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Factors in Improving the Safety of Railway Level Crossing Infrastructure in Indonesia

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ABSTRACT

Railway level crossings in Indonesia remain significant accident-prone areas, contributing to nearly 70% of total railway incidents. Various solutions have been implemented to reduce the risk of accidents at level crossings, including converting them into non-level crossings. However, selecting the most appropriate infrastructure alternative is often challenging because it involves multiple factors, making the process time-consuming and prone to conflict. This study aims to identify and rank the factors influencing improvements in level crossing infrastructure safety using a descriptive-analytical approach. Five main criteria are established in this study—safety, technical, economic, environmental, and social—which are further divided into several relevant sub-criteria based on previous literature. Data were collected through questionnaires distributed to nine expert respondents from government agencies, railway operators, and consulting firms. The results show that accident history, structural durability, maintenance costs, sustainable drainage, and traffic impacts are the most prioritized factors. These findings highlight the need for a quantitative, holistic, and multidimensional approach to decision-making, considering the high level of complexity and potential conflicts of interest among stakeholders. This research provides a foundation for formulating more objective and sustainable policies in designing future alternatives for non-level crossing infrastructure.

KEYWORDS Descriptive Statistical Analysis, Level Crossing, Priority Railway, Safety Improvement

INTRODUCTION

Railway infrastructure has a strategic role in supporting community mobility and driving national economic growth (Nesterov et al., 2022). The double-track construction program (Martin & Witjaksana, 2023), rail electrification (Setiawan, 2024), and reactivation of inactive lines such as Makassar-Parepare with the Government Cooperation with Business Entities (KPBU) scheme (Haq, 2024) are among the strategic plans of the Ministry of Transportation to increase the efficiency and capacity of railway transportation in Indonesia.

However, this development also poses challenges, especially in terms of safety at level crossings. Increasing train frequency has implications for increasing interactions with vehicles and pedestrians at railway and highway intersections. In addition, the growth of urban areas around railway lines has increased traffic density at crossings, increasing the risk of accidents, congestion, and social and economic impacts (Alotaibi et al., 2022). This problem is exacerbated by the growth of motorized vehicles that is not balanced by increased safety facilities and regulations (Wicaksono et al., 2022). Based on data from the Directorate General of Railways, accidents at level crossings account for almost 70% of the total railway incidents in Indonesia. With the number of level crossings continuing to increase, concrete efforts are needed to improve safety at these vulnerable points (Sari, 2021).

Various solutions have been implemented to reduce the risk of accidents at level crossings, including increasing safety by changing the shape of the crossing to a non-level crossing. The types of infrastructure used in non-level crossings include flyovers (Asyrofle & Siswoyo, 2025), underpasses (Rakasiwi, 2021), and elevated railways (Prihatanto et al., 2023) to separate train and vehicle lanes. In addition, safety improvements are also carried out by closing crossings at critical locations (Romadhona & Artistika, 2020). However, the plan to select the most appropriate infrastructure alternative is often a challenge because it involves various factors, such as safety (Liang & Ghazel, 2023), cost (Kowalski et al., 2021), environmental impact (Sanjaya & Puspitasari, 2020), and integration with spatial planning and transportation policies (Abidin et al., 2022). This certainly requires coordination with policy makers (stakeholders) which of course takes time and is prone to disputes (Wicaksono et al., 2022).

The urgency of this research is therefore paramount. Given the high and persistent rate of accidents and the increasing pressure on the railway network, decision-makers urgently require a structured, multi-criteria tool to guide infrastructure investments. Without such a tool, the selection process risks becoming prolonged, prone to stakeholder conflict, and potentially leading to suboptimal outcomes that fail to maximize safety benefits or long-term value for money. The systematic identification and prioritization of key factors, grounded in stakeholder consensus, represent a crucial first step toward developing such a tool.

