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Rails-Next-to-Trails: A Methodology for Selecting Appropriate Safety Treatments at Complex Multimodal Intersections

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Abstract

There are more than 212,000 at-grade railroad crossings in the United States. Several feature paths running adjacent to the railroad tracks, and crossing a highway; they serve urban areas, recreational activities, light rail station access, and a variety of other purposes. Some of these crossings see a disproportionate number of violations and conflicts between rail, vehicles, and pedestrians and bikes. This research focuses on developing a methodology for appropriately addressing the question of treatments in these complex, multimodal intersections. The methodology is designed to be able to balance a predetermined, prescriptive approach with the professional judgment of the agency carrying out the investigation. Using knowledge and data from the literature, field studies, and video observations, a framework for selecting treatments based on primary issues at a given location is developed. Using such a framework allows the agency to streamline their crossing improvement efforts; to easily communicate and inform the public of the decisions made and their reasons for doing so; to secure stakeholder buy-in prior to starting a project or investigation; to make sure that approach and selected treatments are more standardized; and to ensure transparency in the organization to make at-grade crossings safer for pedestrians and bicyclists, without negatively impacting trains or vehicles.

There are approximately 212,000 at-grade railroad crossings in the United States (*1*). Most of these crossings consist of one or more sets of railroad tracks being crossed by a public highway. As the presence of transit rail, especially light rail, increases in our cities, and the nationwide efforts to install multi-use paths next to railroad tracks are successful—The Rails-to-Trails Conservancy—a new level of complexity to at-grade railroad crossings is added. These paths or trails will often run adjacent to the railroad tracks, to serve urban areas, recreational activities, light rail station access, and a variety of other purposes. In most cases they will also be crossing the public roadway close to the railroad tracks, establishing a second point of intersection with the highway and potential point of conflict, as seen in Figure 1. Red Xs mark the two primary points of conflict—the conflict between the pedestrian (yellow) and the vehicle (blue), which in turn leads to the second conflict between the vehicle (blue) and the train (black) in situations where the vehicle is stopping to avoid the pedestrian. Even in cases where a train is not present, having vehicles stopping on tracks is undesirable.

In the state of Oregon, as well as in many other U.S. states, it is illegal for a vehicle to stop on railroad tracks—"Obstructing the intersection" (*3*); but at the same time, it is also illegal to not stop for pedestrians, cyclists, and other users (non-vehicular users) who are crossing in front of the vehicle on a path, sidewalk, or railroad crossing (*4*). When a non-vehicular user is present in, for example, a crosswalk and approached by a car traversing the railroad tracks, the driver of the vehicle is forced to break one of the two laws or put themselves or other road users in danger. To avoid striking the pedestrian who is crossing in the intersection, this will most frequently result in the vehicle dwelling on the tracks to wait for the pedestrian to pass. Aside from being illegal, this poses a threat to the driver, who is in a train's path and may not be able to move out of the way in the event that a train, which would be unable to stop, approaches. As intersections become more complex in urban areas, with higher volumes and an increased level of information that needs to be processed by traffic participants,

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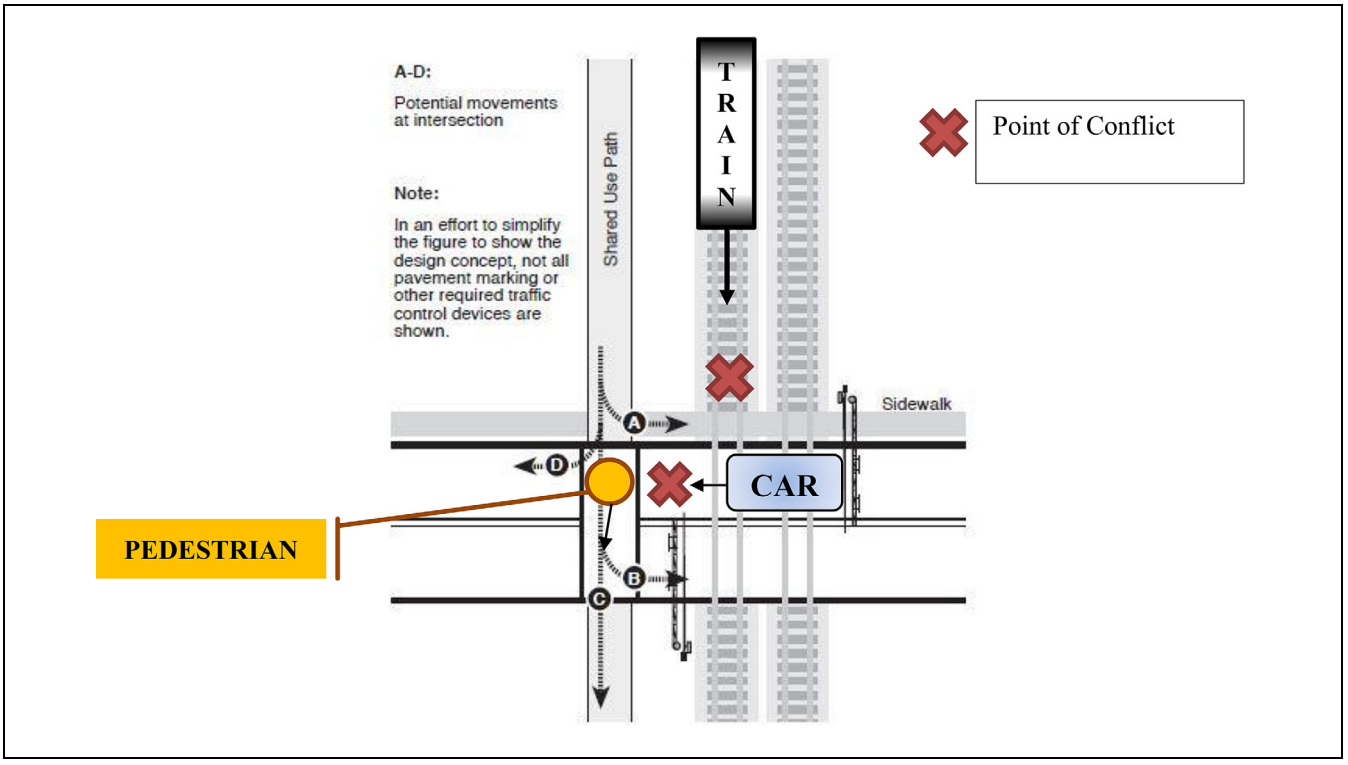

