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The Role of Signal Passing Technology in Enhancing Railway System Safety

Peran Teknologi Signal Passing dalam Meningkatkan Keamanan Sistem Kereta Api

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Abstract

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Abstract (In English, Trebuchet MS 10 pt, Bold, Center)

Railway travel safety is a crucial aspect of modern transportation operations. One of the major challenges in railway systems is the risk of signal passed at danger (SPAD), a condition in which a train passes a red signal without authorization. This study aims to explain how modern signal passing technologies can enhance safety and prevent such incidents. The research method is based on a literature review of signaling system developments, including interlocking systems, Automatic Train Protection (ATP), and train position detection sensors such as track circuits and axle counters. The findings indicate that the implementation of advanced technologies can provide early warnings to train drivers, reduce the potential for human error, and strengthen coordination between control centers and trains. In addition, digital-based technologies such as train-to-ground communication systems have been proven to improve the accuracy of field information. The study concludes that the implementation of integrated signal passing technologies plays a significant role in reducing accident risks, improving operational efficiency, and enhancing the reliability of railway operations in Indonesia.

Keywords: *Signal Passing Technology, Railway Safety Systems, SPAD, Railway Signaling, Transportation Technology*

Abstrak

Keamanan perjalanan kereta api merupakan aspek penting dalam operasional transportasi modern. Salah satu tantangan terbesar dalam sistem perkeretaapian adalah risiko terjadinya signal passed at danger (SPAD), yaitu kondisi ketika kereta melewati sinyal merah tanpa izin. Penelitian ini bertujuan untuk menjelaskan bagaimana teknologi signal passing modern dapat meningkatkan keselamatan dan mencegah insiden tersebut. Metode penulisan dilakukan melalui studi pustaka terhadap perkembangan sistem persinyalan, termasuk interlocking, automatic train protection (ATP), dan sensor pendeteksi posisi kereta seperti track circuit dan axle counter. Hasil kajian menunjukkan bahwa penerapan teknologi yang lebih canggih mampu memberikan peringatan dini kepada masinis, mengurangi potensi kesalahan manusia, serta memperkuat koordinasi antara pusat pengendali dan kereta. Selain itu, teknologi berbasis digital seperti sistem komunikasi kereta-ke-pusat (train-to-ground communication) terbukti meningkatkan akurasi informasi di lapangan. Kesimpulan dari penelitian ini adalah bahwa implementasi teknologi signal passing yang terintegrasi berperan signifikan dalam menekan risiko kecelakaan, meningkatkan efisiensi perjalanan, serta memperkuat keandalan operasi kereta api di Indonesia.

Kata Kunci: *Signal Passing*, Keselamatan Kereta Api, SPAD, Sistem Persinyalan, Teknologi Transportasi.

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1. INTRODUCTION

Railway transportation plays a vital role in supporting mobility, economic growth, and sustainable development, particularly in countries with high population density such as Indonesia. As a mass transportation system, railways are required to operate with a high level of safety, reliability, and efficiency. Any disruption or accident in railway operations may result in significant human, economic, and social losses. Therefore, ensuring the safety of railway operations remains a top priority for railway authorities and operators.

One of the most critical safety challenges in railway systems is the occurrence of Signal Passed at Danger (SPAD), a condition in which a train passes a stop signal without authorization. SPAD incidents can lead to severe consequences, including train collisions, derailments, and infrastructure damage. These incidents are often caused by a combination of factors such as human error, inadequate signaling systems, poor communication, and technical limitations of conventional safety mechanisms. As train speeds and traffic density continue to increase, the potential risks associated with SPAD events also grow.

To address these challenges, railway systems worldwide have undergone significant technological advancements, particularly in the field of signaling and train control. Modern signal passing technologies, such as interlocking systems, Automatic Train Protection (ATP), and train detection devices including track circuits and axle counters, have been developed to enhance operational safety. These technologies are designed to provide real-time monitoring, prevent unauthorized train movements, and support train drivers through automated warnings and control interventions.

