RISSB

Horizons 6.0

Digital Transformation of the Australian Rail Sector

Full Speed Ahead: A Smart Move in

RAIL SAFEWORKING

Protecting Rail Infrastructure and our Workforce through AI Innovation: A Transformative Project - Enhancing Efficiency, Safety and Sustainability

Contents

Introduction

The rail sector's traditional reliance on manual processes and legacy systems limits its operational efficiency and capacity to respond to dynamic market demands. The global shift towards digitalisation presents an opportunity to overcome these challenges, offering ways to optimise operations, improve workers safety, and reduce environmental impacts.

Railway Safety in Australia: Overview

Railway safety is a critical concern for both the public and railway operators in Australia. The nation's extensive railway network is vital for passenger transport and freight movement, making safety protocols essential to prevent accidents, injuries, and fatalities. The Australian railway industry adheres to stringent safety standards and regulations, with ongoing efforts to enhance safety measures through technological advancements.

Document Purpose

The purpose of this report is to explore the potential of Artificial Intelligence (AI) in enhancing Safeworking practices within the Australian rail industry. By conducting a detailed case study and literature review, the report examines current railway safety protocols, the challenges associated with maintaining safe track occupations, and the role AI can play in addressing these issues. The report outlines how AI technologies, through real-time monitoring, predictive maintenance, and automation, can reduce human error, improve communication, and enhance decision-making processes. Additionally, it highlights the importance of aligning AI with existing Safeworking regulations and proposes strategic steps for its implementation, including stakeholder engagement, pilot projects, and ensuring cybersecurity. This report aims to provide insights into how AI can create a safer and more efficient rail network, benefiting both workers and operators.

Importance of Safety during Track Occupations

Ensuring safety during track occupations is paramount due to the potential dangers involved. Workers are exposed to hazards such as moving trains, electrical systems, and heavy machinery. Any lapse in safety protocols can result in severe injuries or fatalities. Therefore, continuous improvement of safeworking rules and the incorporation of advancing technologies to utilise these tools helps keep our people safe and our networks operating

Safeworking & Track Access

Safeworking Systems are rules and equipment to prevent train conflicts by ensuring only one train occupies a track section at a time. Track access during occupation refers to periods when workers are on tracks for maintenance, repairs, or upgrades. These high-risk periods require precise coordination and communication to ensure safety. Despite procedures to minimise risks, human error and unpredictable conditions can still lead to incidents.

The Rise of Artificial Intelligence (AI)

AI, defined as a system's ability to interpret external data, learn from it, and use those learnings to achieve specific goals, has a rich history dating back to the 1940s. The roots of AI can be traced to the work of pioneers like Isaac Asimov, who introduced the Three Laws of Robotics in his 1942 short story "Runaround," [1] and Alan Turing, who developed the code-breaking machine "The Bombe" during World War II [2]. Turing's seminal 1950 paper, "Computing Machinery and Intelligence," laid the groundwork for AI by proposing the Turing Test to evaluate machine intelligence [3].

The official birth of AI as an academic discipline occurred in 1956 during the Dartmouth Summer Research Project on Artificial Intelligence, organised by Marvin Minsky and John McCarthy [4]. This event marked the beginning of what is known as the AI Spring, where rapid growth in AI research gained momentum. Early successes included the development of the ELIZA program, which simulated human conversation, and the General Problem Solver, which could solve simple problems. However, the field faced setbacks in the 1970s, leading to the AI Winter, a period of reduced funding and interest.

The resurgence of AI, often referred to as the AI Fall, began in the late 1990s and early 2000s with the advent of machine learning and neural networks. IBM's Deep Blue, which defeated world chess champion Garry Kasparov in 1997, and Google's AlphaGo, which triumphed over a Go champion in 2015, are notable milestones [5]. These successes were driven by advances in computing power and the availability of large datasets, collectively known as Big Data.

AI's rise in popularity in recent years can be attributed to its transformative impact on various industries and everyday life. In healthcare, AI-powered diagnostic tools outperform human doctors in detecting diseases like skin cancer. In finance, AI algorithms analyse vast amounts of data to predict market trends and manage investments. AI-driven chatbots and virtual assistants, such as Siri and Alexa, have become integral to customer service and personal assistance. Additionally, AI is revolutionising transportation with the development of self-driving cars, which promise to enhance road safety and reduce traffic congestion.

