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GLENCORE WATERVAL EAST - PEDESTRIAN VEHICLE DETECTION SYSTEM (PVDS)

TECHNOLOGY CAPABILITY ASSESSMENT

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Executive Summary

This report outlines the current capability of the People Vehicle Detection System (PVDS) that has been implemented at Glencore Ferroalloy's Waterval East Mine in Rustenburg, South Africa. The assessment was done by the authors of this report within Enterprises University of Pretoria, with a focus on the current status of the technology product that is already in operation.

On top of the technology capability assessment, an investigation was conducted to identify the key learnings of the project team (Waterval East's project team and the product suppliers) that developed and implemented the PVDS. A summary of these key learnings is provided in this report which was disseminated from technical documents provided by the mine as well as from on-site investigations and interviews. These key learnings provide an overview of what the project team went through in developing, implementing and achieving operational success with the PVDS. These spanned across both technical aspects as well as insights in achieving successful adoption by the workforce.

The aim of this report was firstly to provide an independent capability assessment of the PVDS in its current state, for decision-makers to analyse the potential for roll-out to other operations. The second aim was to provide other project team members, that are or that may become involved with CMS/CAS implementation initiatives, with the key learnings that the Waterval East team had gone through. The latter aims to better equip such teams with knowledge to enable a more efficient implementation process for a CMS/CAS initiative. With that said, this report is by no means an all-encompassing guideline for roll-out of the PVDS or for implementation of other systems. Rather, it provides a source of knowledge that would greatly add value to the creation of a guideline for roll-out, or for a project plan for other implementations of this particular technology project type.

The key learnings span across the entire development and implementation lifecycle of the PVDS to date. They include technical problem solving as well as how soft issues were overcome by highlighting important aspects to consider for change management. The physical system assessment was done by investigating current capability (how the system behaves and what is included and excluded in its functionality), as well as by performing tests on a proving ground in order to measure the intelligence and accuracy of the system and its decision-making. In this regard, the PVDS was found to consistently perform according to claims and it showcased great advantages in improving TMM-based safety. This was demonstrated by successfully and repeatably showcasing EMESRT Level 9 requirements, i.e. the PVDS effectively slowed down ("crawled") the controlled vehicles for vehicle-to-vehicle interaction scenarios, and effectively stopped the controlled vehicles for vehicle-to-person interaction scenarios.

During the testing phase, some nuisance issues were also observed. For example, when two vehicles pass one another the system would remain in crawl mode for an extended period even after the vehicles had passed one another. These and a few other inefficiencies were noted in the report. While these inefficiencies impact on productivity, it should be noted that safety wise the testing of the PVDS proved solid. Furthermore, in dealing with current inefficiencies the suppliers demonstrated a strong focus on continuous improvement – particularly to reduce negative impacts on production while still providing optimal safety to personnel.

Purpose

The purpose of this project was to evaluate the current technology status, i.e. the capability of the "PAS1000 Proximity Awareness & Avoidance" system along with the supporting components in the system that together create the People Vehicle Detection System (PVDS), at this point in time, as compared to the current requirements set for its operation within a given user environment (i.e. Waterval East underground Bord and Pillar operation). The scope of this project did not include evaluating the technology product as compared to other similar products, or as compared to requirements outside of the user environment for which this product was designed.

Furthermore, this project aimed to concisely capture the key learnings that the team (Waterval East, as the client/user and implementation team, and the suppliers of the product as the developers and collaborative implementers of the product) went through in developing and implementing the PVDS. This extended to both technical and softer aspects associated with both successful technology implementation as well as successful user adoption to allow efficient operation of the system.

People Vehicle Detections System (PVDS)

The "PAS1000 Proximity Awareness & Avoidance" system at Waterval Mine functions in collaboration with systems from Nerospec, LSC and A&R Engineering, to enable a means to mitigate the risks of mobile machinery incidents involving personnel. The system also facilitates the tracking of personnel and assets in the mine (see Figure 1). The system can be operated as a proximity only system, which provides vehicle to personnel and vehicle to vehicle proximity detection, or in conjunction with fixed readers deployed in the underground workings to provide tracking of personnel, vehicles and other assets as they move through the workings (Murley, 2018[1]).

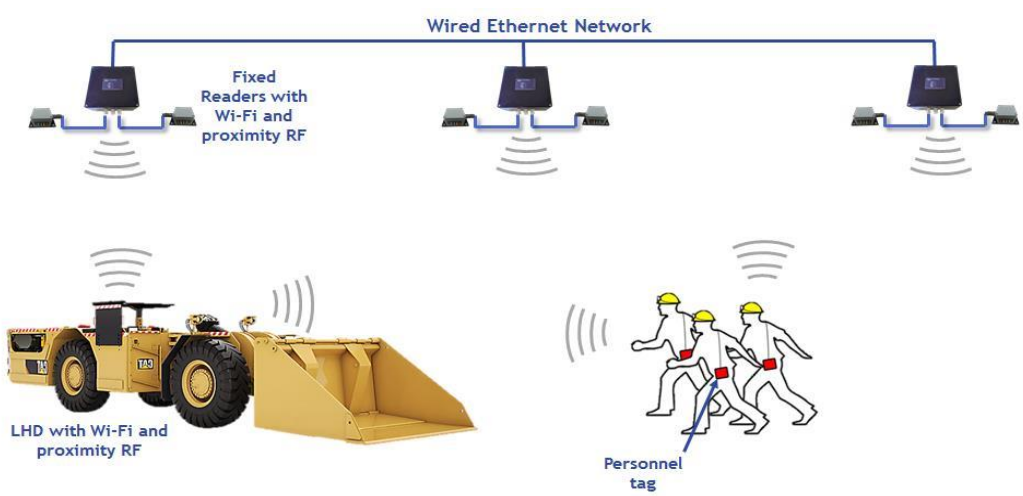

Figure 1: Overview of the PAS1000 for underground TMM applications (Murley, 2018)

[1] *Murley, R. 2018. Trackless Mobile Machine Collision Avoidance System at Glencore Waterval Mine. Whitepaper. Glencore Alloys South Africa (Pty) Limited. Waterval East Chrome Mine*

Abbreviations and Definitions

AI	Artificial Intelligence
CAN	Controller Area Network
CAS	Collision Avoidance System
CMMS	Comprehensive Mine Management System
CMS	Collision Management System
Dynamic zoning	Zones that change their size and shape depending on TMM speed, gear selection, location and configuration (operating mode vs. tramming mode)
DMR	Department of Mineral Resources
EEM	Electronic Engine Management
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMESRT	Earth Moving Equipment Safety Round Table (Industry Alliance)
EMI	Electromagnetic Interference
EiQ	Embedded IQ (Pty) Ltd.
GNSS	Global Navigation Satellite System
LDV	Light Duty Vehicle
LHD	Load Haul Dump
LO	Local Object
LSC	Lamproom Solutions & Consulting (Pty) Ltd.
Level 7 (L7)	The system provides proximity awareness ("Alerts the operator")
Level 8 (L8)	The system provides proximity detection ("Advises the operator")
Level 9 (L9)	The system provides intervention controls ("takes some control from the operator") for "collision mitigation", i.e. the EMESRT definitions take forced "crawl" or forced stop as level 9 compliance, although simply crawl interventions would not enable "collision avoidance" without operator intervention. See Figure 2 for EMESRT level descriptions.
MI	Motion Inhibit
MOSH	Mining Industry Occupational Safety and Health
neroCRAWL	Electromagnetic derating controller that is applied to LDVs, provided by Nerospec
neroGear	Transmission controller allowing for push button gear change and automatic down gearing when intervention control is triggered.
neroHUB	Universal controller, data logger and communications hub provided by Nerospec
Nerospec	Nerospec OSCON (Pty) Ltd.
neroSTAT	Provides real-time overview of machine status to operator, provided by Nerospec
OEM	Original Equipment Manufacturer
PAS1000	This is the intelligence system provided by EiQ that runs the algorithms for decision-making
PID	Proportional–Integral–Derivative
PVDS	Pedestrian Vehicle Detection System
RF	Radiofrequency
RO	Remote Object
RPM	Revolutions Per Minute
SAHR	Spring Applied Hydraulic Release brakes
SANAS	South African National Accreditation System

