IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 22, Issue 1 Ser. 1 (Jan. – Feb. 2025), PP 37-41
www.iosrjournals.org

Evaluating And Enhancing Safety At Railway Level Crossings: A Case Study Analysis Of A Railway Line In Southeastern Europe

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Abstract:
Rail-road level crossings represent critical safety points where road and rail networks intersect, posing significant risks to road users and train operations. This study examines the condition of 26 rail-road level crossings along a railway line located in Southeastern Europe, aiming to identify deficiencies and propose safety improvements. The evaluation of rail infrastructure according to existing documentation revealed numerous issues, including unprotected crossings, damaged or missing equipment, and unsafe conditions. Proposed interventions include the construction of grade-separated crossings, enhanced signage, road alignment adjustments, and equipment replacement. These measures, designed in compliance with international railway safety standards, aim to enhance safety and operational efficiency for both rail and road users.
Key Word: *Railway; Rail design; Rail crossing.*

Date of Submission: 25-01-2025 Date of Acceptance: 05-02-2025

I. Introduction

Assessing and improving safety at railway level crossings (LXs) is a vital issue, especially in areas such as Southeastern Europe, where accidents at these junctions constitute a considerable percentage of railway occurrences. Studies demonstrate that level crossings are perilous sites where trains, automobiles, and people intersect, resulting in a significant yearly toll in fatalities and injuries. In Europe, LX accidents account for over one-third of all railway incidents, leading to more than 300 fatalities a year. This concerning number highlights the immediate necessity for efficient safety protocols and creative strategies to reduce hazards linked to railway crossings.

A possible method for improving safety at level crossings is the deployment of automated traffic control systems. These systems utilize innovative technology to enhance the reliability and effectiveness of railway operations, especially at crossings where human error frequently contributes to accidents [1]. The incorporation of automated functionalities might markedly diminish the probability of accidents between trains and cars, while also enhancing overall traffic management at these vital intersections. A cost-effective methodology for automatic barricading at unmanned crossings has been presented, intending to improve safety while minimizing infrastructure expenses for railway authorities [2,3]. Such solutions are crucial in mitigating the issues presented by unmanned crossings, which are frequently more susceptible to accidents.

Furthermore, the utilization of machine learning and data analysis methodologies has demonstrated significant promise in enhancing safety characteristics at railway level crossings. Recent research indicates that machine learning can proficiently analyze and forecast safety concerns related to grade crossings, facilitating better informed decisions for safety improvements. Through the application of data-driven methodologies, railway operators may pinpoint high-risk crossings and execute focused interventions to diminish accident rates.

In summary, improving safety at railway level crossings in Southeastern Europe necessitates a comprehensive strategy that integrates technical advancements, data analytics, and deliberate infrastructure planning. The objective of this study is to assess the current condition of rail-road level crossings along a railway section in Southeastern Europe and propose targeted interventions to improve safety and functionality. The analysis reviews existing studies, aiming to align proposed solutions with international standards, including European directives on railway safety and interoperability.

II. Literature Review

At-grade railway crossings generate conflicts between road and rail traffic, as cars must consistently yield to trains, which need extended stopping lengths. Challenges escalate when such crossings are situated near traffic junctions due to the separate operation of their control systems. The absence of integration results in two primary

problems: cars waiting at the intersection may obstruct the tracks as a train arrives, and traffic signals may persist in guiding vehicles towards the crossing during a train's transit, resulting in hazardous congestion.

It is essential to design safe and efficient at-grade crossings. Collisions frequently arise from inadequate driving conduct and the intricate interconnections among trains, automobiles, pedestrians, and bicycles. These occurrences, intensified by poor visibility and insufficient alerts, pose considerable safety hazards. Researchers have suggested measures including sophisticated warning systems, automated gates, and pedestrian-oriented amenities to alleviate these concerns. Customizing treatments for locales, particularly in highly populated regions, is essential for enhancing safety.