Despite its potential, AI faces limitations and challenges. The AI effect, where advanced technologies are no longer perceived as AI once they become mainstream, highlights the evolving nature of the field. Moreover, biases in training data can lead to discriminatory outcomes, necessitating robust regulatory frameworks. The opacity of deep learning algorithms, often described as "black boxes," raises concerns about transparency and accountability. As AI continues to evolve, addressing these challenges will be crucial to harnessing its full potential while ensuring ethical and equitable use.

Absolute Signal Blocking and its Application on the PTA Network

Anecdotal Example

The following information is based on personal recount from a Public Transport Authority Western Australia (PTA) Protection Officer, supported by Network Safety Alerts (available through the PTA Vendor Communication Portal) of an event that occurred in 2020 that resulted in Network-Wide change, re-training, and further conditions surrounding the application of the Absolute Signal Blocking (ASB) Safeworking Rule. As you read through this anecdotal example, we encourage you to reflect on your own network environment and current safeworking processes, identifying any similarities or challenges. These insights will be invaluable as we explore the potential of AI to enhance safeworking in the section, "AI Potential to Enhance Safeworking".

"I became an Accredited Protection Officer Level 2 in March 2021 and have never used the ASB Method of Protection to date, despite being accredited to do so."

This is due to PTA Network Directive SD01/22 that stipulates that this Protection Method is only "authorised for use for Infrastructure restoration work in the Danger Zone arising from a Condition Affecting the Network". In other words, ASB is not applicable for Planned Works.

"The incident that precipitated this change was a near-miss resulting from incorrect Blocking Arrangements between the Network Control Officer (NCO), and the Protection Officer (PO). Signal "544" was Blocked instead of "554" on the Joondalup Line, leaving the worksite unprotected, and resulting in a Passenger Train traversing through the worksite and narrowly missing the workgroup". See Figure 1.

There are multiple factors that contributed to the incident; however, it can be concluded that the consequent actions have introduced further long-term risk; the presence of AI technology could have assisted in preventing such an event; and AI Technology can streamline current communication systems and present the user with real-time data, eliminating the tedious processes involved with obtaining and interpreting *all* Safety Alerts and Notifications.

Signal **544** was Blocked as the *Protecting Signal* instead of Signal **554**, leaving the worksite **unprotected** against unauthorised Rail Traffic. An issue of this nature occurred again, in August 2021 (SA04/21) and August 2023 (SIC2023-08).

T- Start Date	Worksite Protection Planning Process on the PTA Network
4-6 Weeks	Project and Maintenance Representatives submit their Track Access Applications in the PTA's Electronic Track Access System.
2-4 Weeks	The Track Access Team review the Applications and Process it through the relevant Workflow/s.
1-2 Weeks	Planned Works with a Work on Track Authority (WOTA) as the intended Safeworking Method will have a Safeworking Protection Plan (SPP) Planned by the "SPP Planner" and Verified by the "SPP Verifier"
3-7 Days	Protection Officer Level 3 (PO3) or Possession Protection Officer (PPO) reviews the SPP after final verification.

Concerns with the Current Worksite Planning Process on the PTA Network

Part of PO2 and PO3 accreditation is being deemed competent in the *selection* of Protecting Signals for a selected Worksite.

The current arrangement of SPP Planning does not allow opportunity for continuous improvement and critical thinking from the Protection Officers themselves, as their only involvement is a review 3 days prior to the commencement of their work.

There is currently only **one** SPP Planner for the *entirety* of the Network's WOTA's. While this is intended for consistency, it is not a sustainable process in an expanding Network.

There are slight misalignments with Training Deliverables vs. Practical Elements of SPP Planning on the PTA Network, and opportunity to improve current arrangements.

ASB's are permitted for 'Conditions Affecting the Network', i.e., emergency/urgent matters, but not for Planned Works.