SHF	Super High Frequency
TMM	Trackless Mobile Machine
ToF	Time of Flight
The product	The PVDS
The suppliers	Nerospec, EiQ and LSC (See Figure 3 for a graphical representation of how they collectively provide the PVDS product). Note that Nerospec functions as the interface between EiQ and LSC with the vehicle OEM. This is not a functional requirement but it is something that some OEMs request for verification and risk mitigation purposes.
UHF	Ultra High Frequency
UV	Utility Vehicle
V2P	Vehicle-to-person
V2V	Vehicle-to-vehicle
WAP	Wireless Access Protocol

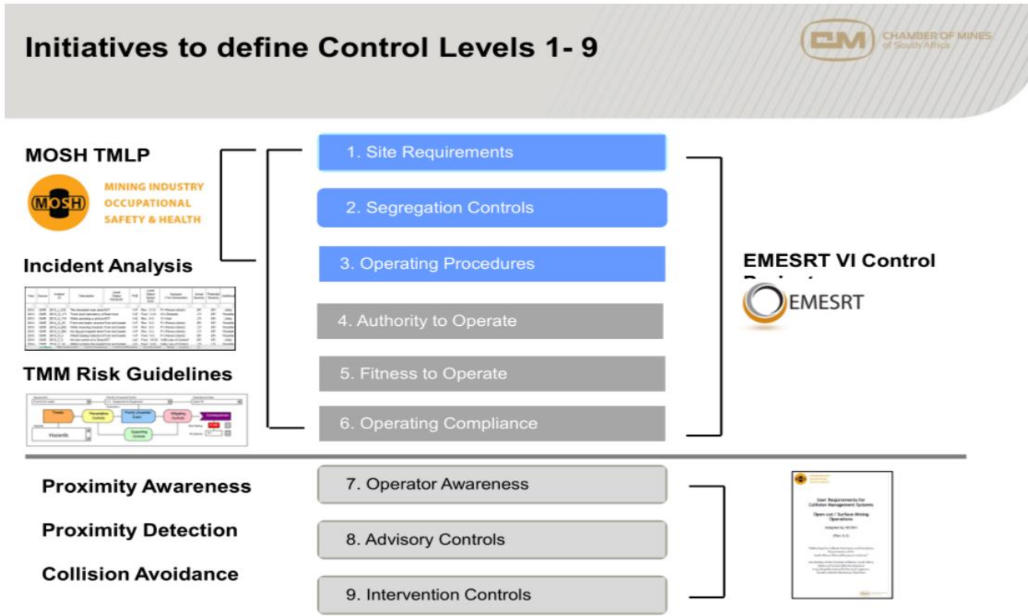

Figure 2: November 2017 EMESRT Control Level definitions adopted in the South African mining industry (Murley,2018[2])

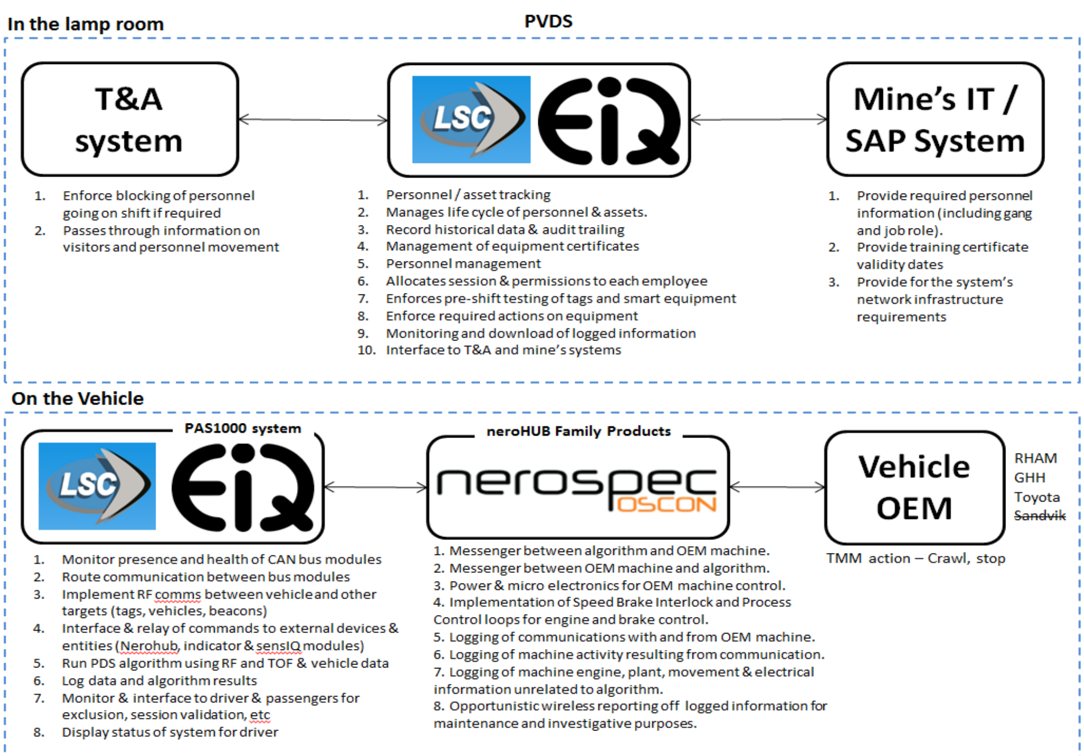

Figure 3: PVDS Suppliers & Solutions Interaction[3]s

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[2] *Murley, R. 2018. Trackless Mobile Machine Collision Avoidance System at Glencore Waterval Mine. Whitepaper. Glencore Alloys South Africa (Pty) Limited. Waterval East Chrome Mine*

1. Implementation Summary

1.1. Phases

This section serves to outline the process followed by Glencore Waterval Mine, in collaboration with the PVDS technology suppliers, on the PVDS project. Information in this regard was limited, however, the key available information was included per phase. The project comprised of seven main phases - Figure 4 displays how these phases were defined at Waterval, along with timeframes and main intention per phase. The remainder of the section briefly discusses the main activities per phase under different sub-sections (as indicated in Figure 3).

