Journal of Railway Transportation and Technology
Vol. 4 No. 2 (2025) 27-36
eSSN: 2830-6880

Accident Risk Analysis at Level Crossings Based on Physical and Operational Characteristics
(Case Study: Crossing Points in Medan City Area)

Aldi B.J. Hamdani[1], Mukhammad Rizka Fahmi Amrozi[2]

[12]Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada
Jl. Grafika No.2, Yogyakarta, 55281, INDONESIA

Article Info

Article history:

Received :
September 29, 2025
Revised :
November 7, 2025
Accepted :
December 17, 2025

Keywords:

Level crossing
Accident risk
ALCAM
Contributing factors
Medan City

ABSTRACT

Level crossings are critical safety points in railway operations due to the interaction between trains and road traffic. In Indonesia, many crossings in urban areas such as Medan operate with limited safety infrastructure, increasing the likelihood of serious accidents. This study aims to evaluate accident risks and propose mitigation strategies for selected level crossings in Medan.
A quantitative risk assessment was conducted using the Australian Level Crossing Assessment Model (ALCAM), which considers infrastructure, exposure, and consequence factors. Data were collected through field observations, interviews with crossing attendants, and secondary records from local transport authorities. Three locations were analyzed: KM 9+30 on the Medan–Binjai line, and JPL 1 (KM 0+640) and JPL 4 (KM 1+325) on the Medan–Tanjung Balai line.
The ungated crossing at KM 9+30 had a risk score of 0.053, JPL 1 the highest at 0.136, and JPL 4 at 0.076. Simulated mitigation strategies substantially reduced risks to 0.020, 0.051, and 0.038, respectively.
These findings demonstrate that ALCAM provides a reliable framework for quantifying risks and prioritizing safety improvements at level crossings in Indonesia.

Corresponding Author:

Aldi B.J. Hamdani
Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada
Jl. Grafika No.2, Yogyakarta, 55281, Indonesia
Email: aldibjhamdani@mail.ugm.ac.id

1. INTRODUCTION

Level crossings are recognized as critical conflict points in railway transportation because of the interaction between trains and road vehicles. In Indonesia, accident risks remain high, particularly in urban areas such as Medan, where many crossings operate without adequate safety facilities. National statistics recorded more than 3,000 crossings below standard, with approximately 1,500 categorized as unofficial [3].

Previous studies highlight that accidents at level crossings are commonly associated with inadequate infrastructure, poor geometric design, driver non-compliance, and unauthorized crossings. Budiharjo et al. [2] found that poor geometric design significantly increases accident risk, while Salsabila [9] emphasized that unauthorized and unmonitored crossings exacerbate collisions. Putra Iswanto et al. [6] reported that accidents may still occur at official crossings due to driver violations, and Read et al. [8] confirmed that road conditions, protective devices, and risk perception also contribute. In Medan, Rahim [7] identified limited facilities and high traffic volumes as key causes of accidents. International studies have also demonstrated alternative methods such as fuzzy logic [10] and preemption strategies [1], though their practical adoption remains limited. Despite these efforts, risk assessments in Indonesia still rely heavily on historical accident data, traffic volume, and train frequency, without integrating multidisciplinary quantitative approaches as in developed countries. To address this gap, this study applies the Australian Level Crossing Assessment Model (ALCAM), which combines infrastructure, exposure, and consequence factors into a unified risk score [5]. By focusing on selected crossings in Medan, the study aims to evaluate physical and operational characteristics, determine zaccident risk levels, and propose mitigation strategies.

The novelty of this research lies in adapting ALCAM to Indonesian conditions, providing an evidence-based framework for prioritizing safety improvements and supporting national railway safety policies.

The novelty of this research lies in adapting ALCAM to Indonesian conditions, providing an evidence-based framework for prioritizing safety improvements and supporting national railway safety policies. Compared to these studies, this research provides a more integrated approach by combining both physical and operational characteristics within the ALCAM framework. Unlike Budiharjo et al. [2] and Salsabila [9]m, who focused primarily on geometric and behavioral aspects, this study quantitatively synthesizes multiple factors to evaluate comprehensive risk levels. Therefore, it bridges the gap between descriptive and quantitave analyses in the Indonesian context.