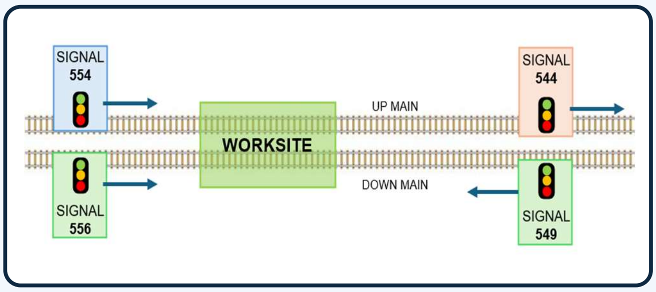


FIGURE 1: Worksite Protection Arrangements

Safeworking Rules and Procedures

Relationship between RSNL and Safeworking

Current safeworking practices across Australian railways are governed by network specific rules and procedures for the safe management of rail traffic to protect workers from unauthorised Rail Traffic during track occupations.

In the context of Australian railway safety, the Rail Safety National Law (RSNL) serves as the overarching legal framework that establishes consistent safety standards and requirements for all rail operations across the country. It provides a unified approach to key safety principles such as worker competency, incident reporting, risk management, and operational accreditation. Rail networks have network specific rules and procedures that are aligned to RSNL requirements. Network specific rules address the unique aspects of networks including operational tempo, infrastructure and risks.

These procedures are designed to ensure compliance with the RSNL while providing practical guidelines for day-to-day operations, such as Safeworking methods, track access, and signalling systems.

Ultimately, the RSNL encourages harmonisation across networks to maintain consistent safety practices, while still allowing for local flexibility where necessary to address the distinct operational needs and risks of each individual network. This approach ensures both national safety coherence and the ability to adapt to varying conditions across different rail environments.

Safeworking within Australian Networks

The table below highlights similarities and differences across networks, showing the challenges faced with different rules but also the potential for a common solution.

Category	Similarities	Differences
Regulatory Framework	All networks must comply with the Rail Safety National Law (RSNL).	Slight differences in state-specific application, i.e., Regulations.
Worker Competency	Workers must meet national competency requirements under RSNL, ensuring safety-critical roles are filled by qualified personnel.	Different networks may have network-specific qualifications or additional certification requirements for roles like Protection Officers or Drivers.
Safety Critical Roles	Key roles like Train Controllers, Protection Officers, and Drivers exist across all networks.	Roles such as Protection Officers may have different levels and classifications across networks, with varying duties and competencies.
Track Access Procedures	Standard procedures are used to safely manage access to tracks during maintenance and operations.	Different networks may use varied methods like Track Occupancy Authority (TOA), Train Orders, or Centralised Traffic Control (CTC) for track access.
Technological Integration	RSNL encourages the adoption of technology to improve safety and efficiency.	Some networks have adopted advanced technology like Positive Train Control (PTC) or ETCS, while others still rely on more manual Safeworking systems.
Competency Management / Records Management	RSNL Section 117, (6) All Rail Transport Operators must maintain competency records	Networks utilise different systems for the management of rail safety worker competency (example: RIW/MTA, Pegasus, 3Squared etc.).

Existing Technology and Safeworking Innovations

- ETW track work apps – network rules inbuilt, reads from encodings and database
- Databases for templates (Sydney trains)
- Control System for Blocking of tracks
- Protection Officer Online Workbook

Challenges in Maintaining Safety

Despite the comprehensive nature of these safeworking rules, maintaining safety during track occupations remains challenging. Human factors such as fatigue, miscommunication, and decision-making errors are significant contributors to safety incidents. Additionally, the dynamic nature of railway environments, with constantly changing conditions and the presence of multiple stakeholders, adds to the complexity of ensuring safety.

The Australian rail industry faces significant challenges in implementing effective safeworking practices due to complex, network-specific rules, human factors, and technological limitations. These challenges create multiple opportunities for oversight, compromising the safety and integrity across all networks within Australia and include:

- Complexity and Variability of Network-Specific Rules
- Human Factors and Communication Breakdown
- Technological Limitations and Integration Challenges

To overcome these challenges, AI offers the potential to unify standards, enhance communication, and seamlessly integrate advanced technologies across all networks. The development and implementation of AI tools will enable real-time, comprehensive analysis of unique situations, allowing decisions to be made with greater awareness and supporting users in their decision-making process, transforming them into co-creators rather than simply recipients of information. By adopting AI-driven solutions, the industry can pave the way for a more resilient, efficient, and secure rail system, equipped to meet the evolving demands of the future.