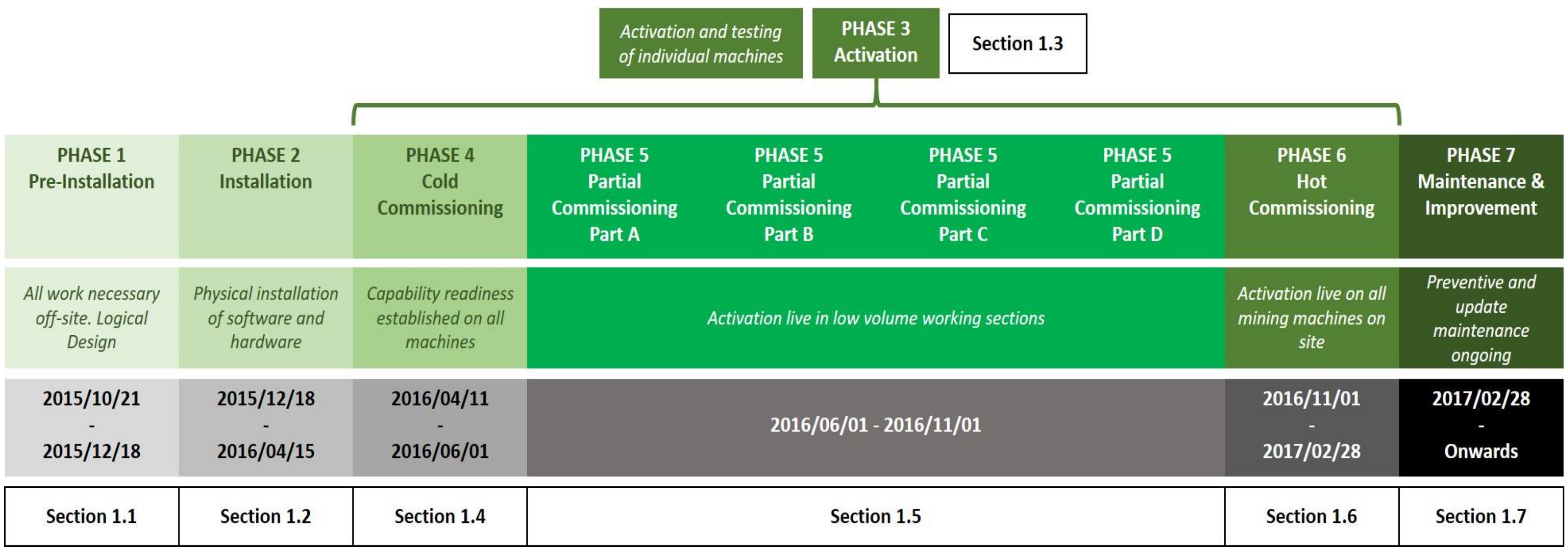

Figure 4: Overview of Glencore Waterval PVDS Project Phases

1.2. Phase 1: Pre-Installation

The following pre-installation activities were conducted during Phase 1:

- Establish state of each machine and identify potential control solution.
- Detailed individual machine audit to wire/hydraulic hose connection level.
- Module level design of non-standard elements of the solution.
- Machine level design of solution specific to each type of TMM.
- Custom design of any specialized componentry required for particular machines.
- System level design of reporting and visualization tools.
- Procurement, production build, and qualification of system components.
- Authoring and qualification of custom firmware and software systems.
- On-boarding and training of dedicated installation personnel.
- Design schematics/documentation for TMM specific installation drawings.
- Design and construction of specialised test equipment for installation personnel.
- Commence OEM activation approval processes.

1.3. Phase 2: Installation

The following installation activities were conducted during Phase 2:

- Project planning and management execution.
- Procurement of special fittings, electronic hardware and mechanical hardware.
- Compilation of installation method statement and installation instructions.
- Expert training for neroHUB installation auto-electricians:
  - Installation method statement (including safety procedures and step by step installation procedure sequence)
  - Interface and control
  - Functional capabilities
  - Configuration options
  - Machine compatibility
- Site establishment (underground and surface workshops):
  - Safe working procedures, medicals, inductions, storage facilities, special tools, team formation.
- Close co-operative working relationships with:
  - TMM mine workshop personnel (Auto-electrical/fitters and mechanical).
  - PVDS installation team members (PVDS technicians and supervisors).
  - Mine engineering, mine production and mine management personnel.
- Meetings, planning work sessions and Installation management reporting.
- Physical installation during work holidays and weekends wherever possible:
  - Electronic equipment (neroHUB and neroSTAT).
  - Harnessing, sensors, actuators, valves, and hydraulics.
- Pre-test of interface and control solutions per machine.
- Integration of neroHUB system with PVDS System.
- Pre-test of a complete system including:

    - TMM complete machine operational responses.
    - LSC CAS detection and neroHUB signalling.
    - neroHUB machine interface/logger/communication.

1.4. Phase 3: Activation

The following activities were conducted during Phase 3:

- Training and 'propaganda' first to familiarize personnel with the system.
- Notification and explanation of anticipated machine behaviour at morning meetings.
- Involvement of production crews as early as possible.
- Empower team leaders and safety reps to promote the system.
- Mining supervisors are critical to site-wide motivation at this stage.
- Avoid the 'blame game" between stakeholders – It's a team effort.
- A three-stage approach was adopted for activation:
    - Implementation Phase 4 (Cold Commissioning).
    - Implementation Phase 5 (Partial Commissioning).
    - Implementation Phase 6 (Hot Commissioning: Total Activation).
- Closed loop feedback from operations, management and technicians

1.5. Phase 4: Cold Commissioning

The following cold commissioning activities were conducted during Phase 4:

- At this stage, the PVDS system was 'detecting' and 'warning' only.
- The neroHUB was in override, only recording what the PVDS system was doing. No interaction between the TMM and the neroHUB was activated.
- The override could be activated at any stage, and the full crawl and stop would then become functional.
- Data were evaluated on a daily basis to ascertain the frequency of proximity occurrences between pedestrian and machine.
- There was a big drive towards awareness and training during this phase.
- Studying the data retrieved facilitated better traffic management underground and on surface.
- This data was used to revise the plans to separate pedestrians and machines.
- Zoning verification was evaluated by the mine:
    - The interactions between pedestrians and machines were reduced.
    - The interaction between machine and machine was reduced.
- Exclusion areas were identified in the tip areas and in workshops.
- Beacon systems were installed, evaluated and adjusted within the exclusion areas such as tip and workshop areas.

1.6. Phase 5: Partial Commissioning

1.6.1. Part 5A

The following partial commissioning activities were conducted during Phase 5A:

- A section with the lowest tonnage profile was identified to start partial activation.
- One LHD was activated in the section at the start of a shift and at the end of the shift the LHD was deactivated into an override mode to travel to the workshop.
- Tip exclusion areas were revised.
- Additional areas were identified where exclusion was required, e.g. Waiting places.
- Adherence to traffic management was initially poor.
- Material loading with a LHD caused problems (employees waiting for LHD in the respective panel and activated LHD can't enter the panel due to the activated machine).
- Malicious stoppages from employees remained a concern (employees approaching the activated LHD to give LHD operator instructions, even mine supervisors caused LHDs to stop due to approaching the LHD).
- Employees were unsure of the zone sizes and what the reaction of the machine when in proximity to the LHD would be.
- Facilitated training and demonstration of an activated LHD in the sections with all crew members to illustrate the response of an activated machine when in proximity to employees.

1.6.2. Part 5B

The following partial commissioning activities were conducted during Phase 5B:

- Facilitated training and demonstration of an activated LHD in the sections with all crew members to illustrate the response of an activated machine when in proximity to employees.
- At this stage activation of 2 LHD’s was done simultaneously. (Activation occurred in the section, deactivation occurred at the end of shift ahead of machines travelling back to the workshops.)
- Traffic management, regarding tramming, was identified to be a challenge whilst in the section.
- Separation of machine loading (ingress) vs hauling (egress) not mandatory, but became necessary for elimination of excessive crawl events.
- Tipping arrangements at tip had to be redefined.
- Congestion, caused at the tip due to machines not parking at designated parking areas, hindered the LHD movement whilst proceeding to the tip.
- Incorrectly reported breakdowns, e.g. machine was reported with a PDS breakdown, only to find an unrelated fault.
- At first, due to the impact of activation, this phase was only implemented in one section.
- Technicians were stationed at the tip area, close to where a machine was operating, to minimize standing time. This turned out to be a problem at a later stage, when activation was rolled out to other sections.