Technological innovations such as intelligent transportation systems (ITS) have created novel methods to improve crossing safety and efficiency [1-5]. This encompasses real-time data exchange, predictive analytics, and connected vehicle (CV) technology, facilitating enhanced communication between trains and traffic signals. For example, CV-based warning systems, as suggested by Wang et al. [1], deliver real-time notifications to road users, therefore diminishing accident chances. Moreover, developments such as automated horn systems, as emphasized by Gent et al. [6], reduce noise pollution while ensuring effective alerts.

Train-car crashes are especially catastrophic due to the significant mass difference, frequently leading to fatalities among vehicle occupants while leaving train passengers unharmed. Nonetheless, these occurrences impose an emotional burden on train engineers and interrupt rail operations, resulting in delays and financial losses due to track closures for inquiry.

Traffic congestion at intersections presents an additional issue. Preemption control systems, which modify traffic signals in response to approaching trains, assist in alleviating congestion and enhancing safety. Although efficient under normal traffic conditions, these systems falter with high vehicle numbers or frequent rail crossings, resulting in significant delays and safety hazards. Congestion can extend to other crossings, exacerbating traffic flow issues and underscoring the necessity for more effective traffic management strategies.

III. Methodology

The study employed a combination of field inspections and document reviews to evaluate the current state of rail-road level crossings. Key steps included:

(a) Field inspections through digital monitoring, focusing on the existing protection measures, the condition of outdoor equipment including traffic signs and barriers, and finally the suitability of crossing geometry and sight distances.

(b) Documentation review. More specifically, the study reviewed existing reports, guidelines, and regulations, including the following as presented in Table 1.

Table 1: The examined documentation.

S/N	Examined Documentation
1	Directive 2001/16/EC amending Council Directive 91/440/EEC on the development of the Community's railways
2	Directive 96/48/EC on the interoperability of the trans-European high-speed rail system
3	Directive 2004/49/EC on the safety on the Community's railways
4	Directive 91/440/EEC on the development of the Community's railways
5	Directive 2001/12/EC amending Council Directive 91/440/EEC
6	Directive 2004/51/EC amending Council Directive 91/440/EEC
7	Directive 2004/50/EC amending Council Directive 96/48/EC
8	European Agreement on Main International Railway Lines (AGC)
9	European Agreement on Important International Combined Transport Railway Lines (AGTC)
10	Trans-European Railways (TER)
11	Analysis of level crossing safety in Europe and beyond, SAFER-LC Project, 2017
12	Level Crossings: A guide for managers, designers and operators, Railway Safety Publication 7, 2011

The railway section between Mitrovica and Leshak, in Southeastern Europe, consists of a total of 26 rail-road level crossings. Among these, 5 are equipped with relay interlocking systems and half barriers, providing a certain level of safety and control. However, the remaining 21 crossings lack proper protection or are only partially safeguarded, primarily relying on road traffic signs to alert drivers and pedestrians. Unfortunately, a significant portion of the outdoor equipment at the secured rail-road level crossings, including road traffic signs, has either been damaged or is missing altogether. This issue poses a serious risk to the safety and operational efficiency of the railway system, as the absence of functional safety equipment can lead to increased vulnerability at these crossings.

An indicative railroad crossing along the examined railway section is presented in Fig. 1, while a detailed map illustrating the locations of the rail-road level crossings is presented in Fig. 2. The map highlights the specific crossings that were thoroughly, offering a visual representation of the distribution and condition of these crossings. The evaluation process provided valuable insights into the current state of the railway infrastructure, identifying

critical areas in need of improvement and further attention to ensure safer and more reliable operation of the railway network.