2. RESEARCH METHOD

This study applied a quantitative risk-based approach to evaluate the safety of selected railway level crossings in Medan, Indonesia. The Australian Level Crossing Assessment Model (ALCAM) was employed as the main analytical framework, integrating infrastructure, exposure, and consequence factors into a single risk score [5].

The research was conducted at three locations representing different operational and protection characteristics: KM 9+30 on the Medan–Binjai line (unguarded crossing without barriers), and JPL 1 (KM 0+640) and JPL 4 (KM 1+325) on the Medan–Tanjung Balai line (guarded crossings), as illustrated in Figure 1. The research flow comprised problem identification, literature review, field surveys, data collection, risk assessment using ALCAM, and sensitivity analysis to determine the dominant risk factors.

These three sites were selected based on accident data from the Directorate General of Railways, representing locations with high, medium and low accident frequencies within the Medan City area. In addition, they reflect different types of protecting and operational environment an ungated rural-type crossing, a semi-urban guarded crossing, and a highly urbanized arterial crossing. This variation enables a comparative evaluation of ALCAM performance under diverse traffic and infrastructure conditions.

(a) (b) (c)

Figure 1. Research location, (a) KM 9+30 (Medan – Binjai line, without barriers), (b) KM 0+640 (Medan – Tanjung Balai line, JPL 1), (c) KM 1+325 (Medan – Tanjung Balai line, JPL 4)

Primary data were collected through direct field observations and interviews with crossing guards. These included road traffic volume and composition, geometric road conditions, visibility, and an inventory of safety facilities such as barriers, signals, and warning devices. Secondary data were obtained from the Medan City Transportation Agency, the Railway Engineering Center Class I Medan, and PT Kereta Api Indonesia, consisting of rail traffic data, technical specifications, and accident records over the past decade.

Field instruments used in this study included digital cameras, measuring tools, traffic counters, voice recorders, and supporting software such as Microsoft Excel, AutoCAD, and Google Earth. These tools were applied to ensure accurate measurement and documentation of field conditions.

Data analysis was performed using ALCAM, which mathematically combines the infrastructure factor (physical and technical conditions), exposure factor (interaction frequency between trains and road vehicles), and consequence factor (severity of potential accidents), as illustrated in Figure 2. The resulting risk scores were converted into accident and fatality probability estimates. In addition, sensitivity analysis was conducted to identify the most influential variables, allowing the prioritization of effective mitigation strategies.

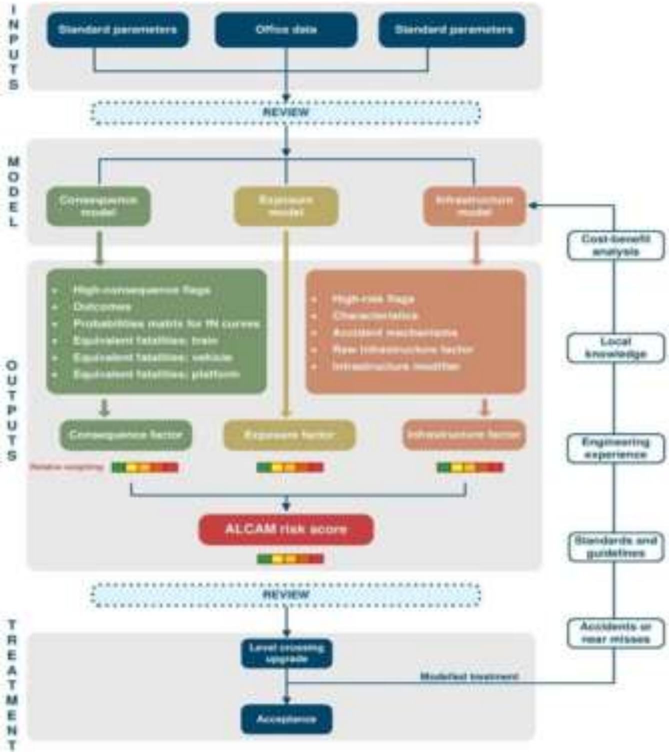

Figure 2. Australian Level Crossing Assessment Model

The research flowchart was developed to provide a comprehensive overview of the stages carried out, beginning with problem identification, literature review, and collection of primary and secondary data, followed by analysis using the Australian Level Crossing Assessment Model (ALCAM). As presented in Figure 3, the flowchart illustrates the systematic sequence of interpreting results, discussion, and deriving conclusions and recommendations.

