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PRIORITY ANALYSIS OF MAINTENANCE AND EVALUATION OF EMERGENCY RESPONSE IN DISASTER-PRONE AREAS: A CASE STUDY OF MRAWAN TUNNEL BH 152A

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ABSTRACT

The road plot of Mrawan - Kalibaru Station in Operation Area 9 Jember is an area with an extreme level of disaster vulnerability, especially at the Mrawan BH 152A Tunnel Point (KM 30+777). The potential for infrastructure failures at this location can interfere with the safety and smooth operation of the train. This study aims to determine the priority maintenance of the Mrawan Tunnel components using the Failure Mode and Effect Analysis (FMEA) method and evaluate the implementation of Standard Operating Procedures (SOPs) for emergency response at the location. This study uses a qualitative descriptive method with data collection techniques through observation, structured interviews, and documentation. The FMEA assessment involved five expert respondents from the infrastructure unit, while the SOP evaluation involved four informants from the operating unit. The validity test of the data uses source triangulation. The results of the FMEA analysis showed that the components with the highest Risk Priority Number (RPN) values were drainage (419,328), sunken ballas (374,272), and corrosion base plate (312,256). Meanwhile, the SOP evaluation showed that the implementation of emergency response in general was in accordance with PT KAI's regulations, but it was not optimal in terms of communication facilities, accessibility, and the absence of special SOPs for tunnel characteristics. This study recommends increasing the intensity of water control-based maintenance and the preparation of SOPs specifically for emergency response of the Mrawan Tunnel to mitigate operational risks

INTRODUCTION

The 9 Jember Operating Area has complex geographical characteristics, stretching from the lowlands to the Gumitir mountains with steep contours and relatively labile soil structure (Haribulan et al., 2019). This geographical condition makes some railway crossings in Daop 9 very vulnerable to natural disasters, especially landslides and floods that can interfere with the safety of railway operations (Law No. 24 of 2007; BNPB, 2016). According to Nashrullah et al. (2023), mountainous

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areas with high rainfall have a dominant level of disaster vulnerability in the high to very high category, so they require comprehensive risk management. The railway safety management system as stipulated in the Regulation of the Minister of Transportation Number 69 of 2018 emphasizes the importance of identifying potential hazards and controlling risks as a preventive effort in dealing with natural disasters (Mulyana, 2023; Atmojo, 2020).

Rainfall intensity is the main natural factor that affects soil stability and the potential for landslides on railway crossings (Haribulan et al., 2019). Average monthly rainfall data in Banyuwangi Regency shows significant fluctuations that have a direct impact on soil density on the main railway line (BPBD Bogor, 2022). According to Barokah et al. (2022), the factors that cause landslides are divided into natural factors and management factors, where rain is the main trigger that can worsen already unstable soil conditions. Disaster mitigation requires an integrated approach ranging from prevention, preparedness, to emergency handling to minimize the impact (Atmojo, 2020; BPBD Bogor, 2022). Effective disaster risk management must include mapping disaster-prone areas, building disaster-resilient infrastructure, and raising public awareness and officers operating in the area (Nashrullah et al., 2023; Mulyana, 2023).

Daop 9 Jember has several points of disaster-prone areas with levels of vulnerability that vary from moderate to extreme (Daop 9 data, 2022). Based on the recorded data, there are seven disaster-prone points spread across various resorts, with four of them having extreme vulnerability status, namely the BH 374 Bridge (Bym-Pb), the BH 129 Bridge (Gn-Mrw), the BH 152A Tunnel (Mrw-Kbr), and the BH 314 Bridge (Sgj-Rgp) (Ramadhan, 2022). Setyono's research (2025) shows that the implementation of emergency response in disaster-prone areas requires improvement, especially in handling infrastructure and material evacuation. The Failure Mode and Effect Analysis (FMEA) method has been proven effective in determining the priority of railway infrastructure maintenance based on the level of failure risk of each component (Shafira, 2025; Cahyabuana, 2015). Evaluation of the implementation of standard operating procedures (SOPs) for emergency response is important to ensure the preparedness of officers in dealing with emergency conditions (Barokah et al., 2022; Nabilla & Hasin, 2022).

