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Systematic Literature Review of Risk Assessment Techniques, Standard and Guidelines for Railway

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Abstract. Railways are a mode of public transportation that can carry large numbers of passengers and commodities and can cover long distances quickly. Based on these advantages, the railway is a mode of transportation that is in great demand by people as their choice of transportation. Thus, this will increase the intensity and frequency of departures, thereby triggering opportunities for errors to occur that threaten passengers' safety. Currently, the paper needs to present risk assessment activities in railways comprehensively. This paper will systematically review the literature on risk management concepts, risk assessment techniques, standards, and guidelines for risk management in railways. It also groups the literature to provide directions and recommendations for distances that future researchers can examine. This study encompasses a review of 60 publications on risk management, risk assessment, and risk analysis in railways from reputable and highly indexed journals over the last ten years. Subsequently, an analysis was conducted on the characteristics of models, methods, and techniques proposed in railway risk assessment. Several countries' standards, regulations, and guidelines on railway safety will also be described. The number of studies examining risk assessment at level crossings is minimal, whereas most accidents occur in this area. Many countries have legislation and guidelines but are still general and do not detail risk assessment activities in areas with a high level of risk.

Keywords: Guidelines; Railway; Railways area; Risk assessment; Standard; Techniques

1. Introduction

Railways are a mode of public transportation that can carry large numbers of passengers and commodities and can cover long distances in a short time. Thus, this will increase the intensity and frequency of departures, thereby triggering opportunities for errors to occur that threaten passengers' safety. Based on these advantages, the railway is a mode of transportation that is in great demand by people as their choice of transportation (Berawi *et al.*, 2015).

Railway accidents worldwide still need attention, even though railway technology is already relatively high. However, the possibility of a hazard that could result in the risk of an accident occurring remains an essential concern for the authorities, the organizing

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company, and all related parties.

According to data from Eurostat Statistics Explained since 2021, the number of train accidents in the European Union is still relatively high. However, there is a tendency to decrease, with 840 accidents spread across several countries, as shown in Figure 1.

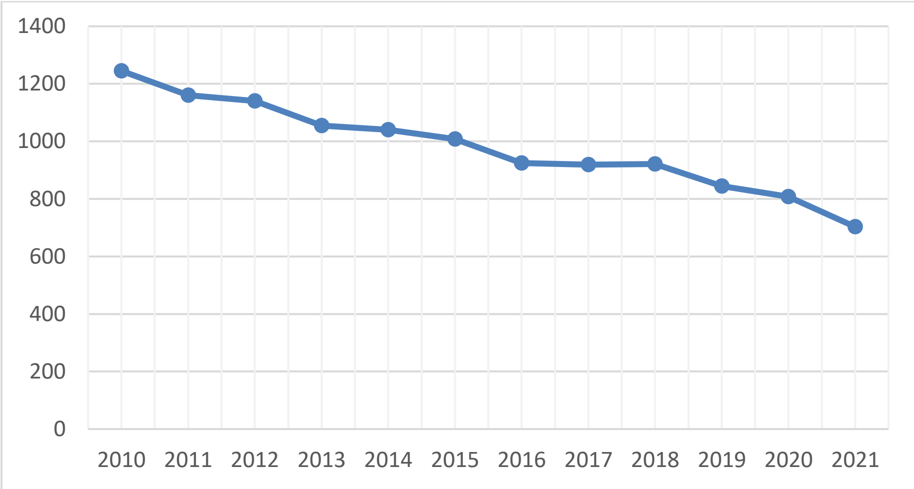

Figure 1 Railways accident rate in the European Union in 2010 -2021

In Indonesia, based on data from the National Transportation Safety Committee in the period from 2012 to 2021, there were 1,621 cases of train accidents that occurred in all operational areas and operational divisions. The majority of accidents occurred at level crossings, accounting for 1,590 cases, followed by 24 incidents involving sleds, and 7 collisions between trains.

In evaluating the occurrence of errors that occur from time to time and determining to prevent, it is necessary to carry out risk identification, risk assessment, risk analysis, and risk evaluation so that it can carry out risk control and determine actions on preventive matters (Papathanasiou, Adey, and Martani, 2016). The activities in this category include estimating the reliability, vulnerability, fragility, and resilience of infrastructure to natural hazards and gradual deterioration processes. For many accidents (such as derailment), preventive maintenance is a critical factor in their reductions (Sasidharan *et al.,* 2017). Although safety is critical to railway operations, such intensive use of the railways increases the likelihood of an accident.

