

Project 1-085

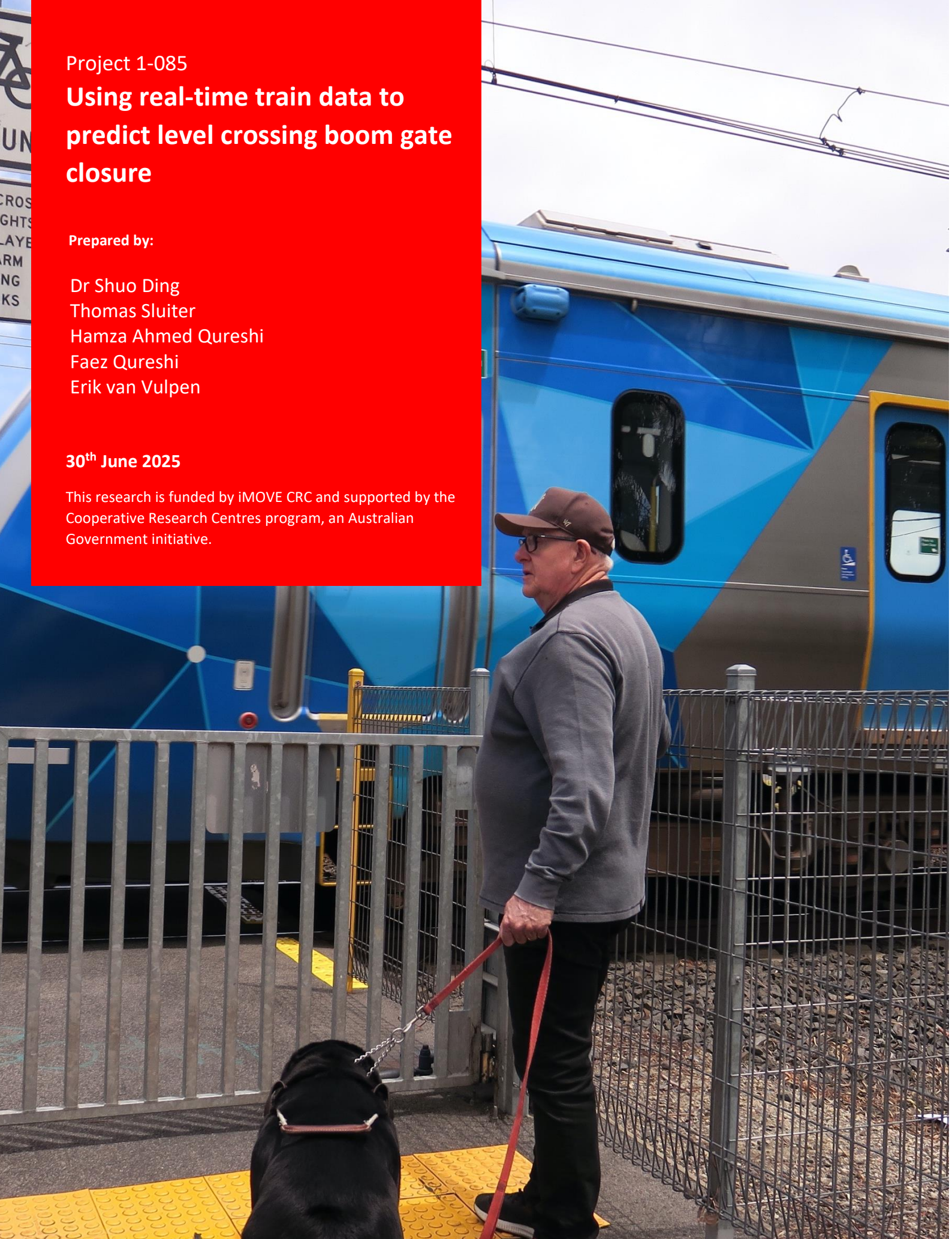
# Using real-time train data to predict level crossing boom gate closure

Prepared by:

Dr Shuo Ding  
Thomas Sluiter  
Hamza Ahmed Qureshi  
Faez Qureshi  
Erik van Vulpen

30<sup>th</sup> June 2025

This research is funded by iMOVE CRC and supported by the Cooperative Research Centres program, an Australian Government initiative.



## Executive summary

The Victorian Department of Transport and Planning (DTP) and Metro Trains Melbourne conducted workshops to explore technology solutions for improving level crossing safety, especially for people with disability and vulnerable road users (VRUs). One key innovation opportunity identified was to use real-time train data to predict boom gate closures, giving pedestrians earlier and more informative warnings before crossing. This was an initiative under the Victorian level crossing safety strategy and supported by iMove.

The proof-of-concept system, “CrossSafe,” was trialled at Diggers Rest. It uses machine learning to predict when boom gates will close, offering progressive alerts: no closure in the next 3 minutes, possible closure in 3 minutes, certain closure in 1 minute, and gates closed.

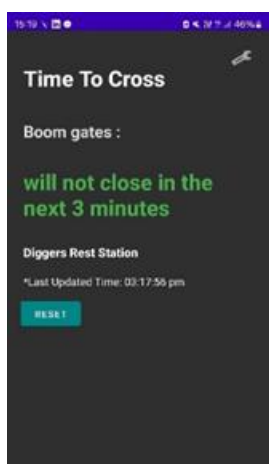


Figure 1 CrossSafe  
POC - screenshot

The system uses open-source train data, an MQTT-based communication framework, and a mobile interface. Despite challenges with data accuracy, prediction errors were acceptable for this use case (5–11 seconds), and a built-in buffer ensured alerts were always early.

Engagement with people with disability showed strong support: 71% reported uncertainty at crossings, and 75% found crossings stressful. Timed alerts appeared especially useful for those with mobility or sensory impairments. International efforts by organisations like TNO (Netherlands) and SNCF (France) confirm global interest in such solutions.

CrossSafe does not interface directly with rail signalling systems, Reducing certification burdens. It complements, rather than replaces, safety-critical level crossing infrastructure. Machine learning models were adapted for each site due to varied infrastructure and signalling behaviour governed by ETS-12-01 and other standards.

Upcoming data improvements—including V/Line GPS upgrades and national data access platforms like TrackR, ARTC’s Advanced Train Management System (ATMS) and DTP’s Public Transport Data Program—will enhance model accuracy and enable broader deployment. The increasing availability of real-time train information for use by third-party applications, such as journey planners and Google-based V/Line train schedules, will support applications such as CrossSafe

A follow-up project is proposed to scale CrossSafe nationally by partnering with state transport agencies and accessibility-focused apps like TomTom and BindiMaps. Integration with C-ITS standards and the Australian National Access Point will support interoperability and long-term adoption across jurisdictions.

# Table of Contents

Executive summary.....	1
Table of Contents.....	2
Acronym List .....	3
1 Summary.....	4
2 Background.....	8
3 Best Practices.....	12
4 End-User Expectations.....	20
5 Datasets Overview .....	27
6 Machine Learning Prediction Algorithms .....	32
7 C-ITS Compliant Prototype Development .....	39
8 Privacy, Consent and Regulation .....	45
9 Assessment and Conclusion .....	47
References .....	54
Appendix A: C-ITS Standard (EU ITS-G5 Release 2) .....	55
Appendix B: VIC Rail System Dataset Overview .....	58
Appendix C: NSW Public Transport Datasets.....	63
Appendix D: Original Scope .....	68

## Acronym List

<b>ADAS</b>	Advanced Driver Assistance System
<b>AI</b>	Artificial Intelligence
<b>ALCAM</b>	Australian Level Crossing Assessment Model
<b>API</b>	Application Programming Interface
<b>ARTC</b>	Australian Rail Track Corporation
<b>CAM</b>	Cooperative Awareness Message
<b>C-ITS</b>	Cooperative Intelligent Transport Systems
<b>CRDI</b>	Customer Real-Time Data Interface
<b>DENM</b>	Decentralized Environmental Notification Message
<b>DLBI</b>	Data Layer Bridge Interface
<b>DSAPT</b>	Disability Standards for Accessible Public Transport 2002
<b>DSRC</b>	Dedicated Short-Range Communications
<b>DTP</b>	Department of Transport and Planning
<b>ETSI</b>	European Telecommunications Standards Institute
<b>GTFS</b>	General Transit Feed Specification
<b>GTFS-R</b>	GTFS-Realtime
<b>GPS</b>	Global Positioning System
<b>HMI</b>	Human-Machine Interface
<b>ICE</b>	In Cab Radio Equipment
<b>ITS</b>	Intelligent Transport Systems
<b>LTE</b>	Long-Term Evolution
<b>MAE</b>	Mean Absolute Error
<b>ML</b>	Machine Learning
<b>MQTT</b>	Message Queuing Telemetry Transport
<b>MTM</b>	Metro Trains Melbourne
<b>NAP</b>	National Access Point
<b>NAPCORE</b>	National Access Point Coordination Organisation for Europe
<b>PIDS</b>	Passenger Information Display System
<b>PII</b>	Personally Identifiable Information
<b>PTV</b>	Public Transport Victoria
<b>RPIDS</b>	Real-time Passenger Information Display System
<b>RSU</b>	Roadside Unit
<b>SNCF</b>	Société Nationale des Chemins de fer Français
<b>SIRI</b>	Service Interface for Real-time Information
<b>TDM</b>	Timetable Data Management
<b>TfNSW</b>	Transport for New South Wales
<b>TLP</b>	Train Location Provider
<b>TN-ITS</b>	Transport Network ITS Spatial Data
<b>V2I</b>	Vehicle-to-Infrastructure
<b>V2P</b>	Vehicle-to-Pedestrian
<b>V2V</b>	Vehicle-to-Vehicle
<b>V2X</b>	Vehicle-to-Everything
<b>V/Line</b>	V/Line Corporation
<b>VRU</b>	Vulnerable Road User

# 1 Summary

The Victorian Department of Transport and Planning (DTP), and Metro Trains Melbourne (Metro) have conducted a series of workshops to explore technological solutions and identify potential use cases to improve level crossing safety. Addressing the long-standing challenges of level crossing safety requires fresh approaches. This was an initiative under the Victorian level crossing safety strategy and supported by iMove.

## *Innovation opportunity*

One of the outcomes of the workshop series was to focus on real-time transport data and use these data to ensure people with disability or other vulnerable road users (VRUs) in advance of the existing information that they have enough time to cross, and ideally, how much time they have before the boom gates close.

Using real-time train location data presents a potential network-wide solution that does not directly interface with the legacy level crossing interlocking or rail signalling systems, reducing certification and safety case overheads.

This use case is also a stepping stone for further level crossing enhancement opportunities. By integrating crossing closure predictions into journey planning, this project can also enhance travel efficiency and safety, potentially extending to predictive capabilities to passive crossings to address safety gaps where there are no active signals. Real time location-based systems will soon be capable of meeting the requirements for safety critical solutions and will be able to provide alerts to road-users for unprotected level crossings.

## *Method*

In this project we collaborated with DTP and Metro to conduct primary research with people with disability, to interview stakeholders with regards to data feasibility, and to develop and test a proof of concept. We systematically evaluated 22 requirements in a feasibility model for this use case. The key two main questions are:

### *1. Do people with disability want and need this solution?*

People with disability do feel anxious about navigating level crossings. Accompanied level crossing trips with people with disability, identified accessibility challenges for vulnerable users, including mobility, sensory, and situational barriers. For users who are slower or worry about falls or incidents when they cross at a level crossing, countdown timers appeal. The timers could indicate how much time there is to cross before the crossing alarm sounds, ensuring that pedestrians are not caught out by the boom gates closure mid-crossing.

Our quantitative research with people with disability shows that 71% feel that level crossings make them feel uncertain. It should be easy for everyone to navigate a level crossing, but 58% disagree with the statement that crossing pedestrian level crossings is easy, and 75% find crossing pedestrian crossings stressful. To some people with disability, the risk of tripping, becoming stuck or caught in between boom gates can result in people with disability avoiding level crossings completely. To others, this is one issue among many that make travelling a stressful experience.

In addition, solutions with similar objectives have been developed in other countries. The Netherlands Organisation for Applied Scientific Research (TNO) and France's national railway company (SNCF), utilised different technology platforms [1, 2], such as Cooperative

Intelligent Transport Systems (C-ITS). While these solutions have not yet been deployed at scale, ongoing initiatives in the Netherlands and France continue to work towards final solutions. These initiatives underscore that the use case is needed.

## 2. Is it feasible?

The proof of concept, which we will call “CrossSafe”, for Diggers Rest’s level crossing predicted the closure of boom gates with sufficient accuracy for this use case (within 5 – 11 seconds). Based on these predictions, it provides information about the closure of boom gates:

- default: boom gates will not close in the next 3 minutes
- 3 minutes in advance: ‘boom gates may close in 3 minutes’ and
- 1 minute in advance: ‘boom gates will close in 1 minute’
- When closed: ‘boom gates are closed, I am going to look for the next train.’

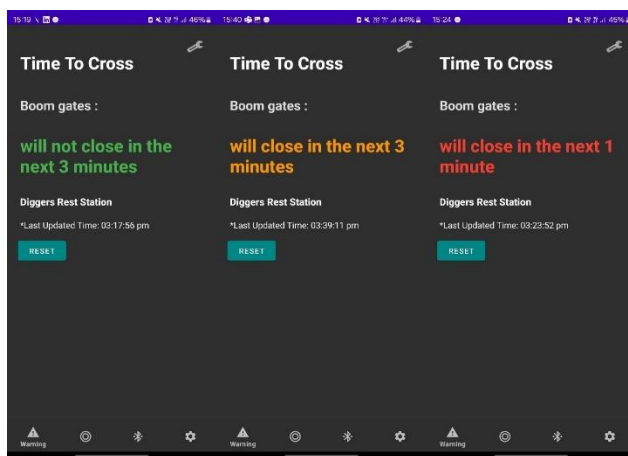


Figure 2 CrossSafe POC (not optimised for accessibility)

The prediction error varied between 11 seconds, 3 minutes away from the crossing to 5 seconds when the train was 1 minute away. These predictions are sufficiently accurate for this purpose, and will be more accurate when we provide more data to the machine learning application. CrossSafe has a built-in buffer that exceeds this inaccuracy to ensure the prediction is always early, never late.

### Lessons learned: Train arrival prediction

Our solution, CrossSafe, aims to provide complementary, not safety-critical information. There is still a need for complete, reliable and accurate data to predict boom gate closure with an acceptable level of accuracy. Data must be available for all trains and all crossings with sufficient reliability and accuracy. The train positioning data is generated with a mix of legacy technologies that are not optimally fit for today’s purposes.

In areas with limited train position data, such as near terminal stations or where trains run at short intervals, we improved accuracy by aligning AI predictions with timetable data. The variability across sites also demonstrated the need for fine-tuning models for specific locations, rather than depending solely on a single, generalised solution.

Public Transport Victoria (PTV) currently provides open-source real-time position data for MTM services to public applications. In addition, we used PTV’s timetable, trip, and station data to enhance the accuracy of level crossing safety predictions. While these open-source

CrossSafe includes a backend server, database, Message Queuing Telemetry Transport (MQTT)-based communication infrastructure, and a mobile phone user interface. To predict boom gate closure times, we applied machine learning algorithms trained on real-time train data to estimate train arrival times. By combining infrastructure data with real-time train information, we achieved sufficient accuracy in predicting boom gate closure events.

The prediction error varied between 11 seconds, 3 minutes away from the crossing to 5 seconds when the train was 1 minute away. These predictions are sufficiently accurate for this purpose, and will be more accurate when we provide more data to the machine learning application. CrossSafe has a built-in buffer that exceeds this inaccuracy to ensure the prediction is always early, never late.

real-time train data are suboptimal—due to relatively low-frequency updates—we demonstrated that, through machine learning and the integration of multiple data sources, CrossSafe still achieves accurate predictions.

#### *Lessons learned: Boom gate closure prediction*

Each level crossing follows national standards and principles set by the Rail Industry Safety and Standards Board (RISSB); however, the way these standards are applied varies locally. This means that timing, design, and infrastructure configurations can differ significantly from one crossing to another.

To enable accurate prediction by the machine learning model, data on actual boom gate closure times in relation to train position is essential. However, certain elements, such as gate descent timing, are not fixed but must occur within a required overall warning period. In the current version of CrossSafe, we addressed the absence of recorded closure times through observational validation, using train positions and timestamps. A future version could incorporate boom gate closure logs, making the development more streamlined and less resource intensive. These challenges reinforced the value of adaptable machine learning models, hybrid data integration, and collaboration with stakeholders, all critical components for broader deployment.

#### *Supporting developments*

In Victoria, our data set included only Metro trains (V-Line trains were being worked on) and we experienced ‘ghost trains’. These trains did not appear on public transport planning apps or timetables at the station and may have come out of a nearby siding.

However, this project is part of a broad trend to use positioning data to improve the customer experience. Planning and navigation apps increasingly use real-time data to assist the user. Governments are increasingly investing in open-source data availability enabling third parties to develop services for passengers. In Victoria two key requirements are being met in the near future.

V-Line trains will soon have modernised hardware (providing accurate GPS locations) that will be accessible for applications like the one proposed in this project. It will provide high-quality real-time GPS data for V/Line trains, including tourist & heritage and maintenance trains.

Additionally, in several states, work is undertaken to develop a standardised access point for data. In New South Wales, Transport for NSW (TfNSW) are reported to be working on project SIRI (Service Interface for Real-time), which will offer real-time location data across the network. In Victoria, DTP is improving real-time public transport data through the Public Transport Data Program (PTDP). Recent updates till June 2025 include enhanced Metro Trains GTFS-R feeds, platform and disruption info, tram and bus details, and a new Open Data Portal introduced on 19 November 2024 [3]. The availability of these data sources will further improve the accuracy of predictive algorithms.

We expect that the imminent introduction of fit-for-purpose datasets, such as those from V/Line’s TrackR application, will further enhance prediction performance and support model scalability across the network. Importantly, as Australia's National Access Point (NAP) is currently under development, aligning with the European NAP framework—including strict

compliance with ETSI standards— will ensure that CrossSafe remains compatible with emerging national infrastructure and is prepared for future global interoperability.

#### *Proposed next steps*

To progress CrossSafe to its next stage, we propose a follow-up project focused on:

- Securing support from transport agencies in other states
- Integrating with required data sources in each jurisdiction
- Partnering with relevant third-party apps
- Maturing and end-user validation of the solution

This next phase will involve direct engagement with state transport agencies to confirm their support and assess data availability. It will also involve collaboration with industry partners, including navigation and accessibility apps already serving the target user group. Rather than operating as a standalone tool, CrossSafe should become a feature within established platforms. Navigation apps such as TomTom and BindiMaps have already expressed interest.

Although the ARTC system covers all trains fitted with ICE radios, it is unlikely to publish this data as open data like passenger services, we still need to recognise the importance of tracking the positions of freight and works trains.

CrossSafe should use common protocols nationwide and not be a standalone solution. This can be achieved by following C-ITS standards. Leveraging internationally recognised standards—such as those developed by ETSI, C-ITS facilitates dynamic traffic management, timely safety alerts, and support for VRUs, while ensuring interoperability across diverse systems and regions. This doesn't mean a delay until C-ITS breaks through; C-ITS also specifies standards for long-range communication.