Figure 1. Mrawan BH 152A tunnel
Source: Researcher Documentation (2026)

The road plot of Mrawan Station – Kalibaru Station is one of the crossings with extreme vulnerability levels in Daop 9 Jember, especially at the point of the Mrawan Tunnel BH 152A at KM 30+777 (BTP Surabaya, 2025). This location has the potential danger of a train crash due to leaking walls and tunnel roofs that cause the track to be submerged in water (Data Daop 9, 2022). Based on the 2025 Railway Travel Graph (Gapeka), this route is traversed by 24 trains every day, both long-distance and local trains, thus demanding optimal safety standards and infrastructure reliability (Gapeka, 2025). Regulation of the Board of Directors of PT KAI Number PER. U/KT.204/XII/1/KA-2018 concerning Operational Standards for Emergency Response Procedures for Railway Operational Disruptions is the main guideline in handling emergency conditions (PT KAI, 2018). The railway safety management system emphasizes the importance of providing emergency support facilities and emergency response procedures that are clear and known to all relevant parties (PM 69 of 2018; Mulyana, 2023).

The Mrawan BH 152A tunnel is a Dutch colonial heritage railway tunnel built in 1901 with a backfill excavation system and has a length of 690 meters (Observation Data, 2026). The characteristics of these old tunnels are high susceptibility to water seepage from walls and roofs, which can worsen the condition of the rail road infrastructure in them (Shafira, 2025). The FMEA method allows for systematic risk identification through assessment of severity, occurrence, and detection ability to determine treatment priorities (Villacourt, 1992; Carlson, 2001; Cahyanti et al., 2024). Shafira's research (2025) shows that components with high Risk Priority Number (RPN) values require priority handling to improve operational safety. High humidity conditions in the tunnel are critical factors that accelerate the degradation of infrastructure components such as ballas, base plates, and drainage systems (Setyono, 2025; BPBD Bogor, 2022).

The high operational frequency on the Mrawan-Kalibaru crossing demands optimal infrastructure reliability to ensure the safety of train travel (Gapeka, 2025). Any operational disruption due to natural disasters can have a significant impact on community mobility and logistics, and has the potential to cause material and immaterial losses for the company (PM 69 of 2018; PT KAI, 2018). The operational standards of emergency response procedures serve as a reference for officers in carrying out their duties and responsibilities during an emergency (Nabilla & Hasin, 2022). Emergency response human resources training and the provision of supporting facilities are crucial aspects in the railway safety management system (Mulyana, 2023; Atmojo, 2020). Coordination between units and external parties such as the police, hospitals, and fire departments is needed to accelerate the process of handling emergencies (Setyono, 2025; Ramadhan, 2022).

The hazard identification in the Mrawan BH 152A Tunnel shows the potential for train crashes due to exceeding tolerance caused by water leakage from leaking tunnel walls and roofs (BTP Surabaya, 2025). This condition is exacerbated by a suboptimal drainage system so that water cannot be drained properly out of the tunnel (Observation Data, 2026). The FMEA method is used to analyze the characteristics of infrastructure relative to potential failures and rank repair priorities based on the probability of occurrence and detection (Villacourt, 1992; Cahyabuana, 2015). Categorization of risk levels based on RPN values is a consideration in determining anticipatory and mitigation actions for the highest risk of failure (Cahyanti et al., 2024; Carlson, 2001). Corrective actions from the results of the potential hazard examination must be monitored to determine their effectiveness in preventing the recurrence of similar disturbances (PM 69 of 2018; Mulyana, 2023).

