibiting high-risk behavior before treatments

U_(T_B)=Total number of non-vehicular users counted before treatments

U_(I_B)= Total number of instances of high-risk behavior exhibited by non-vehicular users before treatments

I_A= Percentage of users exhibiting high-risk behavior after treatments

U_(T_A) = Total number of non-vehicular users counted after treatments

U_(I_A) = Total number of instances of high-risk behavior exhibited by non-vehicular users after treatments

Then the percentage difference between the two numbers is found:

$$\boldsymbol{\frac{I_A - I_B}{I_B} \times 100} \quad (4\text{-}20)$$

A negative result means that the treatments have resulted in a reduction in the number of high-risk behavior exhibited by non-vehicular users.

4.9.1 Alternate Method

This alternate criterion can be used to do before and after comparisons of the observed behavior, in cases where it is not desired to complete calculation. It is meant to supplement the quantitative criteria, or in some situations stand alone as a cost-efficient method for evaluating treatments, heavily relying on engineering judgment.

- Crossing tracks on the diagonal, from the path to the sidewalk on the opposite side
- Walking or other activity on railroad property
- Not yielding to stop signs at the end of trails

4.10 GENERAL OBSERVATIONS

General observations can be made to determine if and how the treatments at a crossing are affecting the exhibited behavior and use of the crossing. This methodology is primarily recommended in cases where no specific actions have been taken, or if the crossing did not exhibit significant issues prior to the efforts being undertaken. It should be used qualitatively to compare observations made prior to changing the treatments or the design of a crossing, with observations made after making changes to a crossing.

4.10.1 Neighborhood Impact

Crossings examined in this research can be located adjacent to neighborhoods, and it is therefore important to consider how new treatments applied to a crossing would affect that neighborhood. Trains may be operating in quiet zones or near residential areas, which is why the noise and light pollution should be either measured or otherwise considered.

4.10.2 Impact on Trail/Shared-Path Use

The goal of installing treatments is to provide a functioning, low-risk environment for all path users by improving treatments at or around the path. To provide this, it is important to ensure that the trail remains attractive and functional for its users. For this reason, it is important to evaluate and consider whether a chosen treatment may deter users or adversely impact path user experience before the treatment is installed.

4.10.3 Treatment Familiarity

If vehicular or non-vehicular users do not recognize or understand the treatment and how they should act and react around it, that can lead to unwanted situations. It is therefore important to ensure that the users understand the chosen treatment or that adequate education and awareness is given.

5.0 IDENTIFIED TREATMENTS

The crossings studied in this research project are paths parallel to railroad tracks with an adjacent road running through the tracks and path. Various path and road user behavior can be observed and quantified at this type of crossing. However, each crossing is unique, and requires intense observation of overarching issues present at the site. Three overarching issues are listed below with specific issues organized as bullet points under the overarching issues.

The purpose of this section is to pair the observed overarching and specific issues present with appropriate treatments as possible solutions to mitigate undesired behavior at the crossing.

5.1 OVERARCHING ISSUES AT RAILROAD/PATH/HIGHWAY CROSSINGS

Issues of railroad crossings adjacent to paths can be categorized into three different overarching problem statements: The Built Environment, Lack of Non-Driver Information and Lack of Driver Information. The different categories do somewhat overlap, but is distinctive in that the Built Environment only considers Best Practice in road design and infrastructure, whereas the two other groups consider things such as behavior. Generally, it can be said that the Built Environment can be directly impacted by design and planning decisions, whereas changes in the two other categories are more indirect and relies on nudging and accommodating human behavior, decision-making and error. Each of these problem statements is outlined below.

5.1.1 The Build Environment

When the built environment is not effectively accommodating its users through structure, adequate travel paths, signage or visibility, it can lead to undesired situations for all road and path-users. Examples of problems that can be found in the built environment include:

- Speed: The posted speed limits inappropriate for the intended road utilization and type.

- Crossing design: The railroad tracks are elevated such that it makes drivers focus more on traversing the tracks which ultimately decreases visibility of other road users.

- Railroad crossing and Path distance: The path and the railroad tracks are too close or inappropriately distanced, making it difficult for motorists to negotiate both elements (railroad tracks and path) in a desired manner.

- Stop line: The distance between the stop line and the tracks, and/or the stop line and the stop line of the opposite direction, and/or the stop line and the path is inappropriate. Though the stop line placement is dictated by the MUTCD and other official manuals, they still may not be ideally placed for the unique site-specific needs at a crossing.

- Insufficient Crossing Infrastructure: Pedestrians are not accommodated through shortest path routing, and therefore choose shortcuts to decrease their travel distance. This includes cutting across areas that are not intended for pedestrians, crossing diagonally, crossing on a track platform, walking on property and generally bolting across to minimize their travel path, even if reasonable accommodation is available.

- Transit stop: Transit stops are located too close to the railroad crossing.

- Road/Street Infrastructure: Lack of grade separation or other form of structure between e.g. the road and the sidewalk can lead to cars unintentionally driving on the sidewalk area, which can be high-risk zones for non-vehicular users.

- Visibility: Inadequate visibility due to vegetation, buildings or lack of street light.

5.1.2 Lack of Path User Information

When a pedestrian or bike reaches the end of a path, they may be exposed to other road user types such as vehicles. It is important to ensure that non-drivers are adequately informed and prepared to proceed. Examples of problems that arise when pedestrians, bikes and other users are not properly informed include:

- Speed: The layout and general use of a multi-use path leads to high bike speeds. In this research, high bike speeds are anything over 20mph. Please refer to Appendix C for more details. Bikes may especially be likely to proceed with crossing a road or crosswalk when already traveling at a high-speed, especially if on a primarily commuter-oriented path.

- Signage: There is a lack of adequate signage for bikes and pedestrians surrounding the crosswalk.

- Non-compliance: There is a high non-compliance rate of existing treatments and a lack of consequences for non-compliance.

5.1.3 Lack of Driver Information

Drivers who are approaching a railroad crossing with an adjacent path require advance notification, information, and knowledge to traverse the crossing in a desirable manner, and not violate laws concerned with both stopping for pedestrians and not stopping on tracks. Examples of problems that can arise when driver information is lacking include:

- Negotiation: If a railroad crossing is near a path, the driver will often treat both locations as two separate crossings, and this separation affects how they negotiate each crossing as two different obstacles, as opposed to one complex crossing. It is for this reason that crossings are generally not placed at curves, as this distracts the driver from paying adequate attention to both the railroad crossing and the curve.

- Vehicle Speed: The actual speeds are too high both compared to posted speed limits and for the intended road utilization and type.

- Signage: There is a lack of adequate signage to inform drivers of upcoming obstacles or attributes of the road. This is both pertaining to the railroad crossing itself, but especially to the path-layout and the possibility of encountering pedestrians/cyclists.

5.2 CATALOG OF TREATMENTS

To gain knowledge of existing active and passive treatments that increase awareness for pedestrians and bicyclists on paths near railroad crossings. A thorough literature review has been conducted on path and railroad treatments in the United States and Europe. Treatments within the scope of this project have been aggregated. Please note that the Manual on Uniform Traffic Control Devices (MUTCD) outlines the rules and regulations associated with implementing a majority of these treatments. If it is unclear from the MUTCD, one may contact MUTCD for further clarification about treatments before being implemented.

The treatment catalog serves as a resource for understanding the purpose, efficacy, and cost of each treatment. Summaries of studies investigating the efficacy of various treatments are included for further understanding of the impact of an implemented treatment.

Note that all of the treatments included in this catalog have pros and cons associated with them, and they are not infallible and do not guarantee that pedestrians, cyclists, and motorists will adhere to them and create a 100% low-risk crossing. These treatments are instead implemented to encourage and organize desirable path and road user behavior.

The information included in the treatment catalog has been reduced to a chart which depicts the various impacts associated with implementing a specific treatment at an at-grade railroad crossing. In particular, it summarizes the cost, maintenance cost, day visibility, night visibility, audibility, sight distance, weather, quiet zone, and light pollution, American with Disabilities Act (ADA) accessibility, duration of treatment, compliance rate, user behavior, and whether it is an Oregon Department of Rail and Public Transit standard. The level of impact of these variables is indicated by three colors: light gray (low), dark gray (medium), and black (high).

Appendix A includes detailed information about primary and secondary treatments recommended for the issues identified in Section 5.1 OVERARCHING ISSUES AT RAILROAD/PATH/HIGHWAY CROSSINGS for both heavy and light rail. The value of these tables is that depending on the site-specific details of the crossing, a quick reference to these tables provides thoughtful treatments as solutions to the issues identified.

5.2.1 Active Treatments

This chart depicts the various impacts associated with implementing a specific active treatment at an at-grade railroad crossing. The variables chosen are the most representative of treatment qualities that a city may consider before implementing the treatment. Cost, Maintenance, Weather Impact, Quiet Zone, Light Emission (light pollution), Duration (of active treatment), Compliance Rate, (user) Behavior, and ODOT Requirement are important considerations and may conflict with other city ordinances or policies. We found these to be the most applicable and representative variables for to consider when deciding between various Active Treatment options.

The following section describes the treatments in more detail.

Table 5.1: Overview of Active Treatments

	COST	MAINTENANCE	WEATHER IMPACT	QUIET ZONE	LIGHT EMISSION	DURATION	COMPLIANCE RATE	BEHAVIOR	REQUIREMENT
Flashing Light Signals	$$	$$							
Bells	$	$							
Vehicle Automatic Gates	$$	$							
Wayside Horn System	$$	$							
In-Pavement Marker System	$$-$$$	$$							
Pre-Signal/Traffic Lights	$$$	$$							
Variable Message Sign/Blank-Out Signs	$$	$							
Dynamic Speed Monitoring Display (DSMD)	$	$							
Pedestrian Automatic Gates	$$	$$							
High-Intensity Activated Crosswalk (HAWK)/Pedestrian Hybrid Beacon	$$	$							
Active and Automatic Rectangular Rapid Flash Beacon (RRFB)	$	$$							

Table 5.2: Legend for Active Treatments

LOW	**MEDIUM**	**HIGH**
$	$$	$$$

- Cost – Cost of treatment. (High: > $250,000. Medium: $25,000 - $250,000. Low: < $25,000)

- Maintenance Cost/Year – What is the annual operations cost? For example, how often do pavement markings need to be painted? (High: > $5,000. Medium: $2,500 - $5,000. Low: < $2,500)

- Weather – Can weather such as fog, snow, or heavy rain obstruct treatment visibility and ultimately efficacy?

- Quiet Zone – Does this treatment potentially breach quiet zone policies?

- Light Emission – Does this treatment potentially contribute to light pollution?

- Duration – Is there significant personal time lost due to the treatment? Significant time here is anything more than adhering to a Yield or Stop sign.

- Compliance Rate- High/Low/Medium/NA based on published treatment research.

- Behavior – Does this treatment permit the possibility of treatment avoidance?

- Oregon Department of Transportation (ODOT) Requirement – Is this treatment required at all railroad crossings by ODOT?

5.2.1.1 Flashing Light Signals

Flashing light signals indicate that a train is approaching and that all road users must come to a full stop at the flashing red lights. Depending on the state of implementation, road users may either proceed after the train passes while the lights are still flashing or they must wait until the flashing stops. In Oregon, "you must treat these devices as a stop sign or red traffic light. Always stop when the lights begin to flash; this means a train is coming" (Oregon Operations Lifesaver, N/A). This is confirmed and supported by Oregon state statutes. It is considered a traffic violation if a driver does not come to a full stop. If there is more than one track, make sure all tracks are clear before crossing. Do not continue through the crossing until it is clear and the lights cease flashing"

According to a case study in Portland, Oregon, a low-rise flash beacon with flashing lights installed a few feet off the ground for pedestrians in tandem with channelization (fencing) treatment improved pedestrian behavior (Boucher, et al., 2008). Another report focusing on driver behavior reports a low compliance rate of flashing light signals by drivers and suggests that to improve efficacy, flashing lights should be paired with automatic gates. In this study, it was found that accident rates decreased by 44% with the addition of gates (Mortimer, 1988). A more recent study focusing on driver behavior supports the idea that flashing lights alone are not optimally effective. This study showed that 67% of drivers violated the crossing when flashing lights and bells were present, and non-compliance rates decreased to 38% when a gate was added (Meeker, Fox, & Weber, A comparison of driver behavior at railroad grade crossings with two different protection systems, 1997).