This study aims to identify and select criteria and sub-criteria based on the concept of sustainable construction for railway level crossings in Indonesia, using descriptive analysis methods. The research also seeks to provide a practical reference for decision-makers and stakeholders in selecting appropriate and sustainable level crossing infrastructure alternatives.

RESEARCH METHOD

The concept of this research is to formulate various criteria along with relevant sub-criteria in selecting alternative infrastructure used at railway level crossings along with their importance weight values based on the perspective of policy makers. The initial criteria in this study come from the development of research criteria by Mathew et al. (2021) and Lajevardi et al. (2022) which are aligned with sustainability aspects by Luo & Yang (2023) and Goulart et al. (2024). The object of the research was carried out in Operational Area VIII Surabaya PT. Kereta Api Indonesia. This study uses descriptive statistical analysis for each variable that has been identified. The results of the research synthesis show that there are at least five criteria that are considered in improving safety at railway level crossings with infrastructure development as in Table 1 below:

Table 1. Criteria for Improving Crossing Safety

	Criteria	Definition
A	Safety	Infrastructure must be able to minimize the risk of accidents, increase user protection, and enable rapid response in emergencies.
B	Technical	Infrastructure must be resilient to environmental conditions, easy to maintain, and support the integration of the latest transportation technologies.
C	Economy	Infrastructure must provide long-term benefits through cost efficiency, energy savings, and positive economic impacts on communities.
D	Environment	Infrastructure must minimize ecological impacts, support emission reductions, and maintain environmental quality in accordance with sustainable transportation principles.
E	Social	Infrastructure must improve user comfort and accessibility and be in harmony with the surrounding environment and public facilities.

This study takes sub-criteria that have been studied in previous studies as well as standards that apply in the construction and railway world. Each sub-criterion is then distinguished by type by referring to the Cost-Benefit Analysis concept. The Cost criterion tends to have a negative impact on infrastructure if the value is higher (lower-better), while the Benefit criterion has a positive impact on infrastructure if the value is higher (higher-better). References to sub-criteria and their types can be seen in Table 2 below.

Table 2. Research Criteria and Sub-Criteria

Code	Criteria and Sub-criteria	Source	Types of Criteria (*Benefit*/*Cost*)
A1	Accident History	(Liang & Ghazel, 2023), (Arisikam et al., 2024)	*Cost*
A2	Driver's Sight Distance	(Tardivo et al., 2021), (Qin et al., 2023)	*Benefit*
A3	Maximum Crossing Capacity	(Ramadan & Özdemir, 2022)	*Benefit*
A4	Ease of Emergency Handling	(Montenegro et al., 2021), (Ogden & Cooper, 2019)	*Benefit*
A5	Potential for Illegal Pedestrians	(Singh, 2021), (Liang & Ghazel, 2023), (Astuti et al., 2024)	*Cost*
A6	Potential for Vandalism	(Sasidharan et al., 2017), (Read et al., 2021)	*Cost*
B1	Structure Durability		*Benefit*
B2	Construction Duration	(Zhang & Fom, 2022), (Hastama & Sahid, 2023)	*Cost*