1.6.3. Part 5C

The following partial commissioning activities were conducted during Phase 5C:

- At this stage, multiple LHDs were activated whilst being driven to the workshops.
- Traffic management from working places to workshop and to surface needed to be revised.
- Mainly due to poor discipline and employees not using dedicated travelling ways.
- The need for Dynamic Zoning and reshaping of Detection Zones was identified.
- An activated machine would detect employees traveling in dedicated roadways assigned to personnel, whilst driving on a TMM dedicated roadway.
- Zoning for these machines needed to be more focused in the direction of travel and avoid having a set-form zone deflecting too much to the side.

1.6.4. Part 5D

The following partial commissioning activities were conducted during Phase 5D:

- Machines in other sections were activated one by one, advancing over shifts.
- The same process as described in Phase 5A, 5B, 5C was followed:
  - Training and demonstration to underground personnel.
  - Revision of traffic management and the discipline thereof.
  - Re-emphasis of loading of material in sections. Focusing on ingress and egress of loading and hauling.
- Breakdown standing time became an issue due to inaccurate breakdown reporting.
- A decision was made that a breakdown, no matter what the status of the machine, would result in a PVDS Technician and Nerospec OSCON technician accompanying the Mechanical Artisan to attend to breakdowns.
- An LHD driver incentive was introduced to motivate crews to participate in the roll-out of this project.
- Ultimately empowering the LHD operators to take action and reprimand employees not adhering to traffic management and unintentionally stopping machines proved to be successful.

1.7. Phase 6: Hot Commissioning

The following hot commissioning activities were conducted during Phase 6:

- All types of machines (LHD, LDV, UV, Drill Rigs) were activated for entire shifts.
- The lessons learned from the preceding phases were applied throughout the mine.
- Additional tweaking of the PVDS system settings was applied, e.g. screen layout simplified.
- Additional improvements to the zone detection rules for Crawl and Stop were applied.
- Sustained 24 hour crawl and stop activation was attained throughout the mine operation.

1.8. Phase 7: Maintenance and Improvement

The following maintenance and improvement activities were conducted during Phase 7:

- Due to the pilot nature of this project, and the increased risk posed to machine production and safety reliability, maintenance of the system forms a large component of the success.
- Continuous maintenance was necessitated due to the extent of the machine modifications and the adverse operating conditions.
- Nerospec and LSC maintain a 24hr presence on the operations, working with mine personnel and mining TMM OEM contractors.
- Machine measurements in response to standard operations and in response to PVDS operator – intervention are continuously acquired and stored for each machine in operation.
- Assessment of ongoing machine measurements continues to give rise to suggestions for improvement to the hardware, firmware and software systems which were created for this project.
- OEM feedback can be given with precise timing and accurate measurements, which helps to improve overall system reliability and reduce mechanical and hydraulic impact damage due to component stress.

2. Key Learnings Summary

2.1. Intent

The main intent of this section is to provide a summary of all of the key learnings relating to the CAS/PVDS developed by Glencore Ferroalloys Waterval East Mine. The summary was compiled by disseminating documents provided by the Glencore Waterval Team at the start of the project, conducting site investigations, and engaging with the project team (Waterval East and supplier personnel).

This document contains a total of 43 key learning areas across 6 main categories (shown in Table 1).

Table 1: Key Learnings per Category

No	Category	Key Learnings	Section
1	Functional Design	Analog to Digital Equipment Conversion	2.2.1
		Antennae and System Components Positioning	2.2.2
		Elliptical Zoning vs. Circular Zoning	2.2.3
		Immediate Stop vs. Crawl and Stop	2.2.4
		Passenger Exclusions	2.2.5
		Zoning Accuracy	2.2.6
		Rapid Product/Component Development and Implementation	2.2.7
		Drill Rig Boom Avoidance/Inhibition	2.2.8
		Positioning of Indicator Modules	2.2.9
		Mine Exclusion Zones	2.2.10
		LDV Proportional Control	2.2.11
		Positioning of Tag Testing Stations	2.2.12
		PVDS/CAS Display Interface	2.2.13
		PVDS/CAS Scenario Design	2.2.14
2	Implementation	Multi-faceted Approach	2.3.1
		OEM Involvement in Installation Planning	2.3.2
		Spares Management and On-site Maintenance Support	2.3.3
		"Hot Seat" Installation of New System	2.3.4
		Change Management	2.3.5
		Adoption Through Empowerment	2.3.6
		Operator Assistance/Training	2.3.7
		Lamp Room "On-the-job" Training	2.3.8
		Full Stop Commissioning	2.3.9
		Upgrade of Personnel Tags	2.3.10
		Lamp Room Commissioning	2.3.11
3	Operation	Standardisation of TMM Hydraulic and Electrical Standards	2.4.1
		Maintenance Battery Limits	2.4.2
		Management through Infringement Reports	2.4.3
		Operator and Supervisor Training	2.4.4
		Include and Effective Management System	2.4.5
4	Testing	Interference	2.5.1
		Tag Obstruction	2.5.2
		Video Recordings	2.5.3
		First Person Accounts and Feedback	2.5.4
5	Impacts	Resolving Line-of-sight Issues	2.6.1
		Productivity Decreases	2.6.2

No	Category	Key Learnings	Section
		Unforeseen Costs	2.6.3
		Excessive Wear on Equipment Brakes	2.6.4
		Machine Reliability, Maintainability and Operability	2.6.5
6	Miscellaneous	Underestimation of <5m Human-Machine Interactions	2.7.1
		Main Purpose of System	2.7.2
		Perceived vs. Actual Proximities	2.7.3
		Current and On-going Developments	2.7.4

2.2. Functional Design

2.2.1. Analog to Digital Equipment Conversion

The PVDS was implemented on diesel-driven non-intelligent equipment at Waterval East Mine. The original challenge was that the TMMs were diesel-driven without any Electronic Engine Management systems (EEM) – thus, initially non-intelligent. This meant that controlling the vehicle's engines needed to be done mechanically or hydraulically. This was ultimately achieved through communication between the vehicle interface system and various hydraulic valves.

With the exception of the Drill Rigs, all diesel engines were Tier 0, non-CAN Bus controlled engines. One of the intended functions of the neroHUB was to upgrade the Tier 0 mechanical non-intelligent machines to a point where they could be electronically controlled by the third party PVDS system. The Waterval East Mine project transformed the entire "non-intelligent machine" fleet to an intelligent (speed and brake system controllable) one, by means of the neroHUB solutions. This solution offered the lowest cost of machine upgrade to a technologically aging fleet of machines. No engine upgrades or replacements were necessary.

Additional Notes or Comments:

Theoretically, installing a CAS on higher technology engines (higher Tier rated engines) would be easier. Electrical/electronic capability on newer engines would simplify control on the collision warning side and exerting control over "more intelligent equipment" would also be easier. However, since the PVDS project dealt with Tier 0 engines, no potential challenges, limitations or required changes in the approach can be foreseen at this stage that may result from working with higher technology engines with pre-installed electrical capability.

With that said, the perception that Tier 1 or above machines facilitate all of the controls necessary for Level 9 is incorrect, especially for underground machines. These machines generally facilitate only engine speed control and engine diagnostic reporting. Brake control, for example, is not included via CAN bus on mining machines.

When you expand the control elements needed for successful Level 9 implementation, beyond simply the engine, to include door switches, safety belts, braking systems, utility features (speed sensors, boom hydraulics, bucket hydraulics, drill control, cassette interfaces, SAHR braking systems), etc., then the challenge remains with interfacing to those systems. Underground machines with CAN Bus engines simplify the control of the engine throttle circuit, but generally do not facilitate any control of non-engine systems – including the braking system.