Figure 1. Conflicts at shared-use paths adjacent to the railroad tracks and perpendicular to the highway (*2*).

there is an increased probability of unintentional non-compliance, leading to conflicts between all types of users.

To adequately address safety concerns at this type of crossing, it is useful to regard these locations as single, complex multimodal intersections. Much literature is available to guide decision-making when it comes to applying treatments to highway–railroad crossings, and also for highway–sidewalk/path crossings, but limited guidance is available for these complex intersections where at least three different types of users are present. There is no standard or accepted methodology for applying treatments that improve safety and passability for all users, while addressing the legal issues previously described. Furthermore, these different types of users and infrastructure are represented by a variety of different stakeholders, both public and private, whose interests—which are potentially conflicting—should all be considered when attempting to mitigate issues or install new treatments at a railroad crossing. These can include railroad organizations, pedestrian/bike advocacy groups, cities and counties, and federal and state agencies, such as the FRA and state Departments of Transport (DOTs).

This paper addresses this gap by presenting a methodology for selecting the most appropriate treatment at a complex multimodal crossing. This is useful as it ensures more transparency in the process, which becomes more streamlined and predictable, to support collaboration with stakeholders. The following section describes existing practice and reviews the available literature. Following that the primary issues and ways of addressing them are presented, followed by conclusions and suggestions for areas of future research.

Existing Practice and Literature Review

There is no standard on how to address or treat at-grade highway–railroad crossings with a path running adjacent to the railroad tracks. The publications that transportation and traffic engineers and planners usually refer to for guidance do not explicitly cover this issue, though most of them mention the specific concerns for pedestrians and bicycles at these locations (*5*, *6*). This means that states, counties, and cities are often left to their own devices when it comes to selecting appropriate treatments. In the best cases, it means that the responsible agency will develop their own specific methodology for addressing this type of intersection and publish these as handbooks. In some cases, this means that the responsible agency will just treat the location as two separate entities, possibly leading to an increase in the confusion for users and in unintentional non-compliance, as their unique influence on each other is not considered. In

Figure 2. Two connecting trailheads on both sides of a highway are separated by a sign prohibiting pedestrian crossings.

other cases, as observed in various locations in Oregon, it may be decided to eliminate the pedestrian crossing, resulting in two unconnected trailheads on either side of a highway and, with that, an increase in the occurrence of illegal pedestrian and bicycle behavior. An example of such a crossing can be seen in Figure 2.

The first example of guidance handbooks on multimodal intersections was published by the Florida Department of Transportation (FDOT) in 1996 and contains experience and knowledge from an extensive field survey of more than 60 locations (*7*). More recently, a structured, flowchart-based methodology was developed by the Minnesota Department of Transportation (MnDOT), who published an extensive research project in 2013, which provides guidance on applicable treatments for complex railroad intersections (*8*). While both publications are informative, neither provide specific recommendations for the best possible solution addressing concerns such as efficacy, capital investment, and maintenance, as well as appearance and acceptance by its various users. The MnDOT lists a wide range of solutions or treatments and does not distinguish between different issues at a crossing, other than by the proxy of its characteristics, and therefore does not specifically address the condition at a specific crossing. This paper presents an approach that narrows down the number of recommendations that are made for an individual crossing, based on its identified primary issues, to be able to make the best possible infrastructure investment within the allocated budget.

This research project was conducted for the Oregon Department of Transportation Rail and Public Transport Division, and reflects this with respect to preferences and approved devices. To be applied in other districts, regional approvals and preferences should be considered. This paper does not examine all possible devices and treatments available nationally.

Primary Issues at Complex Intersections

In the pursuit of a methodology that can be used to select appropriate treatments, the first step was to identify and describe these railroad crossings and the primary categories of issues at them. As previously mentioned, both AASHTO and the *Manual on Uniform Traffic Control Devices* (MUTCD) suggest that this type of complex intersection is handled on a case-by-case basis (*5*, *6*). Treating crossings on a case-by-case basis, without any framework or guidance to inform decision-making and process, is time-consuming and can be perceived as unfair or inappropriate by stakeholders or the public. This paper suggests a methodology for ameliorating this situation.