Although the handling of operational disruptions due to disasters on the Mrawan-Kalibaru road plot has been carried out according to applicable procedures, there are still several obstacles such as access to difficult locations, the lack of special SOPs for the Mrawan BH 152A Tunnel, and communication obstacles in mountainous areas (Ramadhan, 2022; Observation Data, 2026). Research by Ramadhan (2022) shows that the implementation of emergency preparedness on the Garahan-Mrawan road plot is still not optimal, characterized by the lack of special training and the absence of adequately documented SOPs. Evaluation of the implementation of emergency response SOPs is needed to identify gaps between the applicable provisions and the actual conditions in the field (Setyono, 2025; Barokah et al., 2022). Source triangulation is used to increase the validity and credibility of data by comparing information from various sources who have different tasks and responsibilities (Nurfajriani, 2024; Alfansyur & Mariyani, 2020). The preparation of special SOPs that are tailored to the characteristics of the location is important to accelerate the decision-making process and handle disturbances (PT KAI, 2018; Nabilla & Hasin, 2022).

Based on the high vulnerability of the Mrawan-Kalibaru segment to natural disasters, the intensity of congested train operations, and the obstacles found in the implementation of emergency response, a study is needed that specifically assesses the priority of infrastructure maintenance and evaluates the implementation of emergency response SOPs on the road plot. This study aims to determine the priority maintenance of the MRAWAN BH 152A Tunnel components using the Failure Mode and Effect Analysis (FMEA) method and identify the application of operational standards for emergency response

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procedures on the road section of Mrawan Station–Kalibaru Station. The results of this study are expected to provide recommendations to improve safety, infrastructure reliability, and the effectiveness of emergency handling to support the smooth operation of train travel in disaster-prone areas.

METHOD

This research was carried out in the Mrawan BH 152A Tunnel located at Kilometer (KM) 30+777, the road plot of Mrawan Station – Kalibaru Station, Operating Area (Daop) 9 Jember. The selection of the research location was based on the status of location vulnerability which is included in the extreme category of potential natural disasters and railway operational disruptions, as recorded in the data of disaster-prone areas of Daop 9 Jember. Field data collection will be carried out directly in March 2026 by involving observation of the physical condition of the infrastructure and structured interviews with experts and authorized operational officers in the region.

The data used in this study consisted of primary data and secondary data. Primary data was obtained directly from the field through observation of the physical condition of the Mrawan BH 152A Tunnel infrastructure as well as structured interviews with experts and operational officers. Meanwhile, secondary data was obtained from relevant agency documents, including data on disaster-prone areas in Daop 9 Jember, the history of disaster events, the 2025 Railway Travel Graph (Gapeka), as well as related regulations such as the Regulation of the Minister of Transportation Number 69 of 2018 concerning the Railway Safety Management System and the Regulation of the Board of Directors of PT KAI Number PER.U/KT.204/XII/1/KA-2018 concerning SOP for Emergency Response to Railway Operational Disruptions. The combination of these two types of data is used to ensure the completeness of the information and strengthen the validity of the research findings.

Data collection was carried out using three main techniques, namely field observation, structured interviews, and documentation. Observation was carried out directly at the location of the Mrawan BH 152A Tunnel accompanied by the Mrawan Tunnel Guard (PJTW) officer. The researcher used an observation checklist instrument that included 12 aspects of assessment, including the condition of rail road infrastructure (drainage, ballast, rails, base plates, anchors, and rail guards), tunnel structures (walls, roofs, inverts, and portals), as well as supporting objects such as location accessibility, communication facilities, and work equipment. This observation aims to systematically document the actual condition of the infrastructure as a basis for further analysis.

Interviews were conducted using purposive sampling techniques, where informants were selected based on their competencies, main tasks, and functions relevant to the research object. The informants in this study were divided into two groups of panels according to the purpose of the analysis. The first panel was the FMEA assessment panel consisting of five respondents, namely the Head of the 9.7 Rail Road UPT, the Head of the 9.2 Bridge UPT, the Head of the 9.2 Bridge UPT Affairs, the Head of the 9.2 Bridge UPT Work Unit, and PJTW Mrawan. This panel is tasked with assessing the Severity (S), Occurrence (O), and Detection (D) parameters in each tunnel component. The second panel is an emergency response evaluation panel consisting of four informants, namely the Assistant Manager of Daop 9 Railway, Quality Control (QC) of Daop 9 Operations, Head of Mrawan Station, and Head of Kalibaru Station. This panel is evaluated based on emergency response management indicators and monitoring standards in accordance with the Regulation of the Minister of Transportation Number 69 of 2018. In addition to observation and interviews, documentation techniques are also used to collect supporting evidence in the form of archives of handling disturbances, photos of the existing condition of the infrastructure, as well as organizational structures and procedures that apply within PT KAI Daop 9 Jember.