Furthermore, the integration of digital technologies and train-to-ground communication systems has transformed traditional railway operations into more intelligent and responsive systems. By enabling continuous data exchange between trains and control centers, these technologies improve situational awareness, reduce response time, and strengthen coordination across the railway network. As a result, the reliance on human judgment alone can be reduced, thereby minimizing the likelihood of operational errors.

In the Indonesian railway context, the adoption of modern signaling and signal passing technologies is increasingly important due to the expansion of railway infrastructure and the growing demand for safe and efficient transportation. However, challenges related to system integration, technology adaptation, and operational readiness remain. Therefore, a comprehensive understanding of how signal passing technologies contribute to railway safety is essential.

This paper aims to examine the role of modern signal passing technologies in enhancing railway safety and preventing SPAD incidents. Through a literature-based analysis of current signaling systems and safety technologies, this study highlights their effectiveness in reducing accident risks and improving the overall reliability of railway operations. The findings are expected to contribute to the development of safer and more resilient railway transportation systems in the future.

2. METHODOLOGY

This study adopts a qualitative research approach based on a systematic literature review to analyze the role of signal passing technologies in enhancing railway safety, particularly in preventing Signal Passed at Danger (SPAD) incidents. The methodology is designed to identify relevant signaling technologies, examine their operational principles, and evaluate their contribution to safety improvement in railway systems.

2.1 Research Approach

The research employs a descriptive and analytical approach through literature review. Scientific journals, conference proceedings, technical standards, and official reports related to railway signaling systems and safety technologies are reviewed and analyzed. The selected literature focuses on modern signaling systems, SPAD prevention mechanisms, and digital communication technologies in railway operations.

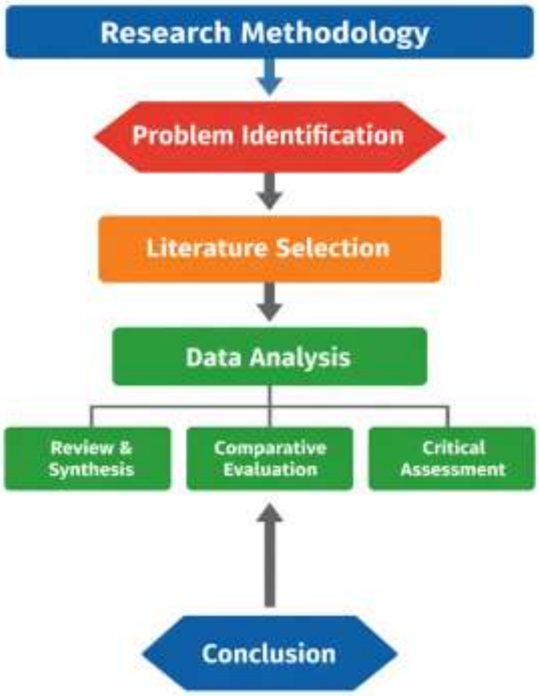

figure 2.1 Research methodology flowchart

2.2 Data Collection Method

Data were collected from secondary sources, including peer-reviewed journals, international railway standards, technical manuals, and publications from railway authorities and operators. The collected data include information on signaling system architecture, operational principles, safety functions, and documented case studies related to SPAD incidents.

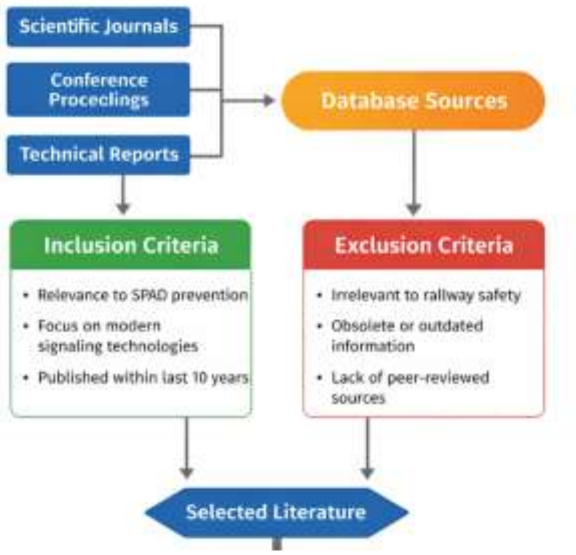

figure 2.2 Literature selection process diagram

2.3 Classification of Signal Passing Technologies

The reviewed technologies are classified into several categories based on their function and application in railway systems, including:

- Interlocking systems
- Automatic Train Protection (ATP)
- Train detection systems (track circuits and axle counters)
- Train-to-ground communication systems

This classification allows a structured comparison of each technology's role in preventing SPAD incidents and improving operational safety.

figure 2.3 signal electric

2.4 Analytical Framework

An analytical framework is used to evaluate the effectiveness of signal passing technologies based on safety-related criteria, such as early warning capability, human error mitigation, system reliability, and operational efficiency. Each technology is analyzed according to its contribution to SPAD prevention and system integration capability.

2.5 Evaluation Parameters

The evaluation parameters used in this study include:

- Ability to prevent unauthorized signal passing
- Level of automation and intervention
- Accuracy of train position detection
- Communication reliability between train and control center

These parameters are derived from established railway safety principles and international best practices.

2.6 Research Limitations

This study is limited to literature-based analysis and does not include field measurements or experimental validation. Therefore, the findings reflect theoretical and documented practical perspectives rather than direct operational performance data.

3. RESULTS AND DISCUSSION

This section presents the results of the literature-based analysis and discusses the role of signal passing technologies in improving railway safety, particularly in preventing Signal Passed at Danger (SPAD) incidents. The discussion focuses on the effectiveness of modern signaling systems, their contribution to operational safety, and their relevance to railway operations in Indonesia.

3.1 Analysis of Signal Passing Technologies

The literature review indicates that modern signal passing technologies play a crucial role in enhancing railway safety by regulating train movements and preventing unauthorized signal violations. These technologies form an integrated safety framework designed to reduce operational risks, particularly those associated with Signal Passed at Danger (SPAD) incidents. By combining mechanical, electrical, and digital components, signal passing technologies ensure that train operations adhere strictly to predefined safety rules.

Interlocking systems represent one of the fundamental elements of railway signaling safety. Their primary function is to ensure that train routes are safely configured and mutually exclusive before a train is authorized to proceed. Interlocking systems prevent conflicting movements by locking switches, points, and signals either mechanically, electrically, or through computer-based systems. This mechanism ensures that a signal cannot display a proceed aspect unless the corresponding route is correctly set and free from conflicts. As a result, interlocking systems significantly reduce the probability of accidents caused by incorrect route settings or human error at the control level.

In addition to route protection, modern interlocking systems offer enhanced flexibility and reliability through electronic and computer-based architectures. These systems enable faster response times, real-time monitoring, and easier integration with centralized traffic control systems. The literature highlights that such advancements contribute to improved operational efficiency while maintaining high safety integrity levels, particularly in complex rail networks with high traffic density.

Automatic Train Protection (ATP) systems further strengthen railway safety by providing continuous supervision of train movement parameters, including speed, location, and signal aspects. ATP systems act as an additional safety layer by monitoring whether the train driver complies with signal indications and operational limits. When a train approaches a signal at danger or exceeds permitted speed thresholds, the system first issues visual and audible warnings to the driver. If corrective action is not taken, ATP automatically intervenes by applying the braking system to prevent unsafe movement.

The effectiveness of ATP systems in reducing SPAD incidents is widely documented in the literature. By minimizing reliance on human perception and reaction time, ATP significantly lowers the risk of accidents caused by delayed responses, misinterpretation of signal aspects, or temporary loss of driver vigilance. Furthermore, ATP systems support standardized safety enforcement across different operating conditions, including poor visibility, adverse weather, and high workload scenarios.

