

# ACCIDENT CHARACTERISTICS AND CONCEPTUAL DESIGN OF HYBRID RISING-BARRIER SYSTEM AT RAILWAY LEVEL CROSSINGS IN INDONESIA

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## ABSTRACT

Level crossing safety remains a persistent challenge in Indonesia, particularly at unguarded crossings and locations protected only by Early Warning Systems (EWS). High accident rates at these crossings indicate the limitations of warning-based systems in controlling risky road-user behaviour, especially in spatially constrained environments with mixed traffic conditions. This study aims to analyse level crossing accident patterns and to evaluate the safety performance of a hybrid protection system integrating semi-automatic rising-barriers with EWS. A case study was conducted in West Sumatra Province using level crossing accident data from 2017 to 2024. The analysis focuses on accident variations by crossing type, road-user characteristics, and the presence of physical safety controls. The results indicate that crossings without physical barriers experience significantly higher accident frequencies, predominantly due to road-user violations. Compared with conventional barrier-gates and EWS-only systems, the hybrid rising-barrier system demonstrates superior potential safety performance by providing direct physical enforcement while remaining suitable for locations with limited road width. The integration of rising-barriers with EWS reduces reliance on user compliance and enhances overall control effectiveness. This study concludes that the hybrid rising-barrier system represents a technically viable alternative for improving level crossing safety in high-risk and space-constrained conditions in Indonesia.

Keywords: Level Crossings, Rising-Barriers, Early Warning Systems, Railway Safety, Accident Patterns.

## 1 INTRODUCTION

### 1.1 Background

Level crossings represent critical interfaces within railway systems, where rail operations intersect directly with road traffic. In Indonesia, level crossings remain widespread, particularly along railway corridors that pass through dense urban areas, residential settlements, and local road networks with limited spatial capacity. These conditions make level crossings one of the most vulnerable points in the railway system, frequently contributing to accidents involving road users, with consequences ranging from serious injuries to fatalities and substantial social losses.

Efforts to improve level crossing safety in Indonesia have primarily relied on conventional barrier-gates and Early Warning Systems (EWS). However, the implementation of barrier-gates often faces practical constraints, including substantial space requirements, high installation and operational costs, and continued reliance on human operators. Conversely, crossings protected only by EWS depend largely on road-user compliance with visual and audible warnings, without providing any physical means to prevent vehicles from entering the crossing during train approach. As a result, EWS-only crossings are particularly vulnerable to violations, especially in environments characterised by mixed traffic and low levels of user discipline. These challenges are further intensified in areas with narrow road widths and high levels of local activity. Many level crossings are located on secondary or local roads where spatial limitations restrict the application of conventional safety infrastructure. Consequently, crossings without physical barriers remain prevalent and are consistently associated with higher accident rates, largely driven by risky behaviours such as ignoring warning signals or attempting to cross immediately before train arrival.

West Sumatra Province provides a representative context for examining these issues. The regional railway network traverses densely populated areas and narrow local roads, creating numerous level crossings with limited protection. Accident records indicate that a substantial proportion of incidents occur at crossings lacking physical barriers, highlighting the limitations of warning-based systems alone. This situation underscores the need for safety solutions that not only warn road users but also provide direct physical control in a manner compatible with spatial constraints.



Figure 1. Early Warning System (Class II Padang Railway Engineering Center, 2023).

Within this context, hybrid level crossing protection systems have emerged as a potential alternative. The integration of Early Warning Systems with compact physical barriers, such as semi-automatic rising-barriers, offers the possibility of enhanced safety performance without the spatial and operational burdens of conventional barrier-gates. Accordingly, this study focuses on analysing level crossing accident patterns and evaluating the safety performance of a hybrid rising-barrier system in comparison with conventional barrier-gates and EWS-only crossings.

## 2 RESEARCH METHODOLOGY

### 2.1 Data Collection

The study adopts a case-study approach centred on West Sumatra. West Sumatra Province was selected as the study area based on the following considerations:

- A relatively high number of level crossings, with a significant proportion lacking physical protection;
- Railway lines intersect dense urban areas, residential settlements, and narrow local roads;
- Persistent occurrence of level crossing accidents, making the region suitable for examining safety performance issues;
- Spatial and operational characteristics that are representative of level crossings in many other regions of Indonesia.

The study uses secondary level crossing accident data for the period 2017 to 2024 obtained from National Railway Safety Records and regional railway engineering authorities. The dataset includes information on:

- Yearly Accident Frequency;
- Fatalities and Severities;
- Crossing types (Active Crossing with Barriers and Guard Post, Active Crossing without Barriers and Guard Post, and Passive Crossing);
- General road-user classifications.