AI in Modern Railways

Artificial Intelligence (AI) is transforming the rail industry by enhancing network operations, improving maintenance protocols, and boosting safety measures. AI technologies are increasingly being used to optimise various aspects of rail operations, ranging from safety monitoring to predictive maintenance and energy efficiency.

AI-Driven Safety Improvements

The integration of AI into rail safety procedures offers significant safety benefits by minimising human errors and enhancing situational awareness. AI systems can quickly analyse vast amounts of data to identify patterns that suggest potential safety threats, allowing for swift, preemptive action.

Example: SNCF Cockpit and Bidirectional Assistant (CAB). The French national railway company, SNCF, has been developing an in-cab AI assistant for drivers [6]. This AI assistant will provide real-time decision support, monitor ongoing events, and suggest quick recovery solutions in case of incidents. It will help drivers maintain safety standards while improving response times to unforeseen events.

Predictive Maintenance and Hazard Detection

AI technologies are proving crucial in the areas of predictive maintenance and hazard detection. By leveraging advanced machine learning algorithms, AI can predict and prevent potential failures before they occur.

Example: Artificial Intelligence at Deutsche Bahn (DB). Deutsche Bahn, the German railway company, utilises AI for image analysis of train car body roofs, reducing inspection times from several hours to a few minutes. AI is also used for data-driven forecasting to optimise wheel replacement schedules, lowering costs and increasing train availability.

Lower waste consumption can also be achieved through more efficient predictive maintenance. When identified issues are dealt before they lead to major failures, it increases the lifespan of the equipment thus reducing downtime and manpower required in operations. Additionally, replacement parts are ordered only when necessary, minimizing excess inventory.

Sustainability and Energy Efficiency

AI is contributing to the sustainability of rail operations by enhancing energy efficiency and reducing greenhouse gas emissions.

Example: VIA Rail Canada - EcoRail. VIA Rail Canada has tested EcoRail, an AI software that provides real-time driving recommendations based on speed, track slope, schedule, and other factors to improve fuel efficiency. This AI-driven approach has achieved up to a 15% reduction in fuel use. Due to the successful trial results, VIA Rail is expanding the use of EcoRail to live train operations [7].

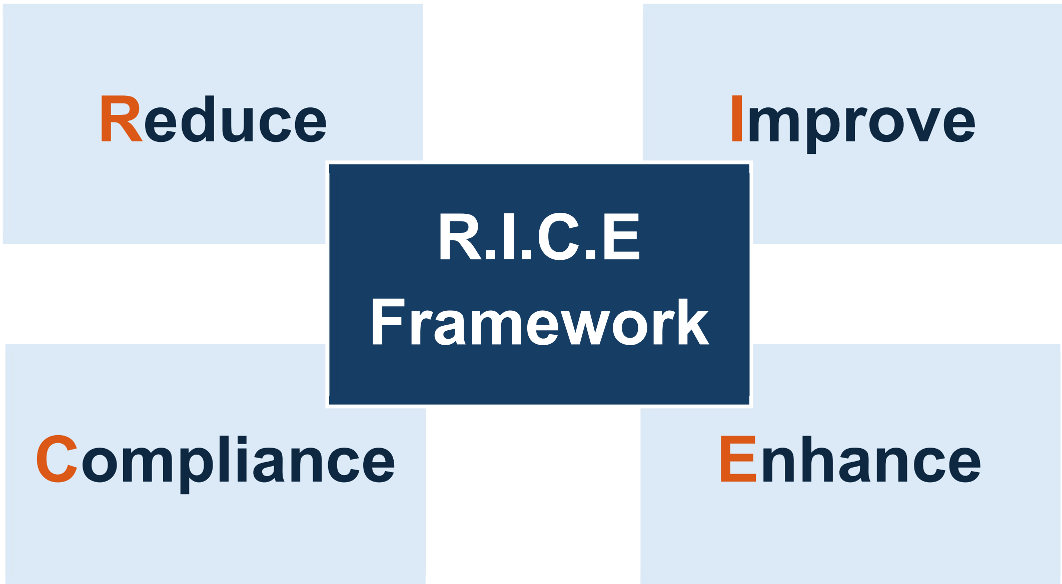
Scheduling Optimisation and Customer Experience

AI tools have been effectively utilised by rail transport operators to optimise train schedules and improve customer experience. AI can particularly benefit other areas such as crew scheduling and network planning [8]. These tools analyse large volumes of data to identify patterns and preferences, which can be used to create more efficient and reliable schedules. As a result, trains run on time more frequently, and passengers experience fewer delays and disruptions.