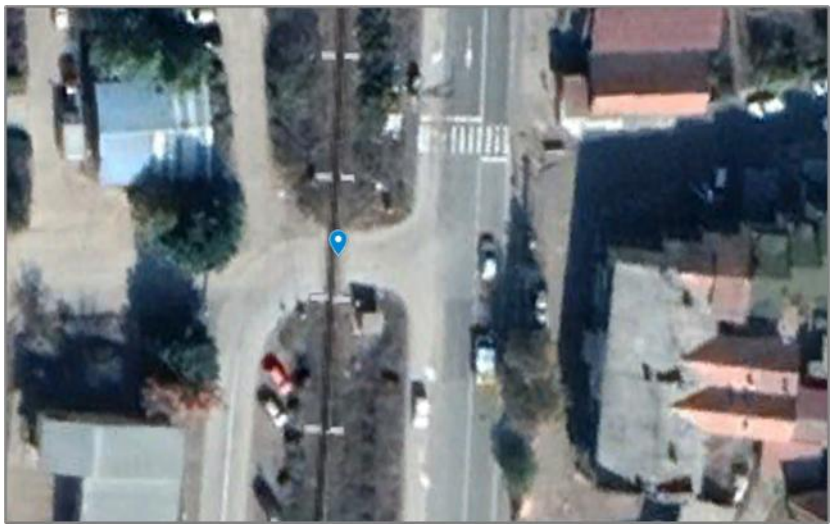

Figure 1: Indicative railway level crossing along the examined railway line.

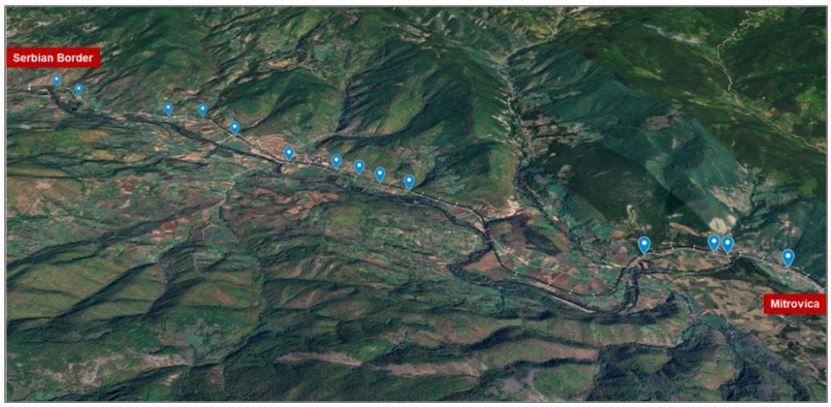

Figure 2: Mapping of the railway level crossings along the examined railway line.

Table 2 provides detailed information regarding the examined rail-road level crossings along the examined railway line.

Table 2: The examined rail-road level crossings.

S/N	Rail-road level crossing	Position on the line
1	Serbian Border - Leshak	168+270
2	Serbian Border - Leshak	168+863
3	Serbian Border - Leshak	170+554
4	Serbian Border - Leshak	171+054
5	Serbian Border - Leshak	171+881
6	Leshak - Leposavic	173+629
7	Leshak - Leposavic	173+952
8	Leshak - Leposavic	174+264
9	Leshak - Leposavic	174+659
10	Leshak - Leposavic	179+487.4
11	Leshak - Leposavic	180+065
12	Leposavic - Slatin e Ibrit	183+291
13	Leposavic - Slatin e Ibrit	185+048
14	Leposavic - Slatin e Ibrit	185+639
15	Leposavic - Slatin e Ibrit	188+532
16	Leposavic - Slatin e Ibrit	189+980
17	Leposavic - Slatin e Ibrit	191+005
18	Slatin e Ibrit - Banja	194+093
19	Slatin e Ibrit - Banja	195+718
20	Slatin e Ibrit - Banja	197+020
21	Slatin e Ibrit - Banja	199+666

22	Slatin e Ibrit - Banja	201+640
23	Banja - Valac	207+419
24	Valac - Zvecan	208+604
25	Valac - Zvecan	210+078
26	Zvecan - Mitrovica	211+481

IV. Results

The primary findings regarding the present state of the existing rail-road crossings, based on the site visit, are:

1. The current level crossings are hazardous, unprotected, and exacerbate unsafe conditions and risks that may result in a collision between trains and vulnerable road users.
2. The distance between the railway line and the main road is insufficient for the longest segment of the section. This fact leads to hazardous conditions due to inadequate seeing distances for oncoming vehicular traffic. Furthermore, the extent of the suggested actions will be constrained in numerous instances.
3. In numerous instances, the outdoor equipment at railway level crossings, including traffic signs, is either broken or absent.
4. Minimal vehicular traffic is noted at the level crossings.

