



Key Insights for the Successful Implementation of Proximity Detection & Collision Avoidance Technology for Reducing Vehicle Interaction Risk

A SURFACE TECHNOLOGY PROVIDER PERSPECTIVE

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Published: 2 April 2025

Enabling your zero harm goals

Each year, 30-40% of mining industry deaths are attributed to the failure of vehicle interaction controls

(EMESRT, 2023)

Armed with a growing body of knowledge from the Earth Moving Equipment Safety Round Table 'EMESRT' and the International Council of Mining and Metals 'ICMM' global vehicle interaction initiatives, the mining industry and associated companies, Original Equipment Manufacturers (OEMs), and technology providers, are able to work together to develop and implement more effective controls and drive the adoption of capable solutions.

Leveraging 20+ years of experience as a global technology provider of Proximity Detection Systems 'PDS' and Collision Avoidance Systems 'CAS' solutions for surface mining operations, in this white paper Wabtec shares key insights on the effective adoption of such technologies.

The knowledge shared in this paper is meant to aid mining companies and their mine sites in undertaking due diligence, creating selection criteria, implementing, and integrating PDS/CAS solutions into existing mine site controls and operations, all in an effort to reduce vehicle interaction risk. As an industry, the ultimate aim is to drive mines towards their zero-harm objectives.

To address the false expectation that technology is a 'silver bullet' solution, Wabtec endorses global alignment of the mining industry with the EMESRT and ICMM global vehicle interaction control improvement (VICI) initiatives. Using the resources these bodies make available to improve the effectiveness and reliability of vehicle interaction controls at the mine site level is a critical first step in expelling the myth.

Topics covered in this white paper include:

- Alignment with industry best practices for controlling vehicle interaction risk by Earth Moving Equipment Safety Round Table 'EMESRT' and the International Council of Mining and Metals 'ICMM'

- The importance of the maturity of mine sites EMESRT Levels 1-7 vehicle interaction controls
- Managing stakeholder expectations that a PDS/CAS technology solution is not a 'silver bullet'
- Alignment with industry functional performance and technical requirements
- Proximity detection versus collision avoidance and the critical differences
- Sensor performance, fusion, and limitations
- Rules and intelligence engine critical to mitigating nuisance alarms during normal operations
- System health monitoring and reporting
- Human factors engineering and operator acceptance
- Technology implementation strategy, installation standards and quality control
- Change management & training programs, reporting and data analytics for actionable insights and maintenance strategies

This white paper also provides details on the challenges, such as:

- Moving from EMESRT Level 7 (operator awareness) and Level 8 (advisory controls) to Level 9 (intervention controls) as it's a journey, not an out-of-box solution
- The growing demand for the coexistence of PDS/CAS technology solutions and Autonomous Haulage Solutions 'AHS'
- Functional safety approach, value-added systems integration, and the applicability of new emerging technologies

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Introduction

The mining industry has made great strides in providing a clear definition and capable solution to the problem of managing vehicle interaction risk. Initially, technology providers were responsible for developing assumed solutions. As operational input was limited, it was inevitable that expectations would misalign in the belief that technology alone would be a 'silver bullet' solution. Vehicle interaction risk was viewed in isolation and void of the need to be integrated with key elements of existing mine site controls, people, and processes.

Nowadays, the perspective has changed dramatically. Technology providers have precise user requirements (combining functional, performance and technical requirements), machine intervention control standards and other key references (e.g. PDS validation framework) that drives the development of capable technology solutions that are operationally integrated with existing controls.

As an active participant of EMESRT & ICMM from the outset, Wabtec identifies the stages and steps of due diligence, selection criteria, implementation and integration of PDS and/or CAS into existing mine site controls and mining operations.



Alignment with industry best practice

Technology solutions must align with industry best practices for vehicle interaction improvement projects to ensure the mine sites can confidently use their solutions to improve the effectiveness and reliability of vehicle interaction controls at mine site level.

EMESRT (Earth Moving Equipment Safety Round Table)

Since 2013, EMESRT has facilitated a global initiative for vehicle interaction improvement projects involving major mining companies, key mining industry OEMs, industry associations, researchers and 3rd party technology providers to improve the effectiveness and reliability of vehicle interaction controls at a mine site.

The EMESRT vision is clear:

A global mining industry free of fatalities, injuries and occupational illnesses associated with operating and maintaining earthmoving equipment.

ICMM (International Council on Mining and Metals)

ICMM is a member companies' CEO initiative. In 2018, with EMESRT support, ICMM launched the Innovation for Cleaner, Safer Vehicles 'ICSV' program.¹

The highest fatality category for ICMM member mining companies is that of mobile equipment accidents attributed to failures of vehicle interaction controls. For this reason, the ICSV program aims to promote vehicle interaction technology that can support industry operational practices and eliminate fatalities by 2025.

Collaborations between mine operators, industry associations, researchers, OEMs and 3rd party technology providers continue as resources are developed and refined to deliver the ICSV objectives. These include practical processes that assist mine sites in integrating technology while supporting the development of 'Capable Solutions' for global market uptake.

According to ICMM, a 'Capable Solution' ready for global market uptake by 2025 should:

1. Deliver better vehicle interaction control performance by improving the quality of decision-making from task execution through to mine operations and design.
2. Consider relevant aspects of the operating environment, production requirements and equipment design.
3. When technology is involved in the solution, it is operationally integrated with existing controls.

The resources developed by EMESRT and ICMM vehicle interaction working groups are available to member and non-member companies. They are designed to assist operating mine sites in delivering successful projects that improve vehicle interaction controls. These resources are based on processes and methods that EMESRT member companies and other operations have successfully applied to systematically improve their vehicle interaction controls with capable solutions.

These resources include:

- ICMM ICSV Vehicle interaction Working Groups
- ICMM ICSV Program VI Knowledge Hub and Knowledge Base, Maturity Framework, white papers, case studies
- EMESRT Vehicle Interaction Knowledge Hub
- EMESRT VI Control Improvement Resources (Guideline, WBS, Work Packages, tools etc.)
- EMESRT Functional Performance Scenarios (Performance Requirement PR-5A: Vehicle Interaction Systems & Discrete Scenario Storyboards)
- ISO standards (e.g. ISO 21815 Earth Moving Machinery – principles of collision warning & avoidance) & other key references (e.g. PDS validation protocol)

Other key industry resources

Other essential mining industry resources on vehicle interaction control improvements include:

- NSW Government MDG-2007 (Feb 2014) Guideline for the selection and implementation of collision management systems for mining.
- Proximity Detection System Validation Framework (ACARP C26028 PDS testing methodology validation framework project).

1. ICMM 2024, Cleaner and Safer Vehicles, accessed 20 May 2024, <https://www.icmm.com/en-gb/our-work/cleaner-safer-vehicles>