This paper will systematically review the literature on risk assessment techniques, standards, and guidelines for risk management in railways. The objective is to present a comprehensive overview of risk assessment activities in railways. The focus is on categorizing the literature to offer guidance and recommendations for areas that future researchers can explore.

2. Methods

This systematic literature review included a thorough, transparent, and replicable literature search and analysis process. This method is suitable because the research objectives require a review of the existing terminology, approaches, standards and laws, frameworks, and risk assessment techniques related to risk management in railways. This paper focuses on grouping the literature to provide directions and recommendations for distances that future researchers can examine, as shown in Figure 2.

This paper reviewed 73 publications covering risk management, risk assessment, and risk analysis on the railway from several reputations and highly indexed journals in the last ten years. The characteristics of the publications are then analyzed regarding the models, methods, and techniques proposed in the railway's risk assessment. It also outlines the standards, regulations, and guidelines employed by various countries worldwide in ensuring railway safety. It also reviews the methods and techniques, analyzes their strengths and weaknesses, then classifies areas of risk assessment that have been carried out and proposes areas that still need to be widely publicized.

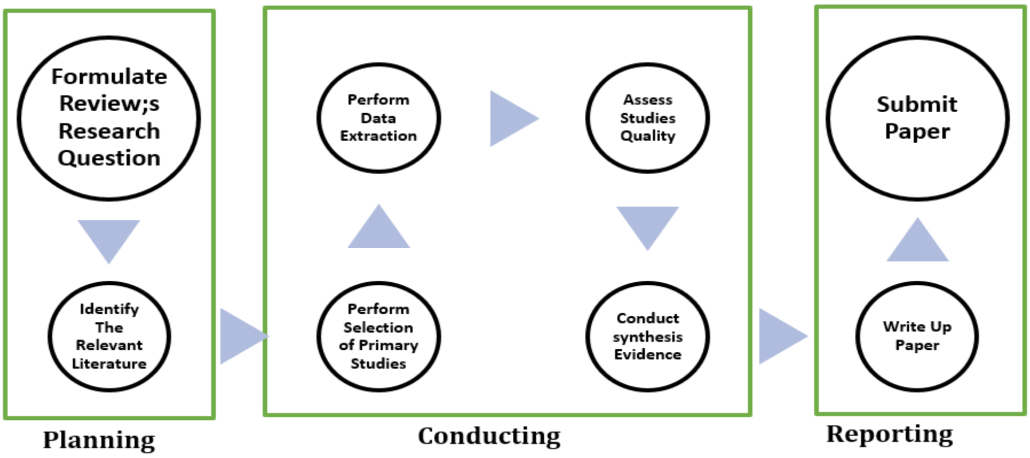

Figure 2 Article Search Process

3. Results and Discussion

3.1. Overview Of Railway Operational Activity

Most railway operations have a number of the same functions of carrying local, long-distance, commuter, and freight passengers. It has a variety of variations in different countries. Railways have two main components: rolling stock such as locomotives, passenger cars, freight cars, and others. The second aspect covers infrastructure, including tracks, stations, shipping facilities, viaducts, tunnels, and other related components. According to (Kumar, Parida, and Katiyar, 2013) the operating system is categorized into the first and second levels.

Assisting in the operation of railways is supported by intrinsic and extracurricular factors. Intrinsic factors are supporting factors that originate in the railroad environment, such as signaling, railroad systems, railroad construction, vehicle types, passenger operations, transportation operations, locomotive operations, maintenance, and feasibility. In comparison, extrinsic factors are external supporting factors, such as the physical geography of the environment, human geography, and historical factors.

3.2. Risk Management In Railway

Railways are one of the most popular modes of public transportation worldwide, including in Indonesia, as they can efficiently transport large quantities of passengers or goods over long distances. According to (Leitner, 2017), railway accident scenarios that are included in hazardous events are into five classifications, namely a) Railway collisions, b) Slipping railways, c) Railroad fires, d) Intersections, and e) Railway accidents (traffic), which is built by classifying the underlying cause according to the characteristics of each event that causes a hazard.