The project will also expand coverage to include train stations across additional states and adopt a citizen science approach, enabling users to contribute to validation and further refinement of both the system and the underlying machine learning model.

## 2 Background

This chapter outlines the background, objectives, and methodology of the project, establishing the context for assessing the feasibility of a predictive alert system for level crossing safety. It details the motivation behind the initiative, the technical and user-focused goals, and the multi-phase approach adopted, including expert input, international benchmarking, machine learning development, and user research. This foundation ensures that the evaluation is grounded in both practical relevance and technical rigour.

### 2.1 Innovation Opportunity

Level crossing safety remains a critical public concern, especially in Victoria, which has over 2,300 public road and pedestrian rail crossings. Incidents at these locations can result in severe or fatal consequences, underscoring the urgent need for innovative safety measures.

To address these long-standing challenges, the DTP and Metro Trains and Victorian Railway Crossing Safety Steering Committee's (VRCSSC)' Rail Crossing Human Factors Group (RCHFG) have facilitated a series of workshops aimed at exploring technological solutions and identifying practical use cases to enhance level crossing safety. This innovation initiative aligns closely with the Victorian Railway Crossing Safety Strategy 2018–2027 [4], which is committed to saving lives and reducing incidents across Victoria's rail network.

A key outcome of these workshops is the focus on leveraging real-time transport data to support VRUs—particularly people with disabilities—by offering timely and predictive safety information. The goal is to provide advanced warnings, including clear estimates of how much time remains before boom gates close, thereby reducing anxiety and improving confidence for users who may require more time to cross safely, as shown in Figure 3.

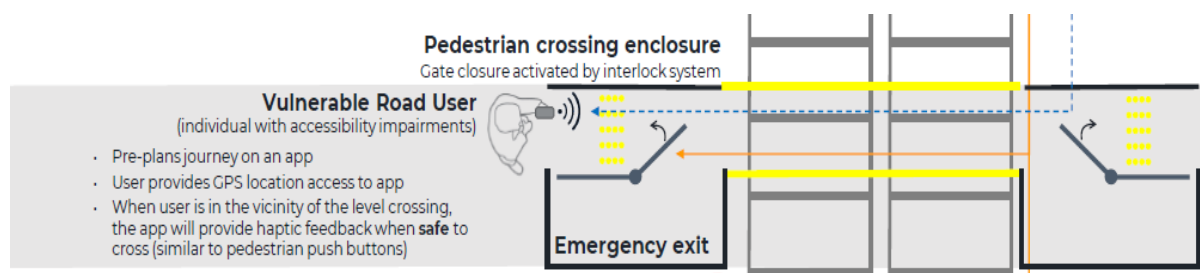


Figure 3 Pedestrians at Level Crossing

People with disabilities often experience stress when navigating level crossings, due to fears of tripping, becoming trapped between closing gates, or not reaching the other side in time. Providing accurate, real-time crossing information has the potential to make their journeys significantly safer and less stressful. A survey of 78 people with disabilities confirmed that knowing the time to cross would reduce stress. 71% reported feeling uncertain, and 75% agreed that level crossings make them feel stressed.

In this project, we explored the feasibility of using open-source, real-time train data to predict boom gate closure times specifically for VRUs. One of the primary challenges lies in the diversity of level crossing technologies across Victoria, which complicates system integration and site-level deployment. However, real-time train location data presents a

promising, scalable solution that can be applied across the network to improve safety at a wide range of crossing types.

## 2.2 Objectives

The objective of this project is to evaluate the feasibility of using real-time, open-source train position data to predict boom gate closure times and provide early warnings, particularly for users navigating passive level crossings. Ensuring safety at these crossings depends on a system grounded in reliable, accurate, and widely accessible data.

At the heart of the project is an investigation into available data sources and the development of a machine learning algorithm capable of accurately predicting level crossing closure timings. This algorithm is designed to support a variety of use cases, with the project focused on assessing both its technical viability and its potential real-world applications.

Another key objective is to assess the acceptance, needs, and requirements of people with disabilities, ensuring the system design is inclusive and addresses the specific concerns of VRUs. This includes evaluating how such users perceive the warnings, what information formats are most effective, and how the solution can reduce anxiety and improve confidence when crossing.

## 2.3 Methodology

The assessment and enhancement of level crossing safety followed a structured, multi-phase methodology designed to gather insights, develop technological solutions, and ensure real-world applicability:

### **Desktop Research: Global Use Cases**

We conducted an extensive review of international best practices and technologies used in level crossing safety systems. This provided a foundational understanding of proven methods and potential innovations that could inform our own solution.

### **Expert Consultation**

We engaged domain experts in railway systems, level crossing operations, data infrastructure, and safety regulation. Their input was crucial in:

- Identifying realistic data integration strategies.
- Understanding safety compliance requirements.
- Anticipating challenges in system deployment and maintenance.

### **C-ITS Standards Compliance**

To ensure global compatibility and future interoperability, the system architecture and backend server were designed in adherence to ETSI C-ITS standards. This standardisation enables seamless communication between the system and various entities, including vehicles and infrastructure, especially for VRUs.

### **Machine Learning Development**

We analysed real-time train position data to identify patterns suitable for predictive modelling. Based on this analysis:

- Machine learning algorithms were developed to predict boom gate closure times.
- Diverse datasets—including timetable, trip information, and infrastructure data—were integrated to enhance prediction accuracy and system reliability.

### User Research: Interviews with People with Disabilities

To ensure the system is inclusive and addresses real-life challenges:

- We conducted qualitative interviews with people with disabilities to understand their experiences and concerns when crossing railway tracks.
- Insights from these interviews informed the design of the end-user mobile app UI, which delivers real-time train arrival and boom gate closure warnings in an accessible format.

## 2.4 Key Evaluation Criteria

To assess the practicality and effectiveness of the proposed solution, the following criteria have been identified and will be used to evaluate its feasibility.

*Table 1 Criteria to Evaluate Feasibility*

<b>Criteria</b>
<b>Overseas Deployment of Similar Systems</b>
<ul style="list-style-type: none"> <li>• There are other countries that have implemented a similar system.</li> </ul>
<b>User Accessibility and Acceptance</b>
<ul style="list-style-type: none"> <li>• The system should meet the needs of diverse users, including those with disability.</li> </ul>
<b>Stakeholder acceptance</b>
<ul style="list-style-type: none"> <li>• The operators and governments should embrace the proposed solution.</li> </ul>
<b>Data Availability</b>
<ul style="list-style-type: none"> <li>• The data should be available for all trains, including work trains and historic (heritage) trains.</li> <li>• The data should be accessible for all level crossings across the network.</li> <li>• Data should be refreshed at a frequency suitable to make accurate predictions.</li> </ul>
<b>Data Reliability</b>
<ul style="list-style-type: none"> <li>• The data sources should be consistent, synchronised, and free from errors.</li> <li>• Redundancy should be in place to mitigate data loss or inaccuracies.</li> </ul>
<b>Data Precision</b>
<ul style="list-style-type: none"> <li>• The data should be accurate and detailed enough to ensure safety and not increase the risk to the user. (Noting this is co-dependent on the safe design of the application)</li> <li>• The data should be detailed enough to differentiate between train types and their respective operations.</li> <li>• Any deviations or inaccuracies in the data should be filtered for further validation.</li> <li>• The train data and trip data should be correlated.</li> </ul>
<b>Prediction Accuracy</b>
<ul style="list-style-type: none"> <li>• The system should accurately predict train arrivals and boom gate closures within sufficient timing thresholds to provide timely warnings to end users.</li> </ul>

<b>Criteria</b>
<b>System Response Time</b>
<ul style="list-style-type: none"> <li>• The system should process data and deliver warnings quickly after detecting a train.</li> <li>• Real-time data processing should be prompt and synchronised with actual train movements to ensure accuracy and reliability.</li> </ul>
<b>Integration Capability</b>
<ul style="list-style-type: none"> <li>• The system must comply with C-ITS standards to support interoperability with cooperative intelligent transport systems and future advancements in rail safety technology.</li> </ul>
<b>Information Delivery</b>
<ul style="list-style-type: none"> <li>• Content of information: ideally, the time when no train is coming and the boom gates are open, and the time until the boom gates will close</li> <li>• Delivery in a format and channel that suits the user</li> <li>• Emerging delivery options (smart canes, smart glasses, connected wheelchairs, etc.)</li> </ul>
<b>Future Enhancements</b>
<ul style="list-style-type: none"> <li>• Opportunities should be explored to incorporate advanced technologies such as machine learning or additional sensors to improve prediction accuracy and data quality.</li> </ul>

## 2.5 Conclusion

This chapter establishes the foundation of the project by clearly defining the motivation, objectives, methodology, and evaluation metrics. These elements provide the framework for assessing the feasibility of a predictive level crossing safety system. In the following chapters, we build upon this framework to conduct targeted research and development, translating these principles into system design, data analysis, and user-centred innovation.

## 3 Best Practices

This chapter outlines key safety standards and technologies for level crossings. It covers Australian design practices, European NAPCORE data framework, and global case studies from the Netherlands and France, highlighting how real-time data and smart systems are enhancing safety and accessibility.

### 3.1 Australian Standards and Practices

In a review of the ETS-12-01 Australian Pedestrian Level Crossing Standards [5], we found that the pedestrian level crossings must be inclusively designed to accommodate all users, including people with mobility, vision, or hearing impairments, as well as those using assistive devices, pushing prams, or accompanied by animals. Nearby community facilities such as schools and hospitals must also be considered. In Australia, a range of control levels exists—from passive signage and pedestrian mazes to active signalisation and gated systems, each offering varying degrees of safety. Design standards account for track angles, walking speed (typically 1.0 m/s, or 0.8 m/s in areas with higher disability prevalence), and crossing distances based on the presence of mazes or tactile indicators. At passive crossings, adequate sight distance is essential to ensure pedestrians can safely detect oncoming trains, with allowances made for slower walking speeds and the highest train approach speeds to determine safe crossing margins. Safety risk assessments for each level crossing will consider multiple factors, including accident history, train type, frequency and speed (especially on high-speed passenger routes), pedestrian usage volume, and the slope and condition of walkways.

The VRCSSC and WSP released a Technology Readiness Roadmap [6] to enhance level crossing safety in Victoria by addressing issues like congestion, pedestrian behaviour, accessibility, and collision risks through technologies such as video analytics, real-time apps, and enforcement cameras. The roadmap categorises solutions by deployment readiness (from now to 10 years), evaluates their roles in monitoring, informing, controlling, and enforcing safety, and highlights integration challenges, infrastructure needs, and user acceptance considerations. As part of the roadmap, WSP identified key technology use cases [7], including a real-time transport app that informs users of level crossing closures and train arrivals to support safer travel decisions and reduce risky behaviour near crossings.

The SIRI 2.0—TfNSW Implementation Specification standardises real-time data sharing across agencies via the TfNSW Message Broker, with local schema extensions and business rules for developers. Customer-facing data is delivered through GTFS-R and APIs, focusing on error handling and scalability [8].

The University of the Sunshine Coast [9] developed a systems approach to improving rail crossing safety, evaluating in-vehicle warning systems and haptic feedback apps for vulnerable users. Their research showed that ITS-based solutions—such as dynamic speed guidance and real-time train alerts—can enhance driver awareness and reduce risk without major infrastructure upgrades. Haptic apps offer tactile cues for sensory-impaired users, improving crossing safety. However, challenges remain with system reliability, integration, and GPS accuracy, especially in rural areas. Further trials and integration into existing transport systems are recommended.

A technical paper presented at the Institution of Railway Signal Engineers [10] highlights the safety risks of using passive and occupational crossings for livestock movement in rural Australia. It reviews technologies—ranging from axle counters to GPS, radar, and acoustic sensors—to provide graziers with early train warnings. While C-ITS shows future potential, current limitations exist in remote areas. The study identifies gaps in risk assessments and proposes a low-cost, scalable solution: the Level Crossing Advance Warning System (LCAWS).

The Australian Level Crossing Assessment Model (ALCAM) is a nationally adopted tool designed to enhance safety at railway level crossings (RLXs) across Australia and New Zealand. ALCAM systematically assesses the risk of collisions by evaluating 85 variables grouped into three key domains: RLX characteristics (e.g. road speed, visibility, traffic volume), RLX controls (e.g. boom gates, signage) and crash mechanisms (e.g. driver error, queuing, poor visibility). It comprises two distinct models—the Road Model and the Pedestrian Model—each structured around three analytical components: Infrastructure, Exposure, and Consequence. These elements combine to generate a risk score expressed as the expected number of equivalent fatalities per year, enabling prioritisation and benchmarking of level crossing risks. ALCAM assessments are based on standardised data collection and interpretation, but do not prescribe upgrades or define acceptable risk thresholds; such decisions remain the responsibility of individual jurisdictions. The tool is supported by the Level Crossing Management System, an online data interface developed by the National ALCAM Committee, allowing authorised stakeholders to manage crossing data and generate risk scores. Since 2013, organisations such as Safe System Solutions have conducted ALCAM assessments, road safety audits, and impact studies—including high-profile collaborations like the Fonterra–Railize project—demonstrating the model's critical role in guiding evidence-based, stakeholder-informed safety interventions. While ALCAM provides a robust risk framework, it is intended to complement, not replace, sound engineering judgement and broader contextual considerations such as near-miss history, local behaviour, and international best practice [11].

### 3.2 Europe NAPCORE

NAPCORE (National Access Point Coordination Organisation for Europe) coordinates National Access Points (NAPs) across Europe to promote the standardisation and interoperability of transport and mobility data. NAPs serve as central platforms where stakeholders can publish and access harmonised transport-related data, enabling consistent data exchange. NAPCORE enhances the discoverability and usability of this data, particularly for multimodal transport systems, supporting more integrated and efficient mobility solutions across the EU. The key data standards for transport interoperability in National Access Points (NAPs) are summarised in Table 2, covering their purpose, focus areas, and how they support seamless data exchange in transport systems:

*Table 2 Key Data Standards for Transport Interoperability in NAPs*

Standard	Purpose / Focus	Use / Function
DATEX II	Standard for the exchange of traffic and travel information (road conditions, traffic events).	Widely used in Europe for real-time, machine-readable system communication.

<b>Standard</b>	<b>Purpose / Focus</b>	<b>Use / Function</b>
<b>mobilityDCAT-AP</b>	Metadata standard for mobility and ITS domains.	Describes datasets and access conditions; enhances discoverability in NAPs.
<b>TN-ITS</b>	Spatial data for ITS; standardises updates to road attributes for digital maps.	Supports applications like navigation and map updates.
<b>NeTEx (Network Timetable Exchange)</b>	CEN technical standard for public transport scheduling data.	Exchanges schedules, routes, stops, and fare-related data across networks.
<b>Transmodel (EN 12896)</b>	Conceptual foundation for public transport data models.	Defines a standardised framework for structuring public transport information.
<b>SIRI (Service Interface for Real-Time Information)</b>	Standard for real-time public transport data exchange.	Enables interoperability for vehicle positions, arrivals, and service delivery.
<b>DATA4PT Project</b>	Promotes the adoption of NeTEx and SIRI in Europe.	Provides tools, training, and documentation for interoperable data-sharing practices.

Australia is exploring the development of a National Access Point (NAP) for transport and mobility data, led by the Department of Transport and Main Roads Queensland (TMR), with the goal of aligning with the European NAPCORE model to enable standardised, interoperable data sharing. This centralised platform would allow stakeholders—public and private—to publish and access harmonised transport data, improving discoverability, quality, and integration. Projects like Level Crossing could benefit greatly, using NAP-supported standards such as DATEX II, TN-ITS, NeTEx, and SIRI to enhance predictive accuracy and system responsiveness. By contributing local datasets and adopting standards like mobilityDCAT-AP, Level Crossing also strengthens the national data ecosystem, advancing safer and smarter mobility solutions across Australia.

### 3.3 Global Use Cases

We present two international use cases that leverage real-time data and advanced algorithms to predict train movements and improve safety at level crossings.

### 3.3.1 The Netherlands TNO Crossing Aid



Figure 4 TNO Crossing Aid Close-up

Dutch ProRail and TNO trialled an early-warning system at pedestrian rail crossings to improve safety and accessibility for vulnerable users, such as the elderly and people with reduced mobility. ProRail data showed these users often feel rushed or avoid crossings due to fear, increasing the risk of accidents. To address this, a prototype crossing aid was developed—a column-mounted screen that alerts users before the standard crossing alarm activates. If no train is detected, it displays two green figures with “You can cross safely.” If a train is detected at a newly installed early detection point, it shows a train icon, giving users extra time to cross before bells and boom gates activate. This early detection system factored in crossing length, average walking speed (0.66 m/s), and train speed. For instance, with a 20 m crossing and a 100 km/h train, the detection point was placed 842 m before the standard trigger to allow a 30.3-second pre-warning.

The system was well-received:

- Users felt safer and less anxious.
- Comprehension was high, and most found the timing appropriate.
- Net Promoter Score (NPS) was 67, with 60% giving it a top score.
- A noted improvement area was the visibility of the train icon in bright sunlight.

This solution enhances crossing confidence and safety for slower pedestrians without altering existing warning systems, offering a low impact yet highly effective upgrade.

### 3.3.2 SNCF's C-ITS for Level Crossing Safety

The SNCF (Société Nationale des Chemins de fer Français) launched advanced safety projects to improve level crossing safety using C-ITS. In France, SNCF oversees over 15,400 level crossings, which account for over 37% of rail-related deaths despite causing less than 1% of road fatalities. Each year, 100–140 collisions result in 25–40 deaths, with 99% caused by road users’ failure to follow traffic rules.

This initiative aims to enhance level crossing safety by deploying advanced detection, communication, and pre-warning technologies, with a focus on reducing accidents, improving driver compliance, and protecting vulnerable road users. As part of broader C-ITS efforts in France and across Europe, SNCF is integrating real-time communication between vehicles and infrastructure to optimise traffic flow, reduce emissions, and prevent collisions and near-misses. The project also addresses the “barrier effect” by providing timely alerts to reduce user anxiety and foster a more predictable, secure crossing environment, especially for vulnerable groups [1].

SNCF traditionally ensures level crossing safety through well-established protocols, including audible and visual pre-closure alerts (bells and flashing red lights), timed barrier operations based on train speed and crossing length, and reopening only after the train fully clears a designated safety zone.

To further improve safety, SNCF’s Innovation and Research Department is advancing the concept of smart crossings by integrating C-ITS to enable real-time communication between infrastructure and connected vehicles. This approach targets reductions in collisions caused by distraction or non-compliance.

In Infrastructure-to-Vehicle (I2V) communication, crossings transmit their real-time status to approaching vehicles, indicating whether the crossing is open, closed, under maintenance, or facing technical issues. Additional messages can include restrictions related to width, height, weight, surface conditions, or speed. In emergencies, drivers may be prompted to use on-site emergency phones. In the reverse direction, Vehicle-to-Infrastructure (V2I) communication allows vehicles to relay critical information—such as a breakdown on the tracks—directly to the crossing infrastructure, enabling faster response and mitigation.

A key advantage of this system is its ability to enhance safety without major infrastructure changes. It uses a control module to monitor relay states and determine crossing status, which is then shared with external systems via a connected transmitter. Aligned with C-ITS trends, it enables communication with vehicles and pedestrians through both ETSI ITS-G5 and LTE networks, improving safety and compatibility across devices [1, 12].