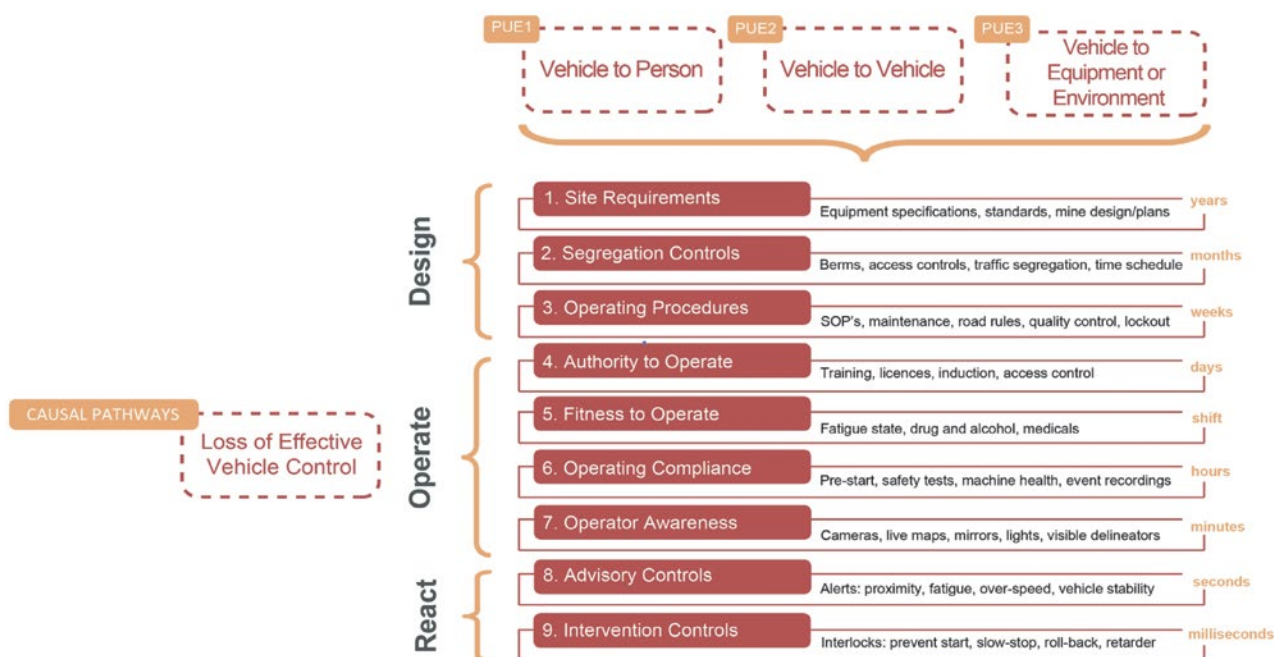
Why is the maturity of EMESRT Levels 1-7 vehicle interaction control framework important?

EMESRT developed the 9 Layer Model of Vehicle Interaction Defensive Controls (Figure 1)² as a foundational concept to understand control effectiveness for exposure to potential unwanted events 'PUE'. This covers vehicle interaction types, namely equipment to person, equipment to equipment, equipment to environment, and loss of control.

Key factors that impact on the effectiveness of the vehicle interaction control model include:

- Dynamic interdependence between control levels
- Control categories operate in different timeframes
- High dependence on real-time human factor decision-making
- To implement adequate Level 8-9 controls, you must first understand the effectiveness of your Level 1-7 control baseline.

Figure 1: EMESRT 9 Layer Model of Vehicle Interaction Defensive Controls



To implement adequate Level 8-9 controls, you must first understand the effectiveness of your Level 1-7 control baseline.

2. EMESRT Rev 3.0 Sept. 2024, Earth Moving Equipment Safety Round Table PR-5A Vehicle Interaction Systems PDF, accessed 16 Oct 2024, <https://www.emesrt.org/wp-content/uploads/PerformanceRequirement-5A.pdf>

EMESRT has developed a Vehicle Interaction Control Improvement 'VICI' framework to identify the control effectiveness in maintaining safe and productive operations, known as the Required Operating State. The steps required are:

Step 1: Understand the 'Problem' not just the 'Symptoms'.

- How effective are the current controls?
- Are there any failure modes (can something go wrong)?
- Does the control address these failure modes?

Step 2: Using the failure modes, 'identify options to address the ineffectiveness'.

How can technology assist?

- Levels 1-7: Technology that helps to improve what we do now.
- Levels 8-9: Technology that replaces what we do now.

It is important the mine site places an emphasis on improving and enhancing the EMESRT baseline control Levels 1-7. This is considered best mining practice. When a mine site doesn't emphasise improving its baseline controls Level 1-7, technology may not deliver an improvement. In some instances, the technology will expose the mine site to additional risk. To realise the full benefit of implementing any technology solution, the mine site must be mature across the design (1-3) and operate (4-7) levels.

Essential resources available include:

1. EMESRT Vehicle Interaction Control Improvement Guide (Figure 2) ³
2. EMESRT Vehicle Interaction Control Improvement Project Full Work Breakdown ³ Structure (WBS) (Figure 3)
3. EMESRT Vehicle Interaction Control Improvement (VICI) Body of Knowledge (Figure 4) ⁴

Figure 2: EMESRT Vehicle Interaction Control Improvement Guide

The overall objective of this procedure is to provide consistent structured guidance for operating sites, so that they deliver projects that improve vehicle interaction (VI) controls.

This **resource is based on processes** and approaches that have been applied at EMESRT & ICMM Member Company operations to systematically improve vehicle interaction controls. This includes the operational integrity of new technology VI controls.

Expected users are site and divisional leaders with the business knowledge and experience to plan and deliver complex business improvement projects.



3. EMESRT Oct 2023, EMESRT Vehicle Interaction Control Improvement (VICI) Project Guide accessed 16 Oct 2024, <https://www.emesrt.org/wp-content/uploads/EMESRT-VICI-Project-Guide-2023.pdf>

4. EMESRT 2024, EMESRT Vehicle Interaction Control Improvement (VICI) Body Of Knowledge, accessed 16 Oct 2024, <https://www.emesrt.org/vici-bok/>

Figure 3: EMESRT VI Control Improvement Project Work Breakdown Structure (WBS) to results level

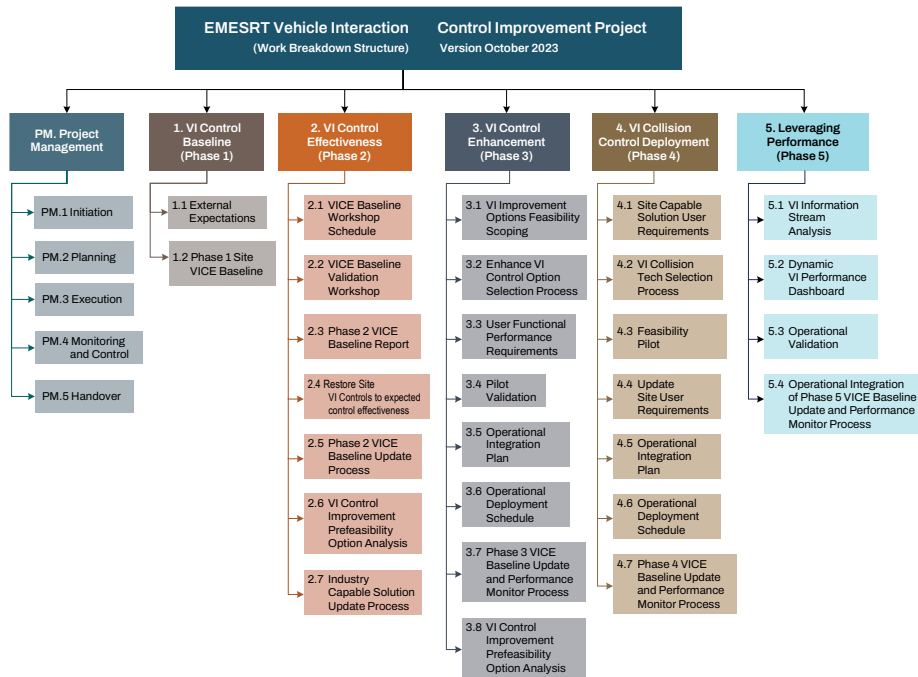
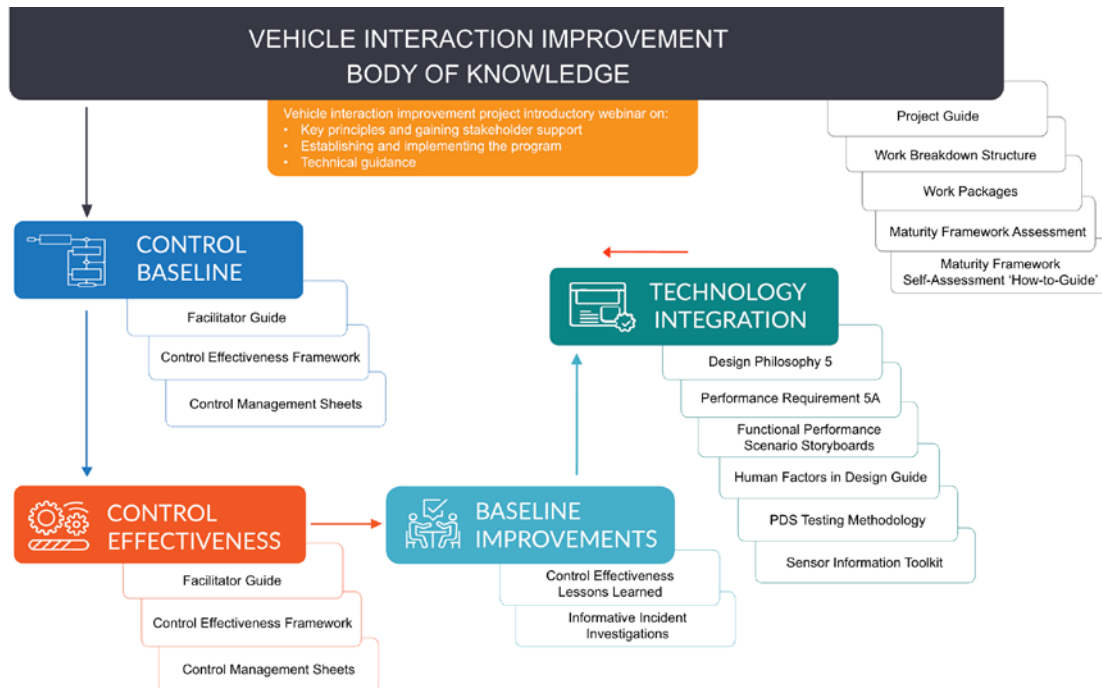