The data from the research was analyzed using two main approaches, namely Failure Mode and Effect Analysis (FMEA) and qualitative descriptive analysis. In the FMEA analysis, the data from interviews and observations from the expert panel were processed to calculate the Risk Priority Number (RPN) value using the RPN = Severity (S) × Occurrence (O) × Detection (D) equation. The RPN values obtained are then categorized into five risk levels, namely Very Low (<20), Low (20–80), Medium (80–120), High (120–200), and Very High (>200). The components with the highest RPN values were identified as a top priority in the maintenance of the Mrawan BH 152A Tunnel infrastructure. Meanwhile, the evaluation of the implementation of emergency response SOPs was carried out by a qualitative descriptive method, where the interview

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results were analyzed and systematically compared with emergency response management indicators in PM 69 of 2018 and procedures in PER.U/KT.204/XII/1/KA-2018. This analysis aims to map the suitability between regulations and actual conditions in the field, identify obstacles faced, and formulate more specific procedural proposals according to location characteristics.

To ensure the credibility and validity of the data, this study uses the source triangulation technique. The data obtained from the results of interviews and observations are crossed and compared between informants who have different perspectives and responsibilities, for example, between the infrastructure and the operations. The suitability of information from these various sources is used to draw objective conclusions regarding the state of preparedness and priority of care at the study site. This triangulation approach is in line with the principle of qualitative research that emphasizes the depth and validity of data through cross-examination from various perspectives, so that research findings can be accounted for academically and practically.

RESULT AND DISCUSSION

Result

Mrawan BH 152A Tunnel Maintenance Priority Based on FMEA Method

The identification of potential failures in the Mrawan BH 152A Tunnel was carried out through field observation accompanied by Tunnel Guard officers (PJTW) and structured interviews with a panel of experts consisting of the Head of the 9.7 Rail Road UPT, the Head of the 9.2 Bridge UPT, the Head of the 9.2 Bridge UPT Affairs, the Head of the 9.2 Bridge UPT Work Unit, and Mrawan PJTW. The assessment was carried out on 12 infrastructure components which were divided into two categories, namely rail road components (rails, anchors, base plates, balas, iron bearings, and rail guards) and tunnel structure components (environmental vegetation, drainage, walls/lining, inverts, and portals). Each component is assessed based on three Failure Mode and Effect Analysis (FMEA) parameters, namely Severity (S), Occurrence (O), and Detection (D), to produce a Risk Priority Number (RPN) value.

Based on the results of data processing, a recapitulation of the RPN value was obtained which showed that there were three components with a very high risk category (RPN > 200) which were the top priorities in infrastructure maintenance. The three components are presented in Table 1.

Table 1. Priority Maintenance of Mrawan Tunnel BH 152A

No	Components	Risk of Failure	RPN Value	Level Risk
1	Drainage	Dirty waterways and sedimentation	419,33	Very High
2	Bullets	Both balls	374,27	Very High
3	Base plate	Base plate corrosion	312,26	Very High

Source: Researcher (2026)

In addition to these three priority components, other components such as rail defects (RPN 307.2), invert subsidence, and cracked walls also show RPN values in the High category (120–200), but are not the main focus because the values are below the very high threshold.