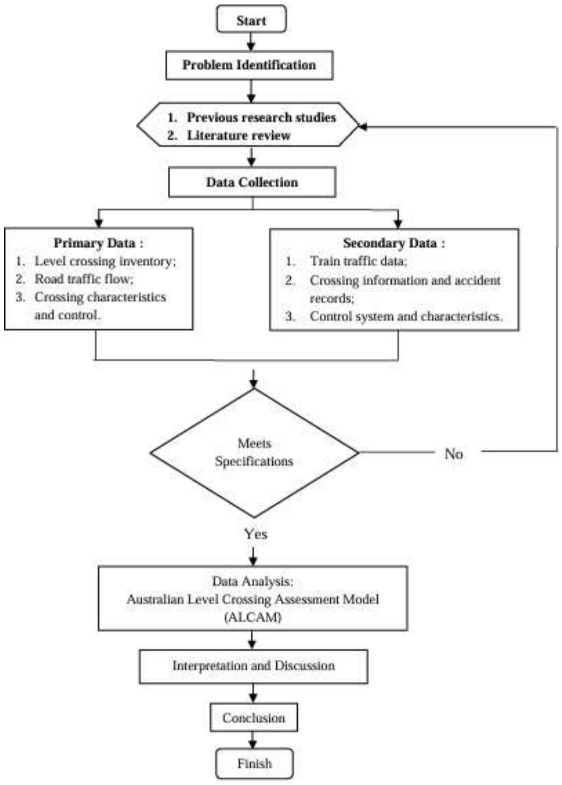

Figure 3. Research flowchart

2.1. ALCAM Calculation and Assumptions

The ALCAM model applies a weighted linear combination of three primary components: infrastructure, exposure and consequence factors. Each component consists of several measurable indicators that are normalized and assigned weighting coefficients based on empirical calibration.

$$R = I \times E \times C \qquad (1)$$

Where ;
R = Alcam risk score (equivalent fatalities per year) ;
I = Infrastructure factor ;
E = Exposure factor ;
C = Consequence factor (Equivalent fatalities per collision).

The risk score R (equivalent fatalities per year) is calculated as the product of the likelihood factor (collisions per year) and the consequence factor C (equivalent fatalities per collision). The likelihood factor is obtained from the multiplication of the infrastructure factor and the exposure factor (E). The infrastructure factor (I) is obtained from field observations and assessments that combine both quantitative measurements and qualitative evaluations from the perspective of researchers, road users and railway operators. The infrastructure score ranges from 0 to 800, where a higher value indicates a greater level of accident risk. While the consequence factor is derived from national accident records in Indonesia over the past ten years, encompassing both guarded and unguarded level crossings.

The exposure factor is expressed as :

$$A_5 = l_u + K \qquad (2)$$

Where :
A_5 = Estimated number of accidents occurring within a five-year period ;
L_u = Unbalanced accident factor representing the imbalance between road traffic volume and train frequency;
K = Additional correction factor reflecting local field conditions.

The additional parameter K is determined using a graph-based calculation or a specific chart designed to represent variations in operational and infrastructure conditions at the analyzed level crossing locations, as illustrated in Figure 4.

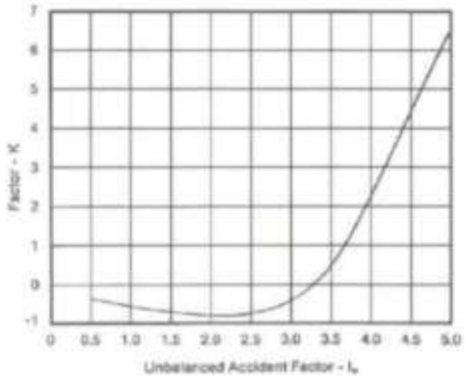

Figure 4. Additional correction factor (K) chart

Based on the chart shown in Figure 4, the resulting polynomial equation is:

$$(-0{,}0329 \times l_u^5) + (0{,}3996 \times l_u^4) - (1{,}604 \times l_u^3) + (2{,}9503 \times l_u^2) - (2{,}891 \times l_u) + 0{,}6549 \qquad (3)$$

The unbalanced accident factor (l_u) is formulated as follows :

$$L_u = 1{,}28 \times (V^{0{,}170}) \times (T^{0{,}151}) / (P^{0{,}171}) \qquad (4)$$

Where :
V = Road traffic volume at the level crossing ;
T = Frequency of train movement across the crossing and
P = Protection factor representing the level of safety measures available at the crossing.

