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Addressing Infrastructure Design Challenges In Constructing At-Grade Rail Crossings Near Road Intersections

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Abstract:
At-grade rail crossings, where railway tracks intersect roadways at the same level rather than being separated by bridges or tunnels, are crucial elements of transportation infrastructure. However, these crossings create significant challenges for rail operations, particularly regarding safety and efficiency. Locating an at-grade rail crossing near a road intersection is generally discouraged due to the increased risk of train delays, reduced visibility for train operators, and the potential for train-road conflicts. While these issues are undesirable, they are sometimes unavoidable when rail infrastructure must be near or across road intersections. This study examines the design challenges of constructing at-grade rail crossings near road intersections. It provides a comprehensive review of the safety and operational concerns, including delays, conflicts, and the potential for accidents. The study also discusses existing guidelines and design practices to mitigate these challenges, offering insights into improving the efficiency and safety of at-grade rail crossings near road intersections.
Key Word*: Railway; Rail design; Rail crossings; Intersections.*

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I. Introduction

The design and construction of at-grade rail crossings near road intersections pose a unique set of technical, and safety-related challenges that have significant implications for modern transportation systems. At-grade crossings, where rail tracks intersect roadways at the same level rather than being separated by bridges or tunnels, are essential components of transportation infrastructure but introduce critical points of conflict between rail and road traffic. These crossings are particularly prevalent in urban and suburban areas, where space and budget constraints often preclude grade-separated solutions, and in rural areas, where lower traffic volumes make grade separation less economically feasible. However, at-grade crossings near road intersections can become focal points for congestion, collisions, and operational inefficiencies, thus requiring careful planning, engineering, and regulatory oversight.

At-grade rail crossings, alternatively known as rail-road crossings, are the intersections of a roadway and a railroad, on the same plane or grade. In these kinds of crossings, trains have the right-of-way. Generally, two different warning systems are used for vehicular traffic management:

1. Active grade crossings, and
2. Passive grade crossings.

In the case of active grade crossings, flashing lights and maybe gates are used to warn the road users of the approach or presence of rail traffic at grade crossings. On the other hand, passive grade crossings do not use flashing lights or gates, and they are based on signs and pavement markings only, intending to advise road users to slow down, yield, or stop at the grade crossing.

Locating an at-grade rail crossing near intersections is generally discouraged [1] as can create several negative issues concerning the driver’s view of the crossing and the tracks, increase the conflicts between road vehicular movements and trains, and finally is challenging for the crossings of the vulnerable users (such as the pedestrians and the bicyclists).

However, this is sometimes unavoidable, and railway infrastructure should be near a road intersection and in some cases to cross the intersection. The scope of this paper is to review the current guidelines and approaches for the implementation of at-grade rail crossings near road intersections.

The remainder of this study is organized as follows. The background section provides a comprehensive review of the infrastructure design challenges for at-grade rail crossings in terms of safety and traffic congestion. The design concerns for at-grade rail crossings, both near road intersections and within road intersections, and are presented based on existing guidelines and approaches. Finally, the last sections summarized the key findings of the study.

II. Infrastructure Design Challenges For At-Grade Rail Crossings

Safety issues

An at-grade railroad crossing results in a right-of-way conflict between the road vehicular traffic and the train traffic. As a train vehicle requires a long distance and time to stop, road traffic is always required to yield right-of-way at an at-grade railroad crossing to a passing train.

Issues arise when a roadway intersection is situated near an at-grade railroad crossing, as the control systems for the railroad crossing and the intersection operate independently. An integrated control system is not feasible because neither jurisdiction is willing to relinquish control over the other. This results in two primary problems. First, when a significant number of vehicles are waiting for the green light at the intersection leading to the railroad crossing, the queue may extend across the tracks. If a train approaches, these vehicles are unable to move until they receive the green light at the intersection. The second issue occurs when the train is passing; the intersection traffic signals continue to allow vehicles to proceed toward the crossing, potentially causing a backup of vehicles that then extend into the intersection.

A key challenge in the design of these crossings is ensuring safety while maintaining the fluidity of both road and rail traffic. Collisions at at-grade crossings, especially those near intersections, often result from improper driving behavior and interactions between trains, motor vehicles, pedestrians, and cyclists, making safety an ongoing priority in transportation research.

Indicative examples of improper driving behavior that contribute to crashes at at-grade rail crossings are presented in Figure 1.