Supplementary information on existing crossing configurations and regional road characteristics was obtained from railway infrastructure databases and technical reports. All data were compiled and categorised to ensure consistency and comparability across different crossing types.

### 2.2 Accident Pattern Analysis

Accident pattern analysis was conducted using descriptive statistical methods, including:

- a. Classification of level crossings into three main categories;
  - 1) Crossings with conventional barrier-gates.
  - 2) Crossings protected only by Early Warning Systems (EWS).
  - 3) Crossings without active protection.
- b. Analysis of accident distribution and trends by crossing type;
- c. Examination of road-user involvement by user category;
- d. Identification of dominant accident patterns associated with the absence of physical barriers and road-user violations.

### 2.3 System Design of the Hybrid Rising-Barrier

A conceptual hybrid protection system was developed to address the shortcomings identified through accident pattern analysis. The proposed system integrates semi-automatic rising-barriers with an existing EWS framework. The design prioritises suitability for narrow road geometries and passive crossings where permanent staffing is impractical. Key components of the system include:

- a. Embedded semi-automatic rising-barriers positioned to physically restrict vehicle access;
- b. Visual and audible EWS units activated by train detection systems;
- c. Emergency Push-Buttons to allow manual intervention to exceptional situations;
- d. Supporting road markings and warning zones to guide road-user behaviour;
- e. CCTV.

The layout was designed with flexibility to accommodate limited underground space and to minimise vehicle entrapment within the crossing area.

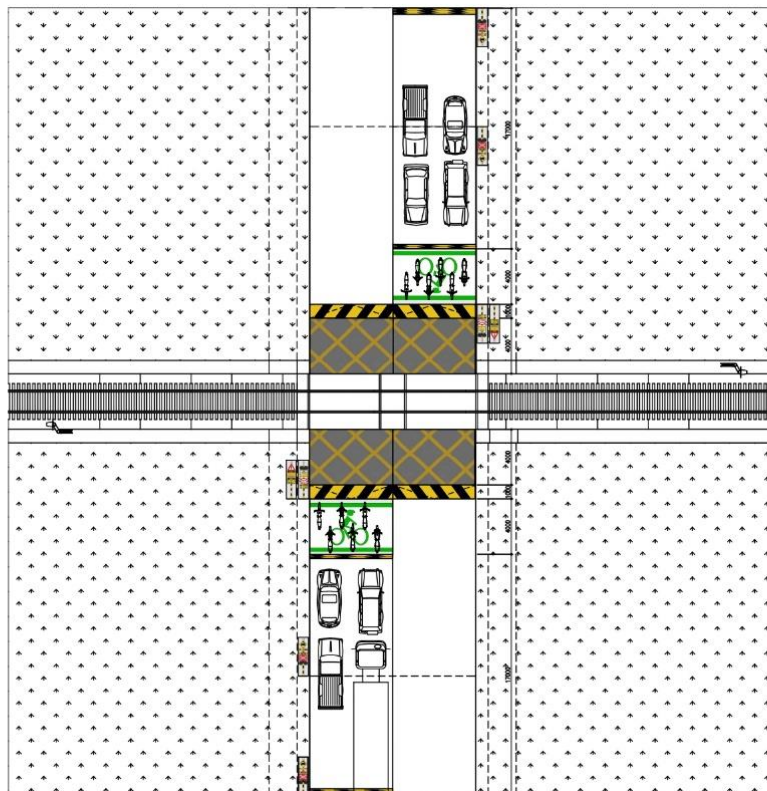


Figure 2. Proposed Layout Design of Rising-Barriers (Author, 2025).

## 2.4 Technical Evaluation

Performance evaluation covered:

- a. Installation feasibility and spatial requirements;
- b. Barrier blocking capability;
- c. Durability under environmental exposure and vandalism;
- d. Integration with detection and warning devices;
- e. Emergency override and manual intervention requirements.

## 3 RESULTS AND DISCUSSION

### 3.1 Level Crossing Accident Patterns

The analysis of level crossing accident data reveals clear differences in accident occurrence across different types of crossings.

Table 1. Accident Distribution by Level Crossing Type (2017-2024)

CROSSING TYPE	TOTAL ACCIDENTS
Active crossings with barriers and guard	7
Active crossings without barrier	45
Passive crossings	127
<b>TOTAL</b>	<b>179</b>

Crossings without physical barriers and those protected only by Early Warning Systems (EWS) consistently exhibit higher accident frequencies compared with crossings equipped with conventional barrier-gates. This finding indicates that warning-based systems alone are insufficient to effectively prevent risky road-user behaviour.