Domin *et al.* (2016) ran a risk assessment of railways that support rolling stock components, which may cause delays and disruptions in transportation service and cause accidents. The infrastructure supporting railway operations is a factor that is also a critical doubt. The suggested framework involves several activities, including hazard hazards identification, risk analysis, appraisal, administration, and control. After describing the reserved framework, it illustrates how it may be used systematically to reduce risk on the ranking trajectory (Sukma, Handayani, and Supriyono, 2023; Martani, Papathanasiou, and Adey, 2016). It raised the object of a railroad study in Europe that carried passenger numbers and the number of goods consistent with the range of infrastructure built chiefly between 1850 and 1950; the risks associated with infrastructure were high. Based on information from several references, Figure 3 can be illustrated.

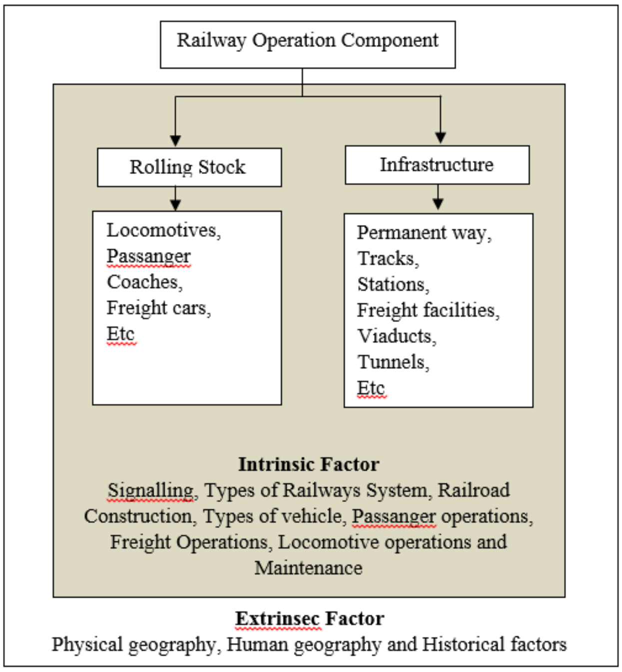

Figure 3 The Illustration of Railway Operation Component

In order to determine whether there are acceptable risk-related stages to infrastructure, it is necessary to have a process to assess the risks associated with each object in the railway circuit consistently and consider the consequences of service provided by the chain if there is an infrastructure failure (Sutalaksana, Zakiyah, and Widyanti, 2019; Martani, Papathanasiou, and Adey, 2016). According to the study, at this time, there was an evident lack of a process to assess risks related to railroad infrastructure and to determine the interventions that would be implemented to reduce these risks (Lidén, 2015). Most available processes, methods, and tools provide a basis for budgeting risks associated with objects or types of objects.

(Leitner, 2017) runs a risk assessment based on the misfortune scenario, as shown in Figure 4. below. Various events that have the potential to carry on to prey are determined by gathering reports of misfortune and running a workshop with railroad safety experts. This constructed model assesses the risk of misfortune for the railroad system. The frequency of events is assessed from historical misfortune data and assessed using the ETA (Event Analysis) technique, and several other safety techniques are also used. This model is similar to risk management in general, which shows three dimensions of the rail system, the cycle system, and the risk management process.

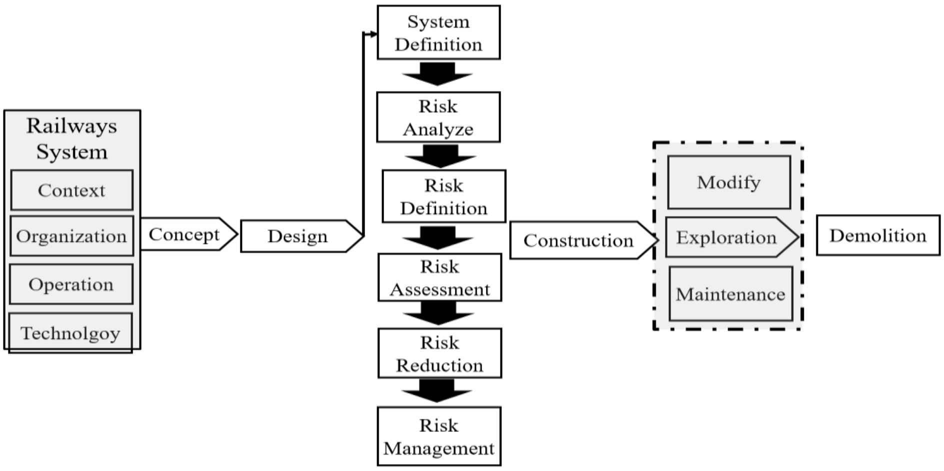

Figure 4 General Process for Risk Management in the Railway Sector, Adapted from Leitner (2017)