Figure no 1: Indicative examples of improper driving behavior that can contribute to crashes at at-grade rail crossings.

Studies consistently show that these crossings are associated with increased risks of collisions and fatalities due to the proximity of vehicles and trains, limited sight distances, and often inadequate warning systems. To address these issues, many researchers have focused on improving signal timing, warning devices, and sight-line management at these crossings. Safety interventions, such as advanced warning systems, automatic gates, and dedicated pedestrian crossings, are among the solutions explored in the literature. These interventions must be carefully adapted to the specific needs of each crossing to maximize effectiveness, particularly in densely populated areas where accidents could have severe consequences.

In recent years, advances in technology have offered new opportunities to address the challenges of at-grade rail crossings. Innovations in intelligent transportation systems (ITS), real-time data monitoring, and predictive analytics have the potential to improve the safety and efficiency of these crossings. For example, ITS can enable communication between trains and traffic signals, allowing for better coordination and potentially reducing delays and collision risks. Literature has begun to explore the potential of these technologies, with a growing body of research focused on pilot projects and case studies that demonstrate their effectiveness. However, the implementation of advanced technologies requires significant investment and coordination across agencies, highlighting the need for further research on the feasibility and scalability of these solutions.

Enhancing Intelligent Transport System (ITS) architecture for integrating railroad operating systems with traffic management systems has been discussed in many recent studies [2-6]. The efficiency of such methods adapts to the ability to provide motorists with advanced warnings of approaching trains through interconnected information systems that integrate traffic management and rail operation networks.

For example, Wang et al. [2] presented recently a novel connected vehicle (CV) – based active warning system tailored specifically for highway-rail grade crossings (HRGCs), utilizing readily available connected vehicle technologies to predict crossing risks and issue real-time auditory and visual alerts to road users, with promising results for enhancing HRGC safety in field applications.

Moreover, other studies discuss the effectiveness of ITS applications in the quality of residents' lives. Gent et al. [7] suggested that automated horn systems, which use stationary horns at crossings to direct roadways, significantly reduce noise pollution and improve residents' quality of life while maintaining effective safety warnings for motorists and pedestrians.

In nearly all collisions between a vehicle and a train, the driver and passengers in the vehicle suffer injuries, often fatal, due to the large mass disparity between the two. In contrast, the train engineer and passengers on board are generally uninjured, although exceptions do occur. Nonetheless, the emotional impact on the train engineer can be profound, sometimes preventing them from returning to their duties. A train's substantial mass and limited braking capability cannot stop within the sight distance of an at-grade crossing, even with full breaks applied. Consequently, when an engineer spots a vehicle on the tracks, they initiate braking immediately and sound the horn but are typically unable to halt in time, watching as the full brake train continues toward the vehicle and often comes to a stop far beyond the crossing.

Apart from potential emotional or minor physical harm to train personnel, such collisions can severely disrupt rail traffic, as operations on the affected and nearby tracks are paused for clearance and investigation. With limited alternatives for rerouting, rail traffic often comes to a standstill, incurring substantial economic losses for the rail industry.

Traffic congestion issues

A roadway intersection situated near an at-grade railroad crossing uses a preemption traffic control system which is alerted when a train is approaching and when the crossing is cleared. Upon receiving the signal of an approaching train, the primary purpose of the preemption control is to enhance the safety of vehicles at risk from the train's proximity. During and after the train's passage, the system also manages traffic congestion caused by vehicles halted at the crossing, typically prioritizing movements across the tracks that were blocked while the train passed.

This preemption system generally manages congestion effectively if the volume of queued vehicles remains moderate. However, when vehicle volumes are high or trains pass with high frequency, the preemption control system struggles to adequately disperse traffic buildup, potentially leading to prolonged delays and operational challenges for the road network. Large vehicle queues can back up over significant distances, sometimes affecting adjacent intersections, and creating safety risks. While the nearby intersection's preemption scheme can help prevent queues from encroaching into that intersection, congestion may still impact upstream and downstream intersections, exacerbating safety concerns.

III. Design Concerns For At-Grade Crossings Located Near Intersections

One of the main issues during designing and constructing a railway line is the ability to ensure clear storage space for vehicular road users at all grade crossings that are located near road intersections. In the absence of adequate storage space, there is a heightened risk of vehicles queuing over railway tracks, thereby increasing the potential for collision with an oncoming train. Therefore, in these cases either the retrofitting of road intersections is required, or specific restrictions should be applied.