Figure 4: EMESRT Vehicle Interaction Control Improvement (VICI) Body of Knowledge





Managing expectations: PDS/CAS is not a 'silver bullet'

To address the false expectation that technology is a 'silver bullet' solution to effectively improving vehicle interaction controls, Wabtec endorses global alignment of the mining industry with EMESRT and ICMM. Using the resources these bodies make available and have been successfully applied globally to improve the effectiveness and reliability of vehicle interaction controls at mine site level, is a critical first step in expelling the myth.

Capable solutions that deliver better vehicle interaction control performance must consider the interrelationship between people, processes, operating environments, production requirements, equipment design, and technology (that is operationally integrated with existing controls, not functioning as a standalone technology solution).

When purchasing a PDS/CAS solution, it is essential the mine site be fully aware of the functional and technical due diligence required to be undertaken. Marketing materials, such as brochures, websites and the like, simply do not provide sufficient technical detail. Without applying industry best practices, such as through the application of the VICI framework, the project will not meet the expectations of the broader stakeholder group.

Alignment with industry's functional, performance & technical requirements

Before making any decision on a PDS/CAS solution, the mine site should determine the alignment with industry's best practice functional, performance and technical requirements as follows:

- Functional and performance requirements for existing vehicle interaction controls (Levels 1-7)
- Functional, performance and technical requirements for new vehicle interaction controls (Levels 8-9)
- Vehicle Interaction Control Effectiveness – Functional Requirements
- EMESRT Performance Requirement PR-5A: Vehicle Interaction Systems (including surface interaction scenarios (baseline) – Figure 5)
- EMESRT Vehicle Interaction (VI) - Functional Performance Scenario Storyboards (Figure 6)
- PDS Validation Framework ⁵
- NSW Govt MDG-2007 (Feb 2014) Guideline for the selection and implementation of collision management systems for mining.

EMESRT Level 7-9 CAS Technology Performance Criteria:

Level 7 Awareness

- Ability to provide enhanced situational awareness
- Alerts the operator to a potential abnormal situation
- Provides context of the situation to the operator
 - Where is it?
 - What is it?
 - How far away is it?
 - What is its heading?
 - How fast is it going?
- Supports visual confirmation for the operator

Level 8 Advisory

- Determines an imminent threat of collision
- Provides a specific voice-based instruction to the operator to intervene (Act)
- Operator assesses the voice-based instruction in conjunction with other contributing factors and then intervenes (Acts)

Level 9 Intervention

- Provides a specific instruction to the machine to intervene (Act)
- Machine assesses the instruction in conjunction with other contributing factors and then intervenes (Acts)
- Relinquish intervention control to the operator should they take evasive action
- Provides a manual over-ride to authorised personnel to recover after a collision intervention scenario has occurred

5. Australian Coal Research Limited 2024, PDS Validation Framework, Mining3, ACARP PROJECT C26028 PUBLISHED 19/01/2021, <https://www.emesrt.org/wp-content/uploads/C26028FinalReport.pdf>

Figure 5:
EMESRT -
Surface Vehicle
Interaction
Scenarios
(baseline) (2024)



Figure 6: EMESRT Vehicle
Interaction (VI) - Functional
Performance Scenario
Storyboards

EMESRT Vehicle Interaction Functional performance scenario storyboards	
Scenario	
1. Tailgating Heavy Vehicle to Heavy Vehicle	
2A. Speeding	
2B. Speed on ramp approach	
3. Wet roads due to overwatering	
4. T-Intersection – light vehicle perspective	
5. Dump areas – dozer configuration	
6A. Loading areas – rotating tracked loading unit	
6B. Loading areas – wheeled loading unit	
7A. Passing stationary heavy vehicle – dump and dig face	
7B. Accessing heavy vehicle – maintenance activities	
7C. Accessing heavy vehicle – operational activities	
7D. Accessing stationary heavy vehicle – assumed un-manned	
7E. Light vehicle inside 30m of stationary heavy vehicles	
8. Segregated roads	
9. Passing roadwork vehicles	
10. Standard CAS – general operational interactions	
11. Unknown grade change	

Proximity detection versus collision avoidance

The industry reference document “NSW Govt MDG-2007 (Feb 2014) Guideline for the selection and implementation of collision management systems for mining”⁶ provides the following definitions:

SAT (Safety Adherence Technology)

Technologies that track and record the operation and performance of equipment for post-event analysis and training (e.g. SCADA systems, event databases, chart recorders).

PAT (Proximity Awareness Technology)

Technologies that help operators identify they are converging to another vehicle, person or infrastructure (e.g. reversing mirrors, flashing lights, reversing sirens).

PDT (Proximity Detection Technology)

Technologies or devices that actively scan for other vehicles or personnel and warn of their presence.

This technology does not automatically take action to prevent a collision (e.g. reversing camera with distance alarm, RF tags, laser scanner, radar).

CAT (Collision Avoidance Technology)

Technology or device/s that actively scan for other vehicles or personnel and takes automatic action to render the equipment to a safe state (e.g. reversing radar with brake control).

CAS (Collision Avoidance System)

The combination of technologies (i.e. SAT, PAT, PDT & CAT) that form a system.

CMS (Collision Management System)

A collective name for the preventative and mitigating controls that reduce the frequency of collision situations and the level of risk to as low as reasonably practicable/achievable (ALARP).

A PDT system is used in the event of a potentially dangerous interaction to automatically generate alarms that instruct personnel to take corrective action to avoid a collision.

A CAT system is used in the event of a potentially dangerous interaction to automatically take appropriate control of equipment to avoid an adverse outcome based on the mine’s risk assessment.

A PDT system, if not based on imminent threat of a collision with specific instructions on the threat and corrective action to be taken by the operator to avoid a collision, can result in proximity annoyance at EMESRT levels 7/8 due to nuisance alarms during normal operations. This can create audio overload, desensitise an operator to genuine collision warnings, breed complacency / normalisation and mistrust in the technology and impact production.

A PDT system based on genuine threat of a collision with specific instructions on the threat and corrective action to be taken by the operator to avoid a collision, provides true Collision Awareness at EMESRT levels 7/8 with exception alarming with no negative impact on production.

A PDT/CAT system’s capability to differentiate between normal safe interactions (e.g. safe passing on straight & curved roads, close interactions during loading & dumping operations) and abnormal / imminent threat of collision will be determined by the sensor(s) performance and ‘rules engine’ intelligence.

Sensor performance, fusion & limitations

‘Sensing’ is the critical input for any PDS/CAS technology solution. It determines the capability, reliability & performance of the ‘rules engine’ that makes intelligent decisions on vehicle interaction threats. As a result, the operator receives information about the nature of the threat and the corrective action to avoid a collision.