The methodology presented in this paper seeks to identify some of the primary issues to streamline the process. These include issues with the built environment or infrastructure, lack of information for path users, and lack of information for drivers. These issues were identified using two different methodologies: first, a thorough literature review into available railroad treatments was conducted, followed by in-person observations and counts, which were further corroborated by video surveillance. Finally, issues were categorized and

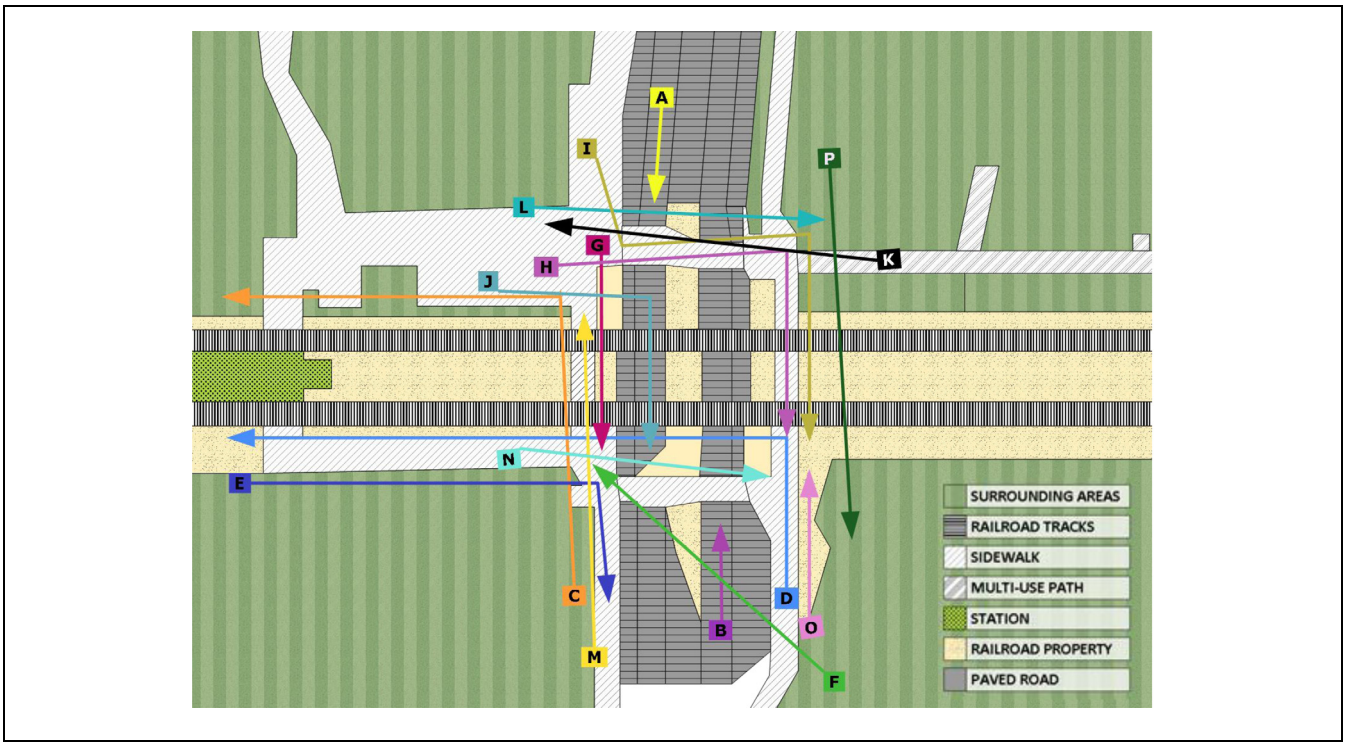

Figure 3. Example sketch of pedestrian and bike movements at a light rail crossing.

appropriate treatments were identified, which are described later in this paper.

Literature Review

In one of the earlier publications on having trails next to railroad tracks, the danger of the crossings was not specifically discussed, even though it was pointed out that most crossings in the U.S. have some form of warning device, other than the required crossbucks. Passive warning signs are not always enough for drivers to be aware of the upcoming railroad and path crossing (*9*). The following research pertains to pedestrians crossing the tracks perpendicularly. As there is limited research, one must look to existing knowledge about behavior and compliance at railroad crossings, though it is not directly applicable. 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% to 38% (*10*). A paper published in 2013 investigated warning devices and signs for pedestrians and cyclists. They compared stated and actual behavior by pedestrians and cyclists and found that many participants were engaged in 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 rates of violation. People who crossed tracks more often generally displayed safer 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 were one or two people (*11*). This was confirmed by another study, which found that children under the age of eight expressed more risky behavior and induced risky behavior among others (*12*).

Field Studies

The second part of the research leading to identifying the primary issues was conducted as a field study of seven different railroad locations in the state of Oregon with the goal of collecting data and gaining more perspective about the issues at these crossings and their roots. With recommendations from the Rail Public Transit Division, seven study sites with different characteristics were chosen. The locations were visited and observed for several hours during summer months and counts were completed for all approaches and movements. Video was also collected for at least 24 h at each crossing.