Train detection systems, such as track circuits and axle counters, are also essential components of modern signal passing technology. These systems provide accurate and continuous information regarding train presence and position on the track. Track circuits detect trains by monitoring electrical continuity in the rails, while axle counters count train axles entering and leaving a defined track section. Both methods ensure that track occupancy information is reliably communicated to the signaling system.

Accurate train detection is critical for the correct functioning of interlocking and ATP systems. Reliable detection ensures that signals display appropriate aspects and prevents the authorization of train movements into occupied track sections. The literature emphasizes that advancements in train detection technology have improved system reliability, reduced false detections, and enhanced safety performance, particularly on lines with high traffic frequency.

Overall, the analysis demonstrates that signal passing technologies operate most effectively when implemented as an integrated system rather than as standalone components. The combination of interlocking systems, ATP, and train detection technologies creates multiple layers of protection that collectively reduce the risk of SPAD incidents and enhance overall railway safety. This integrated approach forms the backbone of modern railway signaling systems and is essential for ensuring safe and reliable train operations.

3.2 Impact on SPAD Prevention

The analyzed studies consistently demonstrate that the integration of modern signal passing technologies has a significant positive impact on the prevention of Signal Passed at Danger (SPAD) incidents. By introducing automated supervision and control mechanisms, these technologies reduce the reliance on human judgment as the sole safety barrier, which has been widely identified in the literature as a major contributing factor to SPAD occurrences.

Early warning mechanisms play a critical role in SPAD prevention by providing timely alerts to train drivers when unsafe conditions are detected. Visual and audible warnings issued by signaling and train protection systems allow drivers to take corrective action before a violation occurs. These mechanisms are particularly effective in situations involving high workload, fatigue, or reduced visibility, where the risk of missed or misinterpreted signal aspects is increased. The literature indicates that the presence of such warning systems significantly lowers the frequency of unintentional signal overruns.

Automatic intervention features, such as enforced braking provided by Automatic Train Protection (ATP) systems, further enhance SPAD prevention by acting as a fail-safe measure. When a train driver fails to respond adequately to warnings or approaches a signal at danger, the system automatically applies braking to prevent unauthorized movement. This function is essential in minimizing the consequences of human error and ensuring that safety limits are not exceeded under any operational condition.

In addition to onboard protection systems, digital-based signaling and train-to-ground communication technologies contribute substantially to SPAD prevention. Real-time data exchange between trains and control centers enables continuous monitoring of train position, speed, and signal status. This continuous communication improves situational awareness for both train drivers and traffic controllers, allowing faster detection of abnormal conditions and more accurate operational decision-making.

The literature also highlights that improved communication reduces the likelihood of miscommunication, delayed responses, and coordination failures during critical situations. By providing accurate and up-to-date information, digital signaling systems support proactive traffic management and timely intervention when potential SPAD risks are identified. Consequently, the probability of SPAD incidents is significantly reduced, even in complex and high-density railway networks.

Overall, the integration of early warning systems, automatic intervention mechanisms, and digital communication technologies creates a multi-layered defense against SPAD incidents. This layered safety approach enhances operational resilience and represents a key advancement in modern railway safety management.

3.3 Human Error Mitigation and Operational Reliability

Human error remains a dominant contributing factor in railway accidents worldwide, particularly in incidents related to signal violations and operational misjudgments. Factors such as fatigue, high workload, limited situational awareness, and misinterpretation of signal aspects can significantly increase the likelihood of unsafe train movements. The findings of this study indicate that modern signal passing technologies play a critical role in mitigating these human-related risks by introducing automated safeguards and decision-support mechanisms into railway operations.

Automated warning systems, including visual and audible alerts, assist train drivers by continuously monitoring operational conditions and providing timely feedback when deviations from safe limits occur. These warnings serve as an additional cognitive support layer, helping drivers maintain awareness of signal status, speed restrictions, and stopping requirements. When combined with automatic braking functions, such as those implemented in Automatic Train Protection (ATP) systems, these technologies ensure that safety is maintained even in situations where human response is delayed or insufficient.