There is a growing variety of proximity sensing technologies available for use in PDS/CAS technology solutions. As expected, these technologies have their own strengths and weaknesses to consider when designing a capable solution. There may be a case to consider sensor fusion using data from multiple sensing technologies to enhance overall sensing performance and robustness, depending on:

1. The sensor performance limitations (including failure modes and sensor health monitoring capability) and,
2. The effectiveness of the underlying mine site Level 1-7 controls.

6. NSW Government Trade & Investment Mine Safety 2014, Guideline MDG 2007 Guideline for the selection and implementation of collision management systems for mining, accessed 20 May 2024, <https://www.resourcesregulator.nsw.gov.au/sites/default/files/documents/mdg-2007-guideline-for-the-selection-and-implementation-of-collision-management-systems-for-mining-2014.pdf>

For example, when a PDS/CAS technology solution operates in a Global Navigation Satellite System ‘GNSS’ denied environment (e.g. under a maintenance workshop roof or in a deep pit near the highwall) are the existing mine site Level 1-7 controls adequate?

A PDS online sensor technology capability tool has been developed to provide users with unbiased information on PDS sensors to assist in their functional and technical due diligence process.

The PDS Toolkit was part of the Mining3 ACARP-funded “PDS Validation Framework – Phase 3” project. The easy to use interface provides a high level summary of the six most prevalent Proximity Detection System (PDS) sensors available to the market, namely:

1. Radio Frequency (RF) Time-of-Flight (ToF)
2. GNSS
3. RADAR
4. Electromagnetic (EM)-Based Sensors
5. Digital Cameras
6. LIDAR

This information has been extracted from the PDS Sensor Capability Assessment document developed by the PDS Project Team, that comprised of Mining3, the University of Pretoria, and the University of Queensland. The document was published and made available to the industry (ACARP C26028 PDS Testing Methodology Validation Framework Project).

The PDS toolkit aims to provide a fundamental understanding of how various sensors operate, individually and in combination. The information from the toolkit guides a mine site’s functional and technical due diligence process by providing information and data for each sensor.

As well as providing individual sensor information, the toolkit contains a spider attribute chart that enables mine sites to quickly compare between the sensors, identifying strengths and weaknesses, for a specific application or attribute. A scoring system is also available under the chart.

The sensor technology deployed in PDT/CAS solutions and the references used to compile assessment documents, are also provided in the toolkit.

A sample extract from the PDS Sensor Capability toolkit for GNSS sensor technology covering Working Principles, Advantages and Limitations is shown in Figure 7⁷.

Other important considerations in the application of GNSS sensor technology include the following:

- Static heading accuracy – using a single GNSS antenna requires minimum vehicle speed/movement for accurate heading from the last known heading. This exposes a risk to an incorrect display of the true position of remote objects relative to the local object, which can lead to a potential collision scenario. A dual GNSS antenna arrangement across all equipment types addresses this deficiency.
- GNSS concurrent multi-constellation capability (e.g. GPS, Glonass, Galileo, BeiDou, QZSS, SBAS), robustness with anti-jamming / multi-path & scintillation mitigation.
- GNSS refresh rate
- GNSS horizontal position and heading accuracy

The supporting vehicle to vehicle ‘V2V’ radio link needs to consider the following factors:

- Standalone peer-to-peer (independent of infrastructure)
- Refresh rate
- Coverage distance
- Immunity to interference, self-test capability, sociability with other RF devices
- 360-degree polar coverage (multiple V2V antennas maybe required on large mining machines, which should be tested as part of site acceptance tests e.g. reliably detecting a light vehicle between the rear tyres or on the off-side of a large rigid body haul truck).

Free access to the PDS toolkit is available to the industry: <https://pdstoolkit.com>⁸

7. Mining3 2024, Global Navigation Satellite System GNSS, accessed 20 May 2024, <https://pdstoolkit.com/global-navigation-satellite-systems-gnss/>

8. Mining3 2024, PDS Toolkit, accessed 20 May 2024, <https://pdstoolkit.com/>

Figure 7: Global Navigation Satellite System (GNSS)

Global Navigation Satellite System (GNSS)

Global Navigation Satellite System (GNSS)-based technology measures the global position and, in some cases, the orientation of vehicles, assets and personnel that are equipped with GNSS receivers. GNSS-based systems rely on radio signals, which have been broadcast from satellites orbiting the earth. GNSS technology is often referred to as the Global Positioning System (GPS); however, GPS refers to the satellite constellation owned by the United States Government. There are several other satellite constellations in operation, with others scheduled for operation in the near future. Examples include the GLONASS (Russia), BeiDou (China) and Galileo (European Union) GNSS constellations.

Working Principles

GNSS-based technology typically consists of one or more antenna, a receiver and, in some cases, Inertial Measurement Units (IMUs). The various satellites broadcast information relating to their identity, time, status and orbit. Broadcast radio signals are received by the GNSS antenna and processed by the GNSS receiver to determine the global position of the GNSS unit. The information contained in the broadcast radio signals is used to measure the distance between GNSS-unit and the satellites. Line-of-Sight (LoS) from at least four satellites are required to measure the global position of the GNSS unit. Some GNSS units include IMUs for enhanced localization performance.

Other commonly used methods for enhancing the performance of GNSS technology is through the use of

differential GNSS corrections and Real-Time Kinematic techniques, which require the use of additional GNSS and communication infrastructure.

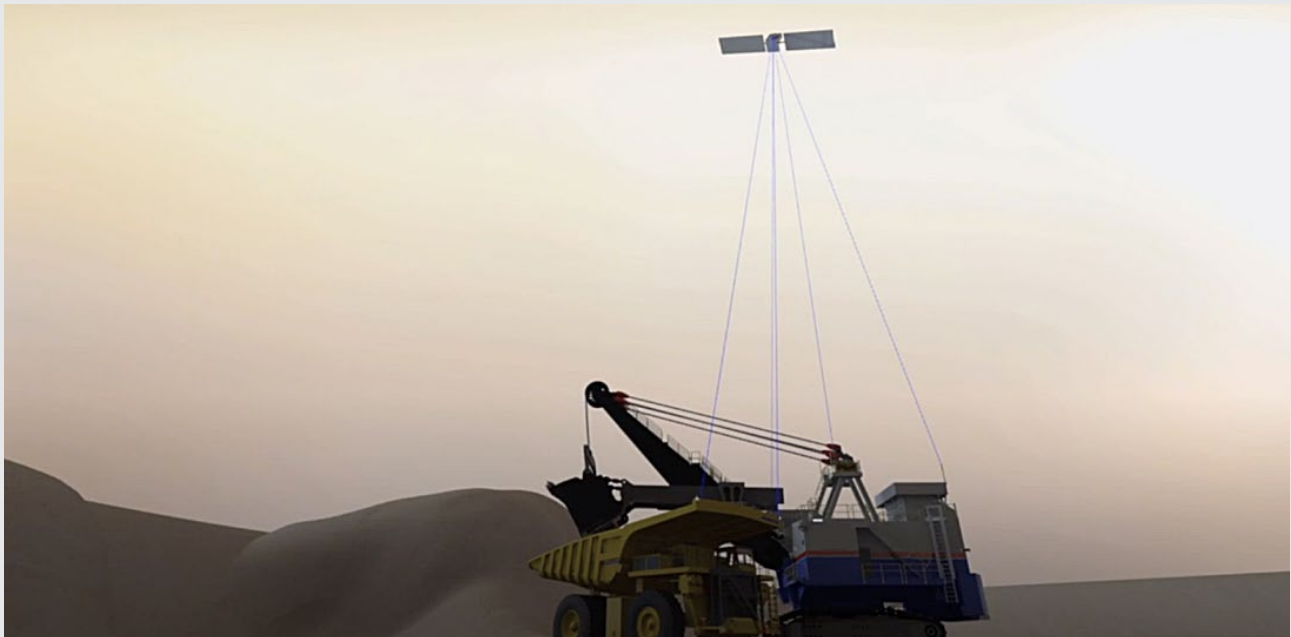
In Proximity Detection System (PDS) applications, GNSS units need to be installed on both the local and remote object, and a communication link is required between the two objects. The global position of both objects is then used to calculate the proximity between the objects.