Figure 5.1: Flashing Light Signal (Mixon, 2015)

5.2.1.2 Bells

According to section 8C.02 of the Manual on Uniform Traffic Control Devices (MUTCD), bells may be added to the flash beacon to emphasize railroad-warning signals and to stimulate auditory senses for all road users. The placement and tone of the bell is important to optimize audibility. However, bells may be the source of noise pollution in some communities (MUTCD, 2009).

The Oregon Department of Transportation (ODOT) requires bells at all signalized railroad crossings.

No additional information or data on its efficacy.

Figure 5.2: Bells (Steck, N/A)

5.2.1.3 Vehicle Automatic Gates

Retro reflectorized red and white gate arm descends in front of crossing when oncoming rail traffic is detected. The gate arm must be in a horizontal position for 5 seconds minimum prior to the trains' arrival. This treatment is most often paired with a flash beacon and bells. To encourage a high compliance rate, the downtime of gates should be minimal to keep frustration levels low and compliance rates high (Richards, Heathington, & Fambro, 1990).

Operation Lifesaver in Oregon clarifies the law at railroad gates. "Gated crossings are a further refinement of flashing light signals. They mean the same as ordinary flashing light signals. Stop when the lights begin to flash and before the gate begins to lower across your road lane. Do not attempt to cross until the gates are raised and the lights have stopped flashing. Do not attempt to drive around the gates. Do not stop directly on a gated crossing where there is the risk of getting trapped on it by lowered gates" (Oregon Operations Lifesaver, N/A).

Automatic gates and lights are expensive to implement and cost $150,000-$250,000 (Ogden, 2007).

Figure 5.3: Vehicle Automatic Gates (N/A, N/A)

5.2.1.4 Wayside Horn System

Railroad crossings in quiet zones must find alternative warning methods to the train blowing its horn down the railroad and disturbing communities. The wayside horn system is made up of a combination of speakers and a flashing red 'X' installed at a crossing. The speakers emit a digitized train horn down onto the tracks, which is quieter when comparted to a train horn which travels down the railroad tracks. The flashing 'X' functions to inform the train crew that the wayside horn system is indeed working, and they then refrain from blowing the train horn when approaching a crossing (WSDOT, 2009). The sound waves moving downward onto the tracks by the wayside horn system allows for the sound warning system to function while also adhering to noise level restraints.

Wayside horn systems are expensive to implement. It costs approximately $100,000 to add this system to a crossing (National Highway Traffic Safety Administration (NHTSA) , N/A). No additional information or data on its efficacy.

Figure 5.4: Wayside Horn System (APWA Reporter, 2007)

5.2.1.5 In-Pavement Marker System

This treatment is used to warn and guide road users and this technology can also be used to enhance road user behavior at railroad crossings. In-pavement flashing LED lights are installed to indicate lanes designated for light rail transit only or to designate intersections where a full stop is necessary.

According to the NCHRP Synthesis 380, “Few formal evaluations have been performed to determine the effectiveness of IPM systems in enhancing roadway safety, operations, or aesthetics. Pedestrian crosswalk applications have been most frequently studied; IPM systems have generally been shown to increase vehicle driver awareness, increase vehicle yielding, reduce vehicle approach speeds, reduce vehicle and pedestrian conflicts, and reduce pedestrian wait times. Considering broader applications of IPM systems, additional studies have generally shown a reduction in vehicle speeds, improved lane-tracking, increased road user awareness, and high public acceptance. More recent studies have been conducted in response to FHWA’s requirements for experimental status. Early results reported from these studies show promise but are generally based on limited data and, as such, cannot be considered conclusive” (Carson, Tydlacka, Gray, & Voigt).

“Oregon has expressed interested in the use of some sort of train-activated, in-pavement flashing lights at high profile, high traffic pedestrian locations” (Boucher, et al., 2008).

This is can be an expensive installation process that ranges from $5,000-$100,000. When this treatment was applied to a highway-rail crossing in Paramount, California to improve sight-distance, it cost about $60,000. It is a system that requires cumbersome installation and maintenance such as removing and replacing LED lights. Visibility of the LED lights is lower during the daytime and this system relies on a power supply.

No additional information or data on its efficacy.

Figure 5.5: In-Pavement Marker System (Bromley, 2013)

5.2.1.6 Pre-Signals/Traffic Lights

This treatment method is typically applied to highway-railroad grade crossings and is used to warn vehicles using pre-signals to mitigate conflict at railroad crossings where vehicles may be in a queue. The pre-signal is used in conjunction with the intersection signal and it requires a traffic signal warrant. More information about the warrant can be found in Section 4C.01 in the MUTCD. When a train is approaching, the red light is activated to stop vehicles before the railroad crossing. "The purpose of installing highway traffic signals in this manner at a crossing is to prevent vehicles from queuing across the grade crossing and finding themselves stopped on the tracks in the area now known as the minimum track clearance distance" (Gilleran, 2006). Although there is no national standard enforcing pre-signals at highway railroad crossings, section 4D.14 and 4D.15 of the MUTCD and FHWA's November 5, 2014 Official Interpretation 8(09)-19(I)

(Positioning of Signal Faces at Pre-Signals) outlines installation and placement standards for the pre-signal.

The pre-signal for the traffic signal ahead of it and emits green, yellow, or red depending on crossing conditions. To create a cohesive and desirable pre-signal, “No Turn on Red” and “Stop Here on Red” sign should also be installed. Regarding heavy rail in Oregon:

“Preemption is required when railroad tracks are located on a roadway within 215 feet of a signalized intersection. When a vehicle clear-out interval (VCOI) is required, the indication for the clearance phases shall be green. VCOI operation shall include a green left-turn arrow if a left turn movement exists, even if the left-turn movement operates permissively. Under normal operation, if the left-turn movement is permissive only, the display of the left-turn green arrow shall be used during rail preemption only. The use of green arrow is not allowed for use by emergency vehicle preemption and transit priority users. Advance railroad detection or other appropriate methods shall be used to provide a pedestrian clear-out interval (PCOI) prior to the vehicle clear-out interval (VCOI). This should be designed to minimize the occurrence of abbreviated pedestrian clearance intervals. In absence of pedestrians, a portion or the entire duration of the PCOI may be utilized to serve the clear-out phase(s), if mentioned in the Crossing order. Part Time Restriction sign(s) shall be posted to prohibit specific turning movement(s) toward the highway-rail grade crossing during preemption, if called for in the Crossing Order” (ODOT, 2015).

For pedestrians, Pushbuttons are provided to non-visually facilitate low-risk pedestrian crossings at grade rail crossings.

There are two types of pushbuttons: illuminated and non-illuminated. Illuminated pushbuttons inform pedestrians on being pushed that it is indeed working by emitting a light. If there is a median or pedestrian refuge, then another pushbutton is provided at the median or pedestrian refuge to facilitate a complete, low-risk crossing. This treatment costs about $1,500 per unit and may vary depending on site specific conditions (USDOT - FHWA, n.d.). A study from 2001 in Windsor, Ontario shows that 16.5% of pedestrians and cyclists used the non-illuminated pushbutton and 12.7% used the illuminated pushbutton (Huang & Zegeer, 2001).

Accessible Pedestrian Signals may also be implemented at a traffic light. This is the audible and physical mode of communicating low-risk crossing conditions to the visual or hearing impaired. This tool provides audible and or vibrotactile information. The crossing is voice activated and the button vibrates when it is pushed to confirm to all road users that pedestrians may desirably cross the designated path. This treatment may cause noise pollution. This cost of this device is $600 and installation costs range from $1000-$10,000 depending on the electric and construction work needed (Rue & Barlow). Research shows that there are higher levels of compliance and levels of pedestrian satisfaction and improved behavior with APS than with the alternative “WALK” and “DON’T WALK” command signals. 66% of participants crossed during the “Walk” command while 99% of participants crossed during the APS Walk command (National

Cooperative Highway Research Program, 2009). No additional information or data on its efficacy.

Figure 5.6: Pre-Signals/Traffic Lights (PSOMAS, N/A)

5.2.1.7 Variable Message Sign/Blank-Out Signs

A variety of Flashing LED Messages are available such as: “Train Approaching,” “Second Train Approaching,” “Warning! Another Train Coming,” and an arrow indicating no right turn. Depending on roadway operations/configuration this may not just be limited to a right turn.

A study conducted in LA showed that two measures of pedestrian behavior were examined: (a) the number of pedestrians entering the track area at 15 seconds or less before a train entered the crossing and (b) the number of pedestrians entering the track area at 6 seconds or less before a train entered the crossing with the flashers activated, a much riskier behavior. The study compared pedestrian behavior before and after installation and found that the installation of the signal reduced the incidence of risky pedestrian behavior by 14 % on the first benchmark and 32 % on the second one (Metaxatos & Sriraj, Pedestrian/Bicyclist Warning Devices and Signs at Highway-Rail and Pathway-Rail Grade Crossings, 2013).

Figure 5.7: Variable Message Signs (Gabree & daSilva, 2014)

5.2.1.8 Dynamic Speed Monitoring Display (DSMD)

A dynamic speed monitoring display is one that is mounted on a regulatory speed limit sign to inform and raise awareness of drivers of their speed in real time. It is often used in school zones to inform and alert drivers of undesired driving behavior. A radar built into the speed nominator relays speed information to passing drivers without being a major distraction.

This device can be used to alert motorists on the highway of their speeds and increase awareness for motorists if they are going above the posted speed limit. This can be especially useful if speed limits have changed around a railroad crossing and motorists need to adjust to a new speed limit. If posted speed limits are lowered at a crossing, this can remind motorists to reduce their speed to the new limit, which ultimately increases reaction time to the railroad crossing.

A study entitled "Long-Term Effectiveness of Dynamic Speed Monitoring Displays (DSMD) conducted in Minnesota show that speeds significantly reduced by 6-8 mph in the 85^{th} percentile speed one year after the dynamic speed monitoring display sign was implemented. Data also revealed that vehicle speeds were reduced overall within a 24-hour day (Sandberg, Schoenecker, Sebastian, & Soler, N/A).

Another study entitled, “Efficacy of Radar Speed Monitoring Displays in Reducing Vehicle Speeds” implemented three DSMDs in Nebraska. In aggregating and comparing traffic speeds before and after implementation, it was found that the mean speed reduced by 3-4mph and the 85th percentile speed reduced by 2-7 mph. Within this study, the DSMD was tested at various other locations, all of which had positive results and showed unanimous efficacy in alerting and slowing down drivers.

If battery operated, there are high maintenance costs, however it can also be implemented with a solar panel to avoid frequent maintenance.

Figure 5.8: Dynamic Speed Monitoring Display (N/A, N/A, n.d.)

5.2.1.9 Pedestrian Automatic Gates

Retro-reflectorized red and white bar descends in front of pedestrian crossing when oncoming rail traffic is detected. This treatment is most often paired with a flash beacon and bells. To encourage a high compliance rate, the downtime of gates should be minimal to keep frustration levels low and compliance rates high (Richards, Heathington, & Fambro, 1990).

Chapter 8C,” Flashing-Light Signals, Gates and Traffic Control Signals” of the MUTCD outlines scenarios in which pedestrian automatic gates would be appropriate. ” Paragraph 11 of Section 8D.06 of the 2009 MUTCD recommends that a separate mechanism be provided for the sidewalk gate if a separate sidewalk gate is provided in addition to the vehicular gate. This paragraph further states that the reason for this recommendation is "to prevent a pedestrian from raising the vehicular gate." This recommendation became necessary because incidents have occurred where a pedestrian lifted the pedestrian gate and this action caused the vehicular gate to also rise" (Kehrli, 2010). Sites that include railroad tracks and have other tracks or a road adjacent to it requires engineering studies that assesses the needs of a pedestrians and whether a pedestrian gate is required (USDOT). If a pedestrian automatic gate is installed, the Federal Railroad Administration (FRA) would regulate the gate operations.

MUTCD 8D.06 and FHWA's Official Interpretation 8(09)-3(I) (Use of Single Gate Mechanisms at Grade Crossings) dated August 24, 2010 clarifies when a separate gate mechanism should be provided for either vehicles or pedestrians. The FHWA suggests that separate mechanisms for pedestrians and vehicles is desired to stay consistent with the MUTCD, however, if an engineering study of a site justifies a single mechanism, then it should be designed as such so that if a pedestrian gate is automatically lifted, it does not impact the vehicle gate.