3. RESULTS AND DISCUSSION

This section presents the characteristics of the observed level cossings, the calculated accident risk levels using the Australian Level Crossing Assessment Model (ALCAM), and the impact of mitigation strategies. The three case study sites were KM 9+30 on the Medan–Binjai line (unguarded), and JPL 1 (KM 0+640) and JPL 4 (KM 1+325) on the Medan–Tanjung Balai line (guarded).

3.1. Characteristics of Level Crossings

Field surveys and secondary data provided a comprehensive inventory of the physical and operational conditions. The collected data included infrastructure inventory, safety facilities, road traffic volume, train frequency, and accident records from 2015–2024. All data were analyzed using the Australian Level Crossing Assessment Model (ALCAM) to assess accident risk levels and formulate technical recommendations for safety improvements.

3.1.1 Crossing inventory

Field observations were conducted to document the actual conditions of the crossings, covering physical, technical, and operational aspects such as infrastructure, road conditions, and safety equipment (barriers, signals, signs, and lighting).

a. KM 9+30 (Medan – Binjai line, unguarded crossing)
   Based on observations and PT KAI Divre I data (Table 1), this crossing is located on Stasiun Road,Lalang Village, Sunggal Subdistrict, Deli Serdang Regency. It has no barriers, linking Desa Lalang with Medan and Binjai via a two-lane local road (type 2/2-U) that is often used as a shortcut (Figure 5).

Table 1 – Road characteristics at KM 9+30 crossing (Medan – Binjai line)

No	Uraian	Keterangan
1	JPL Number	No number
2	Type of level crossing	No gate
3	Operation	-
4	Number of road lanes	Two
5	Road name	Jl. Stasiun
6	City / Regency	Sunggal Subdistrict, Deli Serdang Regency
7	Coordinates	3.604458, 98.604492
8	Road class	IIIC
9	Road status	Village road
10	Road function	Local or neighborhood road
11	Road contour	Flat
12	Road type	2/2-U
13	Road width (m)	5
14	Pavement type	Asphalt
15	Speed limit (km/jam)	40
16	Distance to previous crossing (m)	410
17	Distance to next crossing (m)	1395
18	Minimum sight distance (m)	>700
19	Driver's sight distance (m)	<150
20	Portal distance of crossing to track (m)	-

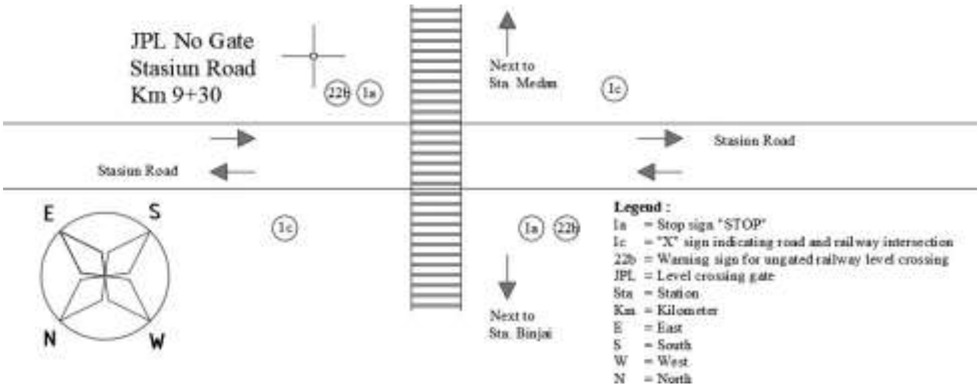

Figure 5. Layout of KM 9+30 crossing (Medan – Binjai line)

b. KM 0+640 (Medan – Tanjung Balai line, JPL 1)
This crossing is located on Jl. M.T. Haryono, a primary arterial route in Medan's transport network. The Class I road connects strategic urban areas, including Jl. Sisingamangaraja and major service centers. With a width of over 12 meters, it carries high traffic volumes with diverse vehicles and serves as a key transport corridor in southern Medan (Figure 6, Table 2).).