Advantages

- GNSS is a mature technology (introduced in the late 1970s) and a vast range of commercial solutions are available
- GNSS allows for Geo-fencing (defining no-go or restricted areas)
- Suitable for long-range applications
- Relatively high accuracy
- Inertial-based solutions can provide high-frequency positioning information as well as attitude (orientation) measurements
- Relatively robust to environmental conditions

Limitations

- Requires infrastructure to be installed onto remote object(s)
- Requires LoS to external infrastructure
- Not suitable for underground applications
- Performance may change depending on the status of the satellite constellations



Rules and intelligence engine

Assuming a high-performance sensing technology and peer-to-peer radio link are in use for detecting and tracking vehicles, objects, people position, heading and speed, then a capable rules engine should support the minimum capability outlined in Table 1. A capable rules engine should provide the flexibility to tailor alarm rules to mitigate nuisance alarms during normal safe vehicle interactions and only generate alarms when there is an imminent threat of collision.

Rules Engine Capability	Value / Benefit
Configurable Detection Zones	<i>Reduces over-alarms with optimised detection zones suited to vehicle dynamics.</i>
Dynamic beams adjust in proportion with vehicle speed and linked to the vehicle braking performance, road gradient and payload.	<i>Reduces over-alarms with optimised detection zones suited to vehicle dynamics.</i>
Configurable Beam Shapes	<i>Optimised beams configured to vehicle footprint & operating state minimizes over-alarms.</i>
Curved Beams	<i>Enables reliable curved zone detection without nuisance alarms.</i>
High Accuracy Sensing (footprint to footprint)	<i>Allows tighter zones for close interactions without nuisance alarms.</i>
Accurate and Fast Heading	<i>Accurate static heading when stationary improves alarm accuracy & situational awareness. Enables reliable curved zone detection without nuisance alarms.</i>
Priority alarming for multiple interactions.	<i>Allows operator to focus on high priority critical alarms, minimizes distraction from other less critical alerts, increases CAS effectiveness.</i>
Use other vehicle operating state (e.g. safe state, stopped but can move off, in forward motion, in reverse motion).	<i>Enables EMESRT "Safe Passing & Accessing HV's" scenario, minimizes over-alarms, can be used for roll-back/forward detection to ensure safe-state.</i>
Use other vehicle closing speed / speed difference (e.g. moving towards or away).	<i>Alarms can be optimised based on threat to prevent over-alarms.</i>
User other vehicle location relative to local vehicle (e.g. front, left, right or rear) to generate specific voice message with threat location & expected response.	<i>Allows improved 360-degree situational awareness by providing context of threat location & intervention response to avoid a collision.</i>
Use relative heading between local & other vehicle (e.g. travelling in same direction used for tailgating scenario, head-on alarms can be differentiated by off-side (away from operator's cabin) or on-side (operator's cabin) with speed dependencies).	<i>Alarms can be optimised based on threat to prevent over-alarms. Able to differentiate between low-risk metal-to-metal interactions and high-risk potential fatality interactions prevents over-alarms.</i>
Play an audio voice message dependent on the type of interaction scenario.	<i>Provides the operator with specific context of threat and intervention response to avoid a collision, reduces operator reaction time and distraction viewing screen.</i>

Table 1: Rules Engine Capability and Value / Benefit

System health monitoring and reporting

A capable PDS/CAS technology solution will provide real-time system health monitoring/diagnostics and report faults to the operator, remote reporting system, and maintenance personnel.

Typical system parameters monitored **will** include:

- GNSS (primary/secondary (where supported))
- Other sensors (TOF, LFM, cameras, radar, LIDAR etc)
- Hardware (processing unit, user interface, cabling)
- Communications (vehicle to vehicle, on vehicle, back to base reporting – WIFI / Cellular / Ethernet)
- Audio System (primary alert mechanism)
- L9 intervention control interface health (where fitted)

Typical system health report **should** include the following:

- Fleet system health dashboard
- Fault event reports (machine ID, type, start/end date & time, location)
- Heatmap
- SMS/email fault reports to maintenance personnel for prompt maintenance response
- Hardware, software and firmware versions (configuration management)
- FMS / Dispatch exception reporting (where supported)

System health monitoring **should** include:

- Standalone self-check capability not reliant on other vehicles being in range or operators reporting on the fault
- Fail-to-safe functionality
- Primary & secondary systems for redundancy and fail-over switching capability
- Remote access over the air for troubleshooting/diagnostics and firmware/software/configuration updates with remote validation

Human factors engineering and operator acceptance

A capable PDS/CAS user interface must be designed to industry best practice and include human factors engineering. This ensures the operator receives the correct information and context to process and respond quickly to voice-based alerts of an imminent threat of a collision. It provides the operator with the expected intervention to avoid a collision.

Operator engagement is critical in the design process to ensure maximum operator acceptance of the user interface in the equipment they operate. A PDS/CAS technology solutions provider must design the user experience from the operator's perspective (i.e. solve the problem of vehicle interaction risk from an operator's perspective). Alarms should be the last line of defence, not the primary means of preventing vehicle interactions.

It is critical to design and maintain the system to a high standard to generate trust in the technology. (As an operator, "when I need it, it must work and be correct".)

The operator's trust in the system increases user acceptance. As operators accept and utilise the system, their criticality and reliance on the system increases.

Industry Case Study Reference:

ACARP C29001_Report (CASE STUDY OF HUMAN CENTRED DESIGN OF NEW TECHNOLOGY IN MINING, Robin Burgess-Limerick, THE UNIVERSITY OF QUEENSLAND, 16/9/2022)⁹

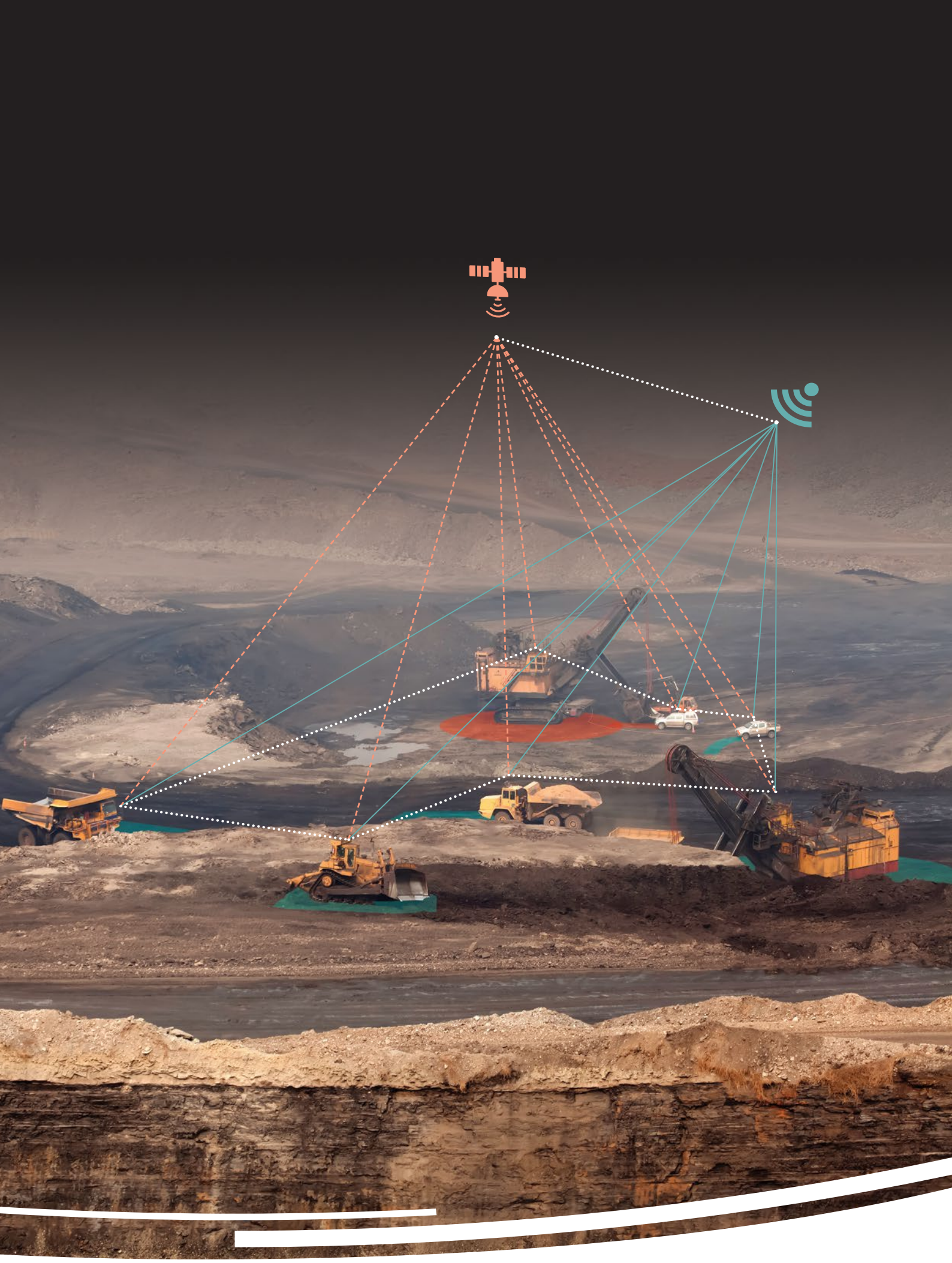
This case study documents the human-centred design process employed when developing a CAS solution for surface mining equipment. The author of the case study developed it through an analysis of relevant documentation, participant observation in relevant workshops and meetings, mine site observation, and interviews with key informants, including operators.