Detailed counts were extracted from the video for both morning and afternoon peaks at all locations, for all approaches and movements. These were separated into pedestrian/cyclist and vehicle/train movements. Sketches were constructed showing the movements associated with the counts. An example of pedestrian and bike movements at a light rail crossing can be seen in Figure 3. This figure shows a location and the observed

Table 1. Example of Video Counts Related to Figure 3

	Video counts		
Movements	July 6, 2016 8 am–9 am	July 5, 2016 5 pm–6 pm	Average/hour
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

movements at this location. The letters correspond to the counts in Table 1. This enables the user to quickly identify the most common movements, which here is movement K from the multi-use path to the sidewalk and station area.

Description of Primary Issues

Using the knowledge gained from the field visits, reviewing the recorded video, and the available literature, the research group identified and described three overarching causes of problems: the built environment, lack of path user information, and lack of driver information. The two latter categories are concerned primarily with human behavior—our actions, skills, and knowledge—whereas the first category is purely concerned with the physical infrastructure and road design, and best practice within these two areas. The built environment category can be directly impacted by engineering and planning, design, and decisions. In the following, the three different categories are described, along with examples of problems that can be identified under each category. This list is not intended to cover all possible issues at at-grade railroad crossings, but encompasses the primary concerns that were observed through field studies and in the literature, and which were found to be the most useful for practitioners.

The Built Environment

The purpose of our transportation infrastructure is to facilitate movements that are safe and efficient. It does so through structure—such as road design, medians, and sidewalks—and through information, such as signage and pavement markings. When the built environment is lacking content, such as visibility or adequate travel paths, the infrastructure is not fulfilling its purpose of safely and effectively accommodating its users. This leads to undesirable situations for everyone, including those participating in the traffic, but also the responsible engineers and planners. The primary issues from the built environment are as follows:

- Speed: The posted speed limits are too high 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 and potentially decreases visibility of other road users and traffic control devices.
- Railroad crossing and path distance: The path and the railroad tracks are located either too close to each other or too far apart, making the crossing harder to negotiate.
- 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.
- 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, for

example, the road and the sidewalk can lead to cars unintentionally driving on the sidewalk area, which can lead to conflicts with non-vehicular users.
- Visibility: Inadequate visibility caused by vegetation, buildings, or lack of street light (*13*).

Lack of Path User Information

This category is concerned with the actions and behavior exhibited by the users of the path running adjacent to the tracks, including pedestrians, cyclists, skateboarders, and a variety of other users. The type of path that runs adjacent to railroad tracks is typically a higher-speed path where the users are undisturbed by the surrounding traffic. When they do reach an intersection that means a change in their environment, they need to safely navigate it. When users are unprepared for an upcoming crossing, they can potentially end up in dangerous situations. It is important to ensure that path users are adequately informed of the upcoming crossing or break in their path and can be prepared to proceed safely. The identified primary issues from lack of path user information include the following:

- 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, even more so if on a primarily commuter-oriented path or high-speed trail.
- Signage: There is a lack of signage for bikes and pedestrians surrounding the crossing, leaving them unaware of upcoming crossings or rules of the road. This can also refer to pavement markings in substandard condition.
- Non-compliance: There is a high non-compliance rate of existing treatments and a lack of consequences for non-compliance (*13*).

Lack of Driver Information

This category concerns the users of the highway who are crossing both the railroad tracks and the path crossing. While pedestrians, cyclists, and others using facilities running perpendicular to the tracks and path also technically belong to this category, they are not explicitly handled in this research and do not seem to pose a significant problem. As with the previous category, it is vital that drivers approaching a crossing have adequate information, knowledge, and prior notification to be able to safely traverse the intersection. The primary issues from lack of driver information are as follows:

- 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 rather than as 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 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 path or rail crossings, and of rules of the road about stopping for pedestrians or the speed limit, for example. This pertains to the railroad crossing itself, but also and especially to the path layout and the possibility of encountering pedestrians/cyclists. This also includes pavement markings being in substandard conditions (*13*).

The three categories with their 14 subcategories together describe the primary issues and an overall picture of potential conflicts at a complex intersection. These mechanisms should all be considered when attempting to prevent undesirable situations or behavior at an at-grade multimodal crossing. The following section will describe the developed methodology.

Addressing Primary Issues

The developed methodology is directed toward agencies attempting to select cost-effective treatments, which addresses primary issues at complex intersections. It assumes that it has already been established that the crossing in question is of concern to public safety. For this purpose, it also assumes that the responsible agency has information about the crossing and/or a methodology for collecting such. The primary issues are then decided based on existing knowledge and categorized according to the three primary categories and their subcategories presented in the previous section.

Outlining the Process

By combining the identified issues described in the previous section with the developed catalog of available treatments, it was possible to develop potential solutions for different situations at a variety of crossings. The process for selecting the treatment is as follows:

1. Type of rail: refers to whether the location carries heavy rail or light rail.
2. Identified issues: These are identified at the agency's discretion from existing or newly

collected data, such as number of trains per day, nearby activities, recent incidents or annual average daily traffic (AADT), field visits, video recordings, or other sources. It is generally recommended that for each crossing no more than five primary issues are selected. For most crossings it seems that between two and four focus areas are the most appropriate to sufficiently cover the issues at the crossing without "over-treating."