Risk management involves the process of risk identification, risk assessment, risk evaluation, risk response, and risk monitoring. Risk identification allows the activities to be identified and the associated risks to be defined. Risk assessment allows evaluating the likelihood of a risk occurring together with its probable outcome or consequence. Risk assessment aims to develop a rational basis for objective decision-making by systematically using available information to estimate the risks involved (Krivolapova, 2017; Leitner, 2017). With this, the decision-makers forecast the effects of any risk (Prakash, Soni, and Rathore, 2017). The effectiveness of risk assessment depends on factors such as the type of risk involved, the purpose of the analysis, and the availability of data and resources (Girgin, Necci, and Krausmann, 2019). Risk Assessment methods can be quantitative, qualitative, or semi-quantitative. While the quantitative method uses numerical values for probability and consequence analysis, the quantitative method is based on the knowledge and judgment of the rater. The risk evaluation phase determines whether a risk is tolerable, enabling decision-makers to take steps or actions to control or monitor risks (Khorsandi and Aven, 2017).

Railway safety risk assessment is designed to assess risks arising from hazards/events that may cause death, minor or major injury, and loss of private and public property (Deivasigamani, de Lacy, and Toward, 2017). In the railroad industry, risks are primarily related to safety and economic management. In an ideal rail network, stakeholders collaborate to effectively convey their safety responsibilities through safety management systems (SMS), reporting systems, safety standards, common safety methods, techniques, and tools (Hadj-Mabrouk). As the railroad industry encompasses various stages, including design, construction, operation, and maintenance, adherence to multiple disciplines and safety regulations is imperative. Each stage involves risks with distinct magnitudes and characteristics.

Furthermore, the real risk is affected by the probabilities and consequences of the identified events. Considering the variability of the parameters governing consequence, the range of conditions under consideration can be broad (Alawad, Kaewunruen, and An, 2020). In such an approach, failures are predicted using various methods, and risks of predicted failures are quantified, enabling preventive maintenance to be carried out and prioritized (Dunsford and Chatzimichailidou, 2020).

In England, there is an external regulator called the *Railway Inspectorate* (RI), which carries out a regulatory function that prioritizes persuasion rather than law enforcement, namely inspecting new infrastructure, conducting public accident investigations, and reporting in detail on work safety (Zuraida and Abbas, 2020).

Liu *et al.* (2019) conducted a study using the mathematical model to analyze risks that affect misfortune in the five parts of railroad operations, such as in Figure 5. The study found improvement in methods and tools for analyzing railroad operations risks. This review model is a good example of analyzing misfortune risk using valid data, and this data illustrates the proper situation for assessing risk. Generally, the railway industry is safety-conscious. Hence, a significant aspect of risk management in railways is directed towards preventing accidents caused by derailments and system failure or degradation (Liu and Yang, 2023; 2022) argue that, in addition to various legislative changes in the European rail industry, technical changes have also created confusion, resulting in increased overall accident risk. Various approaches to rail risk management have been developed to address this challenge. A number of these approaches are summarized. From the description above, previous speakers' studies on risk assessment in various areas of activity on the railway can be summarized in Table 1.

Table 1 Author/ Year To Be Reference

Author / Year	Area
Jin and Junxiang (2019), Liu *et al.* (2019), Lagadec *et al.* (2018), Zhang *et al.* (2018), Bertrand *et al.* (2017), Leitner (2017), Feng *et al.* (2017), Jiang, Wang, and Xing (2015)	Operation
Zhao *et al.*, (2019), Hewings (2016), Li and Wen (2015), Shi *et al.* (2015), Lu *et al.* (2014)	Signal
Consilvio *et al.*, (2020), Leitner (2017)	Maintenance
Peng *et al.* (2016), Yaghoubpour *et al.* (2016)	Human Factor
Otto *et al.* (2019), Tong *et al.* (2014)	Management
Lin, Feng, and Sun (2019), Liu *et al.* (2019)	Power Source
Schuitemaker and Bonnema (2019), Otto *et al.* (2019), Zhang *et al.* (2018), Zhao *et al.* (2017)	Infrastructure
Liang *et al.*, (2018), Nedeliaková, Sekulová, and Nedeliak (2016)	Level Crossing

Based on previous research regarding railways risk assessment in the last ten years in Table 1, most of it was carried out in the internal areas of railroad operations such as operational areas, signaling, maintenance, operators, power sources, management, and infrastructure. Risk assessment on level crossings involves external factors that influence it, such as highways, neighborhoods, and other vehicles.