Figure 5 Smart Level Crossing System of SNCF

In 2019, SNCF joined the C-Roads France project, contributing to the European C-Roads Platform and future ITS developments. It implemented hybrid communication, allowing level crossings to send messages to vehicles via both ITS-G5 and 4G through the national ITS station [1]. New developments were made in 2020 to integrate, in the prototype, the cybersecurity layer of the ETSI standard and the European requirements of Directive 2010/40/EU and the Delegated Act of 3/13/2019 in order to achieve cross-border harmonisation and interoperability [1]. The SNCF Group is leading the TELLi project (June 2024–December 2026) using a modified X73524 trainset as a rolling lab to advance autonomous perception. Equipped with cameras, radar, lidar, and other sensors, it will test signal recognition, obstacle detection, and track monitoring. Trials on TER lines near Limoges, led by GTS France, began in early 2024 to refine environment-perception algorithms [13].

Table 3 Obstacle Detection Systems

Technology Category	Description
<b>Autonomous Perception Systems</b>	<ul style="list-style-type: none"> <li>- Cameras (front and rear) for obstacle detection</li> <li>- Lidar (Light Detection and Ranging)</li> <li>- Radar sensors</li> <li>- Satellite receivers (GPS-based positioning)</li> </ul>
<b>Data Processing &amp; AI</b>	<ul style="list-style-type: none"> <li>- Algorithm development for environment perception</li> <li>- AI-based object detection and tracking</li> <li>- Anonymisation of image data for privacy compliance</li> </ul>
<b>Railway Monitoring &amp; Safety Systems</b>	<ul style="list-style-type: none"> <li>- Railway signalling reading and interpretation</li> <li>- Track condition monitoring and anomaly detection</li> <li>- Onboard image collection system for long- and short-range detection</li> </ul>

Technology Category	Description
<b>Hardware &amp; Sensor Integration</b>	<ul style="list-style-type: none"> <li>- Sensor installation inside and outside trainset (front and rear)</li> <li>- Multi-modal sensor fusion (camera, lidar, radar, GPS)</li> <li>- Data acquisition for real-time and offline analysis</li> </ul>
<b>Connectivity &amp; Data Transmission</b>	<ul style="list-style-type: none"> <li>- Data sharing between consortium members</li> <li>- Cloud storage for anonymized image retention</li> <li>- Secure data transmission to improve autonomous functions</li> </ul>
<b>Privacy &amp; Security Compliance</b>	<ul style="list-style-type: none"> <li>- GDPR-compliant anonymization of personal data</li> <li>- No biometric data processing</li> <li>- Data retention policies ensuring limited usage</li> </ul>
<b>Human-Machine Interaction &amp; Interior Design</b>	<ul style="list-style-type: none"> <li>- Testing new interior design options</li> <li>- User experience evaluation for autonomous train operations</li> </ul>

Table 4 SNCF Test Performance

Metric	Value
<b>Range (Straight Roads)</b>	650m
<b>Range (Curved Roads with Obstacles)</b>	250m
<b>Latency (G5, Straight &amp; Curved Roads)</b>	< 300ms
<b>Range (Difficult Road Configuration)</b>	280m (one side), 70m (other side)
<b>Latency (Difficult Road Configuration)</b>	< 300ms
<b>Range (4G, Depending on Network Quality)</b>	Up to 1km

SNCF partnered with Valeo to test a system where crossings broadcast their status and location via ITS-G5. Vehicles receive and display messages based on their position and speed, providing drivers with timely, relevant information [1]. SNCF equipped an automatic light system (ALS) level crossing with ITS-G5 and GPS antennas, plus control and transmission modules. Table 4 shows the results.

SNCF's driving simulator study with 25 participants showed that clear messages like "level crossing closed" prompted 92% of drivers to slow down earlier, while vague messages led to inconsistent reactions. About 8% ignored all messages, highlighting the need for clear, unambiguous communication. SNCF also supported its tech efforts with public education to raise awareness and encourage compliance at level crossings [1]. These results underscored the need for precise, unambiguous messaging to improve anticipatory behaviours among drivers.

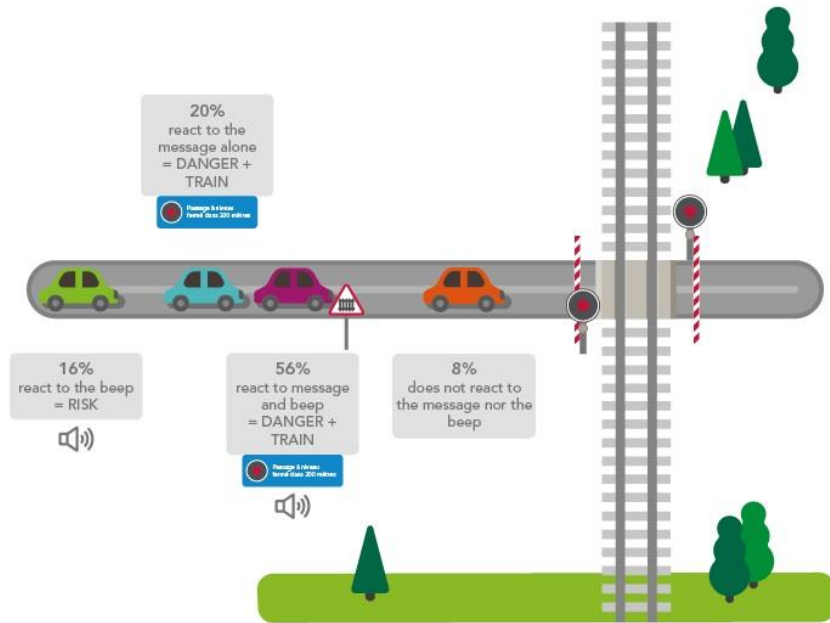


Figure 6 SNCF Driver Simulation Study

### 3.4 Conclusion

This chapter has provided an overview of Australian standards and international innovations aimed at improving level crossing safety. In Australia, inclusive design principles, risk-based assessments, and varying levels of crossing controls guide national practices, while strategic initiatives like the Victorian Technology Readiness Roadmap and the emerging National Access Point (NAP) platform aim to future-proof mobility data sharing. Drawing from global examples, such as the Netherlands' TNO Crossing Aid and France's C-ITS-integrated smart crossings led by SNCF, we observed how real-time data, connected vehicle technologies, and user-focused design can reduce risk, enhance confidence, and support vulnerable road users. These international use cases demonstrate the value of predictive alerts, low-impact infrastructure upgrades, and communication protocols like ITS-G5 and 4G LTE. As Australia moves toward greater alignment with European standards and interoperable platforms, these insights offer valuable guidance for the development of safer, smarter, and more inclusive level crossing solutions.

## 4 End-User Expectations

This chapter presents the findings from an end user study with people living with disability to better understand their experiences at pedestrian level crossings. It outlines key safety challenges, desired improvements, and preferences for receiving time-to-cross information, including user needs, interface design insights, and future technology considerations.

### 4.1 End user Study

We interviewed people with disabilities at 11 pedestrian level crossings in Greater Melbourne to understand their behaviours, challenges, and preferences for receiving time-to-cross information. Many feared tripping, narrow paths, or alarms triggering mid-crossing. Most welcomed the idea of a countdown timer with traffic light cues to reduce anxiety. Desired warning time ranged from 5–30 seconds for experienced users to 2–3 minutes for more cautious individuals. Users favoured in-situ solutions with visual, audio, and haptic feedback, though hands-free delivery and minimal sensory interference were critical. App-based alternatives were acceptable if accessible. Participants also valued layout info and showed strong interest in future C-ITS safety technology.

An online survey conducted from October 2024 to May 2025 gathered responses from 78 Australians with physical or sensory disabilities to explore how real-time train location data could improve level crossing safety. Most participants were over 55, with 73% using mobility aids and over half relying on GPS or maps for navigation. While many used crossings for daily activities, 75% found them stressful, 71% felt uncertain, and over 60% felt unsafe. Despite generally low crossing frequency, 55% crossed at least monthly. A strong demand emerged for assistive solutions: 84% wanted early warnings, and 74% were interested in “time to cross” information, underscoring the need for clear, timely alerts to support safer, more confident crossings.

### 4.2 Key Challenges and Improvements

Key challenges included uneven surfaces, narrow crossings, and poor maintenance, leading many users to fear tripping or tipping, either slowing them down or forcing them to rush. For deaf users, the lack of clear visual cues was especially problematic. As part of a broader, often demanding journey, users rely heavily on their senses to navigate safely. Most expressed support for time-to-cross information, as long as it doesn’t interfere with sensory awareness, and strongly preferred smoother, wider crossings with minimal gaps. Figure 7 presents an overview of the key challenges faced when crossing, while

Table 5 summarises user needs at pedestrian level crossings, including challenges, desired improvements, and preferences for time-to-cross information.



Steep entrances and exits: slow + fear of tipping



Poor levels of maintenance – trip hazards



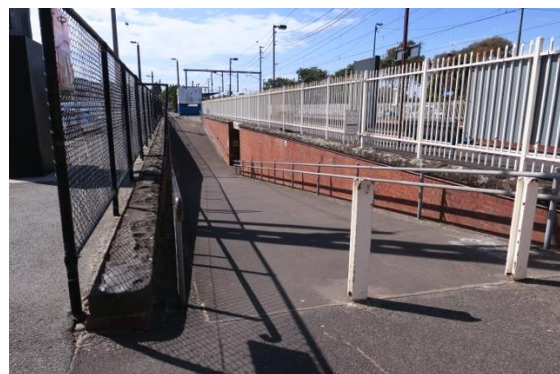
Humps and bumps + different surfaces



Narrow crossings – fear of going off track



Wide or deep gaps – hard with small wheels



Accessibility challenges – Steep ramps



Busy road crossings before a train crossing

No visual indicators at the pedestrian crossing

*Figure 7 Overview of Key Challenges When Crossing*

Table 5 User Needs at Pedestrian Level Crossings

User Type	Key Challenges	Key Improvements	Time-to-Cross Info Desires
<b>Vision impaired</b>	<ul style="list-style-type: none"> <li>• Uneven surfaces</li> <li>• Difficulty identifying gates and train direction</li> <li>• Narrow paths, risk of falling</li> <li>• Time pressure</li> <li>• Poor maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Even surfaces</li> <li>• Clear demarcations for gate location and safe zones</li> <li>• Wide crossings with tactile edge markings</li> </ul>	<ul style="list-style-type: none"> <li>• Highly desirable</li> <li>• Provides peace of mind and reduces rush, especially at unfamiliar crossings</li> </ul>
<b>Deaf or hard of hearing</b>	<ul style="list-style-type: none"> <li>• Difficulty detecting trains</li> <li>• No auditory cues</li> <li>• Reliance on vibrations or visual warnings</li> <li>• Prone to distraction</li> </ul>	<ul style="list-style-type: none"> <li>• Visual indicators for crossing status</li> </ul>	<ul style="list-style-type: none"> <li>• Crucial</li> <li>• Helps compensate for lack of auditory cues and increases crossing confidence</li> </ul>
<b>Wheelchair</b>	<ul style="list-style-type: none"> <li>• Uneven or steep surfaces</li> <li>• Risk of wheels getting stuck</li> <li>• Narrow crossings</li> <li>• Poor maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Level surfaces</li> <li>• Small rail gaps</li> <li>• Wide crossings for safe manoeuvring</li> </ul>	<ul style="list-style-type: none"> <li>• Desirable</li> <li>• Reduces stress and enables more careful, confident crossing</li> </ul>
<b>Powered wheelchair</b>	<ul style="list-style-type: none"> <li>• Uneven surfaces</li> <li>• Risk of tipping or getting stuck</li> <li>• Poor visibility and narrow crossings</li> </ul>	<ul style="list-style-type: none"> <li>• Smooth, even surfaces</li> <li>• Wide, stable crossings</li> <li>• Minimise jolts and gaps</li> </ul>	<ul style="list-style-type: none"> <li>• Moderately desirable</li> <li>• Reduces stress and supports safer, quicker crossing</li> </ul>
<b>Walking frame</b>	<ul style="list-style-type: none"> <li>• Uneven surfaces</li> <li>• Slow crossing speed</li> <li>• Fear of tripping</li> <li>• Poor maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Smooth, trip-free surfaces</li> <li>• Extra crossing time allowance</li> </ul>	<ul style="list-style-type: none"> <li>• Desirable</li> <li>• Provides confidence and reassurance to cross safely</li> </ul>

Most users responded positively to receiving time-to-cross information, as it would reduce the need to rush and ease fears of being caught mid-crossing. An in-situ countdown timer with visual, audio, and haptic cues was preferred for its simplicity and accessibility, though current technology may limit timing accuracy due to varying train speeds. Mobile solutions were seen as useful if integrated with navigation apps and designed to avoid sensory overload. Looking ahead, users welcomed C-ITS technologies for broader traffic safety, suggesting solutions like smart canes, walkers, or wearables that deliver timely, accessible warnings.

### 4.3 User-Interface Design

The user interface shown in Figure 8 presents a clear, accessible "Time to Cross" display designed to inform users of the time remaining before boom gates close at a railway crossing. It uses a simple, colour-coded system that users find intuitive and helpful:

- **Green:** "Will not close in the next 3 minutes" – indicates it's safe to cross calmly.

- **Orange:** "Will close in the next 3 minutes" – alerts users to prepare to stop.
- **Red:** "Will close in the next 1 minute" – signals high urgency to avoid crossing.

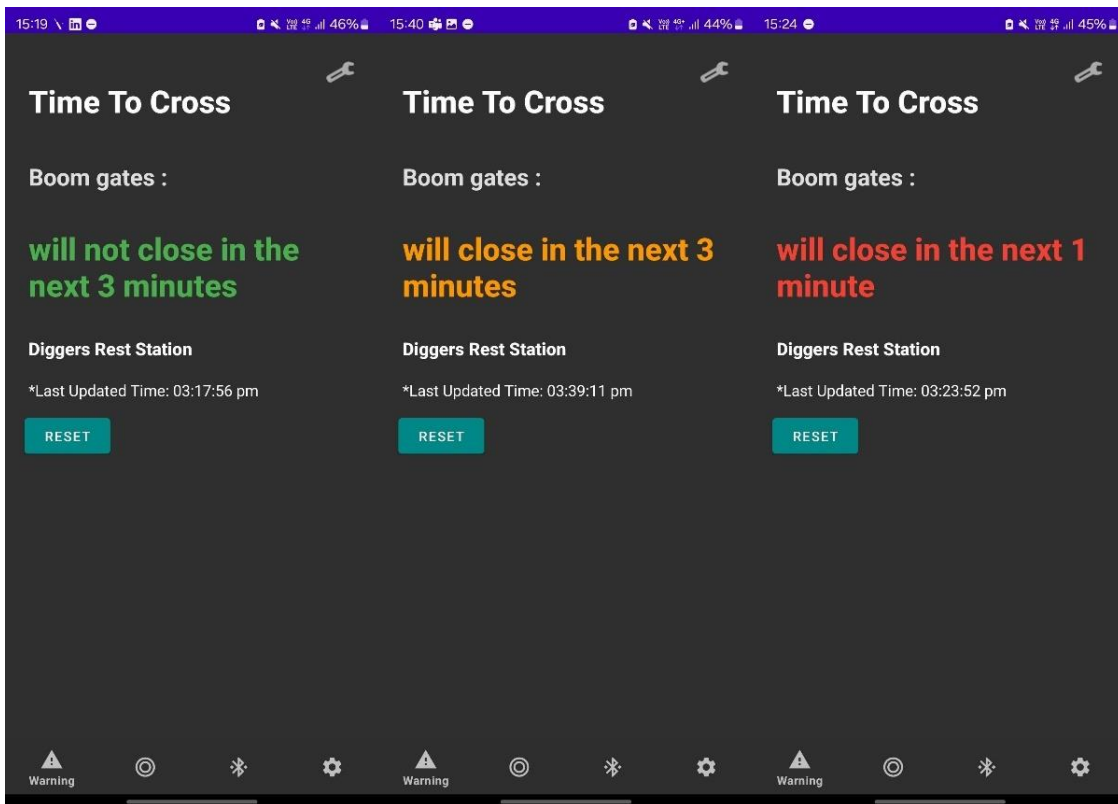


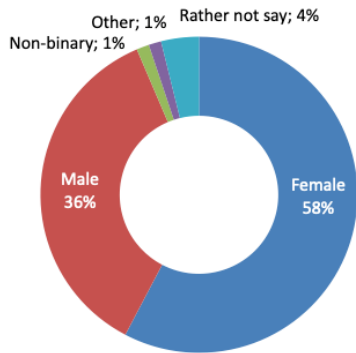
Figure 8 User-Interface Design

Users preferred this minimalist design for its clarity, readability, and low cognitive load. The countdown format is particularly valued, helping users—especially those with mobility or sensory challenges—make informed decisions without feeling rushed. The transition from green to orange to red increases visibility and urgency, with the red screen being the most attention-grabbing. Overall, users expressed strong support for this design, noting that it balances simplicity, visibility, and usefulness, especially under real-world conditions where quick, confident decisions are essential.

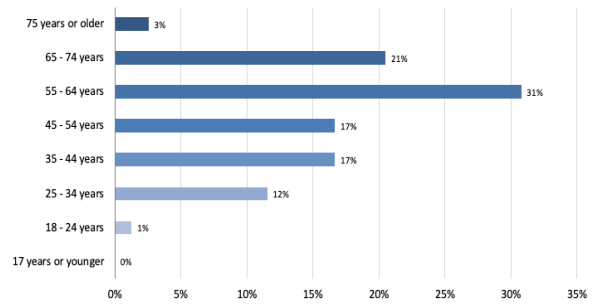
#### 4.4 Quantitative study

This paragraph presents findings from an online survey exploring how real-time train location data could enhance level crossing safety for pedestrians with physical or sensory disabilities. Conducted between October 2024 and May 2025, the survey gathered responses from 78 participants across Australia. It examined crossing behaviour, perceived safety, assistive technology use, and disability types to assess the demand for “time to cross” information and identify effective delivery methods.