3. School locations: Typically, traffic engineers and planners are especially concerned when a location has young children. Khattak and Luo found that children under the age of eight were involved in "excessive gate-related violations in the absence of older crossing users" (*12*). For this reason, recommendations are different and the treatments generally more severe when the crossing is located within 0.5 miles of an elementary or middle school (K–8), or at the responsible agency's discretion.
4. Recommendations for locations: Generally, one primary recommendation is made for each location as identified in the previous three points, with one or more supplemental or secondary recommendations. These supplemental recommendations are marked with either "OR," meaning the two recommendations can be combined but should not necessarily be; or with "AND," meaning that the recommendations should be combined for best results.

Applying the Methodology

Using the process outlined enables the user to identify the primary issues and a selection of appropriate solutions, using the individual prescriptive tables. As the issues and/or parameters of a crossing increases and/or changes, so does the suggested solutions at the agency's discretion. The issues are selected based on a combination of field observations, video surveillance, public comments, previous history of incidents, and engineering judgment. Once the primary issues are identified and the characteristics of the crossings described, the appropriate solutions are selected and sketched. An example of the selection of treatments is given in the following sections. The prescriptive table for heavy rail is shown in Table 2.

Case Study: SE Spokane St, Portland

The crossing at SE Spokane St is a heavy rail crossing located in a mostly residential area in Portland, OR. The path, Springwater on the Willamette, running adjacent to the tracks has high volumes of pedestrians and bicycles throughout the day, as seen in Table 3. The AADT in 1993 was 3,644. The 2016 estimate is 6,000–8,000. On average, this crossing has two train events per day. The highway/railroad crossing is equipped with MUTCD R1-1, R15-1, W10-1, 8B-7, and has a stop line at all approaches. The path/highway crossing is equipped with MUTCD R1-1 and a stop line. A schematic of the crossing at SE Spokane St can be seen in Figure 4.

Based on field observations and video surveillance, the primary issues were identified and described using the proposed methodology as outlined above.

- Stop line: The stop line for westbound vehicles is placed 20 ft from the nearest track and >40 ft from the multi-use path. As the sight distance is categorized as semi-blind because of interior, vegetation, and topography, this results in drivers not being able to fully see the path and the tracks and their respective activity without crossing the stop line. Because of the downhill slope, the angle of the track, and the way the path is designed, this can be difficult to mitigate. It does lead to cars slowly entering onto the tracks and dwelling, and these issues should be ameliorated.
- Speed: This path is heavily commuter-oriented and from observations approximately half of its users are very familiar with the path and the crossing. It is a wide, well-maintained path, further increasing the speeds at which cyclists travel. The straightness of the path also leads to higher speeds and less awareness of the crossing.
- Non-compliance: Both trailheads are equipped with a smaller, lower-positioned version of a stop sign, asking especially cyclists to stop before entering the intersection.
- Negotiation: This intersection seems to be negotiated by the drivers as two separate intersections rather than a single complex intersection: The path, roads, and tracks are spaced far apart and there is limited visibility. Adding the slopes and angles to the mix leads to a situation that is highly complex, as there are many different approaches by different types of users. The unpredictability of the path users also seems to lead to further confusion for the drivers.

Based on the identified and described primary issues, the treatments were selected as shown in Table 4. This

Table 2. Table of Treatments for Heavy Rail

	Category	Treatment	Description
The built environment: design speed	Primary	Reassess speed limits	Reassessing the posted speed limits will encourage more drivers to keep to an appropriate speed.
	Secondary	Ensure that speed limits are posted and visible	Visibly showing and reminding drivers of the speed limits will potentially further enhance the effect of lowering speed limits.
	Primary, nearby school	Include crossing area in school zone	Compliance with speed limits are very good in school zones, which can be utilized in this situation.
	Secondary, nearby school	Reassess posted speed limits *or* Ensure that speed limits are posted and visible	Reassessing the posted speed limits will encourage more drivers to keep to an appropriate speed. *See above*
The built environment: vertical crossing design	Primary	Add signage	When drivers are not automatically aware of the road or of obstructions, signage can help draw their attention toward certain things.
	Secondary	Install rapid rectangular flashing beacons (RRFBs)	RRFBs are generally a good way of allowing pedestrians to make others aware of their presence, without continuously disturbing traffic when no pedestrians are present. This enforces the driver's attention toward path users and enables them to stop or slow down earlier.
	Primary, nearby school	Raised crosswalks	Raised crosswalks provide structure to the crossing, which ensures a focus on both the railroad–highway crossing and the path crossing. Furthermore, it supports users in crossing legally, as it nudges them toward walking on the raised crosswalk as opposed to next to it or diagonally. Raised crosswalks can present problems for certain classes of vehicles.
	Secondary, nearby school	Automatic RRFBs	*See above*
The built environment: horizontal crossing design	Primary	Move path closer to railroad tracks	Moving the path closer to the tracks makes drivers more likely to negotiate the crossing as one complex crossing as opposed to two separate crossings, which in turns make them more aware of activity on both segments of the complex crossing.
	Secondary	Signage *or* Variable message signs	*See above* Good compliance rates have been seen with variable signs that are appropriately designed.
	Primary, nearby school	Move path closer to railroad tracks *or* Install RRFBs	*See above* *See above*
	Secondary, nearby school	Install automatic RRFBs *or* Traffic signal	*See above* Conventional traffic signals are expensive and a last resort option for controlling traffic. When used in combination with automatic gates, traffic lights can in some instances lead to issues with negotiation, as users forget to check both the automatic gates and traffic signal at a location.