Example: Hitachi Rail's 360Flow is a smart mobility platform designed to optimise passenger and vehicle flows in public transport networks. It aggregates real-time data from various sources to monitor occupancy, manage congestion, and predict future demand. The system uses AI and sensors to analyse passenger movements and provide insights for operators to improve traffic management [9], enhance connectivity, and ensure safer, faster travel. It supports decision-making by offering a comprehensive view of transport demand, enabling better resource allocation and planning.

The application of AI in modern railways is gaining momentum in a wide range of areas, providing confidence for the industry to further its use. The next section of this report will explore AI's potential to enhance safeworking procedures and the potential challenges the application would face.

AI Potential to Enhance Safeworking



R.I.C.E. Framework as Proposed by the Ghan:

The R.I.C.E framework is the core of any AI implementation and is developed to help cover key concepts that need to be followed to realise benefit to any organisation. Each of the four facets plays a critical role in ensuring a feasible approach is taken to utilising AI and simply not used for the sake of hosting such technologies. A clearly defined purpose and a benefit statement that covers key points is needed and the R.I.C.E frameworks makes it simple for any organisation to accomplish a high level overview. Each section has a key deliverable, and they are:

Reduction in Human Error

Human error is one of the leading causes of accidents in railway operations. Skill based errors, unsafe actions and poor decision making are key human errors that lead to incidents. In addition to this, other contributing factors such as metal state, personnel resourcing, and personal readiness play a major role in the occurrence of unsafe acts and human error [10]. AI can significantly reduce the likelihood of errors by automating routine tasks, providing real-time data analysis, and offering decision support.

Improved Incident Response Times

Conventional approaches to incident responses have some aspects of time delays. Human centered AI tools involving crowdsourced data can assist in detecting or responding to incidents proactively [11]. AI systems can process and analyse data from a variety of sources at a faster rate than traditional methods.

Compliance with Safety Regulations

AI can also help ensure compliance with safety regulations by automating the monitoring and reporting processes. AI can enhance collaboration and ensure consistency when regulations or network specific rules are amended or developed. This has the potential to reduce the lead time associated with the often complex and time-consuming process involved when implementing regulatory changes in the rail industry.

Enhanced Predictive Capabilities

Predictive analytics powered by AI can identify potential risks before they materialise. Examples of this include predictive maintenance of rail assets and how AI can monitor/track asset condition before critical failures occur.