To deter pedestrians and cyclists from going under or around the automatic pedestrian gate, it is recommended that gate skirts, fencing, and channelization be used in tandem with the gate. Depending on the site-specific conditions and number of treatments needed, a pedestrian gate can cost $75,000-$30.000,000 to implement. No additional information or data on its efficacy.

Figure 5.9: Pedestrian Automatic Gates (N/A, N/A, n.d.)

5.2.1.10 High-Intensity Activated Crosswalk (HAWK)/Pedestrian Hybrid Beacon

The High-Intensity Activated Crosswalk (HAWK) functions very similarly to the Pedestrian Hybrid Beacon listed in the MUTCD. The HAWK was developed in the 1990s and was first implemented in Tucson, AZ to improve behavior of pedestrian crossings at major arterials located at minor street intersections.

A typical HAWK includes:

- A three-pronged red-yellow-red beacon with suplemental signage - "CROSSWALK STOP ON RED" and "PEDESTRIAN CROSSING."
- A pushbutton.
- Pedestrian signal with interval countdown display.

The beacon remains dark when inactive. When a pedestrian pushes the button, the beacon is activated and begins to signal to the road users. The flashing yellow, solid yellow, solid red, and flashing red indicate various levels of signal sequencing to drivers. A dark beacon means that it is inactivated, flashing yellow indicates that the signal has been activated, solid yellow indicates that motorists should reduce speed and be prepared to stop, solid red reuiqres drivers to stop, and flashing red signals indicates that drivers must come to a full stop (USDOT - FHWA, 2010).

According to ODOT, "*… only 1 in 4 drivers yields to pedestrians in the crosswalk. The HAWK signal has been found to significantly increase motorist awareness*" (ODOT, N/A). Portland, Oregon already has HAWK signals installed throughout the city and ODOT is currently gathering data on its efficacy.

Chapter 4F of the the MUTCD (2009), includes information about the application, design, and operation of pedestrian hybrid beacons. "*A pedestrian hybrid beacon is a special type of hybrid beacon used to warn and control traffic at an unsignalized location to assist pedestrians in crossing a street or highway at a marked crosswalk*" (MUTCD, 2009). The design of the pedestrian hybrid beacon should complement signaling regulations. The beacon itself is very similar to the HAWK, however it has one signaling option that differs from the HAWK in that the pedestrian hybrid beacon has *alternating* flashing red rights.

The beacon remains dark if unactivated, and follows a similar signaling sequence as a HAWK.

A study conducted by the FHWA aggregated three years of data pre-HAWK and three years of data post-HAWK at 21 locations and gather the same information for 102 unsignalized intersections and analyzed the crash data set. Their research found that with HAWK installations, there was a 29% reduction in total crashes, 15% reduction in severe crashes, and a 69% reduction in pedestrian crashes. Note that this study was conducted in Tucson, Arizona and results may not be similar in other cities.

The average Pedestrian Hybrid Beacon costs $75,000-$150,000 to purchase and install. This cost range includes site-specific requirements (Michigan Complete Streets Coalition, 2013).

Figure 5.10: High-Intensity Activated Crosswalk (HAWK) (USDOT FHWA, 2016)

5.2.1.11 Active and Automatic Rectangular Rapid Flash Beacon (RRFB)

Rectangular Rapid Flash Beacons or "RRFBs are user-actuated amber LEDs that supplement warning signs at unsignalized intersections or mid-block crosswalks. Pedestrians can activate them manually by a push button or passively by a pedestrian detection system. RRFBs use an irregular flash pattern that is like emergency flashers on police vehicles. RRFBs may be installed on either two-lane or multi-lane roadways" (USDOT - FHWA, 2009).

A study conducted at eighteen sites in St. Petersburg, Florida looked at the efficacy of RRFBs and explored whether they impact the number of motorists yielding to pedestrians. "The results indicated that the device increased yielding levels from single digit or low levels up to 20% to 30% to between 80 and 90% at most sites" (Van Houten & Malenfant, N/A).

Another study evaluated a site for one year and found that the addition of an RRFB increased vehicular yielding compliance from 18% to 81% (Shurbutt, 2009). Case studies published on the MUTCD website recognize the high efficacy of RRFBs during nighttime use. Researchers concluded that there was a near 100% compliance right at

RRBs during nighttime. A pedestrian detection system can be used to trigger an Automatic RRFB.

Though research has not confirmed whether automatic or pushbutton RRFBs are more effective, it is generally better to have automatic pedestrian detectors, because" some passive detection devices can track the progress of a pedestrian as the pedestrian crosses the roadway for extending or shortening the duration of certain pedestrian timing intervals" (MUTCD, 2017). Pushbuttons must adhere to MUTCD Figure 4E-3 location requirements.

The cost of an RRFB "is approximately $10,000 to $15,000 for purchase and installation of two units (one on either side of a street). This includes solar panels for powering the units, pad lighting, indication units (for both sides of street) with RRFBs in the back and front of each unit, signage on both approaches, all posts, and either passive infrared detection or push buttons with audio instructions. Costs would be proportionately higher for additional units placed on a median island, etc." (USDOT - FHWA, 2009).

The FHWA estimates that an RRFB costs on average $22,250 (USDOT - FHWA, N/A). Note that the final cost is likely to deviate from this average depending on site-specific conditions and needs such as interconnecting the RRFB signal with the railroad crossing signal. There have been no outstanding differences in costs between an automatic or pushbutton RRFB.

Figure 5.11: Rectangular Rapid Flash Beacon (RRFB) (N/A, N/A, N/A)

5.2.2 Passive Treatments

This chart depicts the various impacts associated with implementing a specific active treatment at an at-grade railroad crossing. The following section describes the treatments in more detail. Each of these variables were considered and used as a tool to compare the various Passive Treatments. Cost, Maintenance, Day Visibility/Audibility, Night Visibility/Audibility, Sight Distance, Weather, ADA (accessible), Duration (of treatment), Compliance, Behavior, and ODOT Standards were found to be the most representative variables to consider when deciding which Passive Treatment to implement.

Table 5.3: Overview of Passive Treatments

	COST	MAINTENANCE	DAY VISIBILITY/AUDIBILITY	NIGHT VISIBILITY/AUDIBILITY	SIGHT DISTANCE	WEATHER	ADA	DURATION	COMPLIANCE	BEHAVIOR	ODOT REQUIREMENT
Crossbucks	$	$									
Railroad Crossing Advance Sign	$	$									
Look Both Ways	$	$									
Pavement Marking	$	$$									
Tactile Warning	$	$$									
Dynamic Envelope	$$	$$									
Conflict Paint	$	$									
Glow in Dark Paint	-	-									
Rumble Strips	$	$									
Speed Bumps	$	$									
Speed Humps	$	$									
Speed Kidney	$	$									
Speed Cushion	$	$									
Speed Table	$	$									
Grade/Hill	$$	$									
Curves	$$	$									
Raised Crosswalk	$	$									
Bollards	$	$									
Bicycle Rail or Lean Rail	$	$									
Lighting	$	$									
Mirrors	$	$									
Pedestrian Refuge	$$	$									
Channelization (Paving/Delineation)	$$$	$$									
Channelization (Z-Crossing)	$$$	$									
Manual Gates	$	$									
Pedestrian overcrossing, undercrossing	$$$	$									
Quick/Temporary Curb	$	$									
Pedestrian Crossing Flags	$	$									

Table 5.4: Legend for Passive Treatments

LOW	MEDIUM	HIGH
$	$$	$$$

- Cost – Cost of treatment. (High: > $250,000. Medium: $25,000 - $250,000. Low: < $25,000)
- Maintenance Cost/Year – What is the annual operations cost? For example, how often do pavement markings need to be painted? (High: > $5,000. Medium: $2,500 - $5,000. Low: < $2,500)
- Day Visibility/Audibility– Are treatments visible or audible during the day?
- Night Visibility/Audibility– Are treatments visible or audible during the night?
- Sight Distance – Does this treatment provide a fair warning for sufficient stop time?
- Weather – Can weather such as fog, snow, or heavy rain obstruct treatment visibility and ultimately efficacy?
- Americans with Disabilities Act (ADA) – Is this treatment ADA accessible?
- Duration – Is there significant personal time lost due to the treatment? Significant time here is anything more than adhering to a Yield or Stop sign.
- Compliance Rate- High/Low/Medium/NA based on published treatment research.
- Behavior – Does this treatment permit the possibility of treatment avoidance?
- Oregon Department of Transportation (ODOT) Requirement – Is this treatment required at all railroad crossings by ODOT?

Please note that signage is an important and effective tool that can be used to inform path users and road users of what to expect ahead. There is an exhaustive list of appropriate signage for site-specific conditions. The application, rules, and regulations of approved signs can be found in the MUTCD. The signs specifically listed below are either required or most commonly used at crossings. Reviewing other signs available to you is encouraged.

5.2.2.1 Crossbucks Assembly (Crossbucks + STOP or YIELD)

According to section 8B.04 of the Manual on Uniform Traffic Control Devices (MUTCD), a crossbucks and ‘Stop’ or ‘Yield’ is the minimum required signage that should be placed at all public railroad crossings. Additional traffic control devices may be added to the crossbucks sign if needed (FHWA, 2007).

The crossbucks is a white retro reflectorized sign with the words, “Railroad Crossing” written on it. Pedestrians, cyclists, and drivers should yield at the crossbucks sign. This sign is limited in that it does not indicate if there is a train passing in real-time and may prompt road users to ignore it unless there are active indicators of an oncoming train.

The efficacy of the crossbucks alone is not quantifiable, but related research suggests that there is a high non-compliance rate for crossbucks alone. According to Operation Lifesaver, Inc., gates are 80-90% more effective than crossbucks signs. Other research shows that vehicle collision rates are 1.87/100 million crossing vehicles whereas the collision rate is .71/100 million crossing vehicles when gates are present (Raub, 2006). Literature on railroad crossings indicates that there is little certainty of crossbucks compliance for pedestrians and cyclists. However, a study looking at how drivers use their brake function near crossbucks signs show that only 56% of drivers applied the break indicating their yielding to the crossbucks sign (USDOT - FRA, 2014).

A study on stop signs at highway-rail crossings in seven Midwestern states concludes that collision rates increased when ‘Stop’ signs are added to ‘Crossbucks’ signs. The author speculates that there is a lower compliance rate of ‘Stop’ signs at low-volume intersections (Raub, 2006). A recent study on driving performance at ‘Crossbucks’ or ‘Crossbucks + Stop’ conflicts this previous study. This research found that almost 100% of their sample population reduced their speed and engaged their brake at a ‘Crossbucks + Stop’ sign versus just 56% that slowed down at a ‘Crossbucks’ sign (USDOT - FRA, 2014). This was surprising to find since national statistics on incidents at ‘Crossbucks’ vs. ‘Crossbucks + Stop Sign’ between 2008-2012. Suggest that more railroad incidents occurred at ‘Crossbucks’ only signs than at ‘Crossbucks + Stop Signs.’

It costs $1,200-$2,000 to install (FHWA, 2007). There is concern of rollover stoppings onto the tracks, which increases exposure time to the train.

Figure 5.12: Crossbucks + Stop (ODOT, N/A)

The Yield sign emphasizes that road users must slow down and yield to oncoming railroad traffic. Research done by Lumm and Stockton suggest that 'Yield' signs are more effective at having drivers slow to 5 miles per hours or under than 'Stop' signs. It costs $1,200-$2,000 to install (FHWA, 2007).

Figure 5.13: Crossbucks + Yield (ODOT, N/A)

5.2.2.2 Railroad Crossing Advance Sign

A railroad crossing advance sign warns road users that there is a railroad crossing ahead. It is considered a supplemental sign. ” These supplemental signs inform drivers of vehicles carrying passengers for hire, school buses carrying students, or vehicles carrying hazardous materials that a stop is not required at certain designated highway-light rail transit grade crossings, except when a light rail transit vehicle is approaching or occupying the highway-light rail transit grade crossing, or the driver's view is blocked” (FHWA, 2003).

“A round, black-on-yellow warning sign placed ahead of a public railroad-highway crossing. The warning sign tells you to slow down, look and listen for the train, and be prepared to stop at the tracks if a train is coming” (2005 American Association of Motor Vehicle Administrators CDL Manual, 2005).