The design process reflected the requirements of ISO 9241-210 Ergonomics of human-system interaction Part 210: Human-centred design for interactive systems. A multidisciplinary design team followed an iterative process that commenced with a thorough understanding of users, tasks, and environments, involving operators throughout, and the resulting design was refined by user-centred evaluation. The activities undertaken broadly fall into four categories: understanding the context, specifying user requirements, producing design solutions, and evaluating these designs.

The system design was evaluated through field assessments of detailed user and performance requirements across the EMESRT 24 base interaction scenarios plus 15 discrete scenarios. Designers accompanied vehicle operators during staged scenarios to evaluate the collision awareness technology's functionality and the interface's effectiveness in eliciting an appropriate response across each scenario.

The design process undertaken provides an excellent example of a human-centred design process that reduces the risk of system failure by considering human capabilities and limitations in the design process. As a result, the system is consistent with current best practice based on human factors principles for interface design.

9. Australian Coal Research Limited 2024, Case Study of Human Centred Design of New Technology in Mining, The University of Queensland, accessed 20 May 2024 <https://www.acarp.com.au/abstracts.aspx?repld=C29001>



EMESRT Reference: Human Factors In Design Guide (Rev 1, Sept 2024)¹⁰

The key objective of this document is to describe a human-centred design process to support developers and sponsors of new technology related to vehicle interactions.

Implementation strategy

Before the implementation of a PDS/CAS technology solution as part of new vehicle interaction controls, the mine site should consider the following recommendations:

- Vehicle interaction control improvement program to be treated as a project aligned with the EMESRT Work Breakdown Structure 'WBS'. It has a dedicated project manager and is supported by a project sponsor.
- Aim for zero nuisance alarms (or as few as possible) to prevent user normalisation or complacency due to over-alarming.
- Focus on 'operator zero harm' vehicle interactions (i.e. detect vehicle interactions that have a high consequence of a fatality or injury to the operator).
- Key stakeholder engagement (operators, project sponsor, project manager, IT, maintenance, production, engineering, trainers, health & safety).
- Establish a baseline system configuration/alarm logic across multiple mine sites, where applicable, to adhere to a corporate standard (changes by exception only).
- The mine site and the installation team undertake a scoping exercise to agree on the optimal machine installation standard.
- Verify IT and mine site communications coverage, capability and capacity before installation, including initial connectivity tests from machine to mine network to reporting systems.
- Setup reporting system with machine connectivity before the 1st machine installation for data collection during the fleet installation program.
- Silent mode operation (i.e. user interface switched off) to measure baseline vehicle interactions alarms before the PDS/CAS technology solution goes-live. This allows for rules engine optimisation (where required).
- Inspection Test Reports (ITRs) or similar (basis of the 'as-built' documents) for client validation of installation and functionality, including end-to-end connectivity tests from machine to reporting system.
- Managing portable light vehicle systems (procedures for tracking and operating of charging stations).
- Mine site access control using PDS/CAS technology solution triggered boom gate(s) to prevent vehicles from entering the pit area without a PDS/CAS solution.

- Vehicle installations: a dedicated installation bay/hardstand area for cycling through vehicles. At the planning phase, key stakeholders agree to provide continuity of vehicles for installation efficiency.

Installation standards and quality control

To ensure a high quality and consistent installation of PDS/CAS technology solution hardware, the mine site should consider the following recommendations beforehand:

- Develop machine-specific installation kits with a standard build. This is based on the scoping exercise with client sign off on equipment mounting locations, mounting brackets, cable runs, penetrations, machine electrical connections & protection circuits.
- User interface screen mounting location to be specified by the client in consultation with operators of each vehicle type. The position of the screen should be as per the standard 'Position of the Screen – AS4024 Safety of Machinery' as follows:
 - Vertical screen vibration must not impact the operator's ability to read the screen.
 - Screen vibration frequency must match the vibration frequency of the operator.
 - Screen to be placed within 15 to 30 degrees of the field of vision.
 - Where the operator's ability to discriminate colour is essential for the correct use of the screen, the mine site should reduce the 'acceptable' zone because the size of the central visual field (which is sensitive to colour) is smaller than the field of which is sensitive to white light.
 - Screen 'distance from eye to character' is essential for the operator's ability to interpret the symbols on the screen.
 - Screen placement not to create an additional blind spot to the operator's visibility from the cabin.
- All installations to comply with industry/mine site electrical and mechanical guidelines.
- Install anti-vibration shock mounts on all track machines to prevent machine body vibrations from damaging mounting brackets and equipment, in particular where Ground Engaging Tools 'GET' are fitted (e.g. track dozer ripper).
- 'As-built' documentation supplied for every vehicle installation based on Inspection Test Reports witnessed and approved by the client.

10. EMESRT 2024, Human Factors In Design Guide (Rev 1, Sept 2024). Accessed 16 Oct 2024, <https://www.emesrt.org/wp-content/uploads/HumanFactorsDesignGuide.pdf>

Change management program

The mine site must integrate the operation and support of the PDS/CAS technology solution into the mine site's existing systems and procedures in order to align the cultural changes that the PDS/CAS solution brings to the operation.

Recommendations are:

- Key stakeholder communications before/during/after the PDS/CAS technology solution implementation
- Operator training (user interface, pre-start inspections)
- Mine site inductions
- Integration to existing safety training and reporting systems
- Integrate into existing mine site procedures and develop new procedures relating to the introduction of the system (e.g. operations/maintenance procedures)
- Vehicle 'mine readiness' requirements
- Stores spare parts inventory management
- Resource load planning for operations and engineering support
- Configuration Change Management (where required) (e.g. changes to speed, distance and direction parameters)
- Define and develop reporting KPIs that allow the business to validate successes and communicate with stakeholders. This activity will ensure the adoption of change and safety culture objectives are met.

Training programs

To aid in the successful implementation of the PDS/CAS technology solution, the following training programs are required:

Operator Training

- Develop and deliver easy-to-understand, but thorough, user training that explains what the system does, and more importantly explain what the system doesn't do, through the use of animations.
- Pre-start inspections to include PDS/CAS technology solution
- Operator in-cabin quick reference guide
- Mine site procedures for PDS/CAS technology solution failure (based on Trigger Action Response Plan (TARP))
- Investigate integration of PDS/CAS technology solution training on Heavy Vehicle training simulator (where supported)

Installer Training

- Installation
- Testing
- Commissioning

Maintenance Training

- Health report analysis
- Troubleshooting & diagnostics
- Planned maintenance
- Unplanned maintenance
- Repairs

Reporting System User Training

- Event report analysis & actionable insights
- Vehicle Interaction hot spot analysis/heatmaps for review & risk reduction
- Geofences (new and maintenance of existing)
- Historical journey replays for incident analysis & risk reduction
- Reports generation
- Fleet configuration management
- Utilise event data & learnings to improve operator compliance, haul road design, traffic management plan and other Level 1-7 controls in order to reduce vehicle interaction risk.