Beyond individual train operation, integrated signaling systems significantly enhance overall operational reliability. Accurate and continuous train position detection, achieved through technologies such as track circuits and axle counters, enables stable and predictable traffic management. Reliable detection ensures that signals and routes are set correctly, reducing the risk of false clearances and minimizing unexpected operational interruptions.

The literature further indicates that improved operational reliability contributes directly to the efficiency and punctuality of railway services. Consistent signaling performance reduces delays caused by system failures or safety-related stoppages, allowing railway operators to maintain planned timetables more effectively. This reliability not only enhances safety outcomes but also improves service quality and passenger satisfaction.

In addition, the integration of signaling, train protection, and communication systems supports a more resilient railway operation. By reducing dependence on human intervention and ensuring consistent system performance under various operating conditions, modern signal passing technologies strengthen the overall robustness of railway networks. Consequently, the mitigation of human error and the enhancement of operational reliability are closely interconnected benefits of advanced signaling systems.

3.4 Relevance to Railway Operations in Indonesia

In the context of Indonesian railway operations, the implementation of advanced signal passing technologies is becoming increasingly important due to rapid infrastructure expansion, rising passenger demand, and increasing traffic density on both intercity and commuter rail lines. As railway networks grow in complexity, the need for reliable and integrated signaling systems becomes critical to maintaining safe and efficient operations.

The literature suggests that the adoption of modern and integrated signaling systems can significantly improve safety performance by reducing the risk of Signal Passed at Danger (SPAD) incidents and other operational irregularities. Technologies such as electronic interlocking, Automatic Train Protection (ATP), and digital train-to-ground communication systems offer enhanced supervision and control capabilities that are well suited to the operational challenges faced by Indonesian railways. These technologies support safer train operations, particularly on high-density corridors and in urban rail environments.

Despite these potential benefits, several challenges must be addressed to ensure successful implementation. System integration remains a key issue, especially in networks where legacy signaling systems coexist with newer technologies. Compatibility between different generations of equipment and standardization across railway corridors require careful planning and technical coordination. Additionally, maintenance capability is a critical factor, as advanced signaling systems demand specialized technical expertise, reliable spare parts, and robust maintenance procedures to sustain long-term performance.

Personnel training is another essential aspect of implementation. Train drivers, traffic controllers, and maintenance staff must be adequately trained to operate, interpret, and maintain modern signaling and protection systems. The literature emphasizes that insufficient training can reduce system effectiveness and introduce new operational risks, even when advanced technologies are in place.

Therefore, a gradual and well-planned implementation strategy is necessary to maximize the benefits of modern signal passing technologies while minimizing operational risks. Phased deployment, pilot projects, and continuous performance evaluation are recommended to support smooth technological transition. In the Indonesian context, such an approach can facilitate the development of a safer, more reliable, and more resilient railway system aligned with long-term national transportation goals.

3.5 Discussion Summary

Overall, the results of this study demonstrate that signal passing technologies play a critical role in enhancing railway safety and preventing Signal Passed at Danger (SPAD) incidents. The literature-based analysis confirms that no single technology can fully address SPAD risks; instead, effective prevention is achieved through the integration of multiple safety layers, including interlocking systems, Automatic Train Protection (ATP), train detection technologies, and digital communication systems.

The combined implementation of these technologies forms a multi-layered safety framework that strengthens railway operations by addressing both technical and human-related risk factors. Interlocking systems provide route protection and prevent conflicting train movements, while ATP systems offer continuous supervision and automatic intervention to mitigate human error. Train detection technologies ensure accurate and reliable information on track occupancy, which is essential for correct signal operation and safe traffic management. Furthermore, digital communication systems enhance coordination between trains and control centers by enabling real-time data exchange and improved situational awareness.

The discussion highlights that the effectiveness of signal passing technologies is significantly enhanced when they are implemented as an integrated system rather than as isolated components. This integrated approach improves operational reliability, reduces accident risk, and supports more efficient railway operations, particularly in high-density and complex networks. In addition to safety benefits, the findings indicate that modern signaling systems contribute to improved punctuality, service quality, and overall system resilience.