Implementation of Emergency Response SOPs on Mrawan–Kalibaru Road Plot

The evaluation of the implementation of the Standard Operating Procedure (SOP) for emergency response was carried out by comparing the results of interviews and field observations on the emergency response management indicators listed in the Regulation of the Minister of Transportation Number 69 of 2018 concerning the Railway Safety Management System and the Regulation of the Board of Directors of PT KAI Number PER. U/KT.204/XII/1/KA-2018 concerning SOP for Emergency Response to Railway Operational Disruptions. The results of the analysis of the conformity of the implementation of SOPs are presented in Table 2.

Table 2. Suitability of Implementation of Emergency Response SOPs

No	SOP Aspects	SOP Provisions	Field Results	Compatibility

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1	Understanding SOPs	Officers understand the SOPs for emergency response	All informants are aware of the SOP for Emergency Response to Train Operational Disruptions, PPKA Emergency SOPs, and SOP for Handling Perka Disruptions Due to Rail Road Damage	Conform
2	Security	Officers secure the location of the disturbance	Officers stopped train trips and secured the location of the disturbance before handling it was carried out	Conform
3	Coordination	Handling involves coordination between units	Coordination between units has been carried out through operational communication and instructions from regional leaders	Conform
4	HR Readiness	Emergency handling officers are assigned and understand their duties	Officers have understood their respective duties and responsibilities in handling operational disruptions	Conform
5	Facilities and Equipment	Emergency handling equipment is available and ready to use	Equipment is available, but access to disaster-prone locations takes longer to mobilize equipment	Not Optimal
6	Emergency Communications	Communication system supports the acceleration of information delivery	Communication sometimes experiences problems due to the geographical conditions of mountains and tunnels	Not Optimal
7	Training and Preparedness	Officers receive ongoing coaching and training	Training has been carried out, but it still needs to be improved to maintain personnel preparedness	Not Optimal

Source: Researcher (2026)

Overall, four aspects have been implemented according to the provisions, while the other three aspects still need optimization. In addition, it was found that there was no special SOP that specifically regulated the handling of emergencies in the Mrawan BH 152A Tunnel.

Proposed Special Emergency Response Procedures for Mrawan Tunnel BH 152A

Based on the identification of obstacles and characteristics of the research location, the researcher prepared a proposed special emergency response SOP flowchart for the Mrawan BH 152A Tunnel which refers to the Regulation of the Board of Directors of PT KAI Number PER. U/KT.204/XII/1/KA-2018 as well as the results of interviews with informants. This proposed procedure consists of eight main stages, namely: (1) Detection/Information, (2) Reporting, (3) PPKP Receives Reports, (4) PPKP Instructs Related Units, (5) Field Inspection and Handling, (6) Inspection and Handling Reports, (7) Cross-Safe Safety Evaluation by PPKP, and (8) Safe Cross-Decision. If the condition is not safe, further treatment (9A) is carried out; if it is safe, PPKP informs the driver to continue the journey at the permitted speed (9B).

Discussion

FMEA-Based Care Priority Analysis

The results of the FMEA analysis showed that the drainage component obtained the highest RPN value of 419.328, which indicates that the drainage system is the component with the highest risk of failure in the Mrawan BH 152A Tunnel. The high value of drainage RPN is inseparable from the geographical characteristics of the Gumitir mountainous area which has relatively high rainfall, as well as the presence of water seepage from the walls and roof of the tunnel which causes sedimentation and channel blockage water. If the drainage system does not function optimally, puddles in the rail road body can reduce the carrying capacity of the line structure and potentially cause a train to plummet. This finding is in line with the hazard identification carried out by BTP Surabaya (2025), which shows a potential drop due to the track being submerged in water from leaking walls and tunnel roofs.

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The second component with a high RPN value is the ballas of 374,272. Ballas is an important element in the construction of rail roads that functions to distribute the load of the railway and maintain the stability of the track geometry. The lowering or collapse of the ballas can cause changes in elevation and unevenness of the track which has the potential to reduce the comfort and safety of train travel. In the MRAWAN BH 152A Tunnel, the condition of the ballas is greatly influenced by the presence of water coming from a less than optimal drainage system. The stagnant water reduces the carrying capacity of the ballas and causes a gradual deterioration of the rail road structure.