Reporting and data analytics with actionable insights

Subject to the mine site network connectivity from vehicles to a remote reporting system, a capable PDS/CAS technology solution will provide a rich data set in real-time. The mine site can host the reporting system on premise or in the cloud.

The outcomes available from such a reporting system could include:

- Rich data analytics for informed decision-making that enables the mine site to continuously refine and improve the Level 1-7 controls, accelerating zero-harm objectives.
- Asset health monitoring & reporting for maximising PDS/CAS technology solution availability and driving maintenance program
- Vehicle interaction hot spot/heatmap analysis for review & risk reduction
- Insights to improve mine traffic management plan
- Insights to improve haul road design
- Actively monitor & improve Operating Compliance
- Monitor the effectiveness of Operator Training
- Rich geofence management capabilities for scenario management across vehicle types
- In-vehicle monitoring with safety adherence reporting
- Over-the-air PDS/CAS technology solution software and configuration updates (with remote validation) to ensure optimal operation

- Remote monitoring & troubleshooting improves supportability
- Integration with FMS / Dispatch enables centralised exception monitoring & strengthens the value of the PDS/CAS technology solution

Maintenance strategy

In consultation with the PDS/CAS technology solution provider, the mine site must develop an Operational Failure Mode Effect Analysis 'OFMEA' based on the PDS/CAS Design Failure Mode Effect Analysis 'DFMEA' that will drive a criticality-based maintenance program that ensures maximum availability with minimum down-time. When the PDS/CAS technology solution is classified as a 'safety critical system' any down-time will impact production (i.e. if PDS/CAS technology solution is not working, the vehicle is No-Go until PDS/CAS technology solution is operational).

Real-time PDS/CAS technology solution health monitoring & reporting of system faults is crucial, with faults reported to the operator (end-user), maintenance personnel and the PDS/CAS reporting system.

Secondary sensing technology can provide redundancy to primary sensing technology with automatic fail-over switching. This ensures ongoing PDS/CAS functionality (but may reduce capability to a 'limp mode').

Recommended Planned Maintenance Strategy

- System design and component FMEAs generated with planned maintenance strategy developed.
- Scheduled planned maintenance tasks and inspections, including the frequency. Developed and loaded into the mine site maintenance planning program.

Recommended Unplanned Maintenance Strategy

- Assess how the loss of critical functionality affects the user
- Identify what additional controls could be effectively implemented
- Controls to be developed into a Trigger Action Response Plan 'TARP'

Technology Provider Services (SLA)

- Remote technical support (mine to supply remote access)
- Training (Operator, installer, maintenance, reporting system user)
- Alarm analysis
- System health audits
- Software/firmware/configuration support

Challenges moving from EMESRT Levels 7 (operator awareness) & 8 (advisory controls) to Level 9 (intervention controls)

Some of the challenges in the successful journey of a PDS/CAS technology solution from EMESRT levels 7 and 8 to level 9 intervention controls (where required after implementing mature Levels 1-8 controls) can be as follows:

- Level 9 is a journey, not an out-of-box solution
- The mine site must qualify success at Levels 7 and 8 with minimum nuisance alarms for the specified high-risk vehicle interaction scenarios. Where this qualification is not completed, Level 9 will impact production, accelerate vehicle & brake wear and risk exposure to operator normalisation/complacency.
- Level 9 intervention is not a standalone product but an extension of a high-performing and mature Level 7-8 system. Level 9 is a machine control performance level (by scenario, machine type/make/model & mine site operations).
- Core Level 9 capability should include:
 - Take-off / propel inhibit
 - Automatic controlled slowdown/retard from any speed
 - Stop (limited to maximum speed determined by OEM machine type (e.g. ten (10) kph in forward, three (3) kph in reverse))
 - Speed governing (to address loss of control scenario)
- Other functions could include: tray/bowl up inhibit under overhead structures.
- Level 7-9 dynamic detection zones based on speed, braking distance, payload (if available from OEM interface) & road gradient.
- Managing OEM variances in the commands supported in the ISO 21815-2 protocol will impact the performance of an integrated Vehicle Interaction System 'VIS'.
- Real-time PDS/CAS health monitoring is critical to support the ISO 21815-2 protocol 'heartbeat' function. Clarity is required on expected 'fail-to-safe' states for both PDS/CAS technology and OEM Level 9 interface for both stationary and at-speed scenarios.
- Limited global availability of OEM Level 9 interfaces and machine types supported. Some OEMs do not currently support Level 9 interfaces outside of South Africa. In December 2022, South Africa implemented a mandate for Level 9 on Trackless Mobile Machines (TMMs) that present significant interaction risk based on the mine site risk assessment (e.g. haul trucks, ADTs, large wheel loaders).

- Gaining access to OEM braking / retard curves for optimal intervention control to minimise the effort required in conducting and optimising machine-type tests at OEM proving grounds or on mine site machines.
- Potential impact of OEM warranty using 3rd party Level 9 Vehicle Intervention System for machines/ regions not supported by the OEM.
- Level 9 intervention control needs to support all production speed ranges, not just take-off / slow speed 0-10kph scenario. Success will be contingent on the performance capability of the sensor(s) and rules and intelligence engine.
- Wide range of scenarios, supporting configurable detection zones and stop gaps incorporating machine parameters to tune intervention performance.
- A mature integrated PDS/CAS technology solution with intervention control does not require a Level 9 operator override/alarm confirmation function. A secure maintenance bypass/override capability may be required for exceptional circumstances (via risk assessment). Providing an override/alarm confirmation function to the operator introduces additional failure modes as you enable the operator to choose when the intervention control operates or not.
- Challenges in setting up a pre-start test area that exercises PDS/CAS technology solution core Level 7-9 functionality that is integrated with brake testing.
- Stringent planned, unplanned and preventative maintenance programs are required using appropriately skilled and competent personnel.
- There are challenges in managing legal liability when using an integrated Vehicle Intervention System. There is a requirement for multi-party agreements between mine owner, OEM, PDS/CAS technology solution, and 3rd party interface provider (where required). An operational risk assessment is critical to identifying failure modes, mitigating controls, and reducing residual risk.
- The operator is still the primary means of control (as mentioned in ISO 21815-2). The PDS/CAS technology solution (in particular at Level 9 as the last line of defensive controls) should never be considered as a 'silver-bullet' solution to managing vehicle interaction risk. The mine site controls Levels 1-7 are the most effective when mature and implemented effectively.

Coexistence of CAS and Autonomous Haulage Solutions (AHS)

With surface mining Autonomous Haulage Solutions (AHS) growing globally, the challenge of AHS and PDS/CAS technology solutions coexisting is an opportunity for the industry to drive the development and adoption of interoperability solutions.

Current OEM AHS and PDS/CAS technology solutions use proprietary 'vehicle to vehicle' protocols, preventing interoperability between different solutions. When an AHS machine exits the Autonomous Haulage Zone 'AHZ' and switches to manned operations (e.g. for access to the maintenance workshop), currently, the machine needs to be fitted with a standalone PDS/CAS technology solution for detection and interaction with other manned mine vehicles for L7-9 controls. This coexistence adds hardware duplication and creates a potential failure mode when the operator does not manually activate the PDS/CAS technology solution when operating outside the AHZ.

Adopting an existing interoperability standard using the global V2X (Vehicle to Anything) communication standard would allow different OEM AHS and PDS/CAS technology solutions to coexist. The sensor suite must comply with a minimum industry standard performance level for consistent ranging and localisation accuracy between OEM and 3rd party PDS/CAS technology solution vehicles.

Interoperability has been a key EMESRT theme since developing the ISO 21815 standard for EMESRT Level 9 intervention controls. The ISO standard has enabled PDS/CAS technology solution providers to integrate with machine OEMs to allow the machine to automatically intervene to prevent a collision when the operator has failed to respond to the Level 7 and Level 8 controls. Intervention control functions may include take-off / propel inhibit, automatically controlled slowdown from any speed, stopping and speed governing.