Table 2. Accident Distribution by Type of Users (2017-2024)

TYPE OF USERS	TOTAL	2017	2018	2019	2020	2021	2022	2023	2024
Car	99	4	13	10	13	19	8	13	19
Motorcycle	32	4	4	3	2	8	2	8	1
Pedestrian	47	7	16	5	0	3	4	9	3
Animal	1	0	0	0	0	1	0	0	0
<b>TOTAL</b>	<b>179</b>	<b>15</b>	<b>33</b>	<b>18</b>	<b>15</b>	<b>31</b>	<b>14</b>	<b>30</b>	<b>23</b>

In terms of road-user characteristics, accidents are predominantly associated with motorised vehicles. Based on the table, car users are the most affected group, accounting for 99 out of 179 total accidents (55%). This dominance reflects both high traffic volumes and a tendency for road users to proceed despite active warning signals. Such patterns highlight the significant role of behavioural factors in level crossing accidents, especially at locations lacking physical enforcement.

Spatial analysis further indicates that accidents are concentrated at crossings located in dense residential areas and along narrow local roads. Limited sight distance, high local activity, and mixed traffic interactions at these locations increase safety management complexity. Under such conditions, the effectiveness of EWS-only systems diminishes, as road users often rely on perceived time gaps rather than complying with warning indications. Accidents were concentrated in three sections:

- a. Tabing-Duku (68 cases);
- b. Padang-Tabing (25 cases);
- c. Kurai Taji-Pariaman (21 cases).

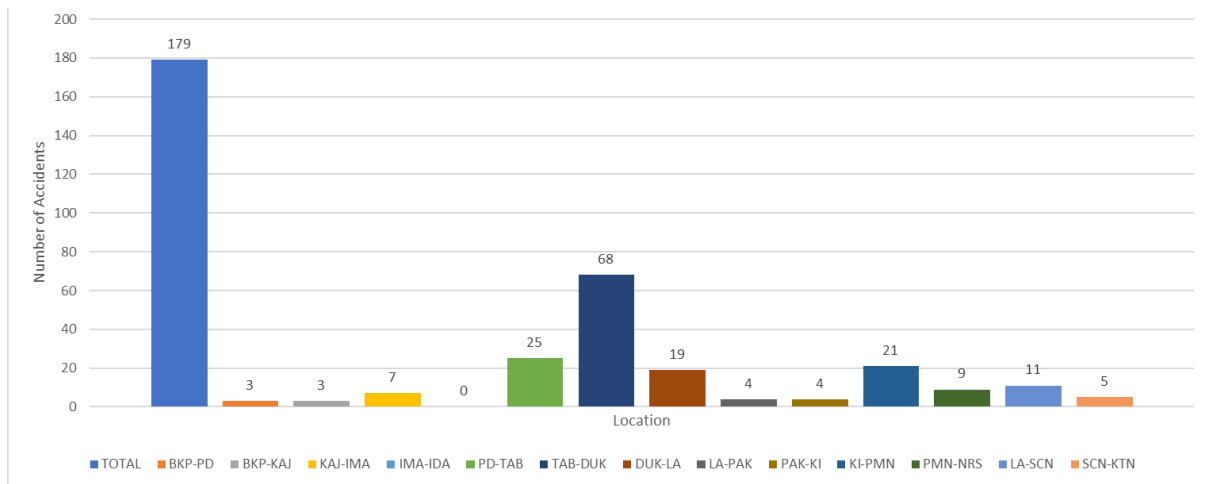


Figure 3. Distribution of Accidents Based on the Locations (Author, 2025).

These locations represent high-risk zones where visibility is limited and crossing control is minimal. Overall, the accident pattern analysis confirms that the absence of physical barriers is strongly associated with higher accident occurrence at level crossings. These results emphasise the need for safety approaches that extend beyond warning systems by incorporating direct physical control measures capable of preventing violations.