2.2.2. Antennae and System Components Positioning

All antennae on the equipment (LDV, LHD, UV and Drill Rig) need to be located in a suitable position to protect against mechanical damage, and not to hinder/impede any maintenance or repairs to the vehicle. The antennae use RF and as such need to be positioned where signal propagation from the machine is good, while being placed in optimal positions. In addition to the antennae, all system devices/hardware need to be positioned to protect against mechanical damage and not to impede operator visibility.

In the case of the LHDs, the positions suitable for the effective detection around were found to be highly vulnerable to damage. The dimensions of the LHD limited the locations where antennae could be positioned. Operator awareness of locations and repeated coaching and communication proved a valuable tool to reduce damages.

Additional Notes or Comments:
Sensor/antennae positions and orientations are important, but some misalignment in certain directions is acceptable and can be worked around. However, if a sensor is misaligned by approximately 90degrees, zone size and shape is affected significantly. The sensor locations are crucial to the zone shapes, but this is largely dictated by the type of sensing technology. Using a different sensing technology may allow more robust antenna/sensor positions, but the primary focus should be on using the most suitable sensing technology.

Furthermore, the risk is that some technologies are susceptible to other factors underground, such as electromagnetic (EM) interference from other systems (gas leak detection/telecom systems etc.). When using RF, the EM spectrum to be used needs to be planned, to avoid potential conflicts between intentionally radiating devices. All electrical/electronic equipment should undergo EMC/EMI compliance testing which greatly mitigates the risk of interference from unintentional radiators.

Theoretically a cage could also be installed around the sensors to protect them from damage, however, this will have an effect on the detection capability. Other sensor technologies might have to be used, which may have a cost implication. Non-conductive cages would need to be used. The PAS1000 system (the intelligence system from EiQ), operates using two distinct RF technologies, one in the Ultra High Frequency (UHF) band and the other in the Super High Frequency (SHF) band. Like almost all RF technologies, the antennae are affected by conductive elements close to them, so position and cages or holders need to be planned carefully. The pods currently used are fairly robust and the positioning of antennae does not pose significant issues. In future, a better way of addressing issues of mounting the antennae would be to collaborate with the vehicle OEMs for all new vehicles such that they provide dedicated mounting placements. This seems to be happening lately for new machine designs, but the problem remains for older mining equipment.

The antennae/sensors are also not installed inside the equipment bodies due to various obstacles with such an approach. For example, signal strength and delay through the body of a TMM, requiring increased signal strength which would result in increased cost. Also, finding appropriate positions and positioning for the antennae within a clustered body with limited mounting space is deemed infeasible. This is due to the fact that the closer the antennae are to each other, the more challenging it becomes for the algorithm to effectively pin-point location. If the antennae are on the outside of the TMM there is a larger distance between the antennae which in turn promote effective triangulation through time of flight and a resulting increase in the sensing accuracy.

Another aspect to consider was that significant training and coaching was required in the early stages of the PVDS project to keep the hydraulic fitters from throwing grills (on which the sensors were initially installed) to the ground. A change management approach was necessary to modify this behaviour and to treat the antennae with more care, thereby reducing damage to them.

An indicator light is also installed on the front of the LHD, indicating its status of interaction with other sensors (vehicles or pedestrians). On LDVs, this indicator is installed on the rear. Positioning of these indicators is important as they should allow maximum visibility to pedestrians and should not create a visual obstruction for operators.

2.2.3. Elliptical zoning vs. Circular zoning

The traffic management plans underground strives to separate pedestrians from TMMs. The environment however limits the area available and certain walkways are next to designated main roadways. The original zones around each LHD lead to a number of unnecessary nuisance interactions (in conjunction with the traffic management plans). By using the six-antennae setup the zones around the LHD was changed to allow for elliptical zoning (Figure 5). Elliptical zoning is only provided on identified high-risk machines. The current setup on LDVs is circular. While this might not present an impact on production, it may definitely cause nuisance alarms to LDV operators.

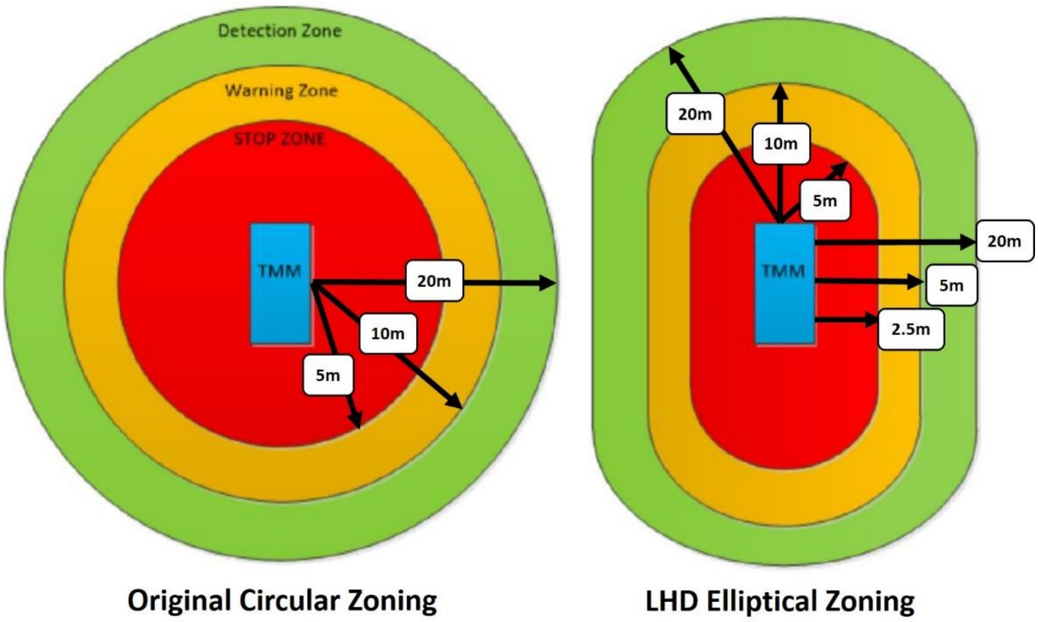

Figure 5: Circular Zoning vs. Elliptical Zoning (Adapted from Murley, 2018[4])

The elliptical zoning on the high-risk machines reduced the nuisance interactions considerably without reducing the safety of detection on the system. The continuous improvement of the underground traffic management plan also reduces the possibility of interactions between pedestrians and TMMs.

Additional Notes or Comments:
This is an important aspect to "get right" in order to allow for permitted travel in close proximity of equipment without leading to equipment stopping and/or crawling. The current elliptical zoning is effective in reducing nuisance interactions, however, it is static and as such poses some limitations (see Section 3 on Proving Ground Testing). The algorithm also introduces an additional 100ms of latency in the detection of targets inside the warning & critical zones.

Currently, the PVDS at Waterval does not have dynamic zoning. However, dynamic zoning has been tested and accepted by Waterval East and the vehicles are scheduled to switch over from static zoning to allow improved efficiency in managing vehicle interactions. The focus of the dynamic zoning to be implemented, is to reduce nuisance (unwanted and unwarranted) stoppages, by adapting the "danger zone" around the TMM to only be taken as in the direction the piece of equipment is travelling. Thus, the "rear" and sides would have smaller "danger zones" to reduce potential interactions with other equipment or pedestrians. This would, as a result, reduce negative impacts on production.

The PVDS systems fitted to drill rigs, also implement a semi-circular zone to the front of the machine when drilling. This keeps pedestrians out of the active boom area, where the drilling is taking place. The zone to the rear of the machine is much smaller, since this area is safer.