Code	Criteria and Sub-criteria	Source	Types of Criteria (*Benefit/Cost*)
B3	Soil Characteristics	(Turkoglu et al., 2024)	*Benefit*
B4	Maximum Train Speed	(Jing et al., 2019), (Montenegro et al., 2021),	*Benefit*
B5	Ease of Maintenance	(Alotaibi et al., 2022), (Binder et al., 2023)	*Benefit*
B6	Ease of Methodology	(Zhang & Fom, 2022), (Prihatanto et al., 2023)	*Benefit*
C1	Construction Cost	(Kowalski et al., 2021), (Hastama & Sahid, 2023)	*Cost*
C2	Land Acquisition Cost	(Murakami et al., 2018), (Kowalski et al., 2021),	*Cost*
C3	Maintenance Cost	(Kowalski et al., 2021), (Liljenström et al., 2022), (Prastowo & Purba, 2020)	*Cost*
C4	Availability of Local Materials	(Jing et al., 2019), (Tardivo et al., 2021)	*Benefit*
C5	Potential for Delay Losses	(Pasha et al., 2021), (Hastama & Sahid, 2023),	*Cost*
C6	Potential for Occupancy Increase	(Szaciłło et al., 2021), (Qian et al., 2024)	*Benefit*
D1	Biodiversity Impact	(Kowalski et al., 2021), (Marković et al., 2022),	*Cost*
D2	Vibrational Impact	(Marković et al., 2022), (Milewicz et al., 2023), (Noruzi et al., 2023),	*Cost*
D3	Sustainable Drainage	(Lajevardi et al., 2022),	*Benefit*
D4	Carbon Emissions	(Sanjaya & Puspitasari, 2020), (Zhou et al., 2021), (Ahsan et al., 2023),	*Cost*
D5	Air Quality	(Tardivo et al., 2021),,	*Benefit*
D6	Waste Generated	(Ahsan et al., 2023), (Wardahni & Latief, 2024)	*Cost*
E1	Pedestrian Accessibility	(Metaxatos & Sriraj, 2015), (Zakharov & Komarov, 2023),	*Benefit*
E2	Traffic Impact	(Catalano et al., 2019), (Pasha et al., 2021),	*Cost*
E3	Architectural Aesthetics	(Xiahou et al., 2022), (Ahsan et al., 2023),	*Benefit*
E4	Traffic Sight Distance	(Hadj-Mabrouk, 2019), (Marcelli & Pellegrini, 2020)	*Benefit*
E5	Passenger Comfort	(Peng et al., 2022), (Ma et al., 2024), (Saxena, 2024)	*Benefit*
E6	Potential for Mobilization Increase	(Li & Love, 2020), (Xiahou et al., 2022), (Madigliani et al., 2024)	*Benefit*

RESULT AND DISCUSSION

Respondent Data

Based on the research objectives, the research sample was selected using purposive sampling, where the selected respondents came from 3 types of agencies, namely the Railway Engineering Center of the Directorate General of Railways of East Java 1 as the person in charge of the railway project, PT. Kereta Api Indonesia (Persero) Operational Area VIII Surabaya as the train travel operator, and consultants as third parties in making considerations. There were 9 experts as respondents in this study. The recapitulation of the respondent profile data for this study can be seen in Figures 1 and 2 below.

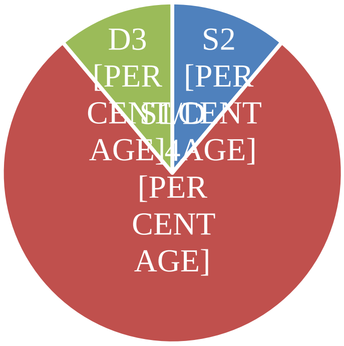

Figure 1. Respondents' Education Level

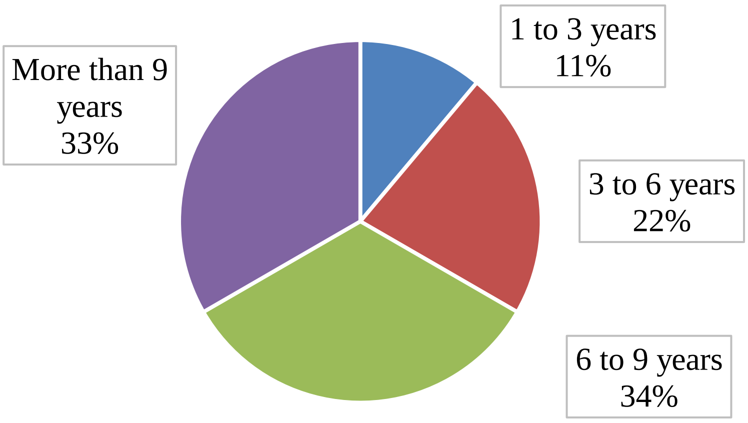

Figure 2. Respondents' Experience Level

Level of Suitability of Variables

The distribution of questionnaires at this stage aims to evaluate the relevance of the variables that have been identified. The questionnaire survey was conducted with a Likert scale of 1 (one) (representing "strongly disagree") and a scale of 5 (five) (describing "strongly agree"), as shown in Table 3 below:

Table 3. Likert Scale for Suitability of Variables

Rating Scale	Definition
5	**Strongly Agree,** meaning the variable is considered Very Necessary
4	**Agree,** meaning the variable is considered Necessary
3	**Neutral,** meaning the variable is considered Quite Necessary
2	**Disagree,** meaning the variable is considered Not Necessary
1	**Strongly Disagree,** meaning the variable is considered Very Not Necessary

Meanwhile, the results of the assessment of the level of suitability of the variables can be seen in Table 4 below:

Table 4. Results of Variable Suitability Assessment

Code	Criteria dan Sub-Criteria	Values from Respondents									Average	Compliance
		1	2	3	4	5	6	7	8	9		
A	SAFETY											
A1	Accident History	5	5	5	5	3	5	4	5	5	4,667	Appropriate
A2	Driver's Sight Distance	1	5	3	5	4	5	5	4	4	4,000	Appropriate
A3	Maximum Crossing Capacity	5	5	3	2	4	5	5	4	4	4,111	Appropriate
A4	Ease of Emergency Handling	5	3	3	1	3	5	3	4	3	3,333	Inappropriate
A5	Potential for Illegal Pedestrians	4	5	5	1	5	4	5	4	4	4,111	Appropriate
A6	Potential for Vandalism	4	4	4	1	4	5	4	4	4	3,778	Tidak Sesuai
B	TECHNICAL											
B1	Structure Durability	5	5	5	5	3	5	5	4	5	4,667	Appropriate
B2	Construction Duration	3	5	5	1	5	5	5	4	4	4,111	Appropriate
B3	Soil Characteristics	5	5	3	2	4	5	4	4	4	4,000	Appropriate
B4	Maximum Train Speed	3	4	5	3	4	5	4	4	4	4,000	Appropriate
B5	Ease of Maintenance	5	5	5	4	4	5	4	4	5	4,556	Appropriate
B6	Ease of Methodology	5	5	5	5	4	5	4	4	5	4,667	Appropriate
C	ECONOMICAL											
C1	Construction Cost	5	5	5	5	5	5	4	4	5	4,778	Appropriate
C2	Land Acquisition Cost	5	4	5	5	4	5	5	4	5	4,667	Appropriate
C3	Maintenance Cost	5	4	5	5	3	5	4	4	4	4,333	Appropriate
C4	Availability of Local Materials	5	4	2	3	5	1	2	4	3	3,222	Inappropriate
C5	Potential for Delay Losses	5	3	2	5	4	3	3	4	4	3,667	Inappropriate
C6	Potential for Increased Occupancy	5	3	5	5	3	5	3	4	4	4,111	Appropriate
D	ENVIRONMENTAL											
D1	Biodiversity Impact	5	3	5	4	4	5	3	4	4	4,111	Appropriate
D2	Vibrational Impact	5	4	2	4	4	5	4	5	4	4,111	Appropriate
D3	Sustainable Drainage	5	5	5	4	5	5	4	5	5	4,778	Appropriate
D4	Carbon Emissions	5	3	2	4	5	5	3	4	4	3,889	Inappropriate
D5	Air Quality	5	3	2	4	4	5	4	4	4	3,889	Inappropriate
D6	Waste Generated	5	4	2	4	4	3	4	4	4	3,778	Inappropriate
E	SOCIAL											
E1	Pedestrian Accessibility	5	5	5	4	5	5	2	4	4	4,333	Appropriate
E2	Traffic Impact	5	5	5	5	5	5	4	5	5	4,889	Appropriate
E3	Architectural Aesthetics	3	3	5	3	5	5	4	4	3	3,889	Inappropriate
E4	Traffic Sight Distance	5	5	5	3	5	1	3	5	4	4,000	Appropriate
E5	Passenger Comfort	1	4	1	4	5	5	4	4	4	3,556	Inappropriate
E6	Potential for Increased Mobilization	5	4	5	5	5	5	4	4	5	4,667	Appropriate