(continued)

Table 2. (continued)

	Category	Treatment	Description
The built environment: stop line	Primary	Move stop line closer to railroad tracks	Moving the stop line closer to the railroad tracks provides better visibility and ability to access the crossing for the driver. There can be some issues with right-of-way with moving the stop line closer.
	Secondary	Raised crosswalks	*See above*
	Primary, nearby school	Move stop line closer to railroad tracks	*See above*
		or	
		Raised crosswalks	*See above*
	Secondary, nearby school	Raised crosswalks	*See above*
		and	
		Dynamic enveloping	Dynamic enveloping makes users more aware of the crossing as a point of conflict, slows down users, and enforces the location as one single complex crossing and not two separate crossings. It is especially a good choice in crossings with high train volumes or in wide crossings.
		and	
		Conflict zone traffic paint ("conflict paint")	Conflict paint is used for marking smaller areas of conflict than dynamic enveloping would. The two can also be used together to improve attention to the crossing overall and to some areas specifically. Note: interim approval
The built environment: insufficient crossing infrastructure	Primary	Supply crossing options	If there is a path present on both sides of a highway, there should be a legal way for a user to cross this highway, within a reasonable distance from the path itself.
		or	
		Relocate crossing	If there is a path present on both sides of a highway, there should be a legal way for a user to cross this highway, within a reasonable distance from the path itself.
		and	
		Add pavement markings	Pavement markings provide structure and information to users about appropriate negotiation.
		or	
		Zebra stripes	Pavement markings provide structure and information to users about appropriate negotiation.
	Secondary	Dynamic enveloping	*See above*
	Primary, nearby school	Install pedestrian refuge	A pedestrian refuge allows the user to cross the road in two or more segments. This gives structure to the crossing and is especially recommended in very wide crossings where RRFBs or similar are too costly for the purposes.
		or	
		Install RRFBs	*See above*
	Secondary, nearby school	Raised crosswalks	*See above*
		and	
		Dynamic enveloping	*See above*
		and	
		Conflict paint	*See above*
		or	
		Overcrossing	Overcrossings and undercrossings are expensive options that are especially recommended close to schools, where children and teenagers often must navigate the crossing. They are generally a nuisance to cyclists and most other users, especially under ADA, but can be a last resort.
		or	
		Undercrossing	*See above*

(continued)

Table 2. (continued)

	Category	Treatment	Description
The built environment: transit stop	Primary	Move transit stop *or*	Moving a transit stop further away from the crossing will have fewer people suddenly start running as they see their bus or train arrive or leave.
		Eliminate stop	Eliminating the transit stop does the same as moving the stop and may be a better option if the location is already adequately served by transit or a nearby stop for the same route.
	Secondary	*Refer to insufficient crossing infrastructure*	N/A
	Primary, nearby school	Move transit stop *or*	*See above*
		Eliminate stop	*See above*
	Secondary, nearby school	*Refer to insufficient crossing infrastructure*	N/A
The built environment: road/street infrastructure	Primary	Implement physical separation *or*	Physical separation keeps users in the desired areas of travel and therefore decreases the potential for conflicts and incidents.
		Pre-made concrete separation blocks	Using pre-made, ready-to-use sections is a faster and more economical way of providing physical separation as described above.
	Secondary	Pavement markings *or*	*See above*
		Zebra stripes	*See above*
	Primary, nearby school	Implement physical separation *or*	*See above*
		Quick curb	*See above*
	Secondary, nearby school	Raised crosswalks *or*	*See above*
		Bollards *or*	Obstructions work well to provide structure, and slow down and guide users toward the areas where they are preferred to walk or bike. Bollards are good because they allow for bike users and ADA users to continue to use the facility, compared to using fencing. Some find that bollards can present a fixed object hazard to cyclists.
		Fencing	Fencing should only be used in cases where it is paramount that users do not attempt to cross undesirably.
The built environment: visibility	Primary	Add signage	*See above*
	Secondary	Refer to horizontal crossing design *or*	N/A
		Maintenance of vegetation *or*	Unmaintained vegetation can potentially decrease visibility.
		Add street lights	Street lights are especially important in denser urban areas with transit running outside of daylight hours available nearby.
	Primary, nearby school	Add signage *and*	*See above*
		Refer to horizontal crossing design	N/A
	Secondary, nearby school	Maintenance of vegetation *or*	Unmaintained vegetation can potentially decrease visibility.
		Add street lights	*See above*

(continued)

Table 2. (continued)