AI Addressing Safeworking Challenges

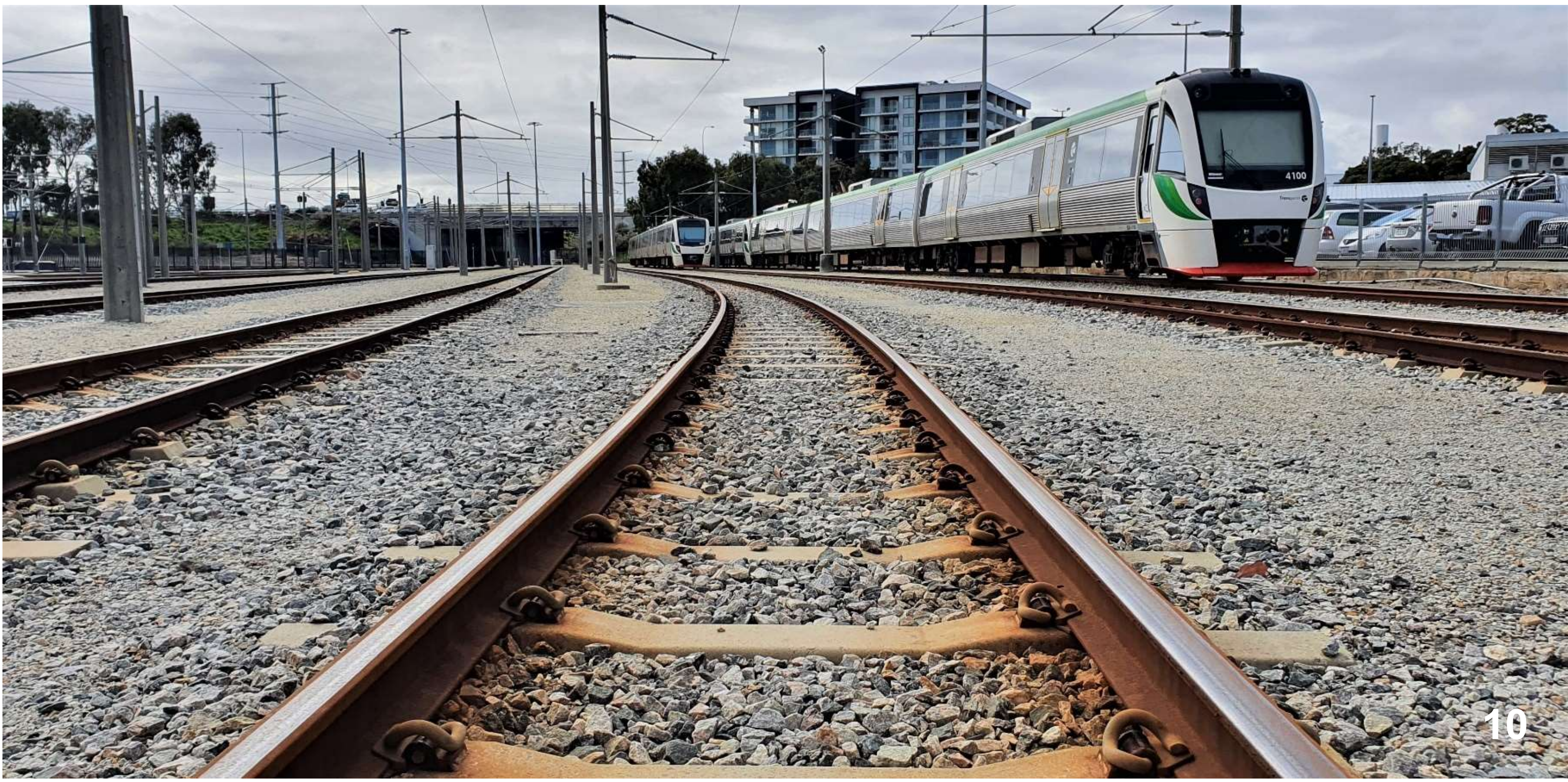
AI alone is not able to replace our Safeworking systems, but it does have the capabilities to enhance applications and address some of the challenges faced. Key areas for potential application of AI systems include:

- Real-time Monitoring: AI systems can continuously monitor track conditions, worker locations, and train movements, providing instant alerts in case of any anomalies.
- Automated Decision Support: AI can assist train controllers by analysing multiple data points simultaneously, offering recommendations or automatically initiating safety measures in critical situations.
- Data Aggregation and Analysis: AI systems can assess databases and apply rules to cross check and add another layer to checking protections applied.

A major benefit of AI is its application in real-time monitoring systems for track access safety. These systems utilise sensors installed along tracks and on trains to collect data on parameters such as track conditions, train speed, and worker locations. AI algorithms process this data in real-time to identify potential hazards and issue alerts to workers and controllers before incidents occur. Existing systems, such as Base2 ICE radios collect positioning, speed and location data to feed information to control centers, and work on track mobile apps such as WOTA, ETW, and ETAP to notify users when approaching or leaving protected areas and well as timing and limitations regarding possessions.