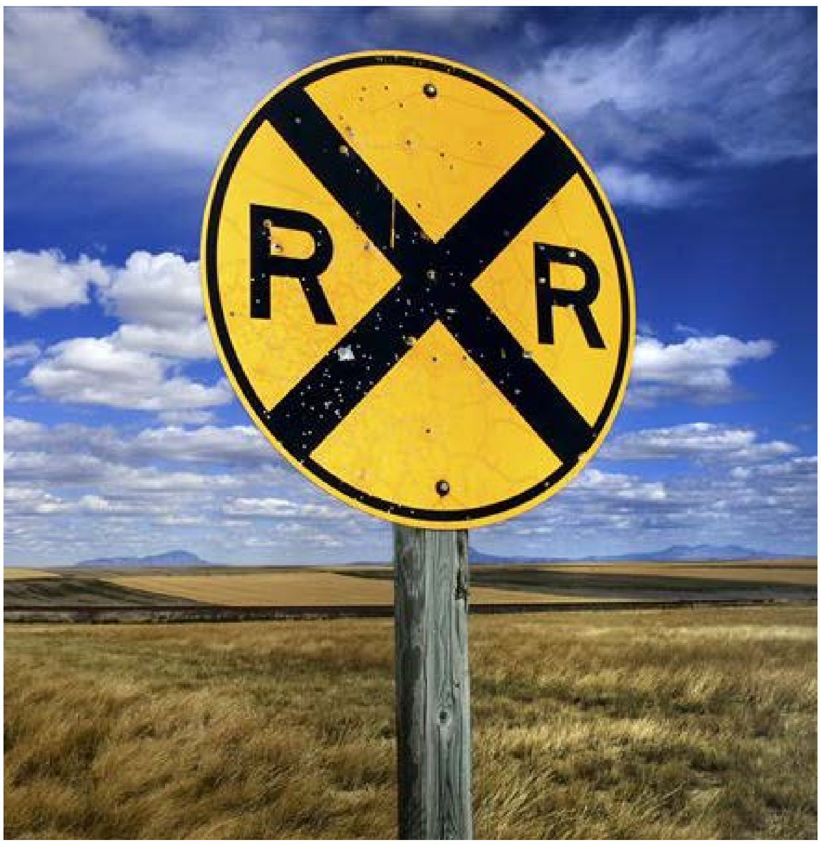


Figure 5.14: Advance RR Crossing Sign (N/A, NA)

5.2.2.3 Look Both Ways Sign

This is additional signage that can be added to a crossing to increase awareness of an approaching train.

The TriMet” Look Both Ways” sign is black text on yellow. This is something ODOT RPTD has permitted the LRT to utilize, but is not a sign that RPTD recognizes as a standard. ODOT RPTD recognizes the MUTCD's R15-8 (black on white regulatory) as the standard.

Therefore, at all light-rail systems in Portland, "Look Both Ways" signs at all "pedestrian crossings adjacent to a gated motorist crossing and at many station platform crossing" have been installed (Korve, et al., 2001). This is a low-cost treatment to remind road users to look both ways and that they are in the presence of train activity. Note that implementation of too many treatments may lead to confusion or ignorance. No additional information or data on its efficacy.

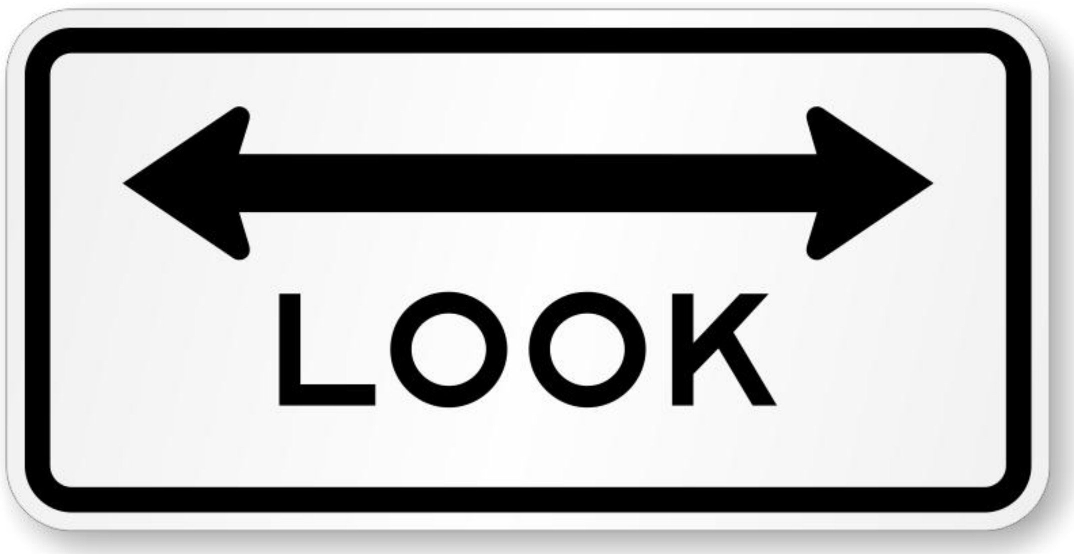


Figure 5.15: Look Both Ways Sign (http://www.roadtrafficsigns.com/Arrow-Traffic-Sign/Look-Arrow-Sign/SKU-X-R15-8.aspx)

5.2.2.4 Pavement Marking

There are a variety of pavement markings present near railroad crossings.

The highway-rail grade crossing is a white RxR symbol that is marked on the road near the advance warning sign and may also include a stop bar to signal that drivers must come to a full stop before the white line if a train is present. Stop lines, crosswalks, and all other pavement markings are included under "Pavement Marking."

Pavement signs painted on the panels near railways with warnings such as "Stop for Trains, Look for Trains in Both Directions, Stop Here, Do Not Stand Here, Watch for Trains. Salt Lake City, Utah is currently evaluating the effectiveness of this treatment option (Boucher, et al., 2008). Though the efficacy of this treatment has not been recorded since then, the UTA Light Rail Design Criteria approves of pavement markings as long as they adhere to Utah MUTCD requirements (Utah Transit Authority, 2015). All pavement markings are prone to low visibility during extreme weather conditions and may require frequent maintenance to maintain visibility and clarity.

Figure 5.16: Pavement Marking (N/A, N/A)

5.2.2.5 Tactile Warning Methods

Tactile warning treatments such as bumps or rumble strips are applied to help pedestrians, cyclists, and the visually impaired identify desired stopping/waiting locations and is also used to delineate railroad platforms (Korve, et al., 2001).

Tactile warning methods may be in conflict with ADA Accessibility Guidelines (ADAAG) and have to be implemented while adhering to ADA requirements. ”Section 4.5 Ground and Floor Surfaces” of ADAAG outlines the rules and regulations affiliated with changes in floor levels. ” Section 10 Transportation Facilities” provides further details about the design and requirements associated with transportation facilities (United States Access Board, 2002).

Road texture such as bumpers and rumble strips for cyclists assist in heightening awareness train presence and forces cyclists to reduce their speed as they approach an at grade crossing and can also serve as an audible warning method (Yeh & Multer, 2008). It is interesting to note that tactile warning treatments may also cause reckless behavior if users try to avoid the textured surfaces (Yeh & Multer, 2008). This is a rather low-cost treatment that requires frequent maintenance to keep markings clear and visible. Snow can obstruct the visibility and effectiveness of tactile treatment methods. Tactile treatment methods are widely used in the United States and there are many professionals in the field who firmly believe that this treatment method undoubtedly improves low-risk behavior for pedestrians, visually impaired, and cyclists. However, there is no additional information or data on its efficacy (Cleghorn, Clavelle, Boone, Masliah, & Levinson, 2009).

Figure 5.17: Tactile Warning (N/A, N/A, N/A)

5.2.2.6 Dynamic Envelope Marking

The MUTCD defines a dynamic envelope “as the clearance required for the train or light rail transit equipment overhang resulting from any combination of loading, lateral motion, or suspension failure” (MUTCD, 2009).

Different design measures can be used to deter road users from dwelling in the dynamic envelope such as barrier curbs and tactile treatments within the envelope to make it uncomfortable to ride a bike or walk on uneven pavement, ultimately discouraging people from dwelling on the tracks. Paint covering the dynamic envelope marking is another treatment option to emphasize train-activated space on the road. Depending on the type of treatment and site specifics, the cost and maintenance levels will vary. According to Transpo Industry Inc., a company that specializes on painting dynamic envelope marking this treatment resulted in a 39% reduction in the number of motorists stopping on or near tracks.

Note that the National Committee on Uniform Traffic Control Devices must approve a dynamic envelope marking.

Figure 5.18: Figure Dynamic Envelope (N/A)

5.2.2.7

Though delineating bike lanes is not mandatory in the United States, pavement markings (typically) can be an effective tool to increase visibility of cyclists on the road. Paint can be added to conflict zones to increase visibility and promote the priority of cyclists and pedestrians over motor vehicles. Green and blue paint are the colors commonly applied to bike lanes in cities such as Portland, Eugene, and New York.

According to the National Association of City Transportation Officials' (NACTO) Urban Bikeway Design Guide, green paint is the color of choice because other colors have other meanings in the pavement marking context. In addition to the paint being green, NACTO recommends that the colored surface be prepared to be skid resistant and retro-reflective to optimize visibility in the dark. They also encourage cities to implement 'Yield to Bikes' signs to clarify and emphasize that bicycles have right-of-way. "Bicyclists familiar with more traditional sharrows have noted that the additional emphasis resulting from the green pavement paint appears to be creating a heightened awareness by the motorists in the lane" (KOA Corporation, 2010).

A study conducted by the New York City Department of Transportation in 2011 evaluated compliance rates and bicycle behavior implications of a bike lane before and after the green paint was applied. The green paint utilized in New York city was noted for its following characteristics: paint did not cause slippery road conditions, asphalt imperfections became more visible with increased wear and tear, green paint was visible during the day and under street lights, and maintenance is required every 3-5 years. Data from the study revealed that “the green paint treatment resulted in fewer instances of drivers encroaching on the bike lane by driving on the bike lane boundary line. Overall, 7% of drivers on the green paint treated streets drove on the bike lane boundary line as opposed to 16% of drivers on streets with the typical non-painted bike lane treatment. The data also showed fewer instances of driving in the bike lane; on average, 4% of drivers drove in the bike lane on green paint treated streets as opposed to 7% of typical streets. The frequency of standing or parking in the bike lane between the two different paint treatments was comparable” (City of New York, DOT, 2011).

Another study conducted by the Florida Department of Transportation in 2008 recorded the interactions between bicycles and motor vehicles before and after green paint was applied to a weaving area. A typical bike lane treatment was repainted with green paint at the conflict points. The results from this study indicate that colored pavement and signage are indeed effective and improve behavior for both bicyclists and vehicle drivers. In fact, results show that significantly more motor vehicles yielded to bicyclists and a fewer percent of motor vehicles used less of the bicycle lane during weaving maneuvers when the bike lane was painted green. This study also indicates that “motor vehicles slowed down 2.0% of the time in the after period compared to 5.8% in the before period. On the other hand, motor vehicles braked more often in the after period (34.6% in the before period versus 36.7% in the after period). Overall, the green paint and signage had positive results and the percentage of conflicts decreased after the lane was painted green (William, Srinivasan, & Martell, 2008).

Note that the use of colored pavements as a traffic control device must be approved by local jurisdiction and the National Committee on Uniform Traffic Control Devices.

Figure 5.19: Conflict Paint (Cieslewicz, seen 2017)

5.2.2.8 Glow in the Dark Paint/Bike Path

This is a very new treatment option in the United States that was installed and completed in February 2017.

Texas A&M University received approval from the Federal Highway Administration to test this specially formulated paint on their campus and record the efficacy of this treatment option. During the day, photo luminescent particles soak up energy from the sun and this energy then emits a luminous soft glow at night. This treatment is currently being tested at Texas A&M. No additional information on its efficacy (Chow, 2017).

Figure 5.20: Glow in the Dark Paint - Day Visibility (Texas A&M, 2017)

Figure 5.21: Glow in the Dark Paint - Night Visibility (Texas A&M, 2017)

5.2.2.9 Rumble Strips

Rumble strips are horizontal markings that can be applied to shared pedestrian and bicycle paths to decrease the speed of cyclists. Rumble strips have been applied to the Los Angeles River path.