## Gender Mix

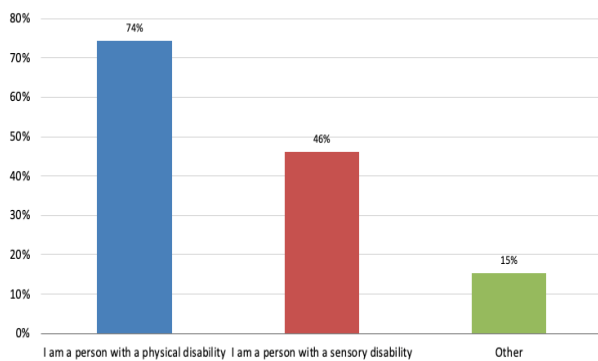


## Age Distribution



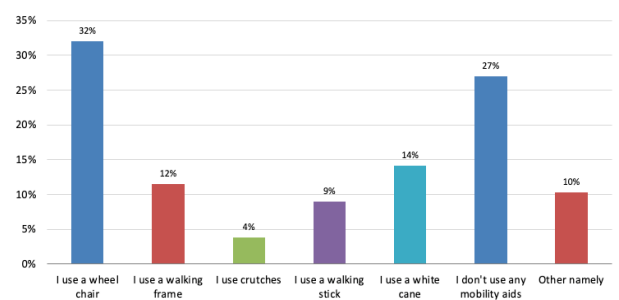
55% is over 55 years of age

## Type of Disabilities



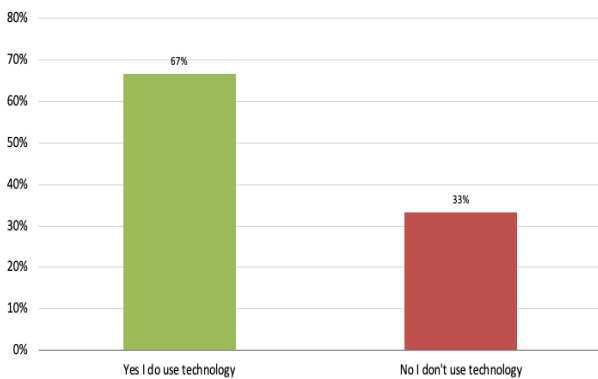
Various participants live with multiple disabilities.

## Mobility Aids



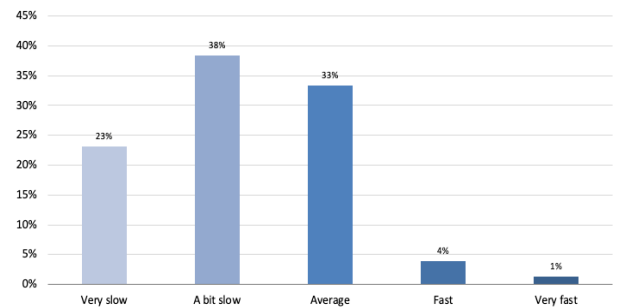
73% of participants used mobility aids of some description

## Technology Use



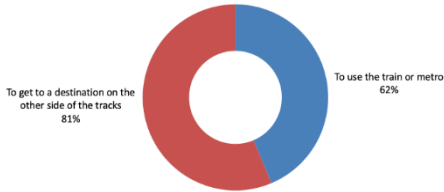
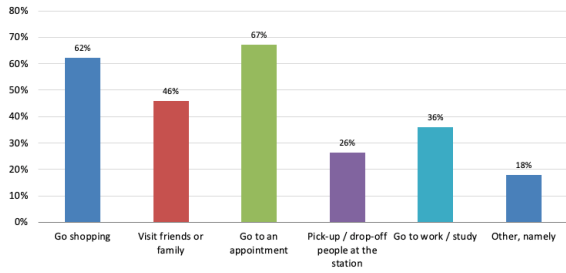
Many people use GPS / Maps systems when navigating in public.

## Crossing Speeds



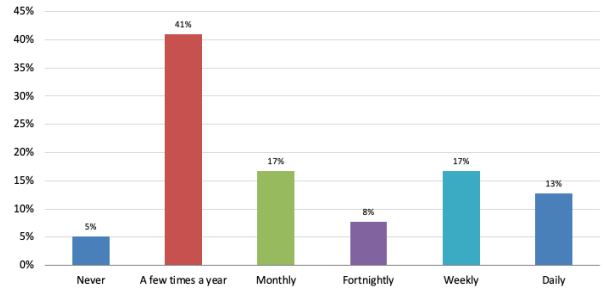
61% reported slow crossing speed, 23% very slow, and 6% fast.

### Crossing Purpose



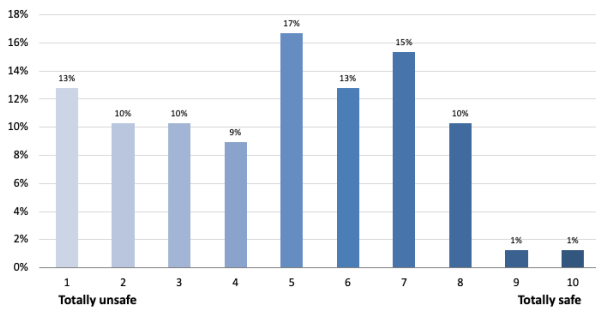
Many need to use level crossings to get around, including going on bushwalks or visiting their favourite coffee shop.

### Crossing Frequency



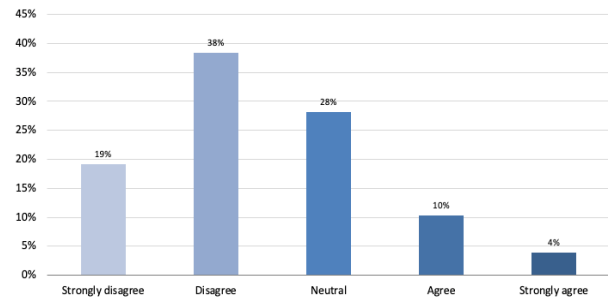
Many participants cross level crossings only a few times per year. Around 55% cross pedestrian level crossings at least monthly.

### Feels Unsafe



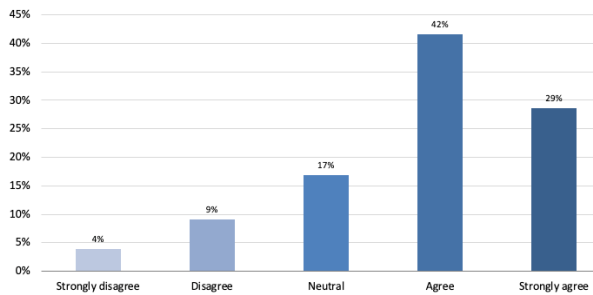
Around 60% of the participants feel (somewhat) unsafe when crossing a pedestrian level crossing.

### Statements on Level Crossings Experiences



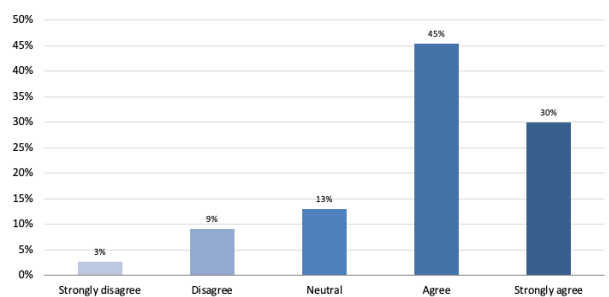
58% disagree with the statement that crossing pedestrian level crossings is easy.

### Feel Uncertain



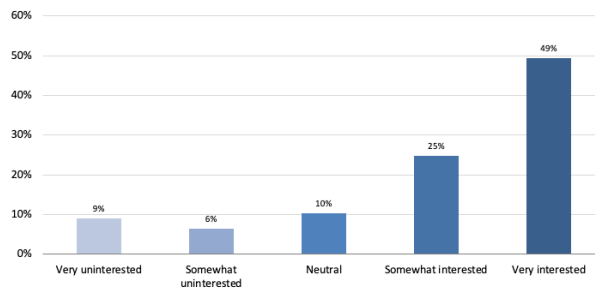
71% feel crossing makes them feel uncertain.

### Feel Stressful



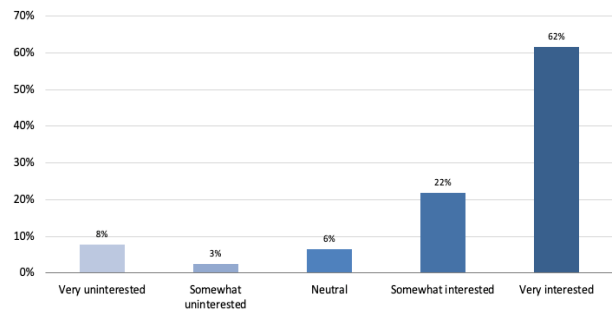
75% find crossing pedestrian crossings stressful.

### Interested in Time to Cross Information



*74% are interested in time-to-cross info, with 49% very interested.*

### Interested in Early Alert at Level Crossing



*84% want early warnings before crossings close; 62% are very interested.*

## 4.5 Conclusion

In summary, the study highlights that people with disabilities face persistent safety challenges at pedestrian level crossings, including uneven surfaces, narrow paths, and unclear cues. Most participants supported simple, in-situ time-to-cross displays with visual, audio, or haptic feedback, emphasising the need for accessible, non-distracting solutions to improve confidence and safety.

## 5 Datasets Overview

This chapter presents insights from rail experts, data specialists, and industry stakeholders on creating, integrating, and using rail system data. It outlines key challenges, best practices, and innovations, underscoring data's vital role in enhancing efficiency, safety, and decision-making.

### 5.1 VIC Rail Data

As part of the project, we engaged with Metro, V/Line, and 4Tel to gather insights on train occupancy sensors, real-time data availability, and train position databases. These consultations clarified data coverage, accuracy, and limitations, and the findings were summarised in a table outlining each data source's characteristics and integration potential.

Appendix B provides a detailed overview of the key systems involved in train location, control, data integration, and passenger information within the rail network. It highlights the roles, relationships, and data accessibility of each system, ranging from foundational systems such as the Train Location Provider (TLP) and the Real-Time Position of Trains System (RTPOTS) to advanced integration platforms such as 4TEL and its associated services. These systems work together to collect, process, and distribute data, supporting critical operations such as train positioning, timetable management, infrastructure monitoring, and real-time passenger information. The systems vary in type (analogue/digital) and accessibility, with many restricted to internal use by authorised operators, while select data, such as public transport timetables and GPS locations, are shared through application programming interfaces (APIs) for broader access. This interconnected ecosystem ensures seamless communication and operational efficiency across rail networks while maintaining robust security and data integrity through controlled access and encryption mechanisms.

As an example [14], 4TEL outlines the technical details of the data interface between VicTrack's Real-time Passenger Information Display System (RPIDS) and Datascout to generate a V/Line General Transit Feed Specification-Realtime (GTFS-R) feed. This is to enable the public to access real-time V/Line train data, including vehicle position information, which was previously not available. VicTrack's RPIDS Performance Hub serves as the data source for this real-time feed, and 4Tel is responsible for managing system integration. This document specifies the flow of data from RPIDS to Datascout's AWS cloud services, which are used to generate the GTFS-R data, ensuring that it mirrors the information presented on V/Line's station PIDS systems.

### 5.2 Open Data Challenges

We met with representatives from Metro, V/Line, and ARTC freight teams to better understand train location tracking and the limitations of relying on a single data source.

Train positions are mainly tracked using legacy track occupancy sensors, which detect a train only when it passes a sensor. These analogue systems are reliable for identifying presence on a track segment but lack precision and continuity, making them unsuitable for time-critical safety applications like pedestrian alerts at level crossings. Public data from PTV reflects this limitation, with updates occurring irregularly due to uneven sensor spacing. As a result, there is inevitably a delay between a train's actual physical position and the real-time

location data published by PTV, due to the reliance on trackside occupancy sensors that update only at specific points along the route. While more advanced systems use real-time GPS for continuous tracking and communication, supporting efficient rail operations, the integration of both methods remains essential for improved accuracy and safety.

Real-time GPS train data can be inaccurate or incomplete, and over-reliance on it may pose safety risks—such as assuming no train is approaching when one is. To address this, the data must be validated and integrated into wider safety systems with additional safeguards.

A notable limitation exists in the current PTV dataset: real-time position data for V/Line trains is not yet available. Although integration is reportedly in progress, this restriction currently prevents us from including V/Line services in our arrival time prediction model for level crossings.

As a result, our predictive algorithms are limited to Metro trains only, excluding V/Line movements, which may affect overall accuracy in regions serviced by both networks. We believe incorporating real-time V/Line data into the PTV dataset would significantly enhance the robustness and precision of these algorithms, and we strongly advocate for its prioritisation in future dataset updates.

### 5.3 Real-Time Train Position Data Access

We downloaded real-time Victoria PTV train data from a public data website<sup>1</sup> and stored it in MongoDB. Table 6 provides a complete list of data fields with examples. Each train record includes key attributes such as vehicle ID, trip ID, latitude, longitude, bearing, and timestamp, among others.

*Table 6 Data Fields in The Real-Time PTV Train Dataset.*

Field Name	Description	Example
<b>VehicleID</b>	A unique identifier for a vehicle (train).	100M-1344T-1350T-87M-88M-99M
<b>TripID</b>	A unique identifier for a particular trip.	253.T5.2-HBE-vpt-29.1.R
<b>Latitude</b>	The latitude of the vehicle in decimal degrees.	-37.77042389
<b>Longitude</b>	The longitude of the vehicle in decimal degrees.	145.0423431
<b>Bearing</b>	The bearing of the train measured in degrees from the horizontal.	35.52464676
<b>Odometer</b>	Distance travelled along the track.	The values are all 0
<b>Speed</b>	Speed of position as reported.	The values are all 0
<b>CurrentStopSequence</b>	The current stop sequence.	The values are all 0
<b>CurrentStatus</b>	Status of the train as it travels through the trip.	The values are all 2
<b>Timestamp</b>	The time when the record was created.	2024-09-12T02:27:12Z

<sup>1</sup> Real-time train positioning open dataset: <https://discover.data.vic.gov.au/dataset/gtfsr-metro-trains-vehicle-positions>

## 5.4 Timetable Data

Table 7 presents a structured overview of the data schema used to represent timetable information. Each entry is nested under a stop ID and includes keys and sub-keys detailing scheduled departures, trip metadata, and interchange options. By leveraging the latest estimated schedules at the station, we can infer train identity and anticipated arrival times—providing valuable input for training and validating our machine learning model against real-time prediction outputs.

Table 7 Data Structure Description for Diggers Rest Station

Field	Description
<b>stop_name</b>	The name of the station (e.g., "Diggers Rest Station").
<b>timetable</b>	List of upcoming departure objects from this stop.
<b>timetable[].scheduled</b>	Scheduled departure time in ISO 8601 UTC format.
<b>timetable[].estimated</b>	The estimated departure time, may be null if unavailable.
<b>timetable[].trip_id</b>	Unique identifier for the trip or service.
<b>timetable[].is_express</b>	Indicates if the service is express ("Yes") or not ("No").
<b>timetable[].run_info</b>	Metadata associated with the specific train run.
<b>run_info.run_ref</b>	Internal reference for the run.
<b>run_info.route_id</b>	Identifier for the route.
<b>run_info.route_type</b>	Type of route; 0 indicates a train.
<b>run_info.final_stop_id</b>	The stop ID of the train's final destination.
<b>run_info.destination_name</b>	The name of the final destination stop.
<b>run_info.status</b>	Status of the run ("updated", "scheduled").
<b>run_info.direction_id</b>	Direction identifier (varies by service).
<b>run_info.run_sequence</b>	Sequence number within the schedule.
<b>run_info.express_stop_count</b>	Count of skipped stops if express.
<b>run_info.vehicle_position</b>	Real-time position data (not used here).
<b>run_info.vehicle_descriptor</b>	Description of vehicle type (not used here).
<b>run_info.geopath</b>	Geospatial path for the run, currently empty.
<b>run_info.interchange</b>	Interchange options: feeder and distributor connections.
<b>interchange.feeder</b>	Connecting service feeding into this train.
<b>interchange.distributor</b>	Connecting service from this train.
<b>feeder/distributor.run_ref</b>	Run reference for interchange service.
<b>feeder/distributor.route_id</b>	Route ID of interchange.
<b>feeder/distributor.stop_id</b>	Stop ID of interchange.
<b>feeder/distributor.advertised</b>	Indicates if interchange is advertised.
<b>feeder/distributor.direction_id</b>	Direction of the interchange.
<b>feeder/distributor.destination_name</b>	Destination of the interchange service.
<b>run_info.run_note</b>	Additional notes associated with the run.

## 5.5 Trip Information Data

By linking the trip ID information with the real-time train data, we can determine the train's direction of travel and its final destination, as defined by the corresponding `direction_id` and `trip_headsign` fields.

Figure 9 Trip Information

Field Name	Description	Example Value
<code>route_id</code>	Unique identifier for the route (e.g., train line).	aus:vic:vic-02-ALM:
<code>service_id</code>	Identifies the service schedule (e.g., weekday/weekend).	T2_2
<code>trip_id</code>	Unique identifier for a specific scheduled trip.	02-ALM--1-T2-2302
<code>shape_id</code>	Identifier for the vehicle's path geometry on a map.	2-ALM-vpt-1.1.R
<code>trip_headsign</code>	Displayed destination for the trip.	Camberwell
<code>direction_id</code>	Trip direction: 0 = one way, 1 = reverse.	1
<code>block_id</code>	Groups trips for continuous operation by one vehicle.	
<code>wheelchair_accessible</code>	Wheelchair access: 1 = accessible, 0 = not accessible.	1

The track shape data—typically represented as a polyline of GPS coordinates—captures the actual path traversed by a train, rather than a simplified straight-line distance between stations. When combined with distance metrics and speed limit profiles, this detailed geometry allows for more accurate estimation of arrival times (ETAs) at level crossings and other critical points. Furthermore, the track shape enables spatial analysis and supports map-based visualisations, offering valuable insights for both operational planning and real-time monitoring applications.

Additionally, a similar dataset for NSW TrainLink services is provided in Appendix C for reference and comparison.

## 5.6 Steps Moving Forward

V/Line's TrackR application, currently in the test stage, provides real-time displays of train locations, train performance and expected arrival and departure times. We have formally requested a sample of this data for evaluation. In parallel, the Public Transport Data Program (PTDP) [3], led by DTP, is improving Victoria's transport network by providing more accurate, timely, and accessible real-time information—such as service alerts, platform numbers, tram endpoints, and bus replacement details—through enhanced Metro trains' GTFS-R feeds and a centralised Open Data Portal to support journey planning. We believe that access to these datasets will be highly valuable in supporting our proposed system for alerting train arrival times, particularly at level crossings. The availability of accurate, real-time location data would significantly enhance the reliability and responsiveness of our alert mechanisms.

## 5.7 Conclusion

This chapter highlights the critical role of accurate, integrated rail data in advancing safety, efficiency, and real-time decision-making across Victoria's rail network. Through consultation with rail operators and data providers, we identified both the potential and limitations of current systems, particularly the reliance on legacy occupancy sensors and the partial availability of real-time GPS data. Our analysis of publicly accessible datasets reveals gaps in update frequency and positional accuracy that limit the effectiveness of time-sensitive applications, such as train arrival alerts at level crossings. However, the V/Line TrackR application and the DTP-led PTDP, both currently in the testing phase, offer promising pathways to address these challenges. We conclude that incorporating these emerging datasets into open platforms will be essential to enhance prediction models and support the deployment of more reliable, data-driven safety solutions.

## 6 Machine Learning Prediction Algorithms

In this chapter, we describe our machine learning model to predict boom gate closures at Diggers Rest Station using real-time train data. By integrating trip and timetable information, the model improves accuracy and supports real-time deployment with built-in reliability features. The approach is scalable for broader use across Victoria.

### 6.1 Demo Station

To demonstrate our approach, we selected Diggers Rest Station level crossing—located at coordinates (-37.626522, 144.719783)—as a representative site on the Sunbury line, which serves trains travelling in both directions to and from Melbourne. At this location, we developed a Machine Learning (ML) model to predict boom gate closure events using real-time train movement data. The model is designed to ensure robust performance across both inbound and outbound services.