Taking this geodata, centralised control and mobile application one step further to maximise the benefits of AI, it is essential to integrate AI systems with existing safety protocols. This integration ensures that AI complements rather than replaces human judgement. AI can support train controllers by providing automated decision-making tools that analyse real-time data and offer recommendations such as:

- detect a worker too close to live track, it can prompt control to issue a warning, initiate communications or halt the train to prevent an accident
- integrate environmental factors such as weather conditions in protection plans, sighting distance calculations etc.
- provide automatic warnings if not normally detected road rail vehicle or rolling stock enters a protection zone or fails to decelerate as required.
- optimise routes, minimising the risk of accidents and avoiding unsafe conditions and maintaining safe distances between trains and workers.
- in emergencies, issue an emergency stop



Risks and Considerations

Balancing Innovation with Safety and Reliability in AI Integration

Historically, Australia's rail industry has been the late majority when it comes to the implementation of new technologies, digital systems and innovative practices. Some of the of the main reasons for this is due to risk appetite, outdated practices, size and demand, lack of network collaboration, the ageing legacy infrastructure on Australia's rail networks, and the significant challenge it is to integrate the decades-old infrastructure with the latest technologies.

This puts Australia in a position where it can leverage insights from leading regions such as Europe, the UK and Asia, where cutting edge technologies are being deployed, such as utilising Artificial Intelligence in predictive maintenance and the use of robotics and automation in track and corridor maintenance, as well as rolling stock manufacturing.

Also, a recent Australia National Artificial Intelligence Centre (NAIC) gives practical guidance to all Australian organisations on how to safely and responsibly use and innovate with artificial intelligence (AI) and recommends 10 A.I. Guardrails as a voluntary practice for organisations in AI implementation across any supply chain. These guardrails should be considered and a bespoke strategy for railway implementation should be proposed to capture the essence of the guardrail in this endeavour.

These emerging technologies offer significant opportunities for enhancing efficiency and safety, potentially leading to reductions in maintenance and operational costs. However, their adoption also presents several risks that must be carefully managed, such as the introduction of any new technology. In the context of AI, these are data and cybersecurity, system failures and workforce implications.

Cybersecurity Threats	System Failures	Workforce
AI systems c may be vulnerable to cyberattacks, where malicious actors could seek to disrupt operations or access sensitive data. Protecting AI systems from cyber threats requires robust security measures, including encryption, access controls, and regular security audits.	While AI can enhance safety, it also introduces new risks, particularly if the AI system fails. System failures could be due to technical issues, such as software bugs or hardware malfunctions. Ensuring that AI systems are robust and include fail-safes, such as manual overrides, is critical to mitigating these risks.	AI systems can improve operational efficiency, however widespread implementation will inevitably transform the nature of roles in the workforce. To preserve existing skills in the rail industry amid an ageing workforce and skill shortages, AI should be integrated to support current workforce roles and not replace them.

Broader AI Risks Identified by the International Union of Railways

Impaired Fairness

AI can produce content that is not clearly identifiable as AI generated, leading to confusion or deception of users.

IP Infringement

Foundation models typically leverage internet-based data, leading to incidents of IP infringement (for example, copyright violations or plagiarism).

Privacy Concerns

AI may heighten privacy concerns through the use of personal or sensitive information for model training.

Third-Party Risk

AI, particularly open source LLMs, can be leveraged to create and disseminate malicious content (such as falsehoods).

Performance & Hallucination Risk

Foundation models may generate factually incorrect or outdated answers.

Malicious Use

Use of third-party AI models and tools can pose the risk that proprietary data is used by public models.

Recommendations

AI can be a powerful tool that has shown true potential. To address the ongoing challenges in railway safety and operations, it is highly recommended that the Australian Rail Networks have a strategic onlook into integrating AI into their existing frameworks.

Capabilities of real-time monitoring, predictive analytics and automated decision can offer substantial support and opportunity to enhance safety and efficiency within each rail network and possibly across rail networks. Improved incident response times through rapid data processing and effective compliance to safety regulations could provide a quantum leap for any rail network. These benefits are recommended for our topic covering safety in track access during occupation/possession.