According to the "Grade Crossing Handbook" of Transport Canada [8], a minimum of 30 meters of clear storage space should be provided between the vehicular grade crossing and the nearest stop-controlled intersection. If this cannot be achieved, the installation of a warning system and the interconnection of that system with the traffic signals (in case of signalized intersection) should be considered. Figure 2 illustrates a typical scheme of a stop-controlled intersection near a railroad crossing.

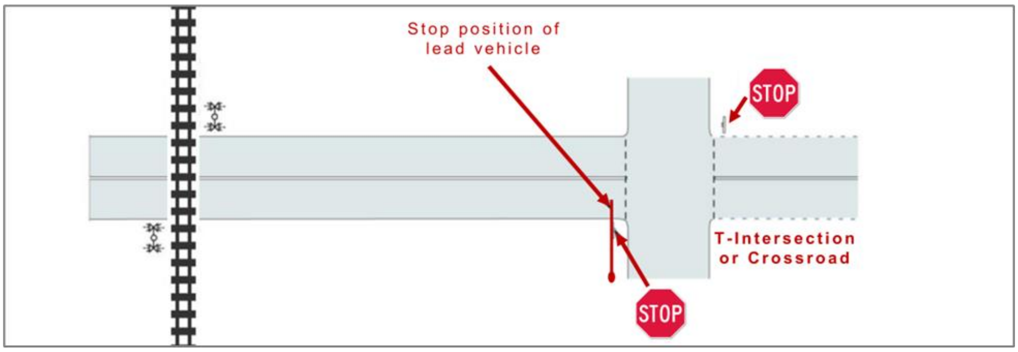

Figure no 2: Typical scheme of a stopped-controlled intersection near a railroad crossing.

The construction of at-grade rail crossings near roadway curves should also be avoided as it can inhibit a driver's view of a crossing ahead. Roadway curves near at-grade rail crossings can inhibit the drivers' view of the tracks approaching the crossing as well. The minimum distance of 30m in that case should be considered along the centerline of the roadway [8] (Figure 3).

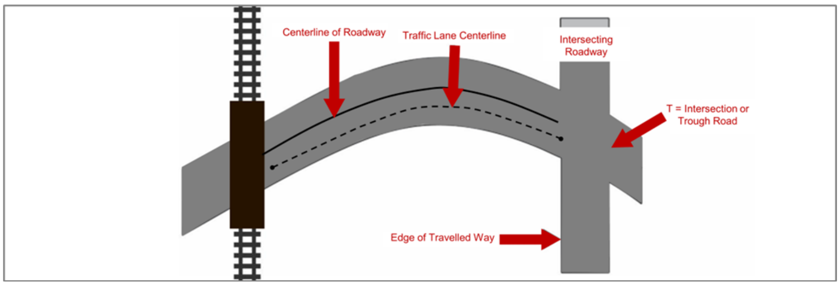

Figure no 3: Typical scheme of an intersection with a curved roadway near a railroad crossing.

According to [9], railroad crossings near roundabouts can contribute to the following two major issues, as illustrated in Figure 4:

1. A queue can be developed on a roundabout approach during peak hours and affect the railroad crossing. In that case, there is a danger for vehicles that may be caught on the crossing and be engaged with a significant risk of a collision with a train (Figure 4, left).
2. A queue can be formed at a railroad crossing back up into a nearby roundabout and affect the operation of the intersection (Figure 4, right).

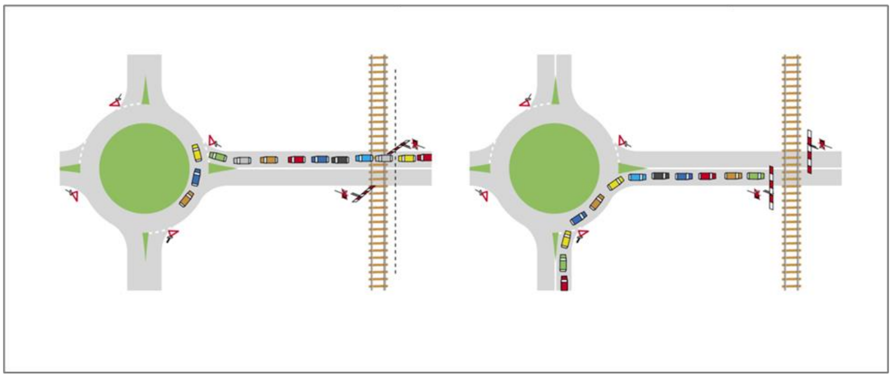

Figure no 4: The major issues of implementing railroad crossings near roundabouts [9].