To improve prediction accuracy, we integrated trip information and timetable data into the model. These inputs help identify specific train runs, estimate scheduled arrival times, and determine travel directions, providing richer context for decision-making. With these enhancements, the predictive model becomes more reliable and context aware.

Leveraging this framework and our consolidated algorithms, the approach is scalable and adaptable, enabling future deployment across all Victorian stations, and potentially nationwide, to support advanced, data-driven level crossing safety systems.

### 6.2 Machine Learning Model Training

To capture the non-linear and dynamic patterns of train movement, a Random Forest Regressor was chosen as the prediction model. This ensemble method is well-suited for regression tasks with complex variable interactions. The model development followed 5 key stages: preprocessing, feature selection, data preparations, model training, and evaluation.

#### 6.2.1 Preprocessing

- **Data Parsing and Filtering:** Raw text-based train data was converted into structured tabular format, filtering specifically for Sunbury (SUY) line trips relevant to the case study.
- **Geospatial Distance Calculation:** The distance between each train's location and the level crossing was computed using precise geodesic methods to account for real-world curvature.
- **Timestamp Standardisation:** All timestamps were normalized to UNIX epoch time to ensure temporal consistency across records.
- **Trip Direction Classification:** Train movements were segregated into inbound and outbound directions using metadata from the trip information database.

#### 6.2.2 Feature Selection

Diggers Rest is a critical location on the Sunbury Line, featuring one road crossing with boom barriers and flashing lights and an adjacent pedestrian crossing with active gates that play a

vital role in real-time traffic control and safety operations. Positioned between major termini, it accommodates both inbound and outbound Metro services. For this project, the focus is limited to Melbourne Metro train data, explicitly excluding V/Line and freight services. The goal is to develop machine learning models to estimate two key events: the departure of a train from Watergardens Station toward the city, and from Sunbury Station heading inbound. These estimates serve as the basis for accurately predicting boom gate activation times, enhancing both safety outcomes and traffic flow around the Diggers Rest level crossings. The predictive model is built on a set of carefully engineered features that capture the spatiotemporal dynamics of train movement, providing the foundation for robust and reliable forecasting.

A track circuit is installed near the level crossing to physically detect when a train occupies the track section. At the same moment the train enters the track circuit, the boom gates begin to flash and lower gradually. This point in time—when the boom gate starts to close—is defined as the alert triggering time for the purposes of our system. The position of the track circuit (latitude and longitude) is determined through field observation and operational experience, as it may not always be explicitly marked in asset databases. The machine learning (ML) training model is designed to predict the timestamp, i.e. time-to-arrival, at which the boom gate begins to close, which corresponds directly to the moment the train occupies the track circuit.

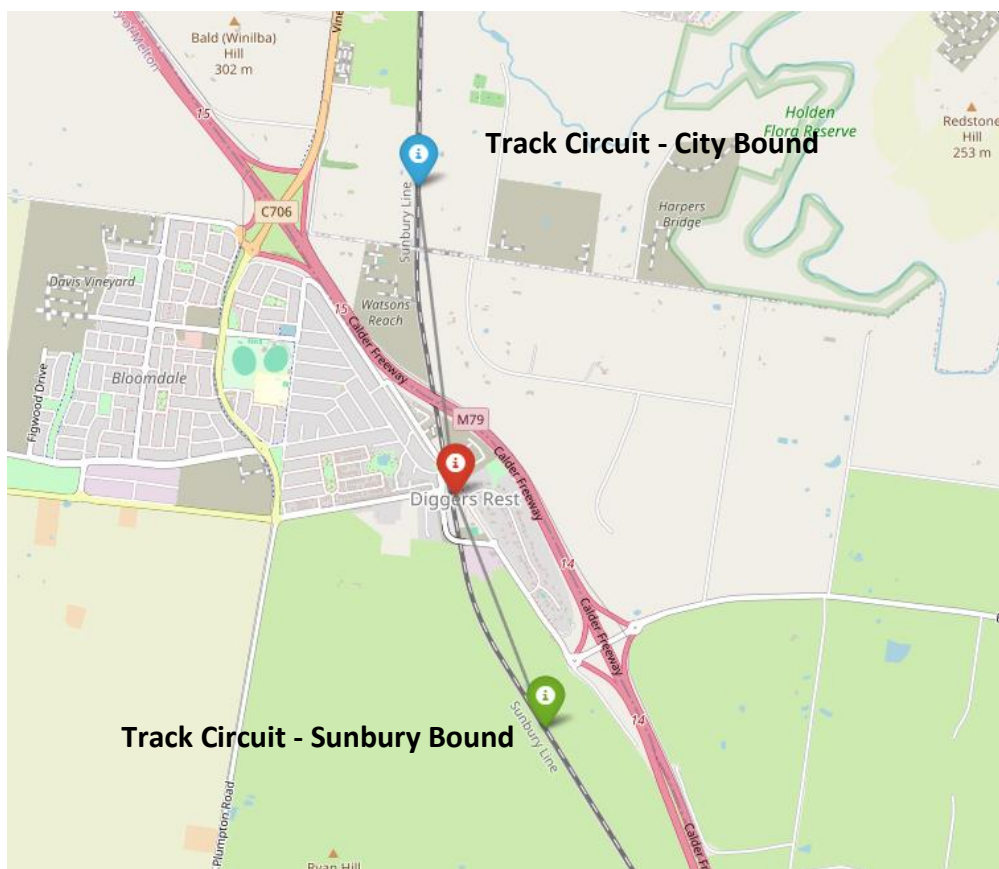


Figure 10 Track Circuit Position

Table 8 ML Features

Feature Name	Description
<b>distance_to_crossing_m</b>	Distance (in meters) to the track circuit
<b>speed_kmh</b>	Instantaneous train speed estimated in km/h
<b>bearing</b>	Train heading in degrees (0–360°)
<b>timestamp</b>	UNIX Epoch Timestamp of the current observation
<b>direction_id</b>	Train direction: 0 = Sunbury-bound, 1 = City-bound
<b>distance_to_prev_m</b>	Distance (in meters) from previous GPS update

These features were selected based on their relevance to train trajectory and time-to-arrival estimation.

### 6.2.3 Data Preparation

The preprocessing pipeline was developed using custom Python tools and consists of the following key steps:

- **Filtering:** Train records were filtered to retain only those within a 100-meter radius of the Diggers Rest level crossing, ensuring relevance to the target location.
- **Interpolation:** Great-circle interpolation techniques were applied to estimate the precise timestamp at which each train crossed the level crossing.
- **Data Splitting:** The dataset was divided into training and testing subsets using an 80/20 ratio, with stratification by travel direction to maintain balance across inbound and outbound trips during model training.

### 6.2.4 Model Training

The model was trained using the following configuration:

- **Algorithm:** Random Forest Regressor, a robust ensemble learning method well-suited for non-linear regression tasks.
- **Hyperparameters:** Configured with 100 decision trees and a maximum tree depth of 10 to balance model complexity and generalisation.
- **Target Variable:** *Time to cross*, defined as the number of seconds remaining for a train to reach the level crossing from its current location.
- **Validation Strategy:** A 5-fold cross-validation approach was employed to evaluate model performance and reduce the risk of overfitting.

### 6.2.5 Evaluation

The performance of the regression model was evaluated using Mean Absolute Error (MAE), which measures the average absolute difference between the predicted and actual crossing times. In Table 9, the predicted arrival time is compared against the actual time when the boom gate starts closing, and as demonstrated, the accuracy is sufficient for this application. This result is based on testing at a single site in Diggers Rest. We believe that by expanding this methodology to multiple stations, similar levels of accuracy can be achieved.

The predictions in the citybound direction showed lower absolute errors (MAE and RMSE) across all thresholds, though relative errors (MAPE) and  $R^2$  values were consistently higher

in the Sunbury direction. This may suggest lower variability or fewer influential factors in the citybound trips, possibly due to shorter approach distances or simpler traffic dynamics.

Table 9 Prediction accuracy test results

Time to Boom Gate Closure Start– Test-Set Results at Diggers Rest Station		
	Sunbury direction: The models were trained on the data of 880 trips and tested on 221 trips.	City direction: The model was trained on 524 trips and tested on 131 trips
<b>MAE</b>	15.6 s	11.44 s
<b>RMSE</b>	19.39 s	15.76 s
<b>MAPE</b>	10.03%	18.33 %
<b>R<sup>2</sup></b>	0.978	0.974
	(≤ 300 s)	
<b>MAE</b>	12.43 s	11.30 s
<b>RMSE</b>	16.36 s	15.61 s
<b>MAPE</b>	11.97%	18.87%
<b>R<sup>2</sup></b>	0.962	0.964
	(≤ 180 s)	
<b>MAE</b>	10.45 s	9.20 s
<b>RMSE</b>	13.53 s	12.82 s
<b>MAPE</b>	15.35%	20.13%
<b>R<sup>2</sup></b>	0.935	0.924
	(≤ 60 s)	
<b>MAE</b>	6.47 s	4.92 s
<b>RMSE</b>	8.90 s	7.22 s
<b>MAPE</b>	23.91%	30.21%
<b>R<sup>2</sup></b>	0.747	0.491

- **MAE (Mean Absolute Error)** – Seconds of variation of the individual prediction vs. the model, whether that’s early or late.
- **RMSE (Root Mean Squared Error)** – Like MAE but it penalises the occasional big misses more, so the value is usually a bit higher.
- **MAPE (Mean Absolute Percentage Error)** – Same idea as MAE but expressed as a percentage of the true time; useful because it’s scale-free.
- **R<sup>2</sup> (Explained Variance)** – How much of the real-world ups-and-downs the model captures. A perfect model would be 1.00.

## 6.3 ML Algorithm Real-Time Implementation

### 6.3.1 Model Deployment and Prediction

The deployed machine learning solution is based on a Random Forest Regressor, selected for its robustness to non-linear feature interactions and its practical interpretability in real-time environments. Two independent models are maintained—one for city-bound and another for Sunbury-bound train directions—to account for directional asymmetries in train behaviour and network conditions. Each model is trained on historical level crossing data using carefully engineered features derived from real-time operational inputs.

Key input features include:

- Current distance to the track circuit towards the level crossing
- Estimated travel speed
- Bearing (direction of motion in degrees)
- Direction category (e.g., inbound or outbound)
- Time elapsed since the last recorded position update

The model predicts the remaining time to reach the track circuit (in seconds), enabling downstream applications to make proactive decisions based on anticipated arrival times.

### 6.3.2 Incorporate Key Boom Gate Timings

The RISSB AS 7658:2020 – Level Crossings: Rail Industry Requirements standard defines the absolute minimum warning time as the shortest permissible interval between the activation of warning devices (e.g., flashing lights) and the arrival of a train at the level crossing, assuming the train is travelling at the maximum permissible approach speed. Table 10 shows the minimum warning time.

These warning times are designed to provide sufficient margins for all users—particularly pedestrians and vulnerable road users—to safely detect the warning and clear the crossing before a train arrives.

To comply with these minimum warning time requirements, railway engineers carefully determine the location of the track circuit—the point on the track where train occupancy triggers the boom gate to begin closing. This location is engineered based on:

- The maximum allowable train speed at the site, and
- The required time margin to allow the boom gates to lower and ensure the crossing is clear.

In our study, we empirically validated the boom gate closure timing through field observations. Specifically:

- We identified the moment the boom gate began closing, and
- Matched that to the train’s GPS position and timestamp at that same moment.

Using this association, we derived the approximate geolocation (latitude and longitude) of the track circuit responsible for triggering the boom gate closure. This data was then used to train our AI model, which predicts the remaining time until the train reaches that track circuit—effectively predicting time to boom gate closure initiation.

While our observational method provides a practical estimate, Metro Trains Melbourne maintains precise boom gate closure logs within its signalling systems, which are not publicly accessible. In future work, collaboration with signalling engineers to access these internal logs could provide accurate ground-truth timestamps, enhance AI model training accuracy, and reduce reliance on manual field validation.

Table 10 AS 7658:2020 Boom gate closing time

Event	Time from Flashing Start
<b>RX-5 flashing light-only installations</b>	25 seconds
<b>RX-5 light and boom barrier installations</b>	30 seconds
<b>Pedestrian level crossings with lights only</b>	20 seconds
<b>Pedestrian level crossings with lights and booms or swing gates</b>	25 seconds

### 6.3.3 System Behaviour and Output

For each actively tracked train near the crossing, the system computes the estimated time of arrival (ETA) by adding the predicted time-to-arrival value to the current system timestamp. Predictions can be optionally post-processed or aligned with known boom gate signal timings to improve temporal alignment with infrastructure logic. These outputs can be streamed to crossing control systems, alerting mechanisms, or live monitoring dashboards, enabling real-time operational awareness and safety response.

The system is designed to operate with low latency, supporting near-instantaneous updates as new data becomes available.

### 6.3.4 Reliability and Failover Mechanisms

To ensure system reliability and robustness under varying data conditions, several safeguards are in place:

- **Buffered Estimates:** In the event of delayed or missing real-time updates, the system falls back on the most recent prediction or scheduled timetable data.
- **Multi-source Redundancy:** Train position and schedule data are cross-validated using multiple sources to reduce dependency on a single data feed.
- **Confidence Scoring:** Each prediction is assigned a confidence score based on the freshness, completeness, and consistency of input data.

For example, after selecting a train route, the system requests all associated stops for that route. It then queries upcoming departure data for each stop, limited to a set number of results, and expands the response to include trip-level metadata. Each result includes real-time estimates, trip classification (e.g. express or stopping), and identifiers such as the run ID. The system uses this run ID to fetch additional metadata describing the vehicle type or rolling stock associated with the trip. These descriptors are useful for both operational diagnostics and historical pattern analysis.

A notable challenge arises at stations that are very close together or near the end of a train line, where travel times can be less than 3 minutes. In such cases, the available real-time data points are limited, reducing the window for early alerts. Despite this, we still can train the AI model, but to improve prediction accuracy by correlating the AI's estimated arrival

time with timetable schedule data. We believe a single solution can't cover all cases. Station-specific factors may still require fine-tuning beyond the general model.

This architecture ensures continuous, accurate, and resilient forecasting of train arrivals at level crossings. By integrating live data streams with predictive intelligence, the system forms a scalable core for smart railway safety infrastructure, capable of expanding to additional crossings and supporting future enhancements.



*Figure 11 Diggers Rest Station Level Crossing*

## 6.4 Conclusion

This chapter demonstrates the development and real-time deployment of a machine learning model to predict boom gate closures at Diggers Rest Station. By leveraging real-time train data, trip information, and timetable inputs, the system accurately estimates train arrival times and supports the timely activation of safety mechanisms. The model's performance, reliability features, and scalability highlight its potential for broader application across Victoria's rail network, contributing to safer and smarter level crossing management.

## 7 C-ITS Compliant Prototype Development

This chapter outlines a cloud-based prototype system that delivers real-time level crossing alerts using ETSI C-ITS standards. It combines machine learning, 4G communication, and MQTT messaging to send DENM alerts to nearby users via a geofencing-enabled mobile app.

### 7.1 ETSI C-ITS Standard

The European Telecommunications Standards Institute (ETSI) ITS-G5 Release 2, is a vital communication standard for Intelligent Transport Systems (ITS) that enables vehicle-to-everything (V2X) communication, improving road safety and traffic efficiency. Developed by ETSI, ITS-G5 supports vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-pedestrian communications, with key features including spectrum allocation, low-latency communication, and enhanced security. Release 2 introduces support for vulnerable road user (VRU) safety, ensuring timely warnings for pedestrians and cyclists. The specification of the C-ITS standard is illustrated in Appendix A.

Our system is designed to prototype a solution that is fully compliant with the ETSI C-ITS standard, specifically utilising Decentralized Environmental Notification Messages (DENMs) to disseminate real-time warning alerts. While C-ITS messages have traditionally been transmitted via short-range communication technologies such as DSRC (Dedicated Short-Range Communications), our implementation leverages the Internet and 4G networks to deliver DENM messages. This approach significantly enhances scalability and accessibility, enabling broader adoption across common end-user devices such as smartphones and connected vehicles. By ensuring the timely delivery of standardised safety alerts, the system supports improved situational awareness and safer interactions at level crossings.

### 7.2 Prototype Design

This section outlines the design and operational architecture of a real-time level crossing alert system, aimed at enhancing pedestrian safety near railway crossings.

#### 7.2.1 System Architecture

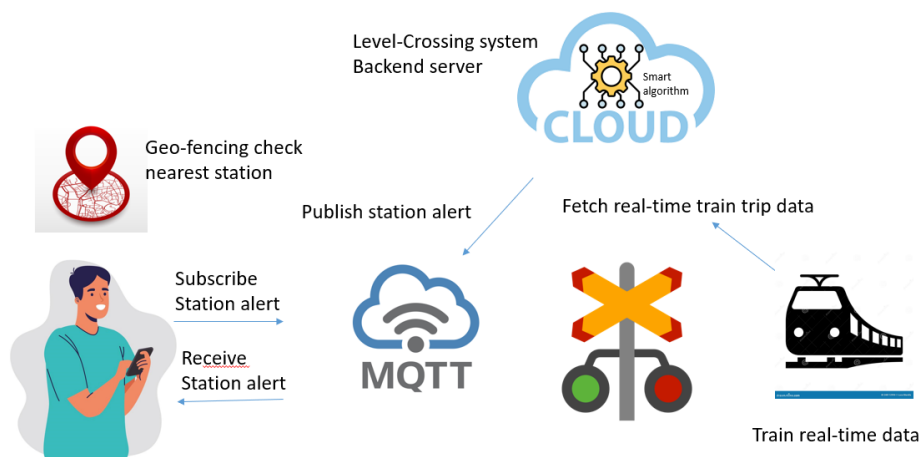


Figure 12 System Architecture Design

La Trobe deployed an Ubuntu-based virtual server on DigitalOcean cloud, configured with 2 CPU cores, 4 GB of RAM, and 256 GB of SSD storage, providing a reliable and scalable environment for hosting our prototype system.

La Trobe installed the Mosquitto MQTT broker on the server, a lightweight and open-source messaging server that implements the MQTT (Message Queuing Telemetry Transport) protocol. MQTT is well-suited for low-latency, real-time communication, making it ideal for delivering C-ITS messages such as DENMs to end-user devices. The broker acts as a central hub to publish and distribute warning messages, enabling subscribed clients—such as mobile apps, in-vehicle systems, or roadside units—to receive timely alerts about approaching trains and level crossing status. This setup ensures efficient, scalable, and reliable message delivery in our prototype system.

On the server, a Node.js-based backend application orchestrates the system’s core functions. It interfaces with Python-based machine learning algorithms to process real-time train position data and calculate the estimated boom gate closure time. In addition to managing data processing, the backend also handles C-ITS communication, including the generation and publication of DENM alerts via the MQTT broker. This architecture ensures seamless integration between data analytics and message dissemination, enabling timely and accurate safety notifications to end users.

Pedestrians use a dedicated Android application equipped with geofencing capabilities to determine their current location and identify the nearest train station. Based on this location, the app dynamically subscribes to the relevant alert topic from the MQTT broker, ensuring that the user only receives location-specific C-ITS messages (e.g., DENM alerts) for nearby level crossings. This targeted subscription approach minimises unnecessary data traffic, reduces battery usage, and delivers timely and relevant safety notifications, enhancing user awareness and response near active railway crossings.