The third component is the corrosion base plate with an RPN value of 312.256. The base plate serves as a link between the rail and the bearing which has an important role in maintaining the stability of the rail position. Corrosion that occurs on the base plate can reduce the strength of the component in withstanding dynamic loads due to train travel. This corrosion condition is exacerbated by the high humidity inside the tunnel, especially in the old tunnel built in 1901 with a backfill digging system that has a high vulnerability to water seepage.

An in-depth discussion of the three priority components shows the systemic relationship between water and humidity factors as the root cause of various failure modes. Drainage that does not function optimally causes water to stagnate, which then accelerates the deterioration in the quality of the ballas and triggers corrosion of the base plate. This pattern shows that water control is a key factor in maintaining the reliability of the construction of the Mrawan BH 152A Tunnel. If the drainage system can function optimally, the risk of damage to other components can be significantly minimized.

These findings support the research of Shafira (2025) who states that the FMEA method is effectively used to determine the priority of railway infrastructure maintenance based on the level of failure risk of each component. In Shafira's study, the components with the highest RPN on the BH 421 Bridge were the corrosion bolt TC (205.6) and the steel shaft (200.9), which suggests that components exposed to humid environments and dynamic loads tend to have a high risk of failure. The consistency of these findings confirms that the FMEA approach can be relied upon to identify critical points in railway infrastructure, both on bridges and tunnels.

Evaluation of Emergency Response Preparedness

The results of the evaluation show that the implementation of emergency response SOPs on the road plot of Mrawan Station – Kalibaru Station has generally been carried out in accordance with applicable regulations. The aspects of understanding SOPs, securing locations, coordination between units, and human resource readiness have been well implemented by the officers involved. All informants, namely the Assistant Manager of the Daop 9 Jember Railway, the Quality Control of Daop 9 Jember Operations, the Head of Mrawan Station, and the Head of Kalibaru Station, stated that they had an adequate understanding of the applicable SOPs and had participated in emergency response safety training.

However, there are three aspects that are not optimal, namely facilities and equipment, emergency communication, and training and preparedness. The main obstacle faced is the geographical condition of the location in a mountainous area so that access to the location of the disturbance is relatively difficult and can only be reached by motorbike at some points. This causes the mobilization of emergency handling equipment to take longer. In addition, the communication system at certain points still experiences obstacles due to the topographic conditions of the region which can hinder the rapid delivery of information. Currently, officers still rely on online messaging applications through mobile networks whose signal quality is not always stable in mountainous areas.

This finding is in line with the research of Ramadan (2022) which shows that the implementation of emergency preparedness on the Garahan-Mrawan road plot is still not optimal, characterized by the lack of special training, the absence of personnel specifically assigned to disaster-prone areas, and the lack of adequately documented SOPs. The similarity in the pattern of findings between the Ramadan study (2022) and this study indicates that the problem of emergency response preparedness in disaster-prone road plots in Daop 9 Jember is systemic and requires more comprehensive intervention.

In addition, Setyono's (2025) research on the disaster-prone road plot of Daop 5 Purwokerto also shows that the implementation of emergency response has referred to the applicable SOPs, but still requires improvements, especially in handling infrastructure and evacuating landslide materials. This strengthens the argument that the general SOPs that apply at PT KAI need to be equipped with more specific procedures according to the characteristics of the location so that emergency handling can be carried out more effectively.

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Integration of FMEA and SOP as Integrated Risk Management

The results of the FMEA analysis and the evaluation of the implementation of emergency response SOPs are closely related in risk management in the Mrawan BH 152A Tunnel. The three components with the highest RPN values, namely drainage (419,328), ballas collapse (374,272), and base plate corrosion (312,256), are potential failures that can develop into operational disruptions that require emergency handling. If drainage conditions that are sedimented are not handled immediately, waterlogging can cause squeezing, reduce the carrying capacity of the bales, and affect the stability of the rail road which has the potential to cause a train to plummet. In these conditions, the implementation of emergency response SOPs is required through the process of reporting to PPKP, verification of field conditions, and the assignment of the Rail and Bridge Road Unit to conduct inspections and handling.