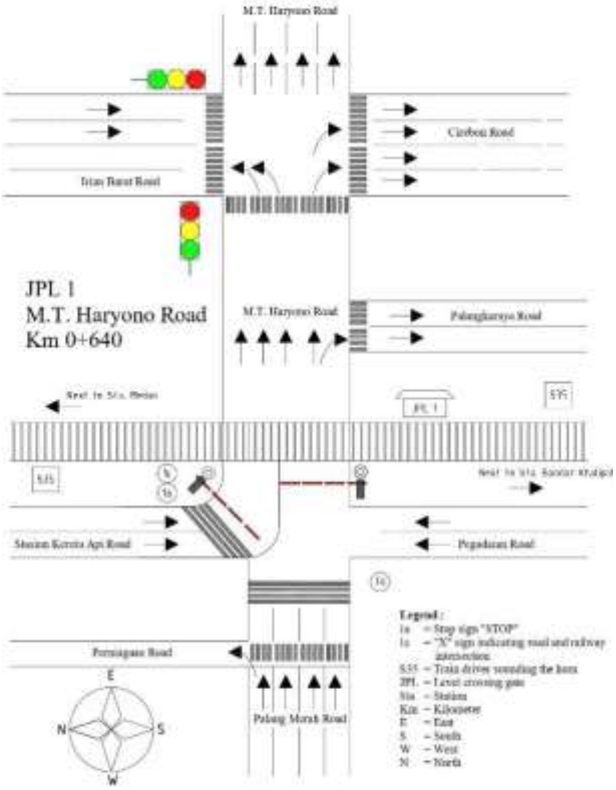

Figure 6. Layout of KM 0+640 crossing (Medan – Tanjung Balai line

Table 2 – Road characteristics at KM 0+640 crossing

No	Description	Information
1	JPL Number	1
2	Type of level crossing	Intersecting and guarded
3	Operation	Electric automatic
4	Number of road lanes	One
5	Road name	Jl. M.T. Haryono
6	City / Regency	Medan city
7	Coordinates	3.585453, 98.682031
8	Road class	I
9	Road status	City road
10	Road function	Arterial
11	Road contour	Flat
12	Road type	5/1-U
13	Road width (m)	24
14	Pavement type	Asphalt
15	Speed limit (km/jam)	40
16	Distance to previous crossing (m)	964
17	Distance to next crossing (m)	443
18	Minimum sight distance (m)	>500
19	Driver's sight distance (m)	<150
20	Portal distance of crossing to track (m)	30 and 40

c. KM 1+325 (Medan – Tanjung Balai line, JPL 4)
Located on Sisingamangaraja Road, this crossing plays a vital role as part of the national road network. Observations revealed important technical and operational characteristics that directly influence traffic safety and the efficiency of both rail and road transport. Table 3 presents its characteristics, and the layout is shown in Figure 7.

Table 3 – Road characteristics at KM 1+325 crossing

No	Description	Information
1	JPL Number	4
2	Type of level crossing	Intersecting and guarded
3	Operation	Electric automatic
4	Number of road lanes	One
5	Road name	Sisingamangaraja road
6	City / Regency	Medan city
7	Coordinates	3.581073, 98.685193
8	Road class	I
9	Road status	Nasional road
10	Road function	Arterial
11	Road countour	Flat
12	Road type	4/2-T
13	Road width (m)	17
14	Pavement type	Asphalt
15	Speed limit (km/jam)	40
16	Distance to previous crossing (m)	171
17	Distance to next crossing (m)	350
18	Minimum sight distance (m)	<500
19	Driver's sight distance (m)	<150
20	Portal distance of crossing to track (m)	8 and 10

Figure 7. Layout of KM 1+325 crossing (Medan – Tanjung Balai line)

3.1.2 Road traffic flow

The results of traffic volume surveys at the three selected crossings are summarized in Table 4. The data indicate significant variations in traffic density across the sites.