*Table 11 Implementation Technology*

<b>Component</b>	<b>Technology Description</b>
<b>Backend Application</b>	<ul style="list-style-type: none"> <li>- Node.js app for orchestration and message handling</li> <li>- Python ML program integration (TensorFlow)</li> <li>- Generates and sends C-ITS DENM messages to MQTT broker</li> </ul>
<b>Communication Layer</b>	<ul style="list-style-type: none"> <li>- MQTT protocol (e.g., Mosquitto)</li> <li>- Topics mapped to train station names</li> <li>- Supports millions of users or more</li> </ul>
<b>Mobile Application</b>	<ul style="list-style-type: none"> <li>- Android Studio native app</li> <li>- Receives MQTT DENM alerts</li> <li>- GPS tracking and geofencing</li> <li>- UI alert to end users</li> </ul>
<b>Machine Learning Model</b>	<ul style="list-style-type: none"> <li>- TensorFlow in Python</li> <li>- Input: train position data</li> <li>- Output: boom gate closing predictions triggering DENMs</li> </ul>

## Melbourne Metro Level-Crossing Real-time Alert Dashboard

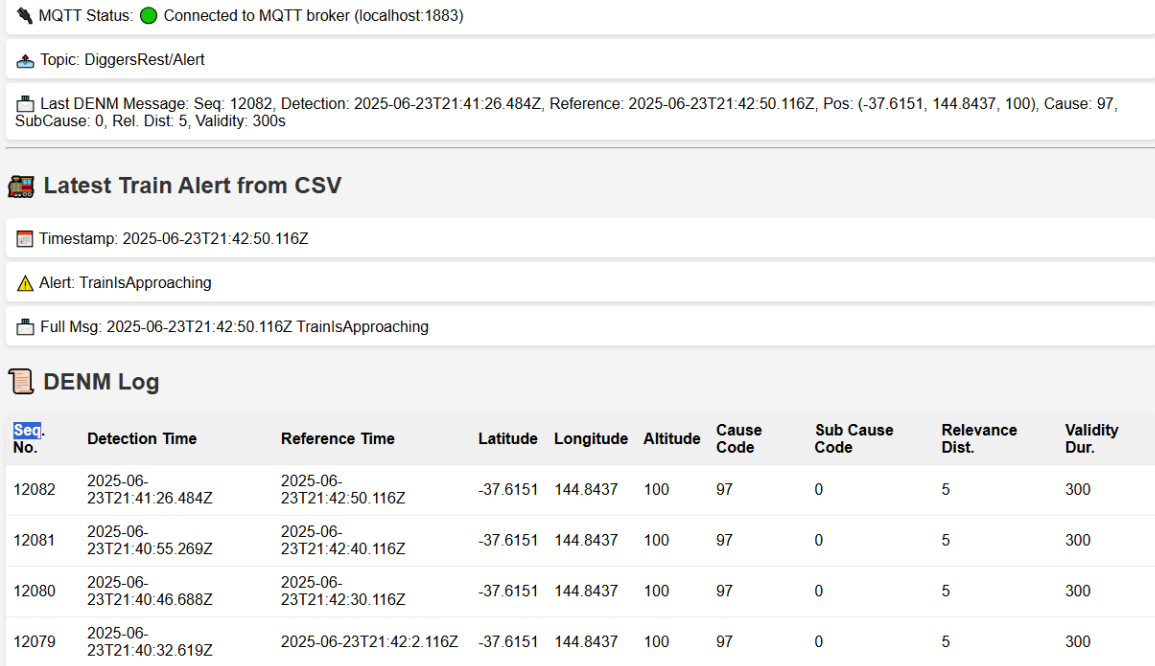


Figure 13 Backend Application Monitoring Dashboard

### 7.2.2 Realtime Train Position Access API

The system authenticates each API request using a Developer ID and shared secret key, generating an HMAC-SHA1 signature appended to the query for secure communication with the PTV API. A dedicated function handles this signing process. Once authenticated, the app retrieves all transport routes, filters for train services by route type, and presents a dynamic list of train lines via the command-line interface for user selection and subsequent queries.

The system continuously ingests real-time data from railway sources to power machine learning (ML) models that predict each train's Estimated Time of Arrival (ETA) at nearby level crossings. The ML models integrate contextual factors—such as train type (express, local) and delay status—to improve prediction accuracy and enable dynamic risk zone classification around crossings.

### 7.2.3 DENM Message Creation

The system includes a core function named `createDENM`, which is responsible for constructing DENMs in compliance with ETSI ITS-G5 standards. These messages are structured into several standardised containers:

- **Management Container:**
  - `detectionTime` and `referenceTime` (timestamps of the triggering event and event occurring time)
  - `eventPosition` (precise geographic coordinates, e.g., Diggers Rest level crossing)
  - `validityDuration`: the valid duration of this message

- relevanceDistance, and station/zone identifiers.
- **Situation Container** describes the nature of the events:
  - causeCode: Represents the general event category.
    - Default: 0 (unspecified condition)
    - Train approach alert: 97 (Hazard)
  - subCauseCode: Reserved for optional context-specific codes.
- **Location & Alacarte Containers:** optional fields that are not used

Once a DENM is generated, the backend publishes it to the MQTT broker under relevant station-specific topics (e.g., /alert/DiggersRest). This topic-based structure allows end-user devices to subscribe only to alerts for nearby stations, ensuring efficient message delivery, reduced bandwidth usage, and timely, location-specific safety notifications.

The C-ITS communication system relies on 4G/LTE networks, eliminating the need for costly short-range Roadside Units (RSUs). This cloud-based approach enables scalable, real-time message exchange between trains, vehicles, and vulnerable road users (VRUs) without the infrastructure overhead of traditional DSRC-based systems.

#### 7.2.4 DENM Control Mechanism

DENM messages are published through a structured process that ensures standards compliance, real-time responsiveness, and interoperability with external systems. Before a message is broadcast, the system checks for overlap with previous alerts to prevent duplication, while high-priority events—such as an approaching train (CauseCode = 97)—immediately override existing messages to ensure timely delivery of critical alerts.

Each published DENM message is broadcast to all connected MQTT clients and simultaneously logged in a human-readable file for traceability. Upon receiving an ML alert request, the backend constructs a new DENM message, validates it, publishes it via MQTT, and returns a confirmation.

The system also applies a controlled publishing policy based on validityDuration (default 300 seconds):

- When no train is approaching, CauseCode 0 messages indicate a neutral state and are throttled to publish only once per validity period, minimising bandwidth use.
- When a train is detected, a CauseCode 97 message is generated and published immediately, overriding prior messages to deliver urgent alerts without delay.

This logic ensures efficient use of resources for routine updates while maintaining uninterrupted, high-priority delivery for safety-critical events.

#### 7.2.5 Alert Dissemination via Mobile Application

The mobile application acts as the user-facing interface for delivering real-time train crossing alerts, leveraging geolocation, geofencing, and lightweight MQTT communication to ensure relevant and timely notifications.

##### **Geofencing and MQTT Subscription:**

- The app continuously tracks the user's GPS location in the background.

- When the user enters a geofenced zone near a train station or level crossing, the app automatically subscribes to the corresponding MQTT topic (e.g., /alert/DiggersRest).
- This ensures users receive alerts only for nearby crossings, optimising battery life and reducing unnecessary data traffic.

#### **Alert Generation and Delivery:**

- On the backend, if an alert is warranted, a DENM is published to the appropriate MQTT topic.
- The mobile app, already subscribed, receives the message, decodes the causeCode (e.g., 97), and calculates the ETA using the referenceTime.
- Users are notified via visual and audible warnings, including countdown timers, alert severity (e.g., colour-coded overlays), and optionally, prediction confidence levels. The app triggers alerts based on ETA: no alert if ETA > 3 minutes, an orange warning if between 1–3 minutes, and a red alert if under 1 minute. This ensures timely, risk-based notifications near level crossings.

#### **Alert Logic for Multiple Trains:**

- The system continuously monitors real-time data from all nearby trains, including:
  - Position, speed, direction, and estimated time of arrival to the level crossing.
- If two or more trains are detected approaching the same crossing:
  - Whether from the same direction (e.g., behind each other) or opposite directions
  - Whether simultaneously or within a short time interval
- The system evaluates each train’s proximity and estimated time of arrival, and:
  - Selects the nearest or earliest-arriving train as the primary trigger.
  - A DENM warning message (CauseCode = 97) will be generated to alert nearby users if the alert condition is met.
- As the first train clears the crossing, the system automatically:
  - Checks if another train is still approaching the level crossing or has passed.
  - If so, a new DENM alert (CauseCode = 97) is triggered for that next train.
- This ensures:
  - Each train that presents a risk is handled independently.
- Only when all trains have passed and no additional hazard is detected:
  - The system sends a DENM message (CauseCode = 0) to signal the end of the alert cycle.

### **7.3 Future Enhancements and Integration Opportunities**

To expand the system’s impact and inclusivity, future enhancements will focus on algorithm refinement, interface accessibility, and integration with public ITS platforms.

Algorithmically, the system will be enhanced to enable accurate boom gate closure

predictions in complex scenarios—such as stalled trains, unexpected rerouting, unscheduled track vehicles, blocked crossings, closely spaced crossings, and weather-induced delays—providing critical early warnings, especially beneficial for users with mobility impairments.

From a user experience perspective, the interface will evolve to accommodate the diverse needs of people with disabilities, including hearing or visual impairments. Enhancements may include personalised alert timing based on mobility profiles, haptic feedback, voice guidance, and large-format visual cues. Interactive features will also allow users—both pedestrians and car drivers—to acknowledge alerts or indicate when they have exited the risk zone, adding a feedback loop to improve situational awareness and system accuracy.

Crucially, integration with public ITS and navigation platforms such as Google Maps, TomTom, HERE, and iMaps is planned to extend alert coverage to a wider user base, particularly vehicle drivers. At managed crossings (with boom gates), in-vehicle systems or mobile apps will deliver timely alerts with information such as:

- Estimated time until the boom gate closure
- Projected wait time
- Recommended actions (e.g., proceed, slow down, reroute)

These alerts help drivers make informed decisions—such as safely diverting, proceeding, or queuing—thereby improving safety and traffic flow near crossings. At unmanaged crossings, where no physical barriers are present, the system will broadcast DENM-based hazard warnings using real-time train speed, location, and direction.

These alerts can be integrated into mobile devices or vehicle telematics APIs, enabling real-time, map-based overlays and audio prompts even in infrastructure-limited environments. The approach supports scalable integration with fleet systems, next-gen ADAS, and autonomous navigation, ensuring predictive safety awareness for all road users.

## 7.4 Conclusion

This chapter demonstrates the feasibility of a standards-aligned safety system for level crossings, showing that existing ETSI ITS-G5 specifications—particularly DENM messages—can effectively support VRU protection without requiring additional roadside infrastructure. By leveraging 4G networks, cloud-based processing, and real-time predictive algorithms, the system delivers timely alerts to pedestrians and cyclists based on actual train movements. This approach enables a scalable, efficient, and future-ready solution, laying the foundation for integrating VRU safety at level crossings into ETSI-compliant C-ITS ecosystems and addressing the unique challenges of road–rail interactions. To broaden the system’s impact, future enhancements will focus on smarter algorithms, accessible interfaces, and integration with public ITS platforms like Google Maps and TomTom.

## 8 Privacy, Consent and Regulation

Protecting user privacy is a foundational principle of this project. As we develop and deploy technology to support pedestrians—particularly those living with disabilities—at level crossings, we are committed to upholding the highest standards of data protection, transparency, and regulatory compliance. This chapter outlines how we approach privacy, how consent is managed, and the regulatory frameworks that guide our decisions.

### 8.1 GDPR

In Europe, privacy protection for digital mobility and pedestrian safety projects is governed by the General Data Protection Regulation (GDPR). Similar projects across the EU follow strict principles such as data minimisation, meaning they only collect the essential information needed to deliver services. Personal data like names, contact details, or exact locations is either not collected or is anonymised or pseudonymized. When user data is needed—for example, to analyse how people use a crossing or app features—explicit, informed consent is required. Users must be informed what data is being collected, why it’s needed, and how it will be used, with the ability to opt out or withdraw consent at any time.

European projects also apply “privacy by design and by default,” building security and user control into the system from the beginning. Data is often processed locally on devices to avoid cloud-based risks, and features like encrypted communication, access logs, and automatic data deletion are standard. Transparency is key: users are informed about their rights, can access or delete their data, and can contact national Data Protection Authorities if needed. This approach ensures that while digital tools improve transport safety and accessibility, they do so without compromising individual privacy.

### 8.2 No Personal Information Stored

At the core of our privacy strategy is the decision to avoid collecting or storing any personally identifiable information (PII) in our system by default. Users can access and benefit from core features of the app—such as real-time train data, crossing countdown timers, and early warning alerts—without having to register, log in, or provide any identifying details. The system operates anonymously, ensuring that no names, contact details, device IDs, or biometric data are captured or stored in the database.

### 8.3 Privacy by Design: Compliance with DSAPT

We strictly follow the principles outlined in the Disability Standards for Accessible Public Transport 2002 (DSAPT), a national regulation in Australia that ensures equitable, accessible, and non-discriminatory transport solutions. DSAPT compliance shapes both our design and deployment strategies—ensuring, for example, that users are not required to provide personal information as a condition of access and that app-based functionalities remain inclusive and usable.

### 8.4 Consent-Based Data Collection for App Improvement

While the base system does not track users, there may be instances where we seek to understand how and where the app is being used, strictly for the purpose of improving its

effectiveness and accessibility. In such cases, any form of usage data collection is preceded by clear, informed, and voluntary user consent.

For example, we may ask users if they are willing to:

- Share anonymous usage patterns (e.g., which features are used most)
- Allow location data to be logged in an aggregate form (e.g., frequency of app use at specific crossings)
- Provide optional feedback through surveys or feature testing

In these scenarios, we:

- Clearly explain why the data is being collected
- Specify what kind of data is involved
- Offer an opt-in mechanism with the ability to withdraw at any time
- Ensure all collected data is anonymised and used solely for research, development, and service refinement

## 8.5 Transparent Communication and Control

We commit to full transparency in how user data is handled. Privacy notices and consent prompts are written in plain language and presented in an accessible format. Users retain full control over their participation in any data collection. The app includes a settings section where users can:

- Review data collection policies
- Change consent preferences
- Delete any previously shared usage data (if applicable)

## 8.6 Alignment with Broader Privacy Regulations

Our approach aligns with broader legal frameworks such as the Australian Privacy Act 1988, the Australian Government Agencies Privacy Code, and, where applicable, international standards such as the General Data Protection Regulation (GDPR). Even though our default implementation avoids personal data, we proactively apply best practices such as data minimisation, secure transmission protocols, and privacy impact assessments when relevant.

## 8.7 Conclusion

Privacy is not an afterthought—it is embedded in the very structure of our solution. By minimising data collection, avoiding the storage of personal information, and seeking explicit consent only when necessary, we maintain trust, support regulatory compliance, and ensure that our technology empowers users without compromising their rights.

## 9 Assessment and Conclusion

As rail networks modernise and urban mobility becomes increasingly complex, the need for intelligent, inclusive, and predictive safety systems at level crossings has never been greater. This document presents a feasibility assessment of a novel alert solution designed to protect all crossing users—especially VRUs—through real-time data integration, machine learning, and C-ITS standards. Drawing on proven results from local field trials and aligned with international best practices, the assessment explores the system’s technical readiness, data reliability, user accessibility, and scalability. The goal is clear: to demonstrate that this solution is not only technically sound and commercially promising but also enhances accessibility and safety for people with disabilities at level crossings, supporting broader deployment across Australia’s rail infrastructure and beyond.

### 9.1 Assessment Criteria and Feasibility Analysis

Table 12 Assessment Criteria

Criteria	Finding/action
<b>Overseas deployment of similar systems</b>	
Other countries have implemented a similar system.	Two similar use cases have been found, one in the Netherlands, based on sensors and additional lights, and one in France, based on C-ITS, providing evidence for the need as well as the technical feasibility. Previous initiatives in Australia’s level-crossing safety include Standards Australia, the Victorian Railway Crossing Safety Steering Committee and WSP, Transport for NSW, the University of the Sunshine Coast, and the National ALCAM Committee.
<b>User Accessibility and Acceptance</b>	
The system should meet the needs of diverse users, including those with disability.	Survey results from 78 participants across Australia with physical or sensory disabilities confirm that the proposed system aligns well with the needs of diverse users. A significant majority—73% using mobility aids and over half aged 55+—expressed strong support for features like early warnings (84%) and “time to cross” information (74%), which they believe would reduce stress and uncertainty. Notably, 75% described level crossings as stressful, and 71% felt uncertain when approaching one, underscoring the emotional and practical challenges faced. The system’s delivery of real-time, context-aware alerts directly addresses these concerns and demonstrates clear potential to enhance safety, independence, and user confidence for people with disabilities.
<b>Stakeholder Acceptance</b>	
The operators and governments should embrace the proposed solution.	Through engagement with technology experts and stakeholders across industry and government, there is growing recognition that the proposed solution offers a valuable additional layer of safety. Leveraging real-time GPS data and machine learning-based prediction, the system provides timely, contextual information that enhances situational awareness, particularly at level crossings where traditional infrastructure may be

<b>Criteria</b>	<b>Finding/action</b>
	limited. Operators and policy advisors acknowledged the system's potential as a non-safety-critical yet highly complementary technology, especially for vulnerable users such as people with disabilities.
<b>Data Availability</b>	
The data should be available for all trains, including work trains and historic (heritage) trains.	DTP's PTDP has enhanced the Metro Trains GTFS-R Service Alerts feed by adding disruption details, delay and bus replacement info, and Route and Direction IDs to support more informed real-time trip decisions. Currently, in Victoria, real-time positional data is available only for Metro Trains services. Access to real-time data for V/Line regional services is not yet available but is under development.
The data should be accessible for all level crossings across the network.	We have obtained basic level crossing data from the DTP for Victoria, including all stations and platforms information. Currently, the Queensland TMR is initiating efforts to expand the Australian National Access Point (NAP) to include comprehensive level crossing data. This initiative aims to centralise and standardise access to critical rail safety infrastructure information, enabling broader integration across states and enhancing national-level transport data interoperability.
Data should be refreshed in a frequency suitable to make accurate predictions.	The current operational prediction interval for level crossing management is typically 10 seconds or more, depending on the frequency and latency of track occupancy sensor updates. Based on the evaluation of our machine learning algorithm, this update interval is sufficient to achieve accurate and timely predictions of train arrivals. The model's precision aligns well with infrastructure constraints and existing safety requirements, making it suitable for real-time deployment.
<b>Data Reliability</b>	
The data sources should be consistent, synchronised, and free from errors.	The data sources used in this system are obtained from the Public Transport Victoria (PTV) data platform. These feeds have been verified to be consistent, temporally synchronised, and free of errors. Their reliability and structured format make them well-suited for integration into real-time prediction algorithms and transport analytics frameworks.
Redundancy should be in place to mitigate data loss or inaccuracies.	To mitigate the risk of data loss or inaccuracies, the system includes fallback logic that activates when real-time data is unavailable or incomplete. In such cases, it estimates train arrival times using recent historical patterns or scheduled timetables, ensuring users continue to receive timely alerts even under degraded data conditions.
<b>Data Precision</b>	
The data should be accurate and detailed enough for safety-critical applications.	This system is not intended to serve as a critical safety application. While the model performs with high accuracy under normal operating conditions, its accuracy is constrained by the limited frequency of real-time data updates.
The data should be detailed enough to differentiate between train types and their respective operations.	At present, the system leverages real-time positional data exclusively from Metro Trains Melbourne. While V/Line services also traverse the Diggers Rest level crossing, real-time GPS or positional feeds for V/Line trains are not currently available via the PTV open data platform. However, timetable data for V/Line services is accessible.
Any deviations or inaccuracies in the data	Real-time train data is continuously monitored, and any deviations or anomalies are filtered for further validation. For example, abnormally