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[4]*Murley, R. 2018. Trackless Mobile Machine Collision Avoidance System at Glencore Waterval Mine. Whitepaper. Glencore Alloys South Africa (Pty) Limited. Waterval East Chrome Mine*

2.2.4. Immediate Stop vs. Crawl and Stop

Controlled Stop was successfully implemented through a combination of both slowdown and motion inhibiting sequencing. In particular, crawl mode (slow down) triggered an engine retardation stage and stop (brake) triggered an 'as fast as possible' braking application. This combination of crawl and stop capabilities offered four significant benefits over immediate stop systems:

- Retardation of the machine when in close proximity to an interactor pre-warned the operator of an imminent stop or braking event.
- Operator comfort was greatly improved due to the less violent nature of a stop event in most cases, since the machine had already slowed down to a crawl speed ahead of the stop event.
- A reduction in brake wear, and less mechanical impact damage was achieved in comparison to a forced uncontrolled stop from higher speeds. This was especially significant, since a high increase in brake wear was still observed once the system was fully activated.
- Limited maximum brake applications on certain machines required that the machine be brought to a complete stop, or hydrostatic swash plates be returned to their neutral positions, before emergency brakes could be applied. The pre-stop slowdown phase facilitated this in many cases.

Additional Notes or Comments:

The addition of a slowdown phase prior to the automatic stop intervention has numerous advantages, but it also provides for a degree of uncertainty. The deceleration from "normal driving" speed to crawl speed during the slowdown phase varies. Factors that influence the deceleration include load, gradient of travel, gear selection and drive type (electrical vs. hydrostatic drive). With the current static zones, this uncertainty requires that the zones are large, with a resulting negative impact on production. There may be potential to use more information, potentially available from the neroHUB, to make the zones dynamic and more intelligent, resulting in a safe system with a lower impact on production.

Refer the Section 3 for information on the repeatability of the slowdown phases from speed to crawl to stop.

These resulting measures and their effectiveness, for collision mitigation, are impacted by various factors, such as the loading on a TMM and the gradient the TMM is travelling against. To allow for these factors, the PVDS is designed to function safely under certain prescribed loading conditions as in accordance with ISO3450[5] and SANS1589[6]. In this regard, the static zones are designed to account for worst case scenarios – which means a fully loaded TMM down a decline.

The upcoming dynamic zoning algorithm would increase the zone size by a small amount when travelling down a gradient. The calculations show, however, that, for the gradients found at Waterval, the change in stopping distance of the machine is not significant.

The upcoming implementation of Dynamic Zoning will also only take the speed of the TMM into account, but not the loading or orientation.

2.2.5. Passenger Exclusions

Passenger and driver exclusion on LDVs are facilitated by a card reader module, which reads the clock card presented by the passenger and determines – via the detection of the cap lamp tag issued to the specific employee – whether that employee is situated inside the vehicle. Originally the position of this card reader was next to the

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[5] *Online reference: https://www.iso.org/standard/42076.html. Accessed 18 June 2018*

[6] *Online reference: https://store.sabs.co.za/pdfpreview.php?hash=8ac2fcd5f3b26a9dd70aef2bfe9fb35b91b059b9&preview=yes. Accessed 18 June 2018*

steering wheel in front of the driver. This position made it difficult and time consuming to exclude passengers as the driver needed to retrieve the clock card from each passenger and exclude them manually. By moving the card reader to the centre of the cabin, between the rear passengers and the driver, the ergonomics of the process was improved.

Additional Notes or Comments:
Exclusion of the passengers and driver is done manually, as opposed to using automatic exclusion zones “within” a vehicle, and personnel tags need to be on the wearer’s chest (to ensure optimal signal strength so tag exclusion is not lost). This approach to exclusion is to prevent a pedestrian in close proximity to the vehicle from synchronizing with the vehicle PVD system – this allows improved authentication that the person wearing the “kit” is the person who is supposed to wear it and also allowed to be excluded.

Several instances occurred when pairing between vehicle PVD system and passenger/driver was lost during travel. As a result, an emergency stop is executed and all passengers and driver need to resynchronize (be excluded in order to allow the vehicle to travel again). It was claimed that this issue had been resolved on newer models of the card reader.

Cards are also not provided with lanyards or other fastening devices, which results in personnel putting the cards in their overall pockets. In the uncomfortable seating position, this results in a lengthy search for the correct card and may unnecessarily increase travel time – or cards could potentially be dropped/lost.

2.2.6. Zoning Accuracy

Originally, the LDVs and UVs were only fitted with three antennae. This provided sufficient detection around the immediate vehicle, however the accuracy of the system was impaired. By adding an additional antenna, the triangulation process could be completed with an increased base set point, tailor made to the dimensions of the LDV/UV, resulting in improved accuracy of the detection system. The LHDs are fitted with six antennae to ensure the accuracy around the TMM is maintained at all times, and also to allow for elliptical zoning.

Additional Notes or Comments:
The triangulation process is tailor made for the vehicle dimensions. The six-antennae arrangement is only on the identified high risk TMMs, in order to provide increased accuracy in tracking surrounding tags. A common misperception is that an increase in antennae numbers increases detection capability, but it is actually simply to improve the geographical orientation of the target. As long as a signal can be received, the distance can measure through Time of Flight (ToF). Figure 6 provides an overview of the ToF concept.

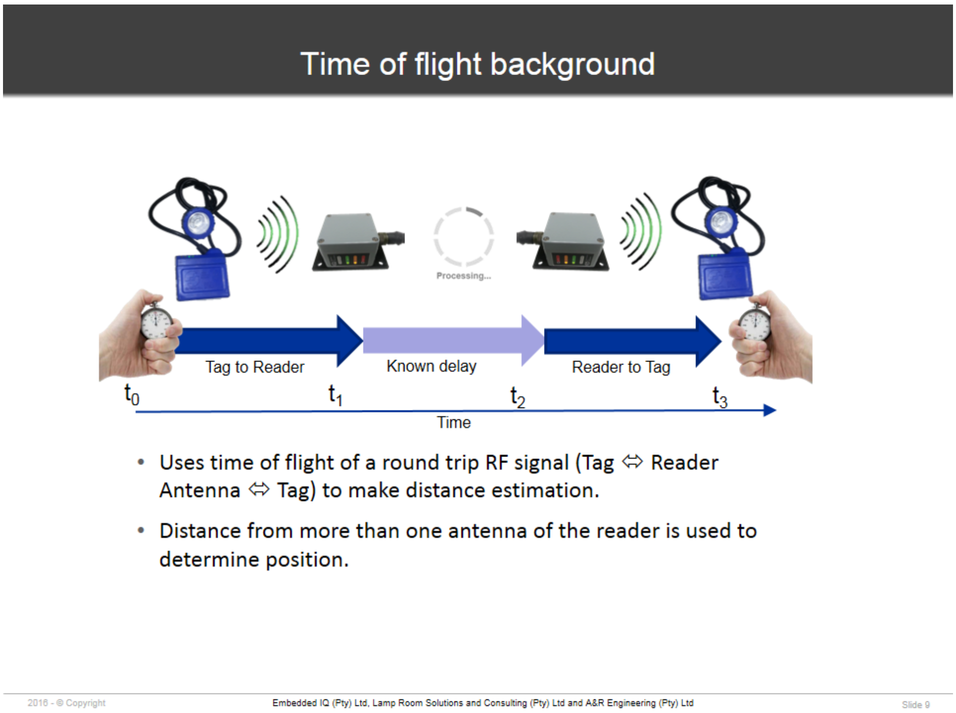


Figure 6: Time of Flight explanation (Lishman, 2018[7])