Table 4 – Road traffic volume at selected crossings

Location	Vehicle Type				
	Motorcycle (MC)	Light Vehicle (LV)	Heavy Vehicle (HV)	Unmotorized (UN)	Road Traffic Volume
	(Vehicles)	(Vehicles)	(Vehicles)	(Vehicles)	(Vehicles / hour)
KM 9+30 (Medan – Binjai line)	5220	825	44	137	6226
JPL 1 KM 0+640 (Medan – Tanjung Balai line)	20492	17662	715	312	39181
JPL 1 KM 1+325 (Medan – Tanjung Balai line)	19484	9198	672	377	29731

3.1.3 Railway traffic flow

Rail traffic observations show variations in both frequency and type of services across the study locations. On the Medan–Binjai line (KM 9+30 unguarded crossing), 24 trains operate daily, mainly commuter services. On the Medan–Tanjung Balai line (KM 0+640 section), 29 trains operate daily.

3.2. Accident Risk Level Analysis

Based on data from the Ministry of Transportation, during 2015–2024 [3]. Indonesia had an average of 4,569 level crossings, with a total of 3,221 accidents, or approximately 322 cases per year. Most accidents occurred at unguarded crossings (245 cases/year), significantly higher than those at guarded crossings (76 cases/year). The ratio of accidents per crossing remained relatively stable, at approximately 0.07 accidents per crossing per year.

3.2.1 Infrastructure factor

a. Raw infrastructure represents risk scoring at level crossings, rated from 1 to 5 across physical and control system elements, with 1 indicatingthe lowest risk and 5 the highest. Table 5 summarize the raw infrastructure matrix assessment for the KM 9+30 Medan – Binjai crossing (unguarded crossing).

Table 5 – Summary of raw infrastructure factor assessment for KM 9+30 Medan – Binjai crossing

No	Level Crossing Characteristics	Conditions		Points	Score	% of total
		Existing	Standard			
	CONTROL DETAILS					
1	Effectiveness of equipment inspection and maintenance	No maintenance and staff	Poor	5	56	13
2	Longest approach warning time	Nothing at all or >30 secs	>30 secs	5	35	8
	ROAD GEOMETRY					
3	Proximity to intersection/control point	8.854 m	>200 m	0	0	0
4	Proximity to siding/shunting yard	8.854 m	>200 m	0	0	0
5	Proximity to station	9.030 m	>200 m	0	0	0
6	Possibility of short stacking	potential to be trapped	Medium	3	21	5
7	Number of lanes (number of lines of traffic)	2 lane(s)	2 lanes	3	21	5
8	Vulnerability to road user fatigue	Uneven road surface	Medium	3	25	6
	ROAD TRAFFIC CONTROL					
9	Presence of adjacent distractions	Some covered by trees and billboards	Medium	3	25	6
10	Condition of traffic control at level crossing	No boom gates installed	Low	5	63	14
11	Visibility of traffic control at crossing	Some covered by trees and billboards	Average	3	29	7
12	Distance from advance warning to level crossing	40m (Southwest; 40m Northeast)	Average	3	33	8
13	Conformance with Standars	7 of 12 meet the standards	Partly	3	46	10
14	Likelihood of vandalism to controls	None vandalism	Low	0	0	0
	ROAD VEHICLES					
15	Heavy vehicle proportion	0,7%	<5%	0	0	0
16	Level of service (vehicle congestion)	Normal-minor decelaration	Lvl B – Reasonably free	1	6	1
17	Queuing from adjacent intersections	40 meters on both sides of the road	None	0	0	0
18	Road traffic speed (approach speed 85th percentile)	44 kph	<60kph	0	0	0
	RAIL VEHICLES					
19	Seasonal/infrequent train patterns	0 irregular train/day	Regular trains	0	0	0
20	Slowest train speed at level crossing (typical)	70kph	>60kph	0	0	0
21	Longest train length at level crossing (typical)	161,654m	60 to 300m	1	4	1
22	High train speed on approach to level crossing	72kph	>60 to 80 kph	1	4	1
	CROSSING GEOMETRY					
23	Number of operational rail tracks	Single track	Single track	0	0	0
24	Condition of road surfaceon immediate approach/departure (not the crossing panel)	Good road surface on both sides	Good	0	0	0
25	Level crossing panel on a hum,dip or rough surface	Rough and uneven asphalt surface at the crossing	Yes	5	35	8
	VISIBILITY					
26	S1 – advance visibility of level crossing from road (SSD)	Clear	100%	0	0	0
27	S2 – approach visibility to train (vehicle approaching level crossing)	Clear	100%	0	0	0
28	S3 – visibility to train (vehicle stopped at level crossing)	Clear	100%	0	0	0
29	Possible sun glare sighting crossing on road approach	Both directions	None known sunglare issue	0	0	0
30	Possible sun glare sighting train	Southeast-Northwest rail track	Known sunglare issue	5	42	9
31	Temporary visual impediments – sighting of crosing	None visual impediments	<1 day/month	0	0	0
32	Temporary visual impediments – sighting of train	None visual impediments	<1 day/month	0	0	0