<b>Criteria</b>	<b>Finding/action</b>
should be filtered for further validation.	high speeds calculated from GPS position changes are flagged to prevent false inputs into the system. Additionally, the moving direction is cross-checked to ensure the train's travel direction aligns with expected movement, further enhancing data integrity and system reliability.
The train data and trip data should be correlated.	In the implemented system, real-time train data is systematically correlated with static trip schedule data to enhance both prediction reliability and operational interpretability. This correlation serves multiple functions: -Direction Identification: The trip dataset contains directional identifiers (e.g., 0 = Sunbury-bound, 1 = City-bound), which are used to classify the real-time train position data and select the appropriate prediction model. -Schedule Alignment: Each real-time record is mapped to its corresponding estimated scheduled time from the timetable. This allows for comparative analysis between predicted arrival times and scheduled expectations, supporting anomaly detection and performance monitoring. -Fallback Alerts: In cases where real-time prediction is unavailable (e.g., due to data delay or dropout), the scheduled timetable acts as a secondary layer, enabling the system to still issue alerts or estimate train arrivals based on planned operations. This integration ensures that the predictive system is resilient, context-aware, and continuously aligned with both live and expected service patterns, contributing to more robust level crossing monitoring.
<b>Prediction Accuracy</b>	
The system should accurately predict train arrivals and boom gate closures within sufficient timing thresholds to provide timely warnings to end users.	The current machine learning model achieves reliable accuracy, suitable for level crossing monitoring and situational awareness. Although not intended for safety-critical automation, it effectively supports public alerts and traffic management. Several challenges were addressed during development: the lack of boom gate closure timestamps was managed through observational validation using train position and time data, with future improvements possible through access to signalling logs. Limited data near terminal or closely spaced stations was mitigated by aligning AI predictions with timetable information. These experiences highlighted the need for flexible, station-specific model adjustments, reinforcing the value of adaptable modelling, hybrid data sources, and collaboration with infrastructure stakeholders to improve prediction accuracy and ensure timely user warnings.
<b>System Response Time</b>	
The system should process data and deliver warnings quickly after detecting a train.	The system is designed to initiate processing as soon as a train is detected within 12 kilometres of the level crossing. Real-time position data is continuously ingested and evaluated, enabling immediate prediction generation. The prediction model updates dynamically as new data points arrive, and accuracy improves progressively as the train approaches the crossing, benefiting from more frequent and precise location updates. This ensures that warnings or alerts can be issued with minimal latency, well in advance of the train's arrival, while maintaining alignment with actual train behaviour on the ground.

<b>Criteria</b>	<b>Finding/action</b>
Real-time data processing should be prompt and synchronised with actual train movements to ensure accuracy and reliability.	Although real-time train position data is derived from track occupancy sensors, it may not always be perfectly synchronised with the physical movement of the train due to detection latency and transmission delay. To address this, the system incorporates a buffering mechanism that compensates for the discrepancy between the reported position and the actual location of the train on the track. This adjustment ensures that predictions remain aligned with real-world conditions, enhancing both the accuracy and operational reliability of the level crossing alert system.
<b>Integration Capability</b>	
The system must comply with C-ITS standards to support interoperability with cooperative intelligent transport systems and future advancements in rail safety technology.	The system is designed to comply with ETSI C-ITS standards, ensuring interoperability with existing and emerging C-ITS. Specifically, it utilises Decentralized Environmental Notification Messages (DENM) to broadcast train-approaching alerts. Unlike traditional short-range communications (e.g., ITS-G5), the alerts are transmitted over 4G mobile networks, enabling wider coverage and forward compatibility with future connected vehicle platforms. This standards-based approach ensures that any C-ITS-enabled roadside or in-vehicle system can receive and interpret the alerts, enhancing safety across both rail and road environments as part of Australia's future intermodal intelligent transport infrastructure.
<b>Information delivery</b>	
Content of information: Ideally, the time when there is no train coming and the boom gates stay open, and the time until the boom gates close.	The system is designed to provide clear, actionable information to end users regarding level crossing status. Specifically, it determines and communicates: <ul style="list-style-type: none"> <li>-Safe Periods: When no train is approaching and the boom gates will remain open for at least the next 3 minutes, the user interface (UI) displays a notification indicating it is safe to cross.</li> <li>-Warning Periods: If a train is expected to arrive within the next 3 minutes, the UI will display a clear alert warning that the boom gate will close within 3 minutes, and further, 1 minute, advising users to avoid attempting to cross.</li> </ul> This logic ensures that users receive timely, context-aware guidance, improving both safety and user confidence in crossing behaviour. The 3-minute threshold is selected based on system prediction reliability and operational safety margins.
Delivery in a format and channel that suits the user.	Interviews indicate that mobile phones remain the most commonly used device among users, and the current user interface design aligns well with interviewees' preferences and accessibility needs. Additionally, in-situ delivery of information—directly at or near the crossing—is particularly preferred by pedestrians for real-time guidance and reassurance.
Emerging delivery options (smart canes, smart glasses, connected wheelchairs, etc.)	To support a wide range of accessible and future-facing human-machine interfaces (HMIs)—such as smart canes, smart glasses, connected wheelchairs, and other assistive technologies—the system broadcasts warning messages using the MQTT (Message Queuing Telemetry Transport) protocol. These messages are published to a central MQTT broker, enabling unlimited client subscriptions. Any smart device with network connectivity and MQTT client capability can receive alerts in real-time.
<b>Future Enhancements</b>	

Criteria	Finding/action
Opportunities should be explored to incorporate advanced technologies such as machine learning or additional sensors to improve prediction accuracy and data quality.	We have successfully implemented machine learning algorithms at Diggers Rest station, achieving satisfactory prediction results. Looking ahead, ML shows strong potential for scalability across a broader network, particularly as more training data becomes available. Additionally, improvements in GPS positioning accuracy are expected to further enhance the precision of predictions and overall system performance.

## 9.2 Conclusion

The proposed level crossing alert system presents a timely and transformative opportunity to enhance transport safety, accessibility, and infrastructure intelligence. Grounded in real-world validation, the current prototype has successfully demonstrated real-time alerting, machine learning–based ETA predictions, and inclusive mobile interfaces for VRUs, particularly disabled and elderly pedestrians.

Field trials at Diggers Rest confirmed the system's practical feasibility, delivering high prediction accuracy (average errors ranging from 5 to 16 seconds), responsive warnings, and positive user feedback—all aligned with the core goals of reducing risk and anxiety at crossings. These results validate not only the technical merit of the system but also its user acceptance and operational readiness.

Globally, similar deployments in countries such as the Netherlands and France reinforce both the need and the viability of this approach. However, our solution distinguishes itself with its predictive intelligence, real-time data integration, and adherence to C-ITS standards, ensuring compatibility with emerging mobility ecosystems, from connected vehicles to assistive wearables.

Key achievements include:

- Accurate and timely train arrival prediction using machine learning models, supporting proactive alerting and enhanced situational awareness.
- Reliable, low-latency alert delivery through a scalable cloud-based backend and data platform, ready for nationwide deployment across stations and diverse user groups.
- Proven usability and acceptance among VRUs during live field testing, demonstrating clear benefits in safety and user confidence.

Critically, the system leverages existing public transport data infrastructure, reducing deployment costs while maximising interoperability. With government interest growing and national initiatives expanding access to rail safety data, the environment is primed for broader implementation.

With a clear roadmap for expansion, strong stakeholder alignment, and a validated technical foundation, this solution represents a scalable, cost-effective investment in the future of connected, inclusive, and intelligent rail safety.

## 9.3 Next Steps

Building on the success of the trial, we propose a focused and scalable next phase to transform this innovation into a statewide—and ultimately national—solution. The goal is to enhance safety, improve user experience, and demonstrate leadership in intelligent transport systems.

### *Enhance algorithm performance and inclusivity*

Future improvements will enhance the AI's ability to accurately predict boom gate closure times in complex scenarios, such as stalled trains, unexpected rerouting, unscheduled track vehicles, blocked crossings, closely spaced crossings, and weather-induced delays. This is especially critical for individuals with mobility impairments who rely on early and reliable warnings to ensure safe crossing.

### *Evolve the user interface for accessibility*

The interface will be refined to meet the needs of diverse users, including people with hearing or visual impairments. Features may include:

- Personalised alert timing based on mobility profiles
- Haptic feedback and voice guidance
- Large-format visual cues

### *Nationwide real-time data integration*

We propose the development of a unified backend that aggregates live train data from all Australian states and territories, in line with the National Access Point (NAP) platform. This will enable scalable coverage and consistent alerts across jurisdictions, positioning Victoria as a national leader in proactive rail safety.

### *Engagement with states and industry partners*

The next phase will involve direct engagement with transport agencies in other states to secure their support and assess the availability of required data sources. It will also involve collaboration with industry partners, including navigation and accessibility app developers already serving the target user group. Apps such as TomTom and BindiMaps have already expressed interest.

### *Expand geographic coverage and apply citizen science*

The project will scale to include train stations and crossings in additional states. A citizen science approach can be adopted, enabling users to contribute to the validation and refinement of the system and machine learning model, particularly in areas with limited data or unique crossing configurations.

### *Seamless integration with future datasets*

When V/Line's TrackR application and DTP's Public Transport Data Program (PTDP) become fully available, both will be integrated to improve the AI's predictive accuracy and extend system coverage across the national rail network—advancing a unified and future-ready rail safety strategy.

*Explore the next phase possibilities: Integrate with public ITS and navigation platforms*

To maximise reach and impact, the system will integrate with widely used platforms such as Google Maps, TomTom, HERE, and iMaps, offering:

- Time-to-boom-gate closure
- Projected wait durations
- Recommended actions (e.g. slow down, reroute, queue)

For drivers, real-time alerts at all crossing types will improve decision-making. C-ITS-based warnings and telematics integration will support voice prompts, map overlays, ADAS (Advanced Driver Assistance Systems), fleet operations, and autonomous navigation.

## 9.4 Final Remarks

As Australia's transport systems evolve toward smarter, safer, and more inclusive networks, this project offers a forward-looking blueprint for intelligent level crossing safety. Grounded in real-world validation, the proposed system demonstrates how predictive AI, real-time data, and C-ITS standards can converge to protect vulnerable road users. By combining technical feasibility with user-centred design and policy alignment, the solution is well-positioned for widespread deployment, beginning with Victoria and extending across state boundaries. With the continued support of stakeholders, this initiative can set a new benchmark for digital safety innovation, ensuring that every crossing becomes not only a point of transit but a model of confidence, accessibility, and intelligent foresight.

## References

- [1] "SNCF uses ITS to make crossings safer." ITS International. <https://www.itsinternational.com/its2/its4/its5/its7/feature/sncf-uses-its-make-crossings-safer> (accessed).
- [2] M. D. G. R. Wijn, J.J.Langefeld "TNO 2018 R10404 Evaluatie Oversteekhulp," TNO, 2018. [Online]. Available: <https://publications.tno.nl/publication/34626443/zHmCWj/TNO-2018-R10404.pdf>
- [3] "Public Transport Data Program." Transport Victoria <https://transport.vic.gov.au/news-and-resources/news/public-transport-data-program> (accessed).
- [4] "VICTORIAN RAILWAY CROSSING SAFETY STRATEGY 2018-2027," PTV, 2018. [Online]. Available: <https://www.ptv.vic.gov.au/assets/default-site/footer/legal-and-policies/eac64e622a/Victorian-Railway-Crossing-Safety-Strategy-2018-2027.pdf>
- [5] *Pedestrian Level Crossings ETS-12-01*, 2023. [Online]. Available: <https://extranet.artc.com.au/docs/eng/track-civil/procedures/grade/ETS-12-01.pdf>
- [6] "Victorian Level Crossing Safety Technology Readiness Roadmap-Technology to mitigate adverse behaviour and improve level crossing safety," WSP for VRCSSC.
- [7] "PS135162 Victorian Level Crossing Safety Technology Roadmap: Prioritised Technology " WSP.
- [8] "SIRI 2.0-TfNSW SIRI Implementation Specification (Using SIRI at TfNSW) v1.1 " Transport for NSW 2021.
- [9] P. M. S. Gemma J. M. Read, Vanessa Beanland, Michael G. Lenné & Neville A. Stanton, "A systems approach to reducing trauma at rail level crossings- Report of findings from Australian Research Council Linkage Project LP100200387," 2016
- [10] T. Sudholz, "PASSIVELY ACTIVE: WARNING SYSTEMS FOR PASSIVE & OCCUPATION LEVEL CROSSINGS IN AGRICULTURAL SETTINGS," IRSE Australasia Technical Meeting Brisbane, 2024.
- [11] "The Level Crossing Management System." ALCAM. <https://www.alcam.com.au/about-alcam/> (accessed 2025).
- [12] V. T. Gérard Hernja. "Transforming level crossings into smart level crossings." [https://www.globalrailwayreview.com/article/106960/transforming-level-crossings-into-smart-level-crossings/?utm\\_source=chatgpt.com](https://www.globalrailwayreview.com/article/106960/transforming-level-crossings-into-smart-level-crossings/?utm_source=chatgpt.com) (accessed).
- [13] "Trialling solutions for the innovative TELLi light train." <https://www.groupe-sncf.com/en/information/video-emergency-call/telli-trials> (accessed).
- [14] "RPIDS DOT VLine GTFS-R data interface description " 4Tel Pty Ltd. .
- [15] J. Freeman, A. Rakotonirainy, T. Stefanova, and M. McMaster, "Understanding pedestrian behaviour at railway level crossings: Is there a need for more research?," (in English), *Road & Transport Research*, Journal Article vol. 22, no. 3, pp. 72-82, 2013. [Online]. Available: <https://search.informit.org/doi/10.3316/informit.729166619796355>.
- [16] *ETSI TS 103 300-3 V2.2.1 (2023-02) Intelligent Transport Systems (ITS); Vulnerable Road Users (VRU) awareness; Part 3: Specification of VRU awareness basic service; Release 2* ETSI, 2023. [Online]. Available: [https://www.etsi.org/deliver/etsi\\_ts/103300\\_103399/10330003/02.02.01\\_60/ts\\_10330003\\_v020201p.pdf](https://www.etsi.org/deliver/etsi_ts/103300_103399/10330003/02.02.01_60/ts_10330003_v020201p.pdf)

# Appendix A: C-ITS Standard (EU ITS-G5 Release 2)

## A.1 ETSI ITS-G5

ETSI ITS-G5 is a critical communication standard designed for ITS to facilitate vehicle-to-everything (V2X) communication. This includes vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P) communications, enhancing road safety and traffic efficiency. ETSI developed the ITS-G5 standard specifically for safety-related applications and real-time communication in ITS.

## A.2 Key Features of ETSI ITS-G5 Release 2

1. **Spectrum Allocation:** ITS-G5 operates in the 5.9 GHz frequency band, which is reserved for ITS communications across Europe. This ensures interference-free communication for safety-critical applications such as Cooperative Awareness Messages (CAM) and Decentralised Environmental Notification Messages (DENM).
2. **Low Latency Communication:** Release 2 introduces further enhancements to the communication protocol, ensuring low latency (under 100 Ms) for time-critical safety applications. This is essential in scenarios like vehicle collision avoidance and pedestrian protection, where any delay could lead to accidents.
3. **Support for VRU Safety:** One of the most significant advancements in Release 2 is its support for VRU safety. The protocol now enables vehicles to communicate with pedestrians and cyclists equipped with ITS-enabled devices, allowing for real-time warnings and enhanced safety at intersections, pedestrian crossings, and train level crossings.
4. **Interoperability:** ITS-G5 Release 2 [15] maintains backward compatibility with earlier versions and continues to ensure interoperability with other communication standards like C-V2X. This ensures that vehicles, infrastructure, and VRUs can communicate effectively, regardless of the communication technology in use.
5. **Security and Privacy:** To protect sensitive data and ensure secure communication, ITS-G5 Release 2 has introduced enhanced security protocols. These protocols ensure that messages sent between vehicles, infrastructure, and pedestrians are protected from tampering, ensuring data integrity and privacy for users.
6. **Message Types Supported:**
  - **DENM (Decentralized Environmental Notification Messages):** Used to broadcast critical alerts, such as hazards or road accidents, to nearby vehicles and infrastructure.
  - **CAM (Cooperative Awareness Messages):** Used for the real-time exchange of vehicle position, speed, and status information.
  - **SPAT/MAP:** This supports signal phase and timing (SPAT) communication for traffic lights and the corresponding map data (MAP) for better coordination at intersections.

## A.2 New VRU Profiles

In Release 2, the VRU Profile is a standardised identifier newly developed in C-ITS to describe the type and sub-type of a VRU, such as:

- Pedestrians (e.g., ordinary, wheelchair users, road workers)
- Cyclists (e.g., standing e-scooter)
- Motorcyclists
- Animals (e.g., service animals)

Table 13 VRU Profiles and Description

Profile	Profile Index	SubProfile Index	VruSubProfile Description
<b>Pedestrian</b>	1	0	Unavailable
	1	1	Ordinary Pedestrian
	1	2	Road workers
	1	3	First responder
<b>Bicyclist</b>	2	0	Unavailable
	2	1	Bicyclist
	2	2	Wheelchair User
	2	3	Horse and rider
	2	4	Rollerskater
	2	5	Standing E-Scooter
	2	6	Personal Transporter
	2	7	E-Bicyclist (Pedelec), up to 25 km/h in Europe
<b>Motorcyclist</b>	3	0	Unavailable
	3	1	Moped
	3	2	Motorcycle
	3	3	Motorcycle + Sidecar right
	3	4	Motorcycle + Sidecar left
	3	5	Seated E-scooter
<b>Animal</b>	4	0	Unavailable
	4	1	Wild animal
	4	2	Farm animal
	4	3	Service animal

This structure is reused in both CAM and DENM, ensuring consistent interpretation across different messages.

In DENM, the `vruProfileAndSubProfile` element is used to describe the type of VRU involved in a reported event. This includes categorising the VRU into a primary profile (e.g., pedestrian, cyclist, motorcyclist, animal) and a more specific sub-profile (e.g., wheelchair user, e-scooter rider, service animal). By including this information in the `denmEvent` container, the system

enables more precise and context-aware hazard notifications, allowing connected vehicles and infrastructure to react appropriately to different VRU types. This enhances situational awareness, supports inclusive safety responses, and ensures interoperability with other C-ITS applications using the same standardised profile structure as defined in ETSI TS 103 300-3 [16].