Though this treatment is intended to slow cyclists and increase awareness of their surroundings, cyclists must focus on the ground in order to anticipate rumble strips instead of being alert and ready to react to their dynamic environment. No additional information on efficacy.

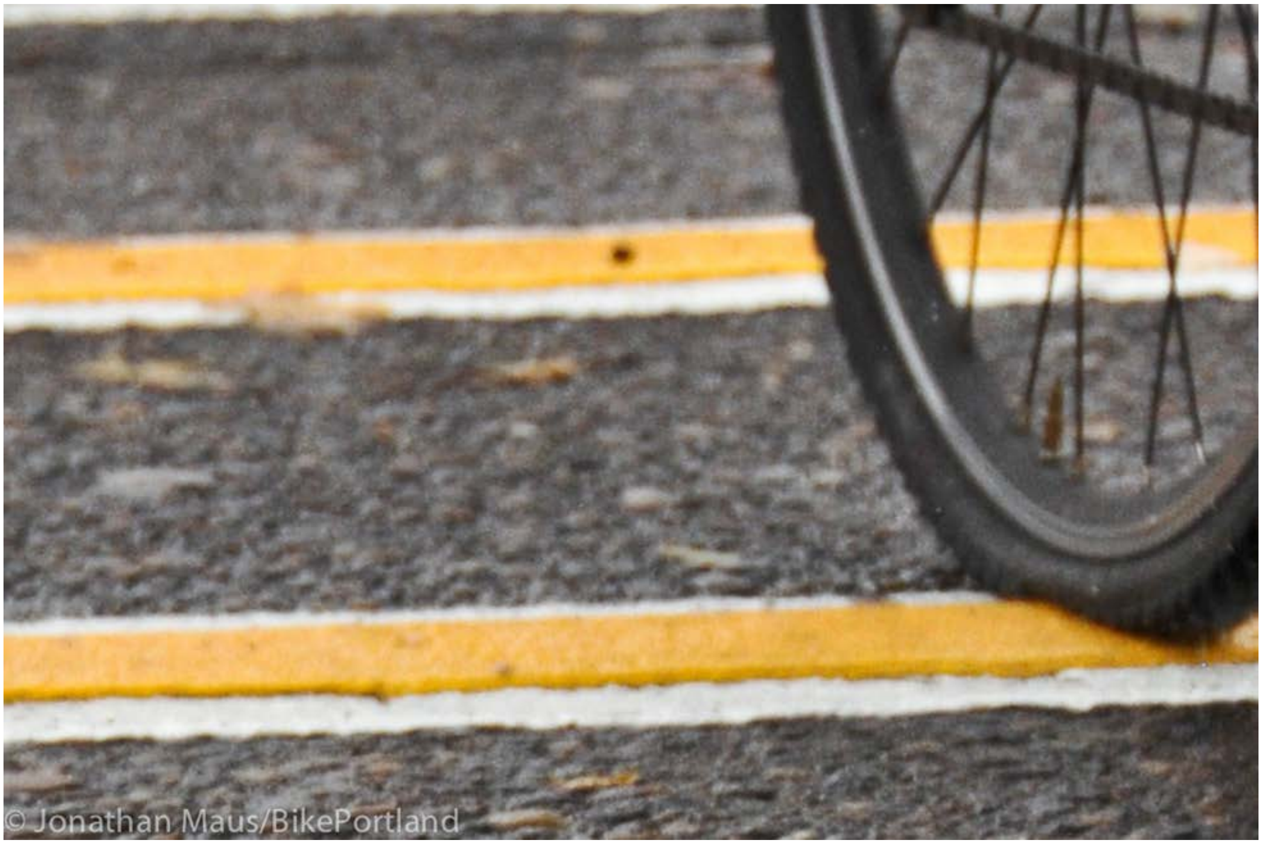


Figure 5.22: Rumble Strips (Maus, 2013)

5.2.2.10 Speed Bump

Speed bumps are another variation of a traffic calming method typically used for vehicles. A speed bump's design differs from that of a speed hump in that it is more severe and aggressive in slowing down vehicles. "A speed bump is also a raised pavement area across a roadway. Speed bumps are typically found on private roadways and parking lots and do not tend to exhibit consistent design parameters from one installation to another. Speed bumps generally have a height of 3 to 6 inches (76 to 152 mm) with a travel length of 1 to 3 feet (0.3 to 1 m)" (Parkhill, Sooklall, & Bahar, N/A). The presence of speed bumps negatively affects emergency vehicles and their time sensitive demands. Speed bumps are not conducive to snowplows or other maintenance vehicles as well and can have weather constraints. Like speed humps, speed bumps in the vehicular context also increase fuel usage and consequently emit more CO_2 and pollutants due to the acceleration and breaking nature of vehicles around them. This however, may be irrelevant if speed bumps are to be repurposed for pedestrian/bike paths. Note that speed bumps could be considered a nuisance and may impair the quality of experience that path users have, possibly leading to treatment avoidance, and it may also pose a challenge for ADA accessibility. Speeds bumps that are implemented for vehicles must be paired with a “Speed Bump” sign, which is included in the MUTCD as Fig. W17-1, but would be written as “Speed Bump” and not “Speed Hump (Moeur, n.d.). Speeds bumps can be implemented in a series to increase speed control. Speed bumps can cost between $540 - $2,300 (Bushell, Poole, Zeeger, & Rodriguez, 2013).

Figure 5.23: Speed Bump (Lakey, NA)

5.2.2.11 Bicycle Speed Humps

This is a traffic calming measure associated with cars, however, this concept can be applied to a path in order to decrease the speed of cyclists as they approach an intersection. The speed humps must consider the speed of the cyclist and topography unique to the site before implementation.

The speed hump can reduce the cyclist's speed near the intersection, and therefore may improve behavior for all road users. According to the Minnesota Department of Transit's Bikeway Facility Design Manual, the general bicycle design speed of 20 mph is desirable on a shared-use path. Bicycle speed humps are not a common treatment option used in the United States; however, European cities such as Groningen have implemented these methods to slow down cyclists and mopeds. According to ITE's recommended practice for vehicles, "A speed hump is a raised area in the roadway pavement surface extending transversely across the travel way. Speed humps are sometimes referred to as "pavement undulations" or "sleeping policemen". Most agencies implement speed humps with a height of 3 to 3.5 inches (76 to 90 mm) and a travel length of 12 to 14 feet (3.7 to 4.3 m). Speed humps are generally used on residential local streets" (Parkhill, Sooklall, & Bahar, N/A). The presence of speed humps negatively affects emergency vehicles and their time sensitive demands. Speed humps are not conducive to snowplows as well and can have weather constraints. Speed humps in the vehicular context also increase fuel usage and consequently emits more CO2 and pollutants due to the acceleration and breaking nature around them. This however, may be irrelevant if speed humps are to be repurposed for pedestrian/bike paths. Note that speed humps could be considered a nuisance and may impair the quality of experience that path users have and it may also pose a challenge for ADA accessibility. Speeds humps that are implemented for vehicles must be paired with a "Speed Hump" sign, which is included in the MUTCD as Fig. W17-1 (Moeur, n.d.). Speeds humps can be implement in a series to increase speed control. According to research conducted in Seattle of vehicle speeds before and after the implementation of speed humps, researchers found that speeds reduced by between 79%-88% (Fucoloro, 2014). The National Association of City Transportation Officials note that that speed humps reduce vehicle speeds to 15-20 mph. Speed humps for vehicles cost an average of $7,500, but can range between $540 - $7,500 (Bushell, Poole, Zeeger, & Rodriguez, 2013) & (Markon, 2008).

Figure 5.24: Bicycle Speed Hump (Zach, 2011)

5.2.2.12 Speed Kidney

This is a traffic calming measure to reduce vehicle speed and road volume and to ultimately improve road use and behavior. A speed kidney consists of two main speed humps that straddle a center complementary speed hump. The speed kidney is typically used for vehicles; however, it is possible to adapt this for cyclists on a path. The design has been carefully constructed to encourage vehicle drivers to slow down and curve along the road to avoid discomfort by having any wheels interact with the humps. The design of the speed kidney does a good job serving various path users and does not obstruct the path for any particular path user. This treatment option can be customized to be ADA accessible.

In a long-term study of the efficacy of speed kidneys implemented in Spain, researchers found that 70% of vehicles followed the curve path encouraged by the speed kidney design and therefore reduced their speeds (Garcia, Moreno, & Romero, 2012). Cost of a speed kidney is ranges between $3,000 - $7,000 (Bushell, Poole, Zeeger, & Rodriguez, 2013). This estimate is based off of the cost of speed bumps, humps, and tables.

Figure 5.25: Speed Kidney (Garcia, Alfredo, N/A)

5.2.2.13 Speed Cushion

A speed cushion is an iteration of a speed table, but differs from it in that it has wide gaps between them to allow for emergency, maintenance, or larger vehicles to traverse them by straddling the speed cushion. According to NACTO, speed cushions are preferred on emergency routes for this reason.

Speed cushions are typically placed in the center of a lane and also placed at the center of where two-way streets join. The size of them can vary, however, to differentiate speed cushions from speed tables, hump, and bumps, speed cushion is 6’x10’ and reach a maximum of 3.25’’ in height (Johnson & Nedzesky, N/A). Two short traffic study surveys were conducted in Berkeley, CA in 2008 to study the effects of speed cushions placed on two streets. Two 24-hour studies showed that “on average, both locations experienced a drop in the 85th percentile speed in the range of 12-14%,” but there was not a reduction in traffic volume (City of Berkeley, 2009). A study from 2003 in Washington DC examining various speed calming treatments placed speed cushion in 2 of 10 chosen locations. Both locations where speed cushions were installed had a posted speed limit of 25 mph. The average speed was 10.1 mph and the 85th percentile speed was 12.6 mph. Below is an informative table on the various vehicle types and their interactions with speed cushions from this study (Johnson & Nedzesky, N/A).

Table 6. Lateral Placement of Vehicles by Vehicle Type for Speed Cushions.

Vehicle Type	Number of Observations	Lateral Placement			
		Center	Over Centerline	Left Tire in Groove	Towards Right, Right Tires in Slot
Passenger Cars	246	39.0	12.2	39.0	9.8
Luxury and High Performance	64	32.8	10.9	53.1	3.1
Pick-up trucks	27	44.4	22.2	25.9	7.4
SUVs and Minivans	103	40.8	8.7	42.7	7.8
Trucks	0	0.0	0.0	0.0	0.0
Buses	0	0.0	0.0	0.0	0.0
Other, (e.g., service vans)	9	33.3	22.2	33.3	11.1

Figure 5.26: Table of vehicle types and their interactions with speed cushions (Johnson & Nedzesky, N/A)

Many of the studies observed that speed cushions caused treatment avoidance and therefore, undesired road conditions. In an attempt to avoid the speed cushion and get their wheels in the pockets between speed cushions, drivers would drift between lanes. They may also cause noise pollution and obstruct the road for snowplows or other maintenance vehicles. Note that speed tables must be paired with a "Speed Cushion" sign to alert path users or road users of its presence, which is included in the MUTCD as Fig. W17-1. Speed Cushions cost an average of $2,800 to install (City of Phoenix, N/A).

Figure 5.27: Speed Cushion (Drdul, 2006)

5.2.2.14 Speed Table

Speed tables are another traffic calming method that is ideally implemented in zones with streets operating at a speed between 25-45 mph. "Speed tables are essentially flat-topped speed humps, and may have a textured material on the flat section with asphalt or concrete for the approaches. Speed tables are sometimes referred to as "trapezoidal humps" or "speed platforms". If marked as a pedestrian crossing, speed tables may also be referred to as "raised crosswalks" or "raised crossings" (NACTO, N/A).

Most agencies implement speed tables with a height of 3 to 3.5 inches (76 to 90 mm) and a travel length of 22 feet (6.7 m). Speed tables generally consist of 10-foot (3.1 m) plateau with 6-foot (1.8 m) approaches on either side that can be straight, parabolic or sinusoidal in profile. The longer lengths of speed tables provide a gentler ride than speed humps and generally result in vehicle operating speeds ranging from 25 to 30 mph (40 to 48 km/h) on streets depending on the spacing between speed tables. Speed tables are generally used on residential collectors, emergency routes or transit routes.