2.2.7. Rapid Product/Component Development and Implementation

The PAS1000 vehicle system is a complex interconnection of modules working together to perform a complex task. In achieving these tasks, while being allowed to exert control over the OEMs, the neroHUB is the central part of the system implemented which provides instructions from the intelligence in the EiQ component to the machine. For this interconnection to function effectively, additional products were custom designed by Nerospec to overcome some of the initial problems experienced during the initiation stage of the Waterval project, these are:

- **neroCRAWL** is activated by a train of electric pulses to de-energise a rare earth magnet, effectively triggering the unit into the derating state. Derating of the throttle is achieved by extending the length of the throttle cable. The unit is reset by releasing, then engaging the accelerator pedal again. The unit will reset if the TMM is travelling below the crawl or safe speed programmed into the neroHUB. The neroCrawl is controlled by Nerospec's neroHUB controller and if required will work with other industrial vehicle controllers.
- **neroGEAR** is an intelligent semi-automatic gear change unit that facilitates automated gear down for CAS crawl and stop and Speed-Brake Interlock functions. The neroGEAR is used for two primary applications – to control the gears by a push button of the joystick and to gear down the TMM into crawl mode and ensure it is in the correct gear for operation where the torque convertor is engaged.
- **neroRELAY** is a purpose-designed auto-electrical product, engineered to protect vehicular electrical systems from inadvertent wiring faults. It was designed to work in conjunction with the neroHUB to improve the longevity of the system during the operation and/or maintenance of the machine side installation when electrical wiring faults were likely to occur. The neroRELAY performs the same function as an ordinary automotive relay, with several specialised advantages. It was developed to interface reliably and repeatably into pre-existing third party auto-electrical systems, even when those systems are potentially faulty or compromised after installation by third party electricians.
- **neroWEAR** makes it possible to monitor brake wear electronically, in real time. The advent of automated crawl and stop has resulted in TMMs being stopped more frequently than during normal conditions,

[7] *Lishman, R. 2018. Combined effort slides between EiQ, LSC and A&R Engineering*

requiring an increase in the frequency of inspection periods. The neroWEAR is designed to complement the Crawl and Stop system by providing an early warning of excessive brake wear.

- **Proportional Hydraulic Throttle Closed Loop Control** was jointly developed between Nerospec and GHH mining machines to facilitate proportional engine RPM control on Tier 0 non-EEM controlled engines. These are the most common engines found on underground LHD's in operation in the Glencore group. It avoids the mine having to replace older engines with newer EEM controlled engines. Achieving proportional control of the engine RPM on Tier 0 engines using fuzzy logic PID control of proportional valves was a significant achievement. It demonstrated to the OEM's that Nerospec could assert accurate RPM control on non-EEM controlled engines in a fail to safe manner. This contributed greatly to the acceptance of the neroHUB by many of the OEM's as the principle CMS interface solution.
- **neroRADAR** is a hybrid speed measurement device used to determine the travel speed of a mining machine in a reliable and non-mechanical way. It is used on all of the Waterval Hydrostatic drive train machines, such as the RHAM Utility vehicles. This was necessitated by the challenges or high costs associated with measuring travel speed on hydrostatically driven mining machines. It utilises doppler radar in the underground environment and switches to GNSS based speed measurement on surface.

Additional Notes or Comments:
Impressive development of "on-the-fly" solutions (with the IP owned by Nerospec. These solutions, or some of them, may not be necessary on newer and more 'intelligent' equipment.

neroCRAWL
neroCRAWL is implemented on all machines that have steel cable-controlled throttle pedal systems. They are installed between the foot pedal and the engine throttle cam. This avoided the requirement to replace engines on such machines. Examples at Waterval include the Toyota LDVs and personnel transport vehicles. Since neroCRAWL does not alter or change any brake or associated component, there are no concerns with certification amendments. All of the Nero-solutions are only installed if they have OEM approval, so as to not affect OEM warrantees. The LDV's braking systems are also certified against the SANS 1589 SANAS requirements specifically for mining machines. Nerospec then provides after sales service on their own components.

neroGEAR
neroGEAR is not used at Waterval East. However, the neroGEAR was specifically designed to allow gear selection limitation, as well as to allow the machine slow down to be assisted by gearing down the engine speed to wheel speed transmission. In the case of the machines at Waterval, none of the transmissions were electrically controlled, which is why the neroGEAR was not used on that installation.

Forcing diesel equipment to operate in lower gears, so as to reduce the maximum speed the TMMs can reach and thus have improved CMS control, would have other implications that should be assessed as well. Points to consider may include increased diesel particulate matter emissions, higher ventilation requirements due to higher unwanted emissions and higher equipment operating temperatures, increased mechanical wear/failure etc.

neroRADAR
At Waterval East Mine, the speed of the TMMs is obtained in various ways, i.e. speedometer gear pickup from the transmission for LHDs, speed pickup on transmission for LDVs, and by using the neroRADAR (radar speed sensor) on the UVs and Drill Rigs.

On top of this, a "5th wheel" is also installed that is an inertial speed sensing system that senses the speed of any vehicle by means of a battery powered device mounted to the wheel itself and a stationary sensing unit that is fixed to the vehicle. Using a combination of sensors, the devices measure the speed of rotation of the wheel, allowing the speed of the vehicle to be measured, as well as its pitch and roll. This device was developed to add redundancy to the speed measurement, given how critical the speed is for determining zone sizes.

The 5'th wheel is used in addition to the neroHUB speed sensing for reliability purposes. This becomes increasingly important when the PVDS system makes use of vehicle speed to determine zone sizing dynamically. It is not a case of "either or", but rather a case of both speed sensors such that the LSC system can compare measurements from 2 disparate sources. In the event that the sources do not agree, the LSC system can force a permanent crawl mode, or even a machine brake lockdown.

There have been failures of 5'th wheels and of neroHUB speed sensors in the past. The operating conditions of these machines dictates the use of dual sensors for such arduous operating conditions, especially if their measurements are to be used as input to safety in critical dynamic zoning.

Effect on support & warrantees from the OEM due to Nero solutions installations

This varies from OEM to OEM, depending on their existing in-place method of support and warranty, as well as the nature of the modifications made to the machine. For instance, many of the machines at Waterval mine are rebuilds and section 21 legal responsibility has already been transferred from the original machine OEM to the re-build companies. In general, however, Nerospec has established specific support for the machine modifications from the OEM's and has letters of support and technical service schedules from the OEM's such that they warrant the modifications. Nerospec also encourages the machine-side hydraulic and electrical modifications and item supply to the machines to be carried out by specific representatives of the OEM's themselves. This was certainly the case at Waterval mine with Sandvik and RHAM Mining Machines. In the case of the AARD and GHH machines, Nerospec obtained permission from the OEM's to make the modifications.

neroHUB override feature

The neroHUB also provides for an override function of the CMS/PVDS. It thus needs to be activated to achieve L9 control, although it never overrides operator control. Furthermore, the neroHUB action can be overridden through a Nerospec tablet (any Android tablet with Wi-Fi and the relevant software). This potentially presents a Cyber-attack / hacking risk, which should be managed accordingly to avoid potential attacks, control and misuse of this function – although this override feature only works by line-of-sight Wi-Fi connection.