Based on the findings from the assessment analysis, targeted solutions and interventions are recommended for implementation in the subsequent phases. Nearly all solutions necessitate minimal technical modifications. The subsequent steps are to adhere to the following indicated methodologies and interventions.

The development of grade-separated crossings is a critical intervention, aiming to convert existing level crossings into overpasses or underpasses, provided the geometry and elevation of the assessed site allow for such a transformation. This approach enhances safety by eliminating at-grade interactions between rail and road traffic. Additionally, a restriction on the aggregate number of rail-road level crossings is proposed by removing successive crossings of lesser significance, ensuring that the road alignment is appropriately reconnected through thorough studies.

The determination of the total number of level crossings must take into account the railway category and the prevailing traffic conditions on both the rail network and the intersecting roads. Where necessary, the construction and renovation of service roads will be prioritized. These service roads, designed to connect removed level crossings, must adhere to minimum width requirements, exceeding 5.5 meters, to accommodate traffic flow safely and efficiently.

In cases where existing equipment is impaired or absent, substitution and installation of the necessary apparatus will be undertaken. The expansion of level crossings to accommodate larger vehicles may also be required in specific locations, addressing the growing demand for freight and oversized vehicle transport. To ensure optimal safety, vertical and horizontal signage for both vehicular and rail traffic must be installed, enhancing the visibility and awareness of road users.

During the construction phase, the prioritization of safe access and egress at the site is essential. The ultimate solutions implemented must guarantee secure ingress and egress for vehicle users at all level crossings. Finally, any technical interventions on the local road network must be complemented by appropriate schematics and measures to safeguard the traffic safety of all road users, ensuring a holistic and comprehensive approach to level crossing management.

V. Discussion

The findings highlight significant deficiencies in the current state of rail-road level crossings along the examined railway line in Southeastern Europe. The lack of adequate protection measures and damaged infrastructure poses considerable risks to road users and train operations. While low traffic volumes may mitigate immediate safety concerns, the potential for future increases in rail and road traffic underscores the urgency of implementing the proposed interventions.

The recommended measures align with international standards and best practices, ensuring their applicability and effectiveness. However, practical constraints, such as geographical limitations and budgetary considerations, may influence the scope of interventions.

VI. Conclusions

This analysis highlights the urgent necessity for safety enhancements at rail-road level crossings on the Mitrovica–Leshak railway line. The existing circumstances—marked by unprotected crossings, impaired equipment, and inadequate sight distances—present significant hazards to both road users and rail operations.

The recommended interventions of the research, which encompass the construction of grade-separated crossings, the reduction of crossing points, and the enhancement of signs and barriers, provide a thorough strategy for risk mitigation.

One of the most critical suggestions involves converting level crossings to grade-separated buildings whenever possible. This option necessitates significant investment and planning, although it provides the most

substantial safety enhancements by completely removing the connection between train and road traffic. When grade separation is impractical, it is essential to improve visibility and protective measures, such automated barriers and sophisticated warning systems, to mitigate accident hazards.

The suggested restriction on redundant or small crossings is an economic strategy for improving safety. Consolidating crossings and providing sufficient alternate routes lowers total risk exposure while preserving connection for road users. The development of service roads adhering to appropriate size and quality requirements will provide unimpeded access.

Replacing damaged or absent infrastructure, including signage, barriers, and other vital equipment, is crucial. These enhancements not only augment the operation of crossings but also foster a safer and more dependable transportation network.

Subsequent research should concentrate on comprehensive feasibility assessments for the suggested treatments, considering geographic, economical, and environmental limitations. Moreover, stakeholder participation, encompassing feedback from local communities, road users, and railway operators, is essential for the effective execution of these initiatives. Monitoring and evaluation frameworks must be instituted to evaluate the efficacy of treatments and inform continuous enhancements.

This study's results and suggestions seek to enhance the safety and efficiency of railway and road transport systems. By emphasizing safety and implementing a comprehensive strategy for infrastructure enhancement, the hazards linked to rail-road level crossings may be markedly diminished, benefiting all users of the transportation network. This project exemplifies a framework for tackling analogous issues in different areas, highlighting the significance of cooperation, innovation, and compliance with global safety regulations.

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