The City of Portland, OR has designed "split" speed tables for designated emergency routes. Split speed tables are also 22 feet (6.7 m) long and extend from curb to centerline on opposite sides of the street. Split speed tables are separated by a longitudinal gap that allows fire trucks to weave around the split speed humps in slalom-like fashion" (Parkhill, Sooklall, & Bahar, N/A). Speed tables may be implemented in emergency respond routes, but could be inconvenient for larger vehicles and cause delays. They may also cause noise pollution and obstruct the road for snowplows and other maintenance vehicles. Note that speed tables must be paired with a "Speed Table" sign to alert path users or road users of its presence, which is included in the MUTCD as Fig. W17-1.

Depending on the materials used and drainage features, speed tables can cost between $5,000 – $15,000 (FHWA, N/A).

Figure 5.28: Speed Table (Lloydminster.ca, 2017)

5.2.2.15 Grades/Hill

Grades on paths can be added to create an incline for cyclists and pedestrians and to effectively decrease their speed as they are forced to go uphill.

The Minnesota Department of Transit, Bikeway Facility Design Manual outlines the following variables a designer must consider when adding a grade to a path: length of the grade, wind velocity, and surface conditions (pavement type, friction levels, and other similar site-specific considerations). The Manual makes a great point that in order for the gradient to be desired and effective, the resulting downhill speed must be considered to ensure a low-risk environment and control for cyclists.

The Minnesota Department of Transit, Bikeway Facility Design Manual also outlines the various grade levels and how they complement population demographics. For example, "grades in excess of 8.3 percent (12:1) exceeds ADA Accessibility Guidelines for pedestrian facilities and should be avoided on shared-use paths unless significant physical constraints exist. Where local State-Aid Route Standards apply, the maximum allowable grade is 8.3 percent" (Lai-Nelson, 2007).

One should refer directly to the ADA Accessibility Guidelines (ADAAG) to better understand if the proposed design of a gradient or hill conflicts with any standing ADAAG rules or regulations. " Section 4.5 Ground and Floor Surfaces" of ADAAG outlines the rules and regulations affiliated with changes in floor levels. " Section 10 Transportation Facilities" provides further details about the design and requirements associated with transportation facilities (United States Access Board, 2002).

Note that the grade/hill should not be unreasonably steep and should not deter cyclists from riding up it or force a majority of users to walk their bicycle uphill. No additional information or data on its efficacy.

5.2.2.16 Curves

Curves can be added to a path to reduce the speed of cyclists. Calculations for site-specific conditions can inform designers what the maximum lean angle can be for a cyclist. No additional information or data on its efficacy.

5.2.2.17 Raised Crosswalk

A raised crosswalk complements typical crosswalk pavement design treatments and methods. A raised crosswalk is another variation of the crosswalk that simply elevates pedestrians and cyclists to the height of the vehicle driver and improves visibility for motorists. It also serves as a speed table for vehicles.

This treatment option is appropriate for low-speed streets that are not a main corridor for emergency vehicles. The raised crosswalk would mimic a large speed bump for emergency vehicles, and this would not be desirable. In case studies of raised crosswalks across the United States, it was found that each raised crosswalk site had a reduction of the 85th percentile traffic speeds. It is interesting to note that there were some drivers who wanted to avoid this raised crosswalk and found other routes – this rerouting may increase congestion and have poor consequences on neighboring arterials. Overall, research has found that raised crosswalks do help lower vehicle speeds (Huang & Cynecki, The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior, 2001). Costs range from $1,500 to $30,000 with an average cost of approximately $8,200 (Bushell, Poole, Zeeger, & Rodriguez, 2013).

5.2.2.18 Bollards

A bollard is a simple, yet effective engineering tool that can be placed on a path near a road intersection to keep vehicles separate from cyclists and pedestrians.

Bollards are used to discourage vehicle drivers from misusing space allocated to cyclists and pedestrians. Bollards can have a range of physical forms (permanent, rising, removable, planters, security, etc.), but they all serve the same function of separating cyclists and pedestrians from vehicles. The cost to implement and maintain the bollards depends on the type of bollard design chosen. However, according to Costs for Pedestrian and Bicyclist Infrastructure Improvements (2013), bollards cost an average of $730.00. No additional information or data on its efficacy.

Figure 5.29: Bollards used to keep vehicles from entering, (N/A, N/A)

5.2.2.19 Bicycle Rail or Lean Rail

This is a simple design concept that encourages cyclists to adhere to traffic laws by creating comfortable rest space. Rails have been designed and implemented in major biking cities such as Copenhagen and Seattle. It is a low-cost amenity that facilitates low-risk road or path behavior. Construction, labor, and materials for one rail cost about $2,000 (Cohen, 2015). No additional information on its efficacy.

Figure 5.30: Bicycle Lean Rail, (Colville-Andersen, Mikael, 2010)

Figure 5.31: Lighting to illuminate railroad tracks and path, (N/A, N/A)

5.2.2.20 Mirrors

Strategic placement of convex mirrors along at rail grade crossings increases visibility and can warn pedestrians and cyclists of an approaching train in advance. This is a low cost and low maintenance treatment that can range between $40-$150 (ULINE, n.d.).

Though this treatment is not common in the United States, it can be repurposed and be applied to paths to increase awareness and visibility of oncoming vehicles or trains for path users.

No additional information or data on its efficacy.

Figure 5.32: Mirror (Phungprachit, N/A)

5.2.2.21 Pedestrian Refuge

This treatment is a designated low-risk waiting zone for pedestrians and bicyclists. This is a relatively low-cost treatment. Costs are site specific. According to the Road Safety Toolkit, this treatment is only 25-40% effective (Road Safety Toolkit, N/A). No additional information or data on its efficacy.

5.2.2.22 Channelization (Paving Delineation)

Adding median barriers to the road or to pedestrian crossings deter risky driving behavior by increasing compliance to the active and passive warning signs present at the railroad crossing. Median crossings are an affordable way to reduce grade crossing collisions.

Wide raised medians can include landscape to add to the built environment and can also accommodate snowplows. Raised medians also serve as a traffic calming measure, forcing drivers to slow down and stay alert. Various case studies by the Massachusetts Bay Transportation Authority, University of Nebraska, Lincoln, Washington State Department of Transportation, and University of Florida showed a significant decrease of railroad violations due to traffic channelization devices. On average, these case studies showed a 68% reduction rate of highway-rail grade crossings (Horton, 2012). A median barrier costs approximately $14,000 to install (Horton, 2012).

5.2.2.23 Channelization (Z-Crossing/Offset Pedestrian Crossing/Barrier/Fence)

Fencing is placed around the track to guide pedestrians and cyclists through a preferred travel pathway. The design of the channelization also forces pedestrians to look into the direction of oncoming trains and the action of opening the gate slows down movement. It is also recommended that the gate be opened towards the user so as to prevent a scenario where a pedestrian is trapped by the swing gate. It is important to note that Z-crossings cannot be applied at two-way single tracks. Placement of channelization must be strategic since a fence cannot feasibly extend and follow all railroads in the United States. Fencing is expensive to install and maintain.

Figure 5.33: Channelization, (Korve, Hans W. , Jose I. Farran, Douglas M. Mansel, et al., 1996)

5.2.2.24 Manual Gates/Pedestrian Swing Gates

Physical gates which pedestrian or cyclists must manually open and shut to access the railroad crossing. This treatment is intended to slow down nonautomotive traffic and therefore increase awareness of crossing. It is recommended that this be a kick gate so that it is also ADA accessible. No additional information or data on its efficacy.

Figure 5.34: Pedestrian Manual Gates, (Korve, Hans W. , Jose I. Farran, Douglas M. Mansel, et al., 1996)

5.2.2.25 Pedestrian Over-Crossing or Under-Crossing

In high pedestrian traffic railroad crossings, adding an over-cross or under-cross may be desirable. It removes pedestrians and cyclists from the dangers of railroad crossings completely. The crossing must be well lit and ADA accessible. Pedestrian over-crossings cost between $2-8 million and under-crossings cost $2-$4 million (Miami-Dade MPO, 2013).

Case studies show that separate pedestrian or cyclist infrastructure such as bridges is desirable. There is a high compliance rate to utilize the bridge if it allows the individual to cross within a similar time frame as crossing directly through the tracks (USDOT - FHWA, n.d.).

5.2.2.26 Quick/Temporary Curb

This is a quick and temporary treatment option to channel pedestrians and bicyclists through a designated low-risk path. This can be especially useful at LRT pedestrian crossings during large city events such as a game day. This is a popular low cost way for cities to temporarily control and restrict vehicle, pedestrian, or bicycle movements. No additional information or data on its efficacy.

Figure 5.35: Temporary Curb, (N/A, N/A)

5.2.2.27 Pedestrian Crossing Flags

Various cities in the United States such as Seattle, Berkeley, Kirkland, Salt Lake City, Bridgeport, and St. Paul have deployed this low-tech crossing device to increase awareness and visibility of pedestrians crossing. The idea behind the pedestrian crossing flag is that motorists are more likely to see and yield pedestrians that are carrying a bright flag. Two holders flank either side of a crossing, and a pedestrian is to pick up and wave the flag as they are crossing and place it back in the holder after completing their crossing.

However, different cities have had different levels of success with the pedestrian flag program. Berkeley invested about $18,000 into purchasing, replacing, and placing flags in their city. However, they found that only 2% of pedestrians used it and it did not completely omit the possibility of a crash occurring. Therefore, Berkeley decided to pull the program and pedestrian flags are no longer offered at crossings. On the contrary, planners in McCall, Idaho found the pedestrian flag program to be successful and that it suits their concerns well. Theft is a nuisance and can implode the pedestrian flag program by increasing costs and depleting flags at crossing stations. Field studies included in Improving Pedestrian Safety at Unsignalized Crossings (2006) found that "sites with crossing flags had motorist yielding rates that ranged from 46 to 79 percent, with an average of 65 percent compliance". The flags are not costly. According to a few articles, it generally costs $4.00/flag.

6.0 GUIDEBOOK FOR PATH TREATMENTS

This section presents the guidebook that was developed based on the previous sections, which can be used to simply and uniformly select appropriate treatments at a rail/highway/path crossing. For examples of application of this guidebook to the seven study sites described in Chapter 3.0, please refer to Appendix D.

6.1 EXAMINE EXISTING CROSSING AND PATH DATA

6.1.1 General Information

City in or Near: Click here to enter text.

Cross Street: Click here to enter text.

Is the crossing illuminated? ☐ Yes ☐ No

(Street lights within 50 feet from nearest rail)

Are there any Schools within .5 miles of Crossing? ☐ Yes ☐ No

Name: Click here to enter text.
Type of Institution: Click here to enter text.
Address: Click here to enter text.
Distance from Crossing: Click here to enter text.

Are there any Transit Stops within 500 ft. of Crossing? ☐ Yes ☐ No

Type: Click here to enter text.
Usage Frequency: Click here to enter text.
Distance from Crossing: Click here to enter text.

What type of development is within 1000 feet of Crossing? *(Check all that apply)*

☐ Open Space (sparsely developed, lightly populated, and/or agricultural)

☐ Residential (single family or multi-family residential area)

☐ Commercial (retail stores, businesses, offices, and/or personal services)

☐ Industrial (manufacturing, construction, factories, and/or warehouses)

☐ Institutional (schools, churches, hospitals, parks, and/or community facilities)

☐ Other: Click here to enter text.

6.1.2 Railroad Information

Transit, Branch, or Line Name: Click here to enter text.

Type of Service: ☐ Heavy Rail ☐ Light Rail

Average Train Count per Day: Click here to enter text.

Speed of Train at Crossing: Click here to enter text.

Of Tracks: Click here to enter text.

Is an adjacent at-grade railroad crossing located within .5 mile of this crossing? ☐ Yes ☐ No

(If yes, complete this form for that crossing)

Describe the sight distance conditions:

Click here to enter text.

Would you say the sight distance is: ☐ Unrestricted ☐ Semiblind ☐ Blind

(At this point, the sight distance conditions should be estimated to best of ability. If it is decided to progress to a field inspection or observation, the sight distance is measured using the AASHTO Green Book approach)

6.1.3 Highway Crossing Information

Average Annual Daily Traffic (Year): Click here to enter text. (Click here to enter text.)