For the first case, the following countermeasures can be applied to mitigate the risk of a potential crash:

1. Installation of signs to alert drivers not to stop on the tracks.
2. Creation of a slip road, at a minimum length of 20 meters, to provide the possibility of release for the vehicles stopped on the tracks (Figure 5).
3. Implementation of signalization at the roundabout approaches to prevent vehicles from entering while the queued traffic clears.

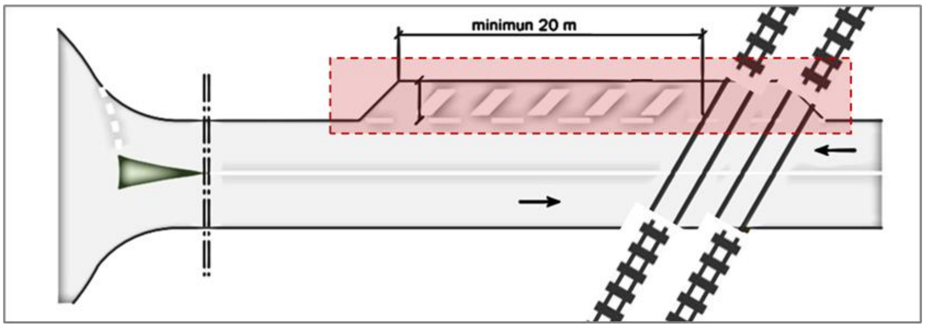

Figure no 5: Creation of a slip road to provide the possibility of release for the vehicles stopped on the tracks.

For the second case, the following countermeasures can be applied to mitigate the risk of a potential crash:

1. Proper signs.
2. Signalization of adjacent roundabout approaches.

Finally,in the case that a rail runs parallel to the highway and crosses one leg of the intersection, the gates should be installed either at all entries of the roundabouts or on rail approach only [1] as illustrated in Figure 6.

The first approach allows the exiting vehicles to clear the roundabout before the train arrives. It is an attractive choice, especially in cases when the rail crossing is close to the roundabout and the storage in traffic lanes between the roundabout and the rail is limited. However, it should be mentioned that delays can be observed, especially when the predominant movement for vehicles is parallel to train movement.

The second approach reduces delays as through, left turn, and U-turn movements are not affected. Moreover, it is noted that this scheme requires a considerable review of the available storage capacity.

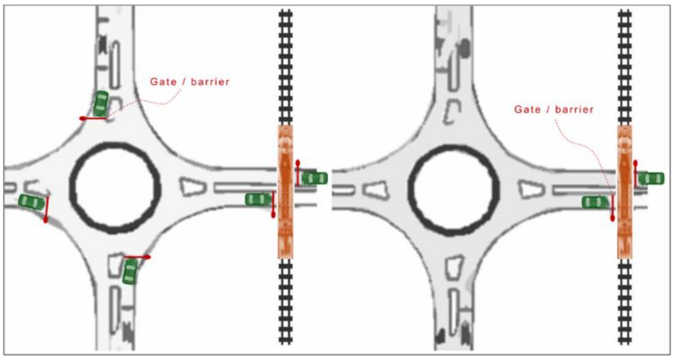

Figure no 6: Rail crossing one leg of the roundabouts: countermeasures to mitigate the risk of a potential crash.

IV. Design Concerns For At-Grade Crossings Within Intersections

There is considerable experience of incorporating at-grade rail crossings and roundabouts globally. Especially for the city of Melbourne in Australia, a significant number of roundabouts exist with tram crossings running along the median through the center of the roundabout. According to [10], roundabouts offer a notable improvement for light rail trains (LRT). The low-speed design for vehicular traffic entering and exiting the roundabout can enhance intersection safety.

The following table summarizes the advantages and disadvantages of incorporating roundabouts and at-grade rail crossings against other types of intersections in the case of urban areas [11].

Table no 1: Advantages and disadvantages of incorporating roundabouts and at-grade rail crossings against other types of intersections.