	Category	Treatment	Description
Lack of path user information: trail speed	Primary	Speed treatment	Many different types of speed treatments are available. They are especially useful on high-volume routes used primarily for commuting. Even if the treatment chosen is ADA-compliant, it should not be implemented on routes with frequent ADA-use.
	Secondary	Add signage	*See above*
	Primary, nearby school	Speed treatment	*See above*
	Secondary, nearby school	Obstructions	Obstructions work well to provide structure, slow down users, and push them toward the areas where they are preferred to walk or bike. A variety of different options are available depending on the location.
Lack of path user information: signage	Primary	Add signage	*See above*
	Secondary	Tactile warning surfaces	This solution can provide critical information, especially to ADA users, and enable access
	Primary, nearby school	Add signage *or*	*See above*
		Variable message signs	*See above*
	Secondary, nearby school	In-pavement marker *or*	This solution is especially useful in urban areas, areas without street lights, and areas with high vehicle speeds.
		Automatic RRFBs	*See above*
Lack of path user information: non-compliance	Primary	Obstructions	*See above*
	Secondary	Variable message signs	*See above*
	Primary, nearby school	Obstructions	*See above*
	Secondary, nearby school	Educational initiatives *and*	Especially near schools it can be important to strengthen the understanding of the dangers of trains to children.
		Variable message signs	*See above*
Lack of driver information: negotiation	Primary	Dynamic enveloping *and*	*See above*
		Conflict paint	*See above*
	Secondary	Signage *or*	*See above*
		Traffic lights	*See above*
	Primary, nearby school	Raised crosswalks *and*	*See above*
		Dynamic enveloping *and*	*See above*
		Conflict paint	*See above*
	Secondary, nearby school	RRFBs *or*	*See above*
		Automatic RRFBs *or*	*See above*
		Traffic lights	*See above*
Lack of driver information: vehicle speed	Primary	Speed treatment *or*	Many different types of speed treatments are available. They are especially useful on high-volume routes with low truck rates.
		Pedestrian hybrid beacon (PHB) *or*	PHBs are generally a good way of allowing pedestrians to make others aware of their presence, without continuously disturbing traffic when no pedestrians are present. This enforces the driver's attention toward path users and enables them to stop or slow down earlier.
		RRFB	*See above*

(continued)

Table 2. (continued)

	Category	Treatment	Description
	Secondary	Conflict paint *and*	*See above*
		Dynamic enveloping	*See above*
	Primary, nearby school	Speed treatments *and*	*See above*
		In-pavement marker *or*	This solution is especially useful in urban areas, areas without street lights, and areas with high vehicle speeds.
		HAWK *or*	*See above*
		RRFB	*See above*
	Secondary, nearby school	Install active speed sign	This reminds motorists of their speed as it compares with the posted speed limit.
Lack of driver information: signage	Primary	Add signage *or*	*See above*
		Add pavement markings	Pavement markings provide structure and information to users about appropriate negotiation.
	Secondary	Refer to insufficient crossing infrastructure	N/A
	Primary, nearby school	Add signage *or*	*See above*
		Add pavement markings *and*	*See above*
		Refer to insufficient crossing infrastructure	N/A
	Secondary, nearby school	Speed treatments *or*	*See above*
		In-pavement markings *or*	This solution is especially useful in urban areas, areas without street lights, and areas with high vehicle speeds.
		RRFBs	*See above*

Note: This table does not include all possible types of treatments and they may be excluded for several reasons, such as that the treatment is not commonly used, is not permitted in Oregon, or is experimental. Several treatments can be interchanged at the responsible agency's discretion.

Table 3. Counts from the Observations and Video Surveillance

Mode of transport	July 7, 2016, 8 am–9 am	July 6, 2016, 5:15 pm–6:15 pm	July 6, 2016, 3:23 pm–4:38 pm
Cars	136	281	439
Pedestrians	55	68	54
Bikes	154	305	250
Trains	0	0	0

table is based on Table 2 but is operationalized to make it easier for the agency using it to mark and review selected treatments. Table 4 is a condensed version of the original table and the full version can be found in the supporting publication (*13*).

The existing stop line is located 20 ft away from the crossing but should be moved slightly further away from the tracks to increase sight distance. The trail carries high volumes of pedestrians and bikes throughout the day, and on average more pedestrians and bikes than motor vehicles enter the crossing. It is in the city's interest to continue to prioritize and support the high volumes of pedestrians and bikes. A raised crosswalk addresses inadequate vertical design issues by increasing the driver's focus on the highway–path crossing, as opposed to solely on the highway–railroad crossing.

The combination of a raised crosswalk, conflict paint, and dynamic envelope further strengthens the