The linkage between FMEA and emergency response SOPs shows that these two instruments function in a complementary role in a railway risk management system. The FMEA method serves as a preventive tool to identify, analyze, and prioritize risks that have the potential to cause operational disruptions. Meanwhile, the emergency response SOP functions as a responsive tool that serves as a guideline for handling if the risk develops into an emergency condition that requires quick and coordinated action.

This integrative approach is in line with the findings of Barokah et al. (2022) who stated that the assessment of potential safety risks requires appropriate handling measures to improve the safety and security of road users passing through disaster-prone areas. In the context of railways, the integration between preventive risk analysis (FMEA) and responsive procedures (SOPs) is an important foundation in realizing a holistic safety management system. Thus, the results of FMEA can be used as a basis for improving emergency response preparedness, where the components with the highest RPN values need to receive more attention in inspection, monitoring, and preventive maintenance activities.

Specific SOPs Based on Location Characteristics

The main novelty of this study lies in the preparation of a proposed special emergency response SOP that is adjusted to the specific characteristics of the Mrawan BH 152A Tunnel. In contrast to previous research that generally evaluated the implementation of general SOPs (Ramadhan, 2022; Setyono, 2025), this study not only identifies gaps between regulations and field conditions, but also formulates procedural solutions that explicitly take into account the unique characteristics of the research site.

Specific characteristics that are considered in the preparation of special SOPs include: (1) the topography of the mountains with access that can only be reached by motorcycle at some points; (2) communication constraints due to geographical conditions that cause the quality of the cellular signal to be unstable; (3) the potential for water seepage from the walls and roofs of old tunnels (built in 1901 with a backfill excavation system) as the main trigger for infrastructure disruptions; (4) high operational frequency (24 KA/day based on Gapeka 2025) that demands a quick response without sacrificing safety; and (5) the systemic linkages between drainage components, ballas, and base plates that have been identified through FMEA.

The proposed SOP flowchart consists of eight stages designed to accelerate response and increase the effectiveness of emergency handling. The novelty of this procedure lies in the adjustment of the coordination flow with accessibility and communication constraints at the location, as well as the existence of a stricter crossing safety evaluation mechanism before the crossing is declared safe for the train to pass.

This novelty contribution to the scientific literature is to provide a procedural model that can be replicated for other sites with similar characteristics, old railway infrastructure in mountainous areas with high levels of disaster vulnerability. This approach also enriches the railway risk management discourse by showing that effective SOPs must not only meet regulatory standards, but must also be contextual to geographical, technical, and operational conditions on the ground.

CONCLUSION

This study concludes that the main priority of maintenance in the Mrawan BH 152A Tunnel based on the Failure Mode and Effect Analysis (FMEA) method is the drainage system with the highest Risk Priority Number (RPN) value of 419,328, followed by the collapsed ballas (374,272) and base plate Corrosion (312,256). These three components have a

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systemic relationship where water and moisture control are the root of the problem that must be prioritized to prevent a decrease in the carrying capacity of the line and the potential for train collapse.

Meanwhile, the evaluation of the implementation of the Standard Operating Procedure (SOP) for emergency response on the Mrawan - Kalibaru road plot shows that the aspects of understanding SOPs, securing locations, coordination between units, and human resource readiness have been running in accordance with PT KAI regulations. However, its application is still not optimal in terms of communication facilities, difficult location accessibility, and periodic training intensity. In addition, the lack of a special SOP that accommodates the unique characteristics of the location is a significant obstacle. Therefore, this study proposes a flowchart for special emergency response SOPs that are adjusted to the constraints of mountain topography and the potential for water seepage. The integration of the results of FMEA as a preventive tool and a special SOP as a responsive tool is expected to be able to improve the reliability of infrastructure and the effectiveness of handling emergencies in disaster-prone areas.

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