Based on the same calculation approach and direct field observations, the raw infrastructure factor values were 375 for JPL 1 (KM 0+640) and 232 for JPL 4 (KM 1+325) on the Medan–Tanjung Balai line.

b. Infrastructure modifier was computed using a linear regression equation comparing raw infrastructure scoreswith ten years of accident data, normalized against traffic volumes and train frequencies. According to Harrison et al. [4], the modifier value was 0.00815 for passive crossings (Makirikiri Road, New Zealand) and 0.00848 for half-barrier crossings, which better represent Indonesian conditions.

3.2.2 ALCAM risk score

Figure 8 presents the final summary of ALCAM for the unguarded level crossing at KM 9+30 on the Medan–Binjai line. Meanwhile, Figures 9 and 10 correspond to JPL 1 at KM 0+640 and JPL 4 at KM 1+325 on the Medan–Tanjung Balai line.

ALCAM Outputs:

Raw infrastructure factor	**445**		
Infrastructure factor	**3,627**		
Exposure factor	**0,052**		
Likelihood factor	**0,188**	**Years between collisions**	**5**
Consequence factor	**0,285**		
Risk score	**0,053**	**Years between fatalities**	**19**

Figure 8. ALCAM summary of the unguarded level crossing

ALCAM Outputs:

Raw infrastructure factor	**375**		
Infrastructure factor	**3,181**		
Exposure factor	**0,150**		
Likelihood factor	**0,477**	**Years between collisions**	**2**
Consequence factor	**0,285**		
Risk score	**0,136**	**Years between fatalities**	**7**

Figure 9. ALCAM summary of JPL 1 with half-barrier

ALCAM Outputs:

Raw infrastructure factor	**232**		
Infrastructure factor	**1,968**		
Exposure factor	**0,136**		
Likelihood factor	**0,268**	**Years between collisions**	**4**
Consequence factor	**0,285**		
Risk score	**0,076**	**Years between fatalities**	**13**

Figure 10. ALCAM summary of JPL 4 with half-barrier

The higher risk score observed at JPL 1 can be attributed to its arterial function and significantly higher road traffic volume, which increases exposure frequency. In addition, socio-economic activities around Jl. M.T. Haryono generate a high proportion of motorcycles and informal traders, leading to frequent violations of crossing rules. These behavioral and environmental factors collectively amplify the probability of collision, consistent with findings by Read et al. [8].

3.3. Summary of ALCAM Mitigation Outputs

The ALCAM results were further evaluated by applying quantitative mitigation measures to each risk factor. This included adjustments in the values of the infrastructure, exposure, likelihood, and consequence factors, along with recalculated risk scores and the corresponding average intervals between collisions and fatalities. A summary of these reductions is presented in Table 6.

Table 6 – Summary of ALCAM Mitigation Outputs

	ALCAM Outputs	**Before (Score)**	**After (Score)**
Location 1 (KM 9+30 Medan – Binjai line)	Raw infrastructure factor	445	164
	Infrastructure factor	3,627	1,337
	Exposure factor	0,052	0,052
	Likelihood factor	0,188	0,069
	Consequence factor	0,285	0,285
	Risk score	0,053	0,020
	Years between collisions	5	14
	Years between fatalities	19	51
Location 2 (Km 0+640 Medan – Tanjung Balai line)	Raw infrastructure factor	375	140
	Infrastructure factor	3,181	1,187
	Exposure factor	0,150	0,150
	Likelihood factor	0,477	0,178
	Consequence factor	0,285	0,285
	Risk score	0,136	0,051
	Years between collisions	2	6
	Years between fatalities	7	20

Location 3 (Km 1+325 Medan – Tanjung Balai line)	Raw infrastructure factor	232	117
	Infrastructure factor	1,968	0,992
	Exposure factor	0,136	0,136
	Likelihood factor	0,268	0,135
	Consequence factor	0,285	0,285
	Risk score	0,076	0,038
	Years between collisions	4	7