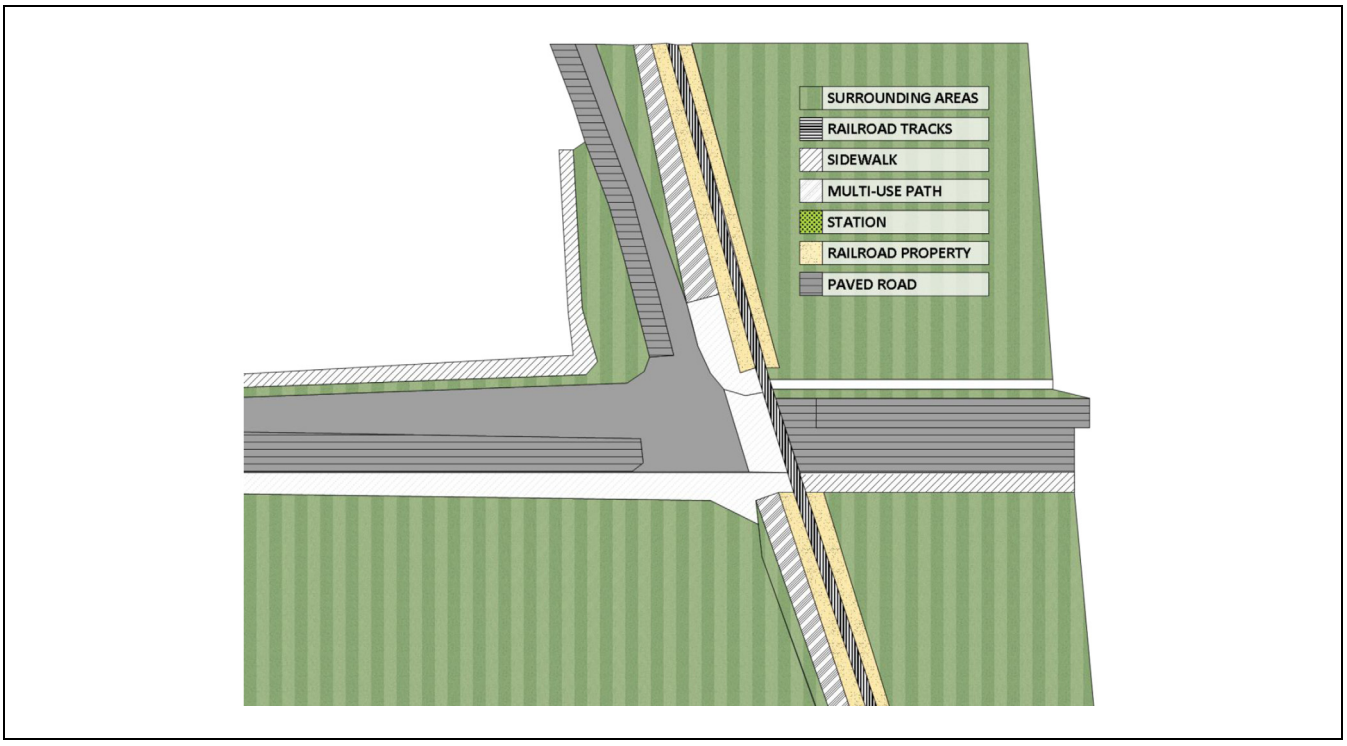

Figure 4. Schematic of the SE Spokane St crossing.

perception of the crossing as a single, complex crossing. This enables motor vehicles to better assess the crossing before entering and therefore negotiate it more safely. This can potentially lead to a decrease in conflicts between users and in the observance of illegal behavior. Further suggestions include adding a slight uphill slope on both sides of the raised crosswalk to nudge bicyclists to decrease their speed as they are approaching. This enables other users to access the raised crosswalk more easily. The changes should be made to ensure compliance with Americans with Disabilities Act (ADA) and Proposed Rights-of-Way Guidelines (PROWAG) requirements. Figures 5 and 6 show the proposed changes.

Conclusions

This research investigated and utilized several different methods and approaches to develop a methodology that can serve to support decision-making when selecting appropriate treatments in multimodal, complex intersections. The proposed methodology is designed to be able to balance a predetermined, prescriptive approach with the professional judgment of the agency carrying out the investigation. It allows the practitioner to utilize collected information about a complex multimodal intersection, apply it to a predetermined set of specifications using engineering judgment, and by that come up with a set of treatments that has previously been found to address the issues identified.

Currently there is not a standardized methodology for selecting appropriate treatments at complex railroad crossings, and they are either treated as two separate crossings or by following guidelines specific to the responsible DOT. Because complex intersections are generally different from each other, having a standardized method that does not allow for engineering judgment is not a preferred option. However, having a standardized set of guidelines that can support the work done by rail divisions and local governments across the country can improve outcomes when selecting treatments. A previously agreed-on methodology allows the relevant agency to streamline their crossing improvement efforts; to easily communicate and inform the public of the decisions made and their reasons for doing so; to secure stakeholder buy-in before starting a project or investigation, which will in turn lead to better outcomes; to make sure that approach and selected treatments are more standardized; and to ensure transparency in the organization to make at-grade crossings safer for pedestrians and cyclists, without negatively impacting trains or vehicles.

Table 4. Selected Treatments for This Location

	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 crosswalks	☐ Move stop line closer to railroad tracks *or* ☐ Raised crosswalks	☐ Raised crosswalks *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 markings	☐ Dynamic enveloping	☐ Pedestrian refuge *or* ☐ Install RRFBs	☐ Raised crosswalks *and* ☐ Dynamic 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 crosswalks *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*

(continued)

Table 4. (continued)

	Crossings not near schools		Crossings near schools	
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* ☐ PHBs *or* ☐ RRFBs	☐ Conflict paint *and* ☐ Dynamic enveloping	☐ Speed treatment *and* ☐ In-pavement marker *or* ☐ PHBs *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

Figure 5. Proposed changes to SE Spokane St.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: AG, EM, ABA; data collection: ABA, PB, MS; analysis and interpretation of results: ABA, AG, EM; draft manuscript preparation: ABA. All authors reviewed the results and approved the final version of the manuscript.

Figure 6. Proposed changes to SE Spokane St.

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