Level of Importance of Variables

At this stage, the ranking is determined based on the results of the previous questionnaire survey, by eliminating research variables that do not meet the consensus of suitability. The assessment at this stage uses a Likert scale of 1 (one) to 9 (nine), with the average value of the respondents' answers indicating the level of priority for the variables being assessed. The assessment scale can be seen in Table 5 below.

Table 5. Likert Scale for Variable Importance

Rating Scale	Definition
1	Absolute Low Interest
2	Very Low Interest
3	Low Interest
4	Slightly Lower Interest
5	Equally Important/Neutral
6	Slightly Higher Interest
7	High Interest
8	Very High Interest
9	Absolute High Interest

Meanwhile, the results of the variable importance level assessment can be seen in Table 6 below:

Table 6. Results of the Variable Importance Level Assessment

Code	Criteria and Sub-criteria	Values from Respondents									Average	Ranking
		1	2	3	4	5	6	7	8	9		
A	SAFETY											
A1	Accident History	9	8	9	8	9	9	7	8	9	8,444	1
A2	Driver's Sight Distance	5	9	5	7	9	7	8	7	8	7,222	3
A3	Crossing Capacity	5	8	9	5	8	7	8	9	6	7,222	4
A5	Potential for Illegal Pedestrians	9	7	9	5	9	5	7	8	8	7,444	2
B	TECHNICAL											
B1	Structure Durability	9	8	9	7	9	5	9	8	9	8,111	1
B2	Construction Duration	8	7	9	5	7	5	5	6	9	6,778	6
B3	Soil Characteristics & Geometry	9	6	9	7	5	9	7	7	8	7,444	4
B4	Maximum Train Speed	9	7	9	8	8	7	7	7	8	7,778	3
B5	Ease of Maintenance	9	7	9	8	7	8	9	7	7	7,889	2
B6	Ease of Methodology	9	7	9	8	7	8	5	7	7	7,444	5
C	ECONOMIC											
C1	Construction Cost	5	8	9	5	5	5	8	7	8	6,667	4
C2	Land Acquisition Cost	9	9	9	6	5	9	5	9	8	7,667	2
C3	Maintenance Cost	9	7	9	8	5	9	7	8	8	7,778	1
C6	Potential for Increasing Occupancy	5	5	9	8	8	3	8	8	8	6,889	3
D	ENVIRONMENTAL											

Code	Criteria and Sub-criteria	Values from Respondents									Average	Ranking
D1	Biodiversity Impact	9	5	9	9	7	3	6	7	8	7,000	3
D2	Vibrational Impact	9	5	9	9	8	5	5	6	8	7,111	2
D3	Sustainable Drainage	9	9	9	9	9	8	7	8	8	8,444	1
E	SOCIAL											
E1	Pedestrian Accessibility	9	9	9	9	9	7	7	9	8	8,444	2
E2	Traffic Impact	9	9	9	9	9	9	8	9	8	8,778	1
E4	Traffic Sight Distance	9	9	9	9	9	5	7	8	8	8,111	3
E6	Potential for Increasing Mobilization	7	5	9	9	8	8	8	9	8	7,889	4

Safety Criteria

The survey results show that accident history is the most prioritized safety factor in improving level crossing infrastructure. This finding reflects the importance of adopting a historical data-based approach in evaluating and intervening at accident-prone locations. In second place, the potential for illegal crossings receives significant attention, as unguarded or poorly equipped crossings are often misused by road users attempting dangerous crossings, thereby increasing the risk of fatal accidents. Meanwhile, driver visibility and crossing capacity have equal priority levels, indicating that both are considered equally important in ensuring train operation safety. Limited driver visibility often causes delayed reactions to obstacles on the tracks, while crossing capacity relates to the intensity of train schedules, which can increase risk if not supported by an adequate safety system.