### 3.2 Technical Performance of The Proposed System

The hybrid rising-barrier system demonstrated several advantages and disadvantages:

Table 3. Advantages and Disadvantages

TOOLS	STRENGTHS	POTENTIAL ISSUES
Rising-Barriers	Provide a strong physical deterrent, preventing vehicles and motorcycles from crossing illegally Ensure high visibility through their robust structure, height, and colour scheme. Operate automatically using train detection, reducing dependence on human operators.	Higher maintenance costs compared to passive systems. Vulnerable to malfunction if the power supply or control system fails. May need additional drainage or foundation reinforcement in flood-prone areas.
Bike-Box	Provides a clear, designated waiting area for cyclists and motorcyclists ahead of other vehicles. Improves visibility of two-wheeled users to train operators and other road users. Reduces risk of being squeezed between vehicles when stopping near the track.	Requires users to understand and follow the markings, which may be unfamiliar to some. Without enforcement, cars or trucks may encroach, reducing its effectiveness. In heavy traffic, cyclists and motorcyclists may struggle to access the bike-box.
Signage (in General)	Provides early warning to all road users about the presence and operation of rising-barriers.	Relies heavily on user attention, signs may be ignored or overlooked Excessive information on a single sign can distract or overwhelm users, reducing comprehension and reaction time. Less effective in poor weather or low-visibility conditions without adequate lighting.
Signage (Category A)	The yellow-black hazard stripes combined with the red STOP sign are highly visible and immediately signal caution. Universal warning symbols and large text improve recognition, even for drivers with limited literacy. Clear and urgent messages such as “TRAIN APPROACHING” and “STOP” provide straightforward instructions, particularly effective for single-track crossings.	Multiple layers of text (“TRAIN APPROACHING”, “STOP”, “RISING-BARRIERS EXISTS”, direction signs) may overwhelm drivers, especially at higher speeds. Smaller text such as “DIRECTION of UPCOMING TRAIN” may confuse some users at double track or more complex layouts.

TOOLS	STRENGTHS	POTENTIAL ISSUES
Signage (Category B)	The train icon and yellow diamond are universally recognised as railway crossing warnings. “SLOW DOWN” with vehicle-specific icons provides immediate, actionable guidance. The message “RISING-BARRIERS AHEAD” alerts drivers to an unusual feature they may not anticipate. Flashing lights enhance visibility and draw attention, particularly in poor condition.	Warnings such as “LOOK BOTH WAYS BEFORE CROSSING” risk being unread in poor visibility or fast approaches. Drivers may concentrate on reading instead of reacting, limiting split-second decision making. Multiple stacked visual elements may take longer to process, especially at higher approach speeds. The combination of four different sign shapes (diamond, rectangle, square, crossbuck) in one pole could cause visual clutter, making it harder to identify the main message at a glance.
Emergency Push-Button	Clear and immediate function: the red button with “WARNING” instantly conveys urgency. Bold yellow-black hazard stripes attract attention from a distance. Placement near the crossing makes its purpose obvious in case of a stuck vehicle or emergency.	In emergencies, some users may hesitate, uncertain of the outcome (stopping the train, alerting staff, or sounding an alarm) Without awareness campaigns, it may be misused or mistaken for other equipment. Labels may be difficult to read in poor lighting or bad weather unless illuminated.
Speed Hump	Physically slows approaching vehicles, allowing more reaction time before the crossing. Enhances driver awareness of hazards, especially when combined with signage. Low-cost and requires minimal maintenance compared to electronic warning devices.	Can be uncomfortable for road users if not well-marked or maintained. May cause sudden braking, posing risks if vehicles are too close together.
Warning Zones	Provides a safe buffer area for vehicles trapped after barrier activation, reducing collision risk.	Markings may fade due to traffic wear and weather, requiring regular painting.



Figure 4. Proposed Rising-Barrier (Author, 2025).

#### 4 CONCLUSION

This study demonstrates that level crossing accidents in West Sumatra are predominantly associated with passive and active crossings without barriers and guard-post (EWS-only), which are strongly influenced by unsafe road behaviour. The main conclusions of this study are as follows:

- a. The proposed system is well-suited for high-risk areas such as Tabing-Duku, Padang-Tabing, and Kurai Taji-Pariaman, where conventional barrier-gates are impractical;
- b. The hybrid rising-barriers + EWS system offers substantial safety improvements at spatially constrained level crossings;
- c. The system's adaptability to narrow road environments and reduced reliance on human operators make it a viable safety intervention for high-risk crossings in Indonesia.

## 5 RECOMMENDATIONS

Based on the findings and conclusions of this study, the following recommendations are proposed:

- a. Integrate hybrid rising-barriers into national design standards under the Ministry of Transportation;
- b. Implement public education campaigns focused on EPB use, safety markings, and the bike-box compliance;
- c. Prioritise pilot implementation in high-accident corridors before large-scale deployment.

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