To proceed with such a venture, it is recommended that:

- An AI authority is established on a regulatory platform to ensure effective and appropriate use within any rail organisation.
- Implementing legislative and regulatory changes would be required to ensure that these new technologies are backed by governing statute and reflect fair opportunity within the sector.
- Changes must reflect appropriate measures to ensure staff and customer safety and provide a strong foundation for any organisation to feel confident in accepting AI into its working environment. Managing AI within any rail organisation will have a few steps to cover.
- Initiating AI change would be to Identify business areas that could benefit from AI and ensuring its backed with viability and feasibility in mind.
- Focus on safeworking methods for track access during occupation as a key business workflow benefiting from AI.
- Explore other business processes/workflows that could benefit and possibly link together to form a cluster of improved processes.
- Ensure coordination for suitable AL model implementation that enhances; not dimmish, human or intangible assets.
- Develop rollout methodology and strategy appropriate to the organisation and affected business unit.
- Tailor training and support systems to educate and upskill the current workforce with the new system.

Ultimately, by adopting AI-driven solutions, the industry can achieve a more resilient, efficient and secure rail network that is capable of meeting future demands and improving overall safety outcomes.

Conclusion

Summary of Findings

AI has the potential to significantly enhance the safety of track access during occupation in Australian railways. By reducing human error, improving incident response times, and providing predictive insights, AI can help prevent accidents and improve the overall safety of railway operations.

The Future of AI in Railway Safety

The future of AI in railway safety is promising, with ongoing advancements in technology likely to lead to even greater improvements in safety and efficiency. However, realising this potential will require careful planning, investment, and the development of new regulatory frameworks.

Final Thoughts on Enhancing Track Access Safety

The integration of AI into track access management represents a significant step forward in improving railway safety. By leveraging AI's capabilities, Australian railways can create a safer environment for workers and passengers alike, ensuring that the nation's railway network continues to operate efficiently and safely.

References

[1] A.-S. a. M. G. G. Brauner, “Runaround by Isaac Asimov and the significance of the Three Laws of Robotics in today's world.,” 2016.

[2] M. &. K. A. Haenlein, “A Brief History of Artificial Intelligence: On the Past, Present, and Future of Artificial Intelligence.,” in *California Management Review, 61(4), 5-14.*, 2019.

[3] A. M. Turing, “Computing machinery and intelligence,” in *Springer Netherlands*, 2009.

[4] G. Solomonoff, “The meeting of the minds that launched AI there’s more to this group photo from a 1956 AI workshop than you’d think.,” in *IEEE Spectrum, (History Of Technology)*, 2023.

[5] A. H. C. J. M. A. G. L. S. G. v. d. D. J. S. I. A. V. P. M. L. S. D. D. G. J. N. N. K. I. S. T. David Silver, “Mastering the Game of Go with Deep Neural Networks and Tree Search,” in *Nature, 529*, 2016.

[6] Systemx Institute of Research and Technology, “CAB- Cockpit and Bidirectional Assistant,” [Online]. Available: https://www.irt-systemx.fr/en/projets/cab/.

[7] VIA Rail Canada, “SUSTAINABILITY INITIATIVE - Moving towards a more sustainable future with artificial intelligence,” 2022. [Online]. Available: https://corpo.viarail.ca/en/news/2022/moving-towards-more-sustainable-future-artificial-intelligence.

[8] R. D. D. L. B. N. F. F. G. R. L. Z. L. R. T. T. V. V. &. W. Z. Tang, “A literature review of Artificial Intelligence applications in railway systems,” in *Transportation research. Part C, Emerging technologies, vol. 140, pp. 103679-.*, 2022.

[9] Hitachi Rail, “Understand transport, match passenger needs and exploit asset capacity,” [Online]. Available: https://www.hitachirail.com/smart-mobility/flow-management/.

[10] Z. P. H. Z. J. Z. J. W. J. H. C. &. L. C. Guo, “sing HFACS to understand human error in railway dispatcher performance: a study of proactive safety inspection records,” in *Ergonomics, pp. 1–14.*, 2023.

[11] Y. M. A. P. H. &. D. A. Senarath, “Designing a Human-centered AI Tool for Proactive Incident Detection Using Crowdsourced Data Sources to Support Emergency Response,” in *igital government (New York, N.Y. Online), vol. 5, no. 1, pp. 1–19.*, 2024.

THE GHAN

Muhsiul HASSAN; Leo DAMICO; Zoe SMITH; Dimitrios HARALAMPIDIS; Luca BANCO; Alexandra RENDINA; Evan STEWART; Muhammad HAFEEZ