3.3. Railway Risk Assessment Framework Based On Guidelines, Standards, and Regulations

Several countries or associations issue several standards, regulations, and laws regarding risk management and railroad safety. Like in the UK. There is an external regulator called the Railway Inspectorate (RI), which carries out the regulatory function that prioritizes the way of persuasion rather than law enforcement, namely checking new infrastructure, conducting accident investigations in public, and reporting in detail on work safety.

Several laws and regulations in Australia regulate rail safety, including the National Rail Safety Regulation, which regulates, audits, and reviews trains. This regulation is under the Rail Safety National (RSNL). This regulation aims to increase railroad safety nationally, conduct research, and gather and publish information related to trains. Each Standard and legislation above has a different focus and scope in railroad safety in each country. However, there are advantages and disadvantages to each of these standards and legislation from the perspective of risk management activities.

The standards and legislation in several countries can be classified into 2 (two), namely Standard and general regulations and some specific ones, as shown in Figure 5.

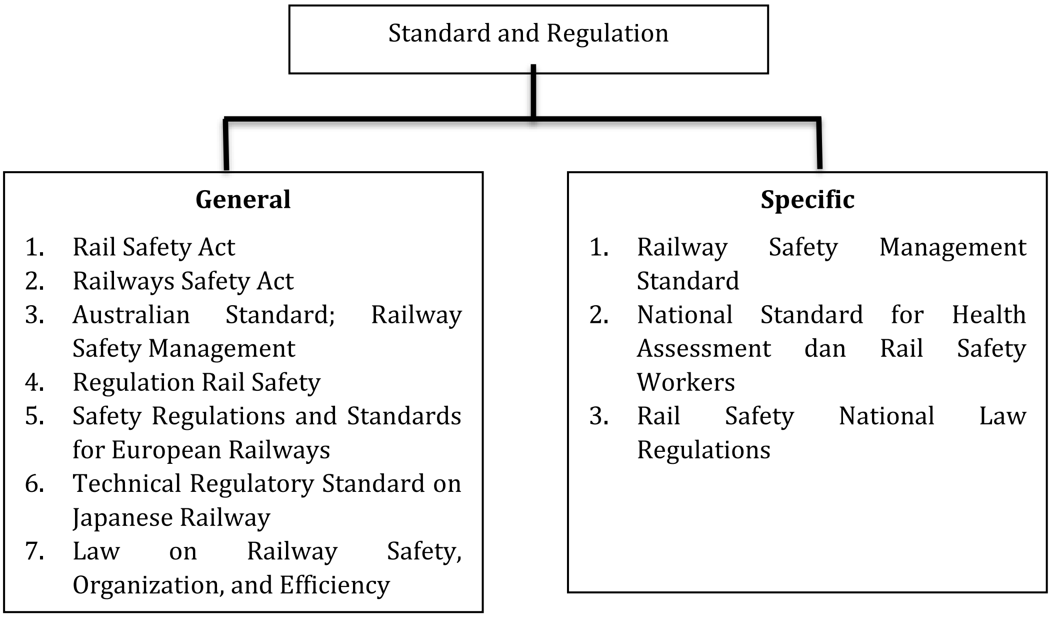

Figure 5 Safety Standard and Legislation International Railroad

In practice, the railway safety standards and laws applied in developed countries mainly cover a broad scope because the train operations are well-systemized and already have independent rail traffic lanes. These laws focus more on policy aspects, legal sanctions, granting accreditation to organizations operating railroad activities, and imposing sanctions on train operating organizations that violate the railway safety system. Hence, the frequency of accidents is rare.