These results support the conclusion that modern signaling and signal passing technologies are essential components of contemporary railway transportation systems. Their strategic implementation is fundamental to achieving safer, more reliable, and more efficient railway operations, and they represent a key foundation for the future development of sustainable railway transportation.

4. CONCLUSION

This study concludes that modern signal passing technologies play a vital role in enhancing railway safety and preventing Signal Passed at Danger (SPAD) incidents. Based on a comprehensive literature review, the integration of interlocking systems, Automatic Train Protection (ATP), train detection technologies, and digital communication systems has been shown to significantly reduce operational risks associated with unauthorized signal passing and human error.

The findings highlight that a multi-layered safety approach is essential for effective SPAD prevention. By combining route protection, continuous train supervision, accurate position detection, and real-time communication, modern signaling systems provide robust safeguards that strengthen both safety and operational reliability. These technologies not only mitigate accident risks but also contribute to improved punctuality, efficiency, and overall service quality in railway operations.

In the context of Indonesian railways, the adoption of integrated signal passing technologies is increasingly important due to network expansion and growing traffic density. However, successful implementation requires careful system integration, adequate maintenance capability, and comprehensive personnel training. A phased and well-planned implementation strategy is therefore recommended to maximize the benefits of advanced signaling technologies while minimizing operational challenges.

Overall, modern signaling systems represent a fundamental component of safe, reliable, and efficient railway transportation. Their continued development and strategic implementation will be crucial in supporting the future growth and sustainability of railway operations in Indonesia and beyond.

REFERENCES

A. P. Irawan, *Design of an Automatic Transfer Switch (ATS) Panel for the Marsudi Luhur Livestock Group*, Department of Electrical Engineering, Universitas Muhammadiyah Yogyakarta, 2020.

Ministry of Transportation of the Republic of Indonesia, *Regulation of the Minister of Transportation of the Republic of Indonesia Number 44 of 2018 on Technical Requirements for Railway Signaling Equipment*, Jakarta, Indonesia, 2018.

N. Muranto *et al.*, "Study of Electrical Power Transfer from PLN to Generator Set during Power Outages Using an Uninterruptible Power Supply (UPS) at Grand Elite Hotel Pekanbaru," Department of Electrical Engineering, Faculty of Engineering, Universitas Lancang Kuning, Pekanbaru, 2018.

G. F. Musyary, *Power Supply Operation Management in Telecommunication Power Supply Devices of the Arnet Division at PT Telkom Bangka Belitung*, Department of Electrical Engineering, Universitas Pertamina, 2020.

Nuralam, *Base Station Planning for WCDMA-Based Mobile Communication Systems in Suburban Areas*, Department of Electrical Engineering, Politeknik Negeri Jakarta, 2016.

D. R. A. Prabowo, *Reliability Study of 20 kV Double Incoming Cubicle Usage with ATS Setting Planning for Load Optimization Above 1 MVA at APJ Surakarta*, Department of Electrical Engineering, Universitas Muhammadiyah Surakarta, 2016.

I. W. Ramadhan, *Design Analysis of Automatic Transfer Switch and Automatic Main Failure Panels*, Department of Electrical Engineering, Universitas Muhammadiyah Yogyakarta, 2019.

E. T. Santoso *et al.*, "Basic Design of Automatic Main Failure and Automatic Transfer Switch Systems for Meeting Room Building 71," in *Proceedings of the Scientific Meeting on Nuclear Device Engineering (PRPN-BATAN)*, 2011.

B. L. Situmorang, *Power Quality Analysis of Automatic Transfer Switch (ATS) during Load Transfer*, Faculty of Engineering, Universitas Tanjungpura, 2019.

Sutrisno and E. Sulaeman, *Design and Implementation of a Telecommunication Infrastructure Model Based on Plesiochronous Digital Hierarchy (PDH) Technology*, Department of Electrical Engineering, Politeknik Negeri Bandung, 2013.