Comments: Click here to enter text.

AADT Data Source: ☐ Count ☐ Estimate ☐ Other ☐ Unknown

Is there high pedestrian volumes on the highway at any time during the day? ☐ Yes ☐ No

Is there high bicycle volumes on the highway at any time during the day?☐ Yes ☐ No

**Please refer to Appendix B to calculate high pedestrian and bicycle volumes.*

Vehicle Speed: Click here to enter text. Mph ☐ Posted ☐ Statutory

Vehicle Type: Click here to enter text.

(Truck, Hazardous Materials, School bus, other)

Type of Warning Devices at Highway:

☐ None

☐ Stop Sign (R1-1)

☐ Yield Sign (R1-2)

☐ Emergency Notification Sign (I-13)

☐ Crossbucks (R15-1)

☐ Other Signs, which: Click here to enter text.

☐ RR Advance Warning Sign (W10-1)

☐ Stop Line

☐ Grade Crossing Pavement Marking (MUTCD 8B-7)

☐ Automatic Gates

☐ Flashing Lights

☐ Audible Device

☐ Traffic Lights

☐ Other: Click here to enter text.

6.1.4 Path/Trail Information

What is the distance between the path/trail and the nearest rail in ft.? Click here to enter text.

(This includes all forms of sidewalks, trails and paths that can be used by any kind of non-vehicular traffic)

Type of Infrastructure: ☐ Sidewalk ☐ Multi-Use Path/Trail

Primary Function: ☐ Recreational ☐ Commute ☐ Both

(This may be hard to determine but the most apparent primary function should be estimated to the best of ability, to inform further decision making, if the function is known)

Is there high pedestrian volumes on the path at any time during the day? ☐ Yes ☐ No

Is there high bicycle volumes on the path at any time during the day? ☐ Yes ☐ No

Type of Warning Devices and Treatments at the Path Crossing

☐ No Path Crossing

☐ None

☐ Stop Sign

☐ Stop Line

☐ Yield Sign

☐ Pavement Markings in Crossing

☐ Marked Crosswalk

☐ Shark Teeth

☐ Barrier/Fencing/Delineation

☐ HAWK Beacons

☐ Rectangular Rapid Flashing Beacon (RRFB)

☐ Other: Click here to enter text.

6.2 INDENTIFY PRIMARY ISSUES

The primary issues at the crossing in question should be identified during the course of the field visit or observation. It is recommended to select between 2 and 4 issues to address. For a full description of the primary issues and their selection, please refer to the Research Report SPR-794.

6.2.1 The Built Environment

☐ **Speed**: The posted speed limits are too high for the intended road utilization and type.
Comment: Click here to enter text.

☐ **Vertical Crossing design**: The railroad tracks are elevated such that it makes drivers focus more on traversing the tracks which ultimately decreases visibility of other road users.

Comment: Click here to enter text.

☐ **Horizontal Crossing Design**: The path and the railroad tracks are inappropriately distanced.
Comment: Click here to enter text.

☐ **Stop line**: The distance between the stop line and the tracks, and/or the stop line and the stop line of the opposite direction, and/or the stop line and the path is inappropriate
Comment: *Click here to enter text.*

☐ **Insufficient Crossing Infrastructure**: Pedestrians are not accommodated through shortest path routing, and therefore choose shortcuts to decrease their travel distance. This includes cutting across areas that are not intended for pedestrians, crossing diagonally, crossing on a track platform, walking on property and generally bolt across in order to minimize their travel path, even if reasonable accommodation is available.
Comment: *Click here to enter text.*

☐ **Transit stop**: Transit stops are located too close to the railroad crossing.
Comment: *Click here to enter text.*

☐ **Road/Street Infrastructure**: Lack of grade separation or other form of structure between e.g. the road and the sidewalk can lead to cars unintentionally driving on the sidewalk area, which can be high-risk zones for non-vehicular users.
Comment: *Click here to enter text.*

☐ **Visibility**: Inadequate visibility due to vegetation, buildings or lack of street light.
Comment: *Click here to enter text.*

6.2.2 Lack of Path User Information

☐ **Speed**: The layout and general use of a multi-use path leads to high bike speeds. Bikes may especially be likely to proceed through a crossing when already traveling at a high-speed, especially if on a primarily commuter-oriented path.
Comment: *Click here to enter text.*

☐ **Signage**: There is a lack of adequate signage for bikes and pedestrians surrounding the crossing.
Comment: Click here to enter text.

☐ **Non-compliance**: There is a high non-compliance rate of existing treatments and a lack of consequences for non-compliance.
Comment: *Click here to enter text.*

6.2.3 Lack of Driver Information

☐ **Negotiation**: If a railroad crossing is inappropriately spaced from a path, the driver will often treat both locations as two separate crossings, and this separation affects how they negotiate each crossing as two different obstacles, as opposed to one complex crossing. It is for this reason that crossings are generally not placed at curves, as this distracts the driver from paying adequate attention to both the railroad crossing and the curve.
Comment: Click here to enter text.

☐ **Vehicle Speed**: The actual speeds are too high both compared to posted speed limits and for the intended road utilization and type.
Comment: Click here to enter text.

☐ **Signage**: There is a lack of adequate signage to inform drivers of upcoming obstacles or attributes of the road. This is both pertaining to the railroad crossing itself, but especially to the path-layout and the possibility of encountering pedestrians/cyclists.
Comment: Click here to enter text.

6.3 INVOLVE STAKEHOLDERS AND PARTNERS

After Step, I and II are completed and all existing data is gathered the primary partners and the stakeholders should be informed, that work is being done to investigate the improvement of an at-grade crossing.

6.4 IDENTIFY EVALUATION CRITERIA

The selection of criteria depends on the issues that has been identified in the previous section of the Guidebook. For more guidance, please refer to Research Report SPR 794.

6.4.1 Selected Criteria

For the railroad crossing in question, the following criteria were selected *(Mark all that apply)*:

☐ Cost
☐ Average Vehicle Delay

☐ Average Pedestrian Delay

☐ Average Bicycle Delay
☐ Sight Distance
    ☐ **Alternate:** Sight Distance
☐ Vehicles Stopping on Tracks
    ☐ **Alternate:** Vehicles Stopping on Tracks
☐ Vehicles Running Red Lights or Active Gates
    ☐ **Alternate:** Vehicles Running Red Lights or Active Gates
☐ Undesired Behavior: Pedestrians, Bikes and Other Non-Vehicular
    ☐ **Alternate:** Undesired Behavior: Pedestrians, Bikes and Other Non-Vehicular
☐ General Observations
    ☐ Neighborhood Impact
    ☐ Impact on Trail/Shared-Path Use
    ☐ Treatment Familiarity

Comments

Comments pertaining to the chosen solution, the measured outcomes etc. can be added in this section:

Click here to enter text.

6.5 DETERMINE TREATMENTS

6.5.1 Heavy Rail Locations

The following treatments are suggested for crossings served by heavy rail, depending on the primary issues identified in Step 2.

Table 6.1: Treatments for Identified Issues at Heavy Rail Locations

	CROSSINGS NOT NEAR SCHOOLS		**CROSSINGS NEAR SCHOOLS**	
The Built Environment	Primary Recommendation	Secondary Recommendation(s)	Primary Recommendation	Secondary Recommendation(s)
☐ Speed	☐ Lower Posted Speed Limits	☐ Ensure that Speed Limits are Posted and Visible	☐ Include Crossing Area in School Zone	☐ Lower Posted Speed Limits *or* ☐ Ensure that Speed Limits are Posted and Visible
☐ Vertical Crossing Design	☐ Add Signage	☐ Install RRFBs	☐ Raised Crosswalks	☐ Install Automatic RRFBs
☐ Horizontal Crossing Design	☐ Move Path Closer to or Further Away From Railroad Tracks	☐ Signage *or* ☐ Variable Message Signs	☐ Move Path Closer to or Further Away From Railroad Tracks *or* ☐ Install RRFBs	☐ Install Automatic RRFBs *or* ☐ Install Traffic Lights
☐ Stop Line	☐ Move Stop Line Closer to Railroad Tracks	☐ Raised Crosswalk	☐ Move Stop Line Closer to Railroad Tracks *or* ☐ Raised Crosswalk	☐ Raised Crosswalk *and* ☐ Dynamic Enveloping *and* ☐ Conflict Paint
☐ Insufficient Crossing Infrastructure	☐ Add Signage *and* ☐ Supply Crossing Options	☐ Dynamic Enveloping	☐ Pedestrian Refuge *or* ☐ Install	☐ Raised Crosswalk *and* ☐ Dynamic

	and ☐ Add Pavement Markings *or* ☐ Relocate Crossing *and* ☐ Add Pavement Markings		RRFBs	Enveloping *and* ☐ Conflict Paint *or* ☐ Overcrossing *or* ☐ Undercrossing
☐ Transit Stop	☐ Move Stop *or* ☐ Eliminate Stop	Refer to Insufficient Crossing Infrastructure	☐ Move Stop *or* ☐ Eliminate Stop	Refer to Insufficient Crossing Infrastructure
☐ Road/Street Infrastructure	☐ Implement Physical Separation *or* ☐ Quick Curb	☐ Pavement Markings *or* ☐ Marked Crosswalk	☐ Implement Physical Separation *or* ☐ Quick Curb	☐ Raised Crosswalk *or* ☐ Bollards *or* ☐ Fencing
☐ Visibility	☐ Add Signage	Refer to Horizontal Crossing Design *or* ☐ Maintenance of Vegetation *or* ☐ Add Street Lights	☐ Add Signage *and* Refer to Horizontal Crossing Design	☐ Maintenance of Vegetation *or* ☐ Add Street Lights
Lack of Path User Information	Primary Recommendation	Secondary Recommendation(s)	Primary Recommendation	Secondary Recommendation(s)
☐ Speed	☐ Speed Treatment	☐ Add Signage	☐ Speed Treatment	☐ Obstructions
☐ Signage	☐ Add Signage	☐ Tactile Warning Surfaces	☐ Add Signage *or* ☐ Variable Message Signs	☐ In-Pavement Marker *or* ☐ Automatic RRFBs
☐ Non-Compliance	☐ Obstructions *or* ☐ Variable Signs	Refer to Insufficient Crossing Infrastructure	☐ Obstructions *or* ☐ Educational Initiatives *and* ☐ Variable Signs	Refer to Insufficient Crossing Infrastructure

Lack of Driver Information	Primary Recommendation	Secondary Recommendation(s)	Primary Recommendation	Secondary Recommendation(s)
☐ Negotiation	☐ Dynamic Enveloping *and* ☐ Conflict Paint	☐ Signage *or* ☐ Traffic Lights	☐ Raised Crosswalks *and* ☐ Dynamic Enveloping *and* ☐ Conflict Paint	☐ RRFBs *or* ☐ Automatic RRFBs *or* ☐ Traffic Lights
☐ Vehicle Speed	☐ Speed Treatment *or* ☐ HAWKS *or* ☐ RRFBs	☐ Conflict Paint *and* ☐ Dynamic Enveloping	☐ Speed Treatment *and* ☐ In-Pavement Marker *or* ☐ HAWKs *or* ☐ RRFBs	☐ Active Speed Sign
☐ Signage	☐ Add Signage *or* ☐ Add Pavement Markings	Refer to Insufficient Crossing Infrastructure	☐ Add Signage *or* ☐ Add Pavement Markings *and* Refer to Insufficient Crossing Infrastructure	☐ Speed Treatments *or* ☐ In-Pavement Markings *or* ☐ RRFBs

6.5.2 Light Rail Locations

The following treatments are suggested for crossings served by light rail, depending on the primary issues identified in Step 2.