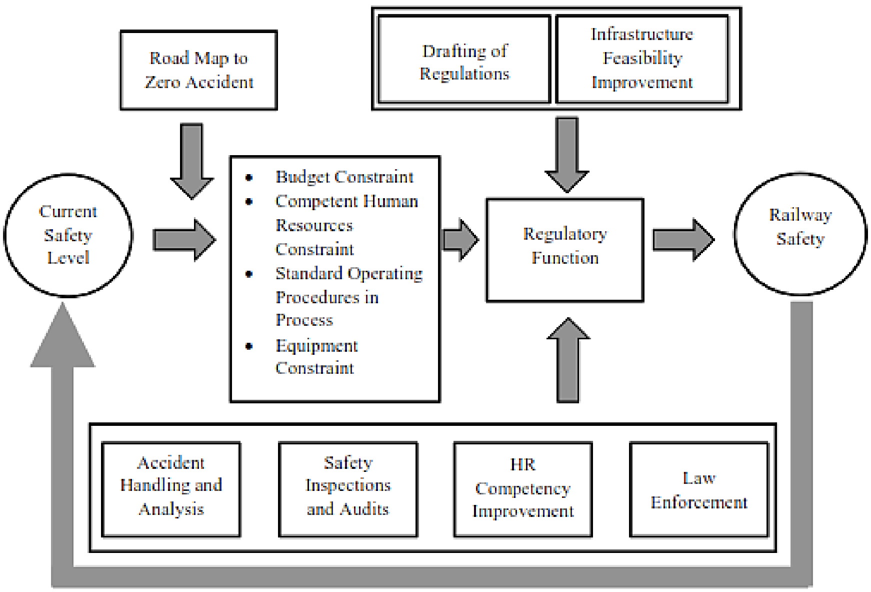

Figure 6 The Mindset of Increasing Railway Safety in Indonesia (adapted from: Indonesian Railways)

The National Economic Research Association (NERA) in London, UK, has established the Safety Regulations and Standards for European Railways, contributing to enhanced rail safety, improved risk management, and reduced risk ratings for European Union railway infrastructure. Across most EU countries, railway infrastructure management operates independently from railway operations. Under the Ministry of Civil Works, a separate agency oversees infrastructure financing and capacity allocation, extending its responsibility across the rail network.

A comprehensive Railway Safety Management System has been implemented in Indonesia, covering railway safety, occupational safety, and health. This system is regulated by the Indonesian Railways Company (Persero) and is based on well-defined safety policies, objectives, plans, procedures, and responsibilities at all organizational levels. It follows a systematic approach to policy, planning, implementation, monitoring, and improvement. Specific policies, such as drug abuse prevention, align with government regulations. Figure 6 illustrates Indonesia's progress in railway safety based on government policies. These policies are conveyed to all workers, guests, contractors, service users, suppliers, and other stakeholders to understand and implement. These policies are reviewed annually to ensure adequate and relevant changes.

Creating a comprehensive safety plan for railway operations involves identifying hazards and assessing and managing risks associated with operational activities and human resources. Every unit within the organization is responsible for hazard identification and risk assessment, following established procedures. Identified hazards inform risk assessments, categorizing risks as extreme, high, medium, or low, guiding the development of risk control plans. The safety directorate is accountable for staying updated on relevant laws and regulations about railway safety and occupational health and sharing this information across the organization. Compliance with these regulations is incorporated into procedures, technical instructions, and work guidelines. Approval holders are responsible for improving crossing safety and reporting results for inspection. The regulation addresses safety equipment and infrastructure at level crossings, detailing authority and responsibility for their implementation and emphasizing periodic monitoring and corrective actions.

3.4. Railway Risk Assessment Method And Technique

Many studies have been conducted from the past to the present that discuss and apply various risk assessment methods (Lyukevich *et al.,* 2020). Some studies use both quantitative and qualitative methods to conduct research. Here, the discussion briefly on researchers conducting risk assessment studies uses the rules. Quoted from European Centre for Disease Prevention and Control in 2019, who collected several sample papers conducting risk assessments on several objects suggesting that the method used for risk assessment by many researchers was to standardize the percentage; Hierarchical Analysis (AHP) is the most commonly used 26% risk assessment method, followed by Failure Mode and Impact Analysis (FMEA) 17%, TOPSIS 12% and VIKOR 5% and 14% of the searched papers using no specific techniques or, in some cases, only aggregation methods.