Nerospec has multiple mechanisms are in place to mitigate against abuse of the override features of the neroHUB. Currently supported mechanisms employed include:

- All override activities are recorded in the neroHUB's deep memory and are reported in the neroHUB machine analytics reporting tools.
- The wireless connections to the neroHUB are WAP2 encrypted and require a unique password to be supplied per machine before connection is made possible.
- The tablets retain standard Android user login password techniques to limit, or at least assign a specific user to any use of the tablet. This is in addition to the separate connectivity password mentioned above.
- neroKEYs require that an iButton key assigned to a specific user is used to place the machine in override mode. The machine is returned back to normal mode (non-overridden) whenever the ignition is cycled, requiring a repeat override function to be performed.
- In the case of a mechanical lock, only specific personnel trained in the use and risks of the override function are issued with physical keys. This system is being gradually retired in preference for the individual person's iButton neroKEY method at the Waterval installation as part of the continuous improvement exercise.

2.2.8. Drill Rig Boom Avoidance/Inhibition

Boom inhibition: To make use of the PVDS to create an effective electronic barrier around the moving parts of machinery to prevent any person coming into contact with the boom or rotating drill steel.

Additional Notes or Comments:

This feature is already installed on all Waterval Drill Rigs. It has been tested, vetted, signed-off and is operational.

2.2.9. Positioning of Indicator Modules

The indicator module is an encapsulated LED light, displaying the current system status in order to ensure that the pedestrians receive feedback of the vehicle status:

- Green – Go (Safe zone)
- Orange – Go but (Warning zone – retardation zone/crawl zone)
- Red – Stop (Critical zone)

Currently, there are three different indicator modules with lights in use at Waterval:

1. The LSC encapsulated beacon light visible externally to the machine. This is used to give pedestrians feedback on the status of the machine.
2. The neroSTAT RED, GREEN, ORANGE LED lights inside the cabin. This is used to inform the operator, attendants, mechanics and the auto electricians on what the state of the machine is.
3. The newer neroKEY 7 LED cluster, which replaces the original 3 LED neroSTAT indicators and adds information regarding overspeed status to the indicator array.

Additional Notes or Comments:

Currently all TMMs at Waterval East have one indicator module installed. On the LDVs the indicator modules are only situated on the back of the LDV. While the other TMMs generally have the modules installed either in front or behind the operator cabin, depending on functional requirements per vehicle type and to attempt maximum visibility of the module by pedestrians.

The visibility of these indicator modules depends on the type of vehicle, actual vehicle field of view and layout. It should be noted, however, that having only one such module did not seem to provide optimal visual indications to surrounding workers. Still, these modules have the primary function of displaying the PVDS or vehicle status, i.e. Detection, Warning, or Critical, but not to serve as a warning to prevent incidents.

2.2.10. Mine Exclusion Zones

Every tip is equipped with an exclusion beacon and a safe zone. Only when all designated employees are in the safe zone, will the LHD be allowed to enter the tip area. The tips are used as waiting places and if pedestrians, who should not be at the tip, are in the area or in close proximity, nuisance stoppages are caused. To prevent this, supervisors need to ensure only employees that are designated are allowed in the tip area. During the commissioning or installation of a new tip, LSC needs to be notified to ensure the relevant beacons are installed. With commissioning of a new tip, the exclusion beacon must be included.

Every workshop is fitted with an exclusion zone for authorized maintenance personnel. These zones are in place to ensure that maintenance can commence effectively. Once a vehicle enters or exits the zone, the system will require acknowledgement of the entry or exit from the operator. If the operator does not acknowledge, the vehicle comes to a full stop. There was no delay in this action which meant that every time a TMM entered or exited the exclusion zones it would stop. The OEM altered the firmware to allow for a delay in acknowledgement to prevent unnecessary stoppages.

Additional Notes or Comments:

Currently, an emergency vehicle still needs to abide by the rules and will need to crawl past another TMM. The reasoning behind this is that an “ambulance” should not injure other pedestrians on its way to an emergency or to treatment. The system can be changed to site specific requirements. Furthermore, during life threatening situations, the PVDS equipment can be bypassed and TMMs can function normally (without CMS) if required to do so.

The exclusion zones visited functioned impressively and according to requirements. Areas were managed as exclusion zones when there are high levels of unavoidable interaction between pedestrians and equipment. On top of workshops and tipping areas, refuelling bays are also managed as exclusion zones.

Prior to the PVDS implementation at the tip, the mine relied on a traffic light system, where the LHD operator would follow instructions from the tip attendant via the traffic light signal.

A technician attending to a breakdown, can be excluded from the machine for live testing purposes under controlled conditions after the relevant permit has been issued. Technicians may be issued with a device in the lamp room called and “exclusion handheld”. This device is linked to the technician and functions as a portable exclusion zone for only the technician (i.e. no other tag can be excluded). The exclusion is easily cancellable and is cancelled if the exclusion handheld is dropped or tilted beyond a horizontal level. This means that if a technician is walking alongside a vehicle and trips or stumbles, the exclusion is cancelled and the PVDS reacts to the detected proximity as usual.

2.2.11. LDV Proportional Control

The diesel driven cable accelerator LDVs proved to be challenging to control proportionally, due to the accelerator cable and mechanical throttle movement being limited. To provide successful and controlled proportional control the following solutions were investigated:

- **Solenoid actuator control with throttle by wire**: By controlling the throttle electronically with an actuator installed on the mechanical mechanism the throttle and response can be controlled by the neroHUB interface unit depending on the physical position of the vehicle, whether it be incline, decline or strike position. This option, however was a costly solution.
- The second solution was a **mechanical tube fitted with an electro magnet** which responds to an output signal from the interface unit. The solution was developed by Nerospec. The magnetic tube inserted in the throttle cable then expands or retracts the physical length of the throttle cable and thereby provides effective control during the crawl phase. This unit was investigated and installed, the device is known as neroCRAWL.

Additional Notes or Comments:

The reason for not implementing a throttle by wire in the beginning was because no highly reliable and fail-to-safe third-party throttle control solution was commercially available at the time of implementation. Nerospec has since developed a neroSERVO device, which is intended to control Glencore Maubra machines in the Eastern limb mines. These devices are currently being prepared for the OEM test and evaluation phase of implementation. They operate in a strictly fail-to-safe proportional servo mode, but were not available at the time of installation at Waterval mine.

Conventional servos cannot be used, as electrical or mechanical failure could leave the throttle in the fully open position. Nerospec spent 3 years developing and testing the new fail to safe neroSERVO to mitigate this risk.

2.2.12. Positioning of Tag Testing Stations

Ensure that the installation of the tags and testing stations inside the lamp room is ergonomic for all employees. Some testing stations were installed too high for certain employees, delaying the testing process.

2.2.13. PVDS/CAS Display Interface

The PVDS interface on the equipment is divided into four quadrants. The quadrant in which the TMM or pedestrian is changes colour and displays the distance to the other TMM or pedestrian. Pedestrians are displayed as dots on TMMs equipped with 6 antennas, with different colours assigned to different classes of pedestrians, e.g. excluded operator and other pedestrians.

Additional Notes or Comments:

On one of the machines, a demonstration was done to show how the display indicates both positioning and distance to pedestrians within the zones of the equipment. This worked very well. The colours of the dots, indicating pedestrians and the excluded operator, did however not display as they should, as was described by the team member present. This does not affect the functionality or safety of the system, but indicates continuous system and/or software updating and improvements as with any technology system. Expect after-care.

2.2.14. PVDS/CAS Scenario Design

Designing for various vehicle-to-vehicle (V2V) and vehicle-to-person (V2P) scenarios underground, was initially done by referring to and modifying guidelines for surface collision management systems. The majority of the scenarios at Waterval, were designed on a “common sense” basis to attempt covering highest risk scenarios. These are combinations of straight line V2V (forward and reverse), V2P (forward and reverse), junctions and crossings, and human