In Release 2, there is a new VRU Awareness Message (VAMs). In VAM, the `vruProfileAndSubProfile` identifies the type and subtype of the vulnerable road user (e.g., pedestrian, e-scooter rider, wheelchair user). This enables receiving systems to understand the user's mobility context, improve risk assessment, and ensure consistent interpretation across CAM, DENM, and other C-ITS messages.

ETSI ITS G5 Release 2 is the latest version of the C-ITS communication standard and continues to evolve, particularly in its enhanced support for VRUs in ETSI TS 103 300-3 V2.2.1 (2023-02) [16]. In the future, embedding richer VRU-specific information into DENM messages will significantly expand C-ITS application scenarios for VRU safety, such as blind pedestrian guidance, group crossing alerts, and precise warnings at high-risk areas like level crossings. This direction not only aligns with ongoing technical advancements but also reflects our strategic interest in extending intelligent transport services to better protect vulnerable users in complex traffic environments.

## Appendix B: VIC Rail System Dataset Overview

This appendix summarises key rail data systems used across Victoria, highlighting their functions, data flows, formats, and access levels. These interconnected platforms support real-time train tracking, operations, passenger information, and safety, forming the foundation for applications like level crossing alerts and VRU-focused solutions.

Table 14 VIC Rail System Datasets

System	Description	Relationship with Other Systems	Type (Analog/Digital)	Availability to Access
<b>TLP (Train Location Provider)</b>	Collects real-time data from track circuits (only at track boundaries) and telemetry devices, determining train positions.	Provides train position data to RTPOTS and interfaces with telemetry devices to emit positions at track circuit boundaries (inconsistent lat/lon)	Analog/Digital	Internal, limited to authorised railway operators
<b>RTPOTS (Real-Time Position of Trains System)</b>	An internal system at Metro that displays real-time train positions based on data from TLP.	Receives processed data from TLP and displays it for Metro users but does not generate the data itself.	Digital	Internal, restricted to Metro operations
<b>Datasets - Public Transport Victoria</b>	A governmental body that receives real-time train position data.	Queries DLBI for real-time data at set intervals (e.g., every 30 seconds). Utilises TLP data for transport management.	Digital	Limited public access through selected data feeds via API
<b>DLBI (Data Layer Bridge Interface)</b>	Provides an interface for querying train position data with geographic coordinates.	Publishes data processed by TLP and makes it available for querying by systems such as PTV. Utilises HTTP REST interface.	Digital	Internal, accessible to DTP, PTV and authorised systems

<b>System</b>	<b>Description</b>	<b>Relationship with Other Systems</b>	<b>Type (Analog/Digital)</b>	<b>Availability to Access</b>
<b>DTRS (Digital Train Radio System)</b>	A system that maps TDM data to physical fleet identifiers and is used for non-mainline areas.	Provides mapping between TDM and fleet data; primarily relevant for non-mainline areas and fallback data usage.	Digital	Internal, used by railway operations
<b>TDM (Timetable Data Management)</b>	Contains timetables that specify train routes, stops, and passenger service details.	Input for TLP; mapped by DTRS to fleet for accurate positioning and used in conjunction with geographic coordinates.	Digital	Internal, accessible to authorised railway staff
<b>TCMS (Train Control Management System) / ATS (Automatic Train Supervision)</b>	Manages and monitors train operations, processing train position data from TLP.	Sends train position data in RD node format and follows a similar processing pipeline as TLP.	Digital	Internal, used for train management and supervision
<b>Interlocking System</b>	Controls train routing and interfaces directly with TLP to provide telemetry data.	Acts as a key interface for TLP, contributing rail telemetry data and signal status.	Analog/Digital	Internal, operated by railway signalling teams
<b>CRDI (Customer Real-Time Data Interface)</b>	Provides data for real-time passenger information, such as train arrival times on apps.	Connects to systems such as TTP (Train Tracking Platform) for data that feeds public apps and passenger displays.	Digital	Public access through transportation apps
<b>Signalling Systems</b>	Includes physical signals on tracks (traffic lights,	Integrated with TLP to indicate	Analog/Digital	Internal, visible to train

<b>System</b>	<b>Description</b>	<b>Relationship with Other Systems</b>	<b>Type (Analog/Digital)</b>	<b>Availability to Access</b>
	points) that indicate train status.	track occupancy and provide train movement data.		operators and controllers
<b>Boom Gate Trigger System</b>	Activated by Axle Counters occupancy to manage level crossings.	Interfaces with track circuits to trigger relay systems when a train occupies a track segment.	Analog/Digital	Internal, managed by rail safety systems
<b>ARTC Freight Train Real-Positioning Data</b>	Tracks train locations on ARTC's network, integrating with RIMs (Rail Infrastructure Management systems).	Provides GPS data and location reporting for operational and planning purposes. Reports data to DTP and other relevant parties.	Digital	Internal, available to authorised ARTC partners
<b>ICE (in Cab Radio) System</b>	A communication system used on ARTC networks for reporting train positions via GPS. Compatible units are fitted to all V/Line and freight trains.	Provides data input for ARTC's RIMs and other applications; uses 4G and satellite for communication with backup processing rules.	Digital	Internal, operated within ARTC network
<b>RIMS (Rail Infrastructure Management System)</b>	Manages and supports rail operations using real-time data from ARTC and other sources.	Integrates GPS data from ICE radios and supports other real-time operations through APIs and connected systems.	Digital	Internal, for use by rail operations
<b>NCIS (National Train Communications System)</b>	An Australian Defined Interstate Rail network and selected regional areas managed by ARTC.	Used for operational data management	Digital	Internal, managed by ARTC and VicTrack

<b>System</b>	<b>Description</b>	<b>Relationship with Other Systems</b>	<b>Type (Analog/Digital)</b>	<b>Availability to Access</b>
		across rail networks and supported by VicTrack for system integration.		
<b>4TEL</b>	A platform used by ARTC to provide applications and data services to rail customers.	Acts as an output channel for ARTC's real-time data, extending services to bodies such as V/Line.	Digital	Limited, provided to authorised rail bodies
<b>RPIDS Performance Hub (4TEL)</b>	Central data integration and distribution hub for V/Line real-time data	Integrates data from 4Trak services, connected with Datascout for GTFS-R feed	Digital	Limited access via secured accounts for Datascout
<b>4Trak GPS Data Service (4TEL)</b>	Provides GPS data for locomotives including position, speed, and direction	Connected to RPIDS and used by Datascout to generate GTFS-R data	Digital	Accessible every 30 seconds with secure polling
<b>4Trak Timetable Query Service (4TEL)</b>	Supplies timetable data, run numbers, and state transitions	Integrated with RPIDS, supports GTFS-R data generation	Digital	Accessible by Datascout at 30-second intervals
<b>Datascout Integration (4TEL)</b>	External system for data retrieval and GTFS-R generation	Interfaces with RPIDS for real-time data, monitored by 4Site	Digital	Whitelisted access through VicTrack firewall
<b>Track Circuit Derived Data (4TEL)</b>	Simulates GPS data based on track occupation	Matches track circuit data with geonodes in RPIDS	Digital	Always available when GPS data is not accessible
<b>4Site Monitoring (4TEL)</b>	Monitors data access and system reliability for Datascout	Integrated with RPIDS to trigger alerts for access lapses	Digital	Operates continuously, alerts triggered if

System	Description	Relationship with Other Systems	Type (Analog/Digital)	Availability to Access
				access lapses > 2 hours
<b>VicTrack Firewall and WAF (4TEL)</b>	Security layer ensuring controlled data access	Secures data flow between Datascout and RPIDS	Digital	Access limited to whitelisted IPs from Datascout's AWS

## Appendix C: NSW Public Transport Datasets

To explore the potential for expanding our solution nationwide, we accessed real-time train position data from the Transport for New South Wales (TfNSW) Open Data Hub. This platform provides real-time and historical data on service alerts, locations, and timetables for trains, buses, ferries, and other transport modes in NSW. The following tables describe the various data formats available through this source<sup>2</sup>.

Table 15 An Example of A Vehicle Position Feed Entity in The NSW Dataset

```
entity {
  id: "11"
  vehicle {
    trip {
      trip_id: "120W.956.158.32.A.8.83068904"
      schedule_relationship: SCHEDULED
      route_id: "WST_1a"
    }
    position {
      latitude: -33.74928
      longitude: 150.69421
    }
    timestamp: 1733408126
    congestion_level: UNKNOWN_CONGESTION_LEVEL
    stop_id: "Mountains.PH11/12/28 Exit Loc"
    vehicle {
      id: "3646.8126.1092.3404.1464.1953.2896.2070"
      label: "23:48 Central Station to Penrith Station "
    }
  }
}
```

Table 16 Data Fields in NSW Real-Time Dataset

Field name	Description	Example	Availability in PTV data
<b>latitude</b>	The latitude of the vehicle in decimal degrees		Yes
<b>longitude</b>	The longitude of the vehicle in decimal degrees		Yes

<sup>2</sup> Public Transport - Real-time Trip Update API v2: <https://opendata.transport.nsw.gov.au/data/dataset/public-transport-realtime-trip-update-v2/resource/de258245-9075-4c36-b5ad-790ea48bf08f>

Field name	Description	Example	Availability in PTV data
<b>bearing</b>	The bearing of the vehicle measured in degrees from horizontal		Yes
<b>speed</b>	Speed of position as reported (average speed)		NO
<b>current_stop_sequence</b>	current_stop_sequence	2	Yes
<b>current_status</b>	Status of the vehicle as it travels through the trip. Values can be: INCOMING_AT STOPPED_AT IN_TRANSIT_TO	IN_TRANSIT_TO	NO
<b>timestamp</b>	This timestamp is the time to which the latitude, longitude and bearing are relevant.		Yes
<b>congestion_level</b>	This value is always populated with a default value which indicates an unknown level of congestion.		No
<b>stop_id</b>	The stop_id value indicates the last location at which the vehicle stopped. The ID corresponds to a location in stops.txt		No
<b>vehicle { id: }</b>	The vehicle ID is the run number of the trip the vehicle is currently completing.		
<b>vehicle { label: }</b>	The vehicle label is a value which customers can use to identify the trip.	11:05am (142) Moree Town - Grafton City	No. PTV data only has trip ID which is not able to identify the direction

Field name	Description	Example	Availability in PTV data
			of the train.

The following table describes the columns present in the Sydney Trains vehicle data file. This dataset captures real-time location and identification information for trains operating in the Sydney rail network.

Table 17 Sydney Trains and Metro Train Data

Field Name	Description
<b>VehicleTimestamp</b>	Unix timestamp when the record was generated by the train vehicle.
<b>VehicleID</b>	Unique identifier for the train unit (numeric).
<b>TripID</b>	Unique trip or service identifier for a scheduled run.
<b>Latitude</b>	GPS latitude coordinate of the train.
<b>Longitude</b>	GPS longitude coordinate of the train.
<b>FetchTime</b>	Time when the system fetched the record, in local time.

The table below describes the meaning of each field found in the GTFS trip file or similar sources derived from it. These fields help define scheduled public transport trips such as those operated by Sydney Trains and Metro.

Table 18 Trip data

Field Name	Description
<b>route_id</b>	The ID of the route. This links to the route's information such as name and type.
<b>service_id</b>	The ID of the service schedule. This defines which days the trip runs.
<b>trip_id</b>	Unique ID for the specific trip instance. It ties together stop times and schedules.
<b>shape_id</b>	ID referencing the path taken by the vehicle, used to draw the route on a map.
<b>trip_headsign</b>	The destination or direction displayed to passengers (e.g., 'Thirroul').
<b>direction_id</b>	Binary value (0 or 1) indicating the direction of travel for a trip on a route.
<b>block_id</b>	Optional ID used to group trips that are operated consecutively by the same vehicle.
<b>wheelchair_accessible</b>	Indicates accessibility: 0 = no info, 1 = accessible, 2 = not accessible.
<b>route_direction</b>	Human-readable description of the route direction, including station sequence.
<b>trip_note</b>	Optional note providing additional information about the trip (e.g., alerts or special notes).
<b>bikes_allowed</b>	Indicates bicycle policy: 0 = no info, 1 = bikes allowed, 2 = bikes not allowed.

Table 19 GTFS Stop Data

Field	Description
<b>stop_id</b>	Unique identifier for the stop. Often numeric but can also be alphanumeric.
<b>stop_code</b>	Public-facing short code (e.g. on signage). Optional, often same as stop_id.
<b>stop_name</b>	The full name of the stop or station, including location details.
<b>stop_lat</b>	Latitude of the stop location in decimal degrees.
<b>stop_lon</b>	Longitude of the stop location in decimal degrees.
<b>location_type</b>	Indicates the type of the location: 0 = Stop/platform, 1 = Station, 2 = Entrance/Exit, 3 = Generic Node.
<b>parent_station</b>	For stops that are part of a larger station (e.g. platforms), this references the station's stop_id.
<b>wheelchair_boarding</b>	Indicates wheelchair accessibility: 0 = No info, 1 = Accessible, 2 = Not accessible.
<b>level_id</b>	The level (floor) of the stop (e.g., Level 0, Level 1, Basement). Optional field.
<b>platform_code</b>	Platform label for physical platforms (e.g., 1, 2, A). Optional field.

Table 20 GTFS Stop Time Table

Field	Description
<b>trip_id</b>	Unique identifier for the trip. This links to the trip's route, service, and direction.
<b>arrival_time</b>	Scheduled time of arrival at the stop (format: HH:MM:SS).
<b>departure_time</b>	Scheduled time of departure from the stop (format: HH:MM:SS).
<b>stop_id</b>	Identifier for the stop; corresponds to entry in the stops.txt table.
<b>stop_sequence</b>	Order of the stop for the trip; starts at 1 and increments.
<b>stop_headsign</b>	Optional text identifying the destination displayed to riders.
<b>pickup_type</b>	Indicates if passengers can be picked up at this stop (0 = regular, 1 = no pickup, 2 = must phone agency, 3 = driver asks passenger).
<b>drop_off_type</b>	Indicates if passengers can be dropped off at this stop (same codes as pickup_type).
<b>shape_dist_traveled</b>	Distance travelled along the shape (route path) in meters from the beginning of the trip.
<b>timepoint</b>	Indicates if arrival/departure times are exact (1) or approximate (0).
<b>stop_note</b>	An optional free-text note about the stop.

Table 21 GTFS Pathway Table

Field Name	Description
<b>pathway_id</b>	A unique identifier for the pathway. Typically composed of the connected stop IDs and a descriptor (e.g., type and direction).
<b>from_stop_id</b>	The starting stop ID where the pathway begins.
<b>to_stop_id</b>	The destination stop ID where the pathway leads.
<b>pathway_mode</b>	Type of pathway: 1 = Walkway, 2 = Stairs, 3 = Travelator, 4 = Escalator, 5 = Elevator, 6 = Fare gate, 7 = Exit gate.
<b>is_bidirectional</b>	Whether the pathway can be used in both directions: 1 = Yes, 0 = No.

<b>traversal_time</b>	The expected time to traverse the pathway in seconds.
-----------------------	---

The following table describes the available routes provided by transit agencies, including long and short names, types, and colour codes used for visualisation.

*Table 22 GTFS Route table*

<b>Field Name</b>	<b>Description</b>
<b>route_id</b>	Unique identifier for the route. Typically contains agency and service type.
<b>agency_id</b>	Identifies the transit agency associated with the route.
<b>route_short_name</b>	A short, often numeric name identifying the route, e.g., '10BM'.
<b>route_long_name</b>	A full, descriptive name of the route, often including major destinations.
<b>route_desc</b>	A textual description of the route, such as 'Temporary buses'.
<b>route_type</b>	The type of transport used on this route (e.g., 0=Tram, 1=Subway, 2=Rail, 3=Bus, 4=Ferry, 5=Cable car, 6=Gondola, 7=Funicular).
<b>route_color</b>	Route colour specified in hexadecimal RGB (e.g., '00B5EF'). Used for mapping and UI.
<b>route_text_color</b>	Text colour used in conjunction with `route_color` for legibility.
<b>exact_times</b>	Indicates whether `exact_times` is enforced: 1 = times are strictly adhered to, 0 = approximate.

## Appendix D: Original Scope

This project was meant to only include phase 1, but we opted to include the development of a very basic proof of concept in order to enable a less theoretic feasibility analysis.

Project Strategy / Scope of Work		
<p>This project will be conducted in three phases. After phase 1 and 2, there will be a hold point.</p>		
This project's original scope: Implementation framework and feasibility	Phase 2: Develop proof of concept	Phase 3: Real-life testing and final optimisation
<p>1.0 Establish a working group and project governance</p> <p>1.1. Scan global opportunities. Activity: Market research. More options than phone? What are all the applications of the algorithm?</p> <p>1.2. Implementation requirements. Activity: Stakeholder engagement railroad operations and end user apps – e.g., include active and passive crossings?</p> <p>1.3. End user requirements: Activity: Workshops: recruit commuters and co-design options for prototyping and testing. Conduct literature or primary research with road users for benchmarking. Invite users of both uses cases</p> <p>1.4. Privacy, consent, regulation, data requirements and implications for consent. Stakeholder engagement</p> <p>1.5 Technical and data requirements: design system architecture in collaboration with road operator IT. Conduct test for latency requirements.</p> <p>1.6. Design the project's next steps to produce a convincing business case, including end user metrics and benchmarks to demonstrate safety improvement</p>	<p>2.1 Develop an algorithm to calculate ETA and downtime of the boom gate. Establish performance indicators including accuracy, complexity, robustness, and absence of false alarms.</p> <p>2.2 Develop proof of concept app for validation purposes.</p> <p>2.3 Extensive lab testing to ensure the reliability of the applications.</p> <p><b>Controlled field trial</b></p> <p>2.4 Simulate scenarios in streets and test with researchers only, at various locations in Australia</p> <p>2.5 Assess technical and operational performance under controlled conditions, particularly in terms of accuracy and data delivery.</p> <p>2.6. Provide compliance and type testing (TBC) recommendations.</p>	<p>3.1 Develop app for: Android and iOS app development and integration into 'host apps' journey planner and wayfinding app for blind, integrate the level crossing and alert systems with existing public transport authority API for proof-of-concept testing.</p> <p>3.2 Controlled test road users: - Deploy the level crossing alert system in designated areas. End users' research: qualitative (people with disability) Quantitative (journey planning app users)</p> <p>3.3 Assess the business case for implementation. Activity: stakeholder workshop</p> <p>3.4 Optional (not included): Longitudinal trial. Examine the effectiveness of the integrated detection and commuter behaviour system with on-road testing.</p> <p>3.5 Prepare business case and next steps (e.g., dissemination of the app, webinars)</p>
Deliverables		
<p>A market overview report, best practices and if there are, other technology options.</p> <p>A clear understanding of implementation requirements and limitations</p> <p>A project plan that incorporates a test strategy, the outline of the implementation business plan.</p>	<p>Functional prototypes for the level crossing boom gate time estimation and alert system.</p> <p>Lab and street test result report: Performance benchmarks and evaluation criteria for system success, including those to meet railroad and operator requirements.</p>	<p>A tested solution for the level crossing boom gate time estimation and alert system</p> <p>A business case that summarises the technology performance, safety improvements, user acceptance, and provides deployment recommendations.</p> <p>Summaries and webinar materials, including the business case, to disseminate knowledge across road infrastructure agencies and industry.</p>