Table 6.2: Treatments for Identified Issues at Light Rail Locations

	CROSSINGS NOT NEAR SCHOOLS		**CROSSINGS NEAR SCHOOLS**	
The Built Environment	Primary Recommendation	Secondary Recommendation(s)	Primary Recommendation	Secondary Recommendation(s)
☐ Speed	☐ Lower Posted Speed Limits	☐ Ensure that Speed Limits are Posted and Visible	☐ Include Crossing Area in School Zone *and* ☐ Install Active Speed Signs	☐ Lower Posted Speed Limits *or* ☐ Ensure that Speed Limits are Posted and Visible
☐ Vertical Crossing Design	☐ Add Signage	☐ Install RRFBs	☐ Automatic RRFBs	☐ Raised Crosswalks
☐ Horizontal Crossing Design	☐ Move Path Closer to Railroad Tracks	☐ Signage *or* ☐ Variable Message Signs	☐ Move Path Closer to Railroad Tracks ☐ Install Automatic RRFBs	☐ Install Automatic RRFBs *or* ☐ Traffic Lights
☐ Stop Line	☐ Move Stop Line Closer to Railroad Tracks	☐ Raised Crosswalk	☐ Move Stop Line Closer to Railroad Tracks *or* ☐ Raised Crosswalk	☐ Raised Crosswalk *and* ☐ Dynamic Enveloping *and* ☐ Conflict Paint
☐ Insufficient Crossing Infrastructure	☐ Add Signage *and* ☐ Supply Crossing Options *and* ☐ Add Pavement Markings *or* ☐ Relocate Crossing *and* ☐ Add Pavement	☐ Dynamic Enveloping	☐ Install Pedestrian Refuge *or* ☐ Install RRFBs	☐ Raised Crosswalk *and* ☐ Dynamic Enveloping *and* ☐ Conflict Paint *or* ☐ Overcrossing *or* ☐ Undercrossing

	Markings			
☐ Transit Stop	☐ Move Stop *or* ☐ Eliminate Stop	Refer to Insufficient Crossing Infrastructure	☐ Move Stop *or* ☐ Eliminate Stop	Refer to Insufficient Crossing Infrastructure
☐ Road/Street Infrastructure	☐ Implement Physical Separation *or* ☐ Quick Curb	☐ Pavement Markings *or* ☐ Marked Crosswalk	☐ Implement Physical Separation *or* ☐ Quick Curb	☐ Raised Crosswalk *or* ☐ Bollards *or* ☐ Fencing
☐ Visibility	☐ Add Signage	Refer to Horizontal Crossing Design *or* ☐ Maintenance of Vegetation *or* ☐ Add Street Lights	☐ Add Signage *and* Refer to Horizontal Crossing Design	☐ Maintenance of Vegetation *or* ☐ Add Street Lights
Lack of Path User Information	Primary Recommendation	Secondary Recommendation(s)	Primary Recommendation	Secondary Recommendation(s)
☐ Speed	☐ Speed Treatment	☐ Add Signage	☐ Speed Treatment	☐ Obstructions
☐ Signage	☐ Add Signage	☐ Tactile Warning Surfaces	☐ Add Signage *or* ☐ Variable Message Signs	☐ In-Pavement Marker *or* ☐ Automatic RRFBs
☐ Non-Compliance	☐ Obstructions *or* ☐ Variable Signs	Refer to Insufficient Crossing Infrastructure	☐ Obstructions *or* ☐ Educational Initiatives *and* ☐ Variable Signs	Refer to Insufficient Crossing Infrastructure
Lack of Driver Information	Primary Recommendation	Secondary Recommendation(s)	Primary Recommendation	Secondary Recommendation(s)
☐ Negotiation	☐ Dynamic Enveloping *and* ☐ Conflict Paint	☐ Signage *and* ☐ Traffic Lights	☐ Raised Crosswalks *and* ☐ Dynamic	☐ RRFB *or* ☐ Automatic RRFBs

			Enveloping *and* ☐ Conflict Paint	*or* ☐ Traffic Lights
☐ Vehicle Speed	☐ Speed Treatment *or* ☐ HAWKS *or* ☐ RRFB	☐ Conflict Paint *and* ☐ Dynamic Enveloping	☐ Speed Treatments *and* ☐ In-Pavement Marker *or* ☐ HAWK *or* ☐ RRFB	☐ Active Speed Sign *or* ☐ HAWK *or* ☐ RRFB
☐ Signage	☐ Add Signage *or* ☐ Add Pavement Markings	Refer to Insufficient Crossing Infrastructure	☐ Add Signage *or* ☐ Add Pavement Markings *and* Refer to Insufficient Crossing Infrastructure	☐ Speed Treatments *or* ☐ In-Pavement Markings *or* ☐ RRFBs

6.6 SELECTED TREATMENTS

Use the following section to enter the treatments selected from the previous table.

Identified Issue 1: Click here to enter text.

Selected Treatment 1: Click here to enter text.

Selected Treatment 2: Click here to enter text.

Selected Treatment 3: Click here to enter text.

Identified Issue 2: Click here to enter text.

Selected Treatment 1: Click here to enter text.

Selected Treatment 2: Click here to enter text.

Selected Treatment 3: Click here to enter text.

Identified Issue 3: Click here to enter text.

Selected Treatment 1: Click here to enter text.

Selected Treatment 2: Click here to enter text.

Selected Treatment 3: Click here to enter text.

Comments

Comments pertaining to the chosen solution, the measured outcomes etc. can be added in this section:

Click here to enter text.

6.7 DETERMINE BUDGET AND RELATIVE COST

The cost are separated into two categories in the below tables. The first table contains costs that needs to be included in the budget, no matter which solution or treatment is chosen (except for No Treatment). The second table contains the relative cost estimate of the different options that can be chosen from. The railroad operating the crossing in question should be closely involved with completing cost estimates.

Table 6.3: Relative Project Costs

Task	Relative Cost Estimate
Project Scoping	$-$$
Environmental (NEPA) Compliance	$-$$
Design	$-$$
Mobilization and Administration	$-$$
Basic Annual Maintenance	$

$: <$25,000 $$: $25,000-$250,000 $$$: >$250,000

Table 6.4: Your Project Costs

	Your Estimated Project Cost
Project Scoping	$Click here to enter text.
Environmental (NEPA) Compliance	$Click here to enter text.
Design	$Click here to enter text.
Mobilization and Administration	$Click here to enter text.
Basic Annual Maintenance	$Click here to enter text.

See The Catalog of Treatments in Research Report SPR-794 for Estimated, Relative Treatment Costs.

Table 6.5: Your Treatment Costs

	Your Estimated Treatment Cost
Signage, Path	$Click here to enter text.
Signage, Road	$Click here to enter text.
RRFBs	$Click here to enter text.
Tactile Warning Systems	$Click here to enter text.
Click here to enter text.	$Click here to enter text.
Click here to enter text.	$Click here to enter text.
Click here to enter text.	$Click here to enter text.

Your Project Budget: Click here to enter text.

Total Anticipated Project Cost: Click here to enter text.

6.8 EVALUATION

The following section can be utilized to compare the evaluation criteria before and after installation of treatments.

Table 6.6: Comparison of Evaluation Criteria Before and After Treatments

Evaluation Criteria	Base Case	After Application
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.

Comments

Comments pertaining to the chosen solution, the measured outcomes etc. can be added in this section:

Click here to enter text.

6.9 PLEASE ADD SKETCHES AND PHOTOS IN THE FOLLOWING SECTION

7.0 CONCLUSIONS AND RECOMMENDATIONS

This report summarizes research conducted on road or path treatments in order to improve user experience for various modes at an intersection with an active railroad parallel to a path, and a perpendicular road. Seven crossing locations in Oregon served as the case studies for this research project. A field study of these sites revealed the unique assets, insufficiencies, and challenges at each site, and the field study was also an opportune time to conduct pedestrian, bicycle, and vehicle counts. The counts were supplemented by reviewing approximately 150 hours of surveillance footage, and depicting movements in a diagram designed for each site.

Oregon has 1,889 at-grade, public railroad crossings. Active railroads with a parallel path, and a perpendicular road are especially challenging, since there are multiple modes sharing the same area. All modes - pedestrians, cyclists, and drivers, and stakeholders - the City and Railroads - are important participants in the activities that occur at these crossings. This research project explored opportunities for road and path design improvements using a broad range of treatments options. These treatments were aggregated and distilled from a comprehensive literature review that explored road and path treatment options, their efficacy, and cost in the United States and Europe. To match treatment options with unique site conditions, a Guidebook has been created to methodically identify unique issues at a site and suggests the appropriate treatment to resolve them. The Guidebook has been exemplified for all seven sites.

Chapter 2 is a comprehensive literature review that investigates the possible reasons for railroad incidents in Oregon between 2013-2016, and summarizes Oregon Legal Statutes, Policy Documents, Academic Publications, Popular Media, International Policy Documents and Recommendations, and Treatment and Processes. Legal statutes control activity at crossings for all road and path users, and various policy documents suggest that the complexity of the whole intersection specified in this research project, is not holistically addressed. The review of academic publications domestically and abroad revealed information about pedestrian behavior and the efficacy of various treatments and justified the application of treatments at various locations. For example, it was learned from these publications that automatic pedestrian gates are effective treatments, or that there is a possibility of treatments reflecting rail type (light or heavy) and speed of train. There are also other elements that unintentionally create undesired pedestrian behavior, such as a transit stop near railroad tracks, because this forces pedestrians to engage in high-risk behavior in order to catch their bus or train on time. Incidents continue to occur at railroad tracks, and there is certainly room for improving conditions at these intersections.

Chapter 3 Field Surveys summarizes the seven crossing locations in Oregon that served as the case studies for this project. A field study of these sites revealed the unique assets, insufficiencies, and challenges at each site. The current conditions, highway/rail crossings treatments, highway/path crossing treatments, bike and pedestrian facilities, diagram of movements, table of counts, and other observations are described in detail and supported with images of the crossing for each site. This gives the reader a good understanding of each site, and also provides readers with a template for how to best assess the sites that they are surveying.

Chapter 4, Evaluation Criteria, organizes and explains eight overarching criteria to evaluate the efficacy of various treatments. The eight criteria are: Unintentional Non-Compliance, Cost, Average Vehicle Delay, Sight Distance, Vehicles Stopping on Tracks, Vehicles Running Red Lights, Undesired Behavior: Pedestrians, Bikes, and other Non-Vehicular, and General Observations. These criteria serve as reliable proxies for the efficacy of new treatments.

Chapter 5, Identified Treatments (Section 5.1), organizes and explains three overarching problem statements: The Built Environment, Lack of Path User Information, and Lack of Driver Information. These statements help identify appropriate road and path treatments. Section 5.2, The Catalog of Treatments, summarizes the function, efficacy, and cost of various treatments. These treatments were aggregated and distilled from a comprehensive literature review that explored road and path treatment options in the United States, Canada, and Europe. There are 39 treatments in total, which have been organized as either active or passive treatments. These treatments are then applied to the parameters of the Identified Treatments in Chapter 5.

Chapter 6, the Guidebook, is a pragmatic, user-friendly tool that has distilled all of the information learned in Chapters 1-6. The Guidebook is intended to be used by city employees to survey and assess the current treatment conditions of paths parallel to railroad tracks with a perpendicular road. It allows for the user to enter in relevant information about the intersection found through city records and Google Maps. The Guidebook assists in identifying current road and path treatments, issues observed, and new treatments that can improve user experience at the intersection. It separates sites between heavy/light rail, and crossings that are located near/not near a school. This allows for a more thoughtful and customized solution for each site.

It is apparent that it can be challenging to select appropriate treatments at railroad crossings, as they are all unique in their design and context. The tool presented in this report is therefore not aiming to solve all at-grade railroad crossings, but instead to provide a framework and a context for deciding on appropriate treatment options for paths adjacent to railroad tracks. It requires the application of good engineering judgment in all events, as no two crossings are similar. As these issues are often involving a multitude of stakeholders and public agencies, the methodology can provide a platform for discussion and agreement on appropriate solutions. The authors hope that this research can provide a beginning point for continuing research into at-grade railroad incidents and hopefully be part in making our roads low-risk, even when many different interests and activities are present in the same location.

7.1 FUTURE RESEARCH

This research has revealed opportunities for further research at intersections where there is a path parallel to active railroad tracks and a perpendicular road. The ideas include the following:

1. Conduct more frequent vehicle, pedestrian, and bike counts and diagram these movements to increase understanding of path and road user behavior.

2. There is a dearth of current information on the efficacy of path and road treatments near railroads. Conducting studies that measure the efficacy of road and path treatments can increase credibility for treatment implementation in the field.

3. Publish a document that organizes accurate and current costs of all listed treatments.

4. Identify most common near-misses and develop a new treatment to change path or road user behavior.

5. Identify situational and contextual factors that plays a role in the occurrence of incidents at railroad crossings.

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