Advantages	Disadvantages
Light rail trains (LRT) and roundabouts have already been successfully implemented in both Europe and Australia.	Drivers may lack familiarity with roundabouts.
Provide more space to near signalized intersections	Conflicts between vehicular traffic and light rail trains (LRT)
Less queue storage area is required for left turns	Pedestrian crossings
Light rail trains (LRT) receive full priority at roundabouts, resulting in reduced delays.	Near busy signal

According to [1], railways that are designated to be constructed within the roadway median and through the center of the roundabout, result in the following challenges to be considered:

1. The placement of the crossing concerning the roundabout.
2. Traffic flow patterns and the availability of storage space for queued vehicles.
3. The choice between railroad gates and roadway signals.
4. The timing and sequence of preemption, accounting for factors such as queue clearance, train speed, and other relevant considerations.

In the case of a gated rail crossing through the center of a roundabout, it is recommended to be accommodated in the following two ways [1], as illustrated in Figure 7 and Figure 8:

1. Provision of gates only on the circulatory roadway, at the at-grade rail crossings.
2. Provision of gates across all roundabout entries.

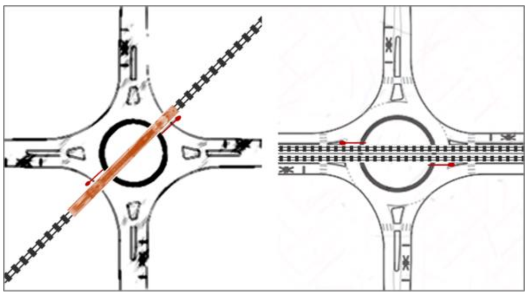

Figure no 7: Gated rail crossing through the center of a roundabout: providing gates only on the circulatory roadway, at the at-grade rail crossings.

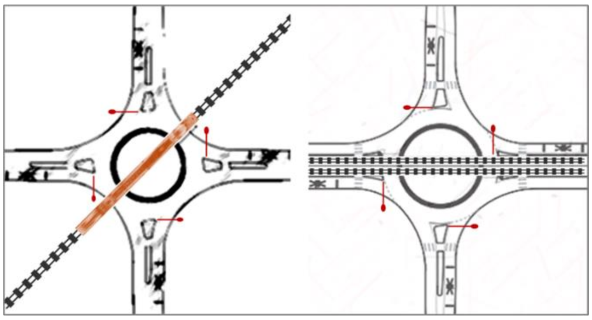

Figure no 8: Gated rail crossing through the center of a roundabout: providing gates across all roundabout entries.

For both cases, the railway can cross the roundabout within the roadway median and through the center of the roundabout, or diagonally through the center of the roundabout. The main characteristics of each scheme are presented in Table 2.

Table no 2: The main characteristics of the different schemes concerning the case of gated rail crossings through the center of a roundabout [1].

	The railway crosses the roundabout within the roadway median and through the center of the roundabout.	The railway crosses the roundabout diagonally through the center of the roundabout.
Gates on the circulatory roadway	Advantages: - delay reduction. - an attractive choice in cases of (a) low left-turn volumes across the track, (b) large diameter that can store left-turn vehicles, and (c) multilane roundabout that reduces queues by allowing through movements bypass left-turn movements. Disadvantages: - identification of traffic conflicts between rail, queued vehicles, and through movements.	Advantages: - an attractive choice in cases of (a) heavy right-turns, as benefits on the reduction of delays can occur, and (b) large diameter that can store through and left-turn vehicles.
Gates at all entries	Advantages: - increase road safety levels by preventing interactions between vehicles and the rail. Advantages: - increase in delays.	Advantages: - increase road safety levels by preventing interactions between vehicles and the rail. - an attractive choice in cases of small diameters, where queue storage on the circulatory roadway is limited. Disadvantages: - increase in delays.

V. Conclusion

This research emphasizes the significant issues related to at-grade rail crossings located near roadway intersections. Although these crossings are essential to transportation networks, they pose considerable dangers to both rail and road operations, such as delays, diminished visibility, and the possibility of accidents. The findings highlight the necessity of meticulous design to mitigate these issues, stressing the relevance of efficient visibility management, traffic flow coordination, and safety protocols for at-risk users. Proper use of existing rules and best practices can alleviate the negative effects of such crossings and improve both safety and operational efficiency. This research offers significant insights for enhancing the design of at-grade rail crossings adjacent to road junctions, aiming to reduce conflicts and optimize the interaction between rail and road traffic. Future endeavors must concentrate on the ongoing enhancement of these design solutions, considering advancing technology and safety regulations, guaranteeing a smooth and secure amalgamation of rail and road infrastructure.

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