Technical Criteria

Regarding technical aspects, structural durability emerged as the main priority factor. Strong and durable structures reduce the frequency of major maintenance and minimize the risk of structural failure that could lead to disruptions or accidents. Ease of maintenance ranks second because the frequency and effectiveness of maintenance significantly determine the operational condition of crossings. The maximum train speed factor ranks third, reflecting that crossing design must consider train speed to ensure system compatibility and the safety of both passengers and road users. Furthermore, soil characteristics and geometry, as well as ease of construction methodology, hold equal priority values, indicating that geotechnical conditions and implementation techniques are viewed as equally vital for construction efficiency. Construction duration ranks lowest, suggesting that while important, construction time is not the primary consideration compared to structural quality and long-term functionality.

Economic Criteria

Under the economic criteria, maintenance costs rank highest, emphasizing that the financial sustainability of crossing operations is prioritized over initial investment. This shows that stakeholders regard long-term efficiency as more crucial than construction expenses alone. Land acquisition costs rank second, highlighting the importance of addressing administrative and socio-economic aspects related to land procurement—particularly in densely populated or high-value areas. Conversely, the potential for increased occupancy ranks third, indicating that while the economic benefit of higher traffic volumes is considered, it is secondary to direct cost-related factors. Construction costs rank lowest, suggesting that in Indonesian railway projects, initial expenses are not the main determinant as long as long-term benefits and passenger safety can be ensured.

Environmental Criteria

Within the environmental criteria, sustainable drainage ranks as the top priority. This underscores the awareness that sound water management and drainage systems are essential for infrastructure safety and resilience to climate change. Vibrational impacts occupy the second position, recognizing that vibrations from train movement can affect both structural integrity and community comfort. Biodiversity impacts rank last in this criterion, suggesting that while environmentally relevant, this aspect is considered less urgent in the specific context of level crossings compared to direct risks to infrastructure and human safety.

Social Criteria

In the social dimension, traffic impacts rank highest, highlighting the importance of evaluating disruptions caused by crossings on road traffic flow, especially in densely populated urban areas. Congestion resulting from prolonged waiting times at crossings often creates inconvenience and potential violations by road users, ultimately compromising safety. Pedestrian accessibility ranks second, reflecting growing attention to the safety and comfort of non-motorized users. Traffic visibility ranks third, emphasizing the importance of crossing designs that ensure road users can clearly see oncoming trains or warning signs. Lastly, the potential for increased mobility ranks lowest, indicating that the long-term mobility benefits for communities are regarded as less pressing than reducing the immediate risks and negative impacts associated with level crossing operations.

CONCLUSION

This study demonstrates that the selection of safety-enhancing infrastructure for railway level crossings in Indonesia requires a multidimensional approach encompassing safety, technical, economic, environmental, and social aspects. The analysis results reveal priority criteria that reflect the real needs and diverse perceptions of stakeholders. Consequently, factors such as accident history, structural durability, maintenance costs, sustainable drainage, and traffic impacts emerge as the main considerations in determining the optimal type and approach to infrastructure development. These findings reinforce the argument that development decisions must be based on systematic evaluation rather than solely relying on technical standards, static regulations, or sectoral preferences.

Further research is strongly recommended to develop a multi-criteria decision-making model that is not rigid or exclusive to specific alternatives. Each infrastructure option should be assessed using proportional weighting, even if it does not completely satisfy a single dominant criterion. This approach ensures that the resulting solutions remain inclusive of local conditions, budget constraints, and on-site dynamics. In addition, the exploration of innovative infrastructure alternatives—particularly those not yet implemented in Indonesia—is necessary to expand the portfolio of solutions adaptable to both urban and non-urban contexts. More specific and in-depth studies are also needed for each criterion, focusing on managerial implications, long-term investment potential, project reliability throughout the life cycle, and issues of regulatory and cross-institutional coordination.

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