Functional safety approach

When some mining customers classify PDS/CAS technology solutions as a 'critical safety system' and Level 9 intervention controls are implemented on mining machines, the question of compliance with functional safety standards (with safety integrity level) is raised and directed to the PDS/CAS technology solutions provider and machine OEM. This topic created much debate during the early EMESRT and ICMM vehicle interaction workgroups and triggered the publication of a joint industry paper developed by the Construction and Mining Equipment Industry Group (CMEIG), EMESRT, and ICMM and has been published (White Paper and Guiding Principles Functional Safety for Earthmoving Machinery, version 0.5, 5/3/2020), which is available via the CMEIG website. (<https://www.cmeig.com.au/wp-content/uploads/CMEIG-EMESRT-ICMM-White-Paper-and-Guiding-Principles-for-Functional-Safety-on-Earthmoving-Machinery-Ver.-0.5-March-2020.pdf>)¹¹

The increase in the level of automation of earthmoving machinery (e.g. autonomous haul trucks, collision avoidance systems) has led to the introduction of non-deterministic systems that cannot be analysed using traditional (or established) functional safety methodologies. There are standards under development to address this gap. In the interim, a risk-based approach is recommended. The intention of the white paper is to guide the approach to functional safety for mobile earthmoving machinery. It also provides guidance for the interim approach to non-deterministic systems (e.g. PDS/CAS) whilst standards for these are being developed.

EMESRT Perspective

EMESRT is a global initiative involving major mining companies. EMESRT engages with key mining industry OEMs to advance equipment design to improve safe operability and maintainability beyond standards. EMESRT recognises the need for clarity and a unified approach to functional safety.

EMESRT commenced working on vehicle interaction in 2013, with the first project being the development of an interface protocol between the PDS/CAS technology solution and machines (ISO 21815). The role of functional safety within the protocol and with vehicle interaction, in general, was raised as a concern to be dealt with.

ICMM Perspective

In 2018, ICMM launched the ICSV initiative, which includes a workstream on vehicle interaction. ICMM identified the requirements for these systems to comply with functional safety principles as one of the roadblocks to the continuing development of this technology. The number of standards, limited applicability to earthmoving machinery, and emphasis on different standards in different jurisdictions all work towards delaying the introduction of new technology. Developing a common approach across surface and underground mining will overcome these issues and allow more rapid development and uptake of new technology. ICMM intends the applicability of this white paper to extend beyond earthmoving machinery to include other mobile machines used on mine sites.

Wabtec Perspective

To Wabtec's knowledge, no PDS/CAS technology solution currently available on the market, has been designed for compliance with functional safety standards with a defined Safety Integrity Level 'SIL' which would drive significant increases in the cost of a PDS/CAS technology solution and complexity of maintenance and deployment practices. Some PDS/CAS technology solutions do, however, support real-time health monitoring & reporting using a self-test function, which supports a 'fail-to-safe' mode of operation.

It is recommended that a PDS/CAS technology solution product development & product lifecycle management process is closely aligned with the functional safety product lifecycle guidelines. A risk-based approach is adopted in the interim whilst standards for non-deterministic systems like PDS/CAS technology solutions are being developed.

11. CMEIG 2020, White Paper and Guiding Principles Functional Safety for Earthmoving Machinery, accessed 20 May 2024 <https://www.cmeig.com.au/wp-content/uploads/CMEIG-EMESRT-ICMM-White-Paper-and-Guiding-Principles-for-Functional-Safety-on-Earthmoving-Machinery-Ver.-0.5-March-2020.pdf>

Value-added systems integration

Investing in a PDS/CAS technology solution as part of a VICI program can sometimes be seen as a necessary but unwanted purchase. A PDS/CAS technology solution is often not perceived as an enabler to improve production or increase efficiency. However, many opportunities exist to add value by leveraging the PDS/CAS technology solution hardware, sensors and data.

Some examples are as follows:

- Use of the PDS/CAS technology solution to determine the effectiveness of the Level 1-7 controls (e.g. operator compliance, driver behaviour, haul road design, traffic management plan).
- In-Vehicle-Monitoring System 'IVMS' capabilities present in PDS/CAS technology solutions could include speeding, harsh braking/cornering, safe state, seat belt on, and driver ID.
- Use of the PDS/CAS technology solution user interface as an electronic pre-start inspection checklist.
- Use of the PDS/CAS technology solution hardware to support reduction in other system(s) hardware such as the GNSS antennas, antenna mast etc.
- Use of API for data sharing between PDS/CAS technology solutions and Fleet Management System 'FMS'/Dispatch for 'exception' reporting and operator ID capture (where an FMS is fitted).
- Using the PDS/CAS technology solution for real-time OEM machine health & productivity monitoring for asset reliability solution.
- Integration of the PDS/CAS technology solution with fatigue monitoring systems where the fatigue state is linked to alarm logic rules.
- Using the PDS/CAS technology solution system sensors for haul road condition monitoring.
- Using the cornering speed from the PDS/CAS technology solution to imply tyre wear.
- Integration of the PDS/CAS technology solution with other in-vehicle telematics systems.
- Using the PDS/CAS technology solutions API for data sharing with other mining systems.

Applicability of new emerging technologies

The following emerging technologies are maturing their applications in surface mining and other sensing applications:

- Smart cameras using artificial intelligence 'AI' for remote video object detection and classification. Typical applications can include people detection/vehicle detection not fitted with an active PDS/CAS technology solution, edge and void detection, GET tooth wear and missing tooth detection, road condition monitoring, operator fatigue monitoring, PPE compliance monitoring, environment monitoring.
- Light Detection and Ranging 'LiDAR' with 3D point cloud generation. Typical applications may include PDS/CAS technology solution remote object detection, AHS, road condition monitoring, road network map generation, stockpile imaging.
- Radio Detection and Ranging 'RADAR' – mmWave radar used in AHS and some PDS/CAS technology solutions with challenges managing nuisance alarms, detection zone coverage, and environmental factors.
- Surface Based Augmentation System 'SBAS' for improved GNSS accuracy, which is soon to be commercially deployed in Australia and other regions.
- Vehicle to Everything 'V2X' ISO communications standard for interoperability between OEM and 3rd party PDS/CAS technology solutions. With growing adoption of V2X in the automotive industry, some PDS/CAS technology solutions are emerging in underground mines using V2X.
- Video, LiDAR and GNSS data collected from fixed and moving assets can capture highly accurate and reliable machine interaction, road user and environment information. Edge computing, AI, machine learning, and advanced mobility algorithms enable efficient and accurate processing of these high-resolution data sources to provide additional insights into vehicle interaction risk and operations, collision prevention, and improve productivity and efficiency of operations.

Conclusion

In conclusion, the pervasive risks associated with vehicle interactions in mining operations requires a multifaceted approach that operationally integrates advanced proximity detection and collision avoidance technologies with existing mine site controls, whilst considering key aspects involving people, processes, operating, environment, production requirements and equipment design. The strategic alignment with industry best practices for vehicle interaction control improvement by global mining industry bodies such as EMESRT and ICMM to drive the adoption of 'capable solutions' that have proven to deliver better vehicle interaction control performance at a mine site level, are vital for advancing towards zero-harm objectives.

Furthermore, it is imperative for stakeholders to understand that while these technologies are critical components in the safety ecosystem, they are not panaceas but parts of an integrated solution that demands a robust implementation strategy, effective change management, and continuous operator engagement. Effective communication and management of expectations are crucial in ensuring that the adoption of these technologies leads to tangible improvements in safety and operational efficiency.

By fostering a culture of safety that prioritizes comprehensive risk management and leverages technological advancements, mining operations can mitigate vehicle interaction risks. This approach not only enhances the safety and efficiency of mining operations but also supports the industry's unwavering commitment to safeguarding the lives of its workforce.

Please note that the information provided on this white paper does not, and is not intended to, constitute legal advice; instead, all information, content, and materials available in this white paper are for general informational purposes only. Information in this white paper may not consistute the most up-to-date legal or other information.

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In his current role as Principal Consultant, Craig is responsible for supporting a global commercial team in new product sales and business growth opportunities, supporting new product development and product support teams, driving customer success and providing thought leadership.



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