Follow the concept of Reliability, Availability, Maintainability, and safety (RAMS), which is a tool and methodology that combines reliability, availability, maintenance, and security techniques in a way that is tailored to the goals of the system (Nugraha, Silalahi, and Sinisuka, 2016). At railways, the RaMS concept integrates reliability, availability, maintenance, and safety characteristics following the operational objectives of the railway. A series of methods is employed in each RAMS component discipline, including Fault Tree Analysis (FTA), Failure Mode Effect Critical Analysis (FMECA), etc. (Hendra *et al.,* 2023; Hidirov and Guler, 2019; Al-Douri, Tretten, and Karim, 2016).

The researchers also predicted the occurrence of accidents with accident prediction models and language. Abioye *et al.* (2020) analyze the common factors in the existing accident and hazard prediction formulas, and this formula is used because of its accuracy in predicting the number of accidents., Singh *et al.* (2022), Pasha *et al.* (2022), Singh *et al.* (2021), and Mathew *et al.* (2021) uses a multi-objective mathematical model with an exact and heuristic solution approach designed to predict accidents and hazards on level crossings, this model shows the superiority of the exact optimization method because it obtains Optimal Pareto Front within acceptable computation time, prioritize their studies on level crossings that consider safety, economy, environment, and community.

Each of the above methods has its advantages and disadvantages. The advantages and disadvantages of these methods can be seen in the table 2:

Table 2 Advantages and Disadvantages of Methods

Techniques / Methods	Advantages	Disadvantages
Failure Mode and Effect Analysis (FMEA) (Boral *et al.,* 2020; Balaraju, Raj, and Murthy, 2019; Liu, 2016; Mawane and Muyengwa, 2018; Sarkar and Bhavnani, 2014)	Quickly determine the most critical and quantitative and qualitative events.	Unable to estimate the environmental impact caused
Fuzzy Logic (Wang *et al.,* 2021; Hadáček *et al.,* 2020; Sarkar and Singh, 2020; Jin and Junxiang, 2019; Andrić, Wang, and Zhong, 2019; Gul and Celik, 2018; Rahmatin *et al.,* 2018; Martin and Nilawati, 2018; Li, Tong, and Li, 2014)	Can understand the correlation between variables and their rational nature.	It is challenging to determine the parameters.
Fault Tree Analysis (FTA) (Yang, Chen, and Wang, 2022; Zhang *et al.,* 2020; Dindar, Kaewunruen, and An, 2018; Dindar *et al.,* 2017; Leitner, 2017; Baig, Ruzli, and Buang, 2013; Jafarian and Rezvani, 2012)	Deductive and provide qualitative views quickly.	There is no guarantee that early events have been identified by
Bow Tie (Huang *et al.,* 2022; Hughes *et al.,* 2018; Parkinson, Bamford, and Kandola, 2016)	It can show causal relationships in high-risk and easy-to-understand scenarios, the relationship between the causes of events.	It does not provide a framework for assessing risk control.

4. Conclusions

This research makes a significant contribution to the field of risk management in railway operations by addressing a notable gap identified in the existing literature. While previous studies have extensively covered risk assessments in various aspects of railways, including operations, signaling, maintenance, human factors, management, resources, and infrastructure, there has been a noticeable lack of focus on risk assessment at level crossings. Despite level crossings being the locations with the highest frequency of accidents, the number of studies specifically examining risk assessment in this critical area is minimal. The scarcity of research in this specific domain can be attributed to the absence of specific legislation and detailed guidelines pertaining to risk management in railway operations. The existing laws and guidelines, although applicable, are found to be general and lack the necessary specifics required for conducting comprehensive risk assessments, especially in high-risk areas such as level crossings. In response to this gap, the current study recommends the use of the Failure Mode and Effect Analysis (FMEA) technique as a suitable risk assessment approach for railways. FMEA is highlighted for its ability to efficiently identify both the most critical quantitative and qualitative events, providing a valuable tool for enhancing risk management strategies in railway operations. However, it is crucial to acknowledge the limitations within this study, which may pose challenges for future researchers. These limitations include the need for further exploration of additional risk assessment techniques to enhance effectiveness and a more in-depth examination of critical areas posing risks to railways. Therefore, this research not only identifies an existing gap but also offers a practical recommendation for addressing it, thus contributing to the advancement of risk management practices in the railway industry.

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