4. CONCLUSION

The observations show variations in the conditions of level crossings: (a) Jl. Stasiun, Lalang Village, unguarded crossing, only equipped with signs, with a traffic volume of 6,226 vehicles/day (5,220 motorcycles) and 24 train movements/day; (b) Jl. M.T. Haryono (JPL 1), equipped with half barriers, signs, and loudspeakers, with a traffic volume of 39,181 vehicles/day (approximately 19–20 thousand motorcycles) and 29 train movements/day; (c) Jl. Sisingamangaraja (JPL 4), with similar facilities, a traffic volume of 29,731 vehicles/day (19,484 motorcycles), and 29 train movements/day.

Based on the ALCAM calculation, the highest accident risk is found at JPL 1, Jl. M.T. Haryono, with a score of 0.136 (fatality estimated once every 7 years, likelihood once every 2 years). JPL 4, Jl. Sisingamangaraja, has a risk score of 0.076 (fatality once every 13 years, likelihood once every 4 years). Meanwhile, Jl. Stasiun, Lalang Village, records a risk score of 0.053 (fatality once every 19 years, likelihood once every 5 years).

Sensitivity analysis indicates that the main risk factors include the control system, warning time, proximity to intersections, and compliance with standards. Mitigating these factors has been shown to reduce risk, and with accurate data, ALCAM has the potential to be applied on a national scale.

This study is limited by the relatively small number of case study locations and by reliance on available secondary data. Further research should expand to more diverse geographical areas, integrate behavioral and socioeconomic factors and validate ALCAM risk scores with real accident frequency data to enhance reliability for national application.

ACKNOWLEDGEMENTS

The author would like to express sincere gratitude to the academic supervisors, Ir. Mukhammad Rizka Fahmi Amrozi, S.T., M.Sc., Ph.D., IPM and Ir. Latif Budi Suparma, M.Sc., Ph.D., for their invaluable guidance, constructive feedback, and continuous support throughout this research. Appreciation is also extended to the Medan City Transportation Agency, the Railway Engineering Center Class I Medan, and PT Kereta Api Indonesia for providing essential data and field access.

REFERENCES

[1] A. Anagnostopoulos, “Assessing safety and infrastructure design at railway level crossings through microsimulation analysis, “*Future Transportation*, vol.5, 2025, doi: 10.3390/futuretransp5010024.

[2] A. Budiharjo, F. Habibah, and F. Tohom, “Evaluation study of level crossings on direct crossing routes (JPL) in Semarang City, “*Media Komunikasi Teknik* Sipil, vol. 30, no. 2, pp. 215 – 214, 2024, doi: 10.14710/mkts.v30i2.65494.

[3] Directorate General of Railways, *Number of level crossings in Indonesia 2015 –* 2024. Jakarta, Indonesia: Ministry of Transportation, 2024.

[4] N. Harrison, et al., "*Traffic impact assessment – Rangitikei District Council industrial plan change*," Rangitikei District Council, 2019.

[5] National ALCAM Committee, *The Australian Level Crossing Assessment Model (ALCAM) in Detail*. National ALCAM Committee, 2016.

[6] A. P. Iswanto, et al., "Safety improvement analysis at Tanggulangin–Porong railway level crossing (Case study: JPL 75 KM 31+368*)," Jurnal Keselamatan Transportasi Jalan (Indonesian Journal of Road Safety)*, vol. 9, no. 2, pp. 92–102, 2022, doi: 10.46447/ktj.v9i2.433.

[7] M. Y. Rahim, "*The influence of the level crossing at M.T. Haryono Road with the railway on traffic characteristics*," Undergraduate thesis, Universitas Muhammadiyah Sumatera Utara, Medan, 2017.

[8] G. J. M. Read, et al., "What factors influence risk at rail level crossings? A systematic review and synthesis of findings using systems thinking," Safety Science, vol. 138, p. 105207, 2021, doi: 10.1016/j.ssci.2021.105207.

[9] S. Salsabila, "*Analysis of accident factors at railway level crossing in Simpang Empat Lorong, Pariaman City*," Undergraduate thesis, Universitas Muhammadiyah Sumatera Barat, 2023.

[10] I. Ilić, et al., "Application of fuzzy logic in railway crossing safety analysis," in *Proceedings of the International Symposium on Rail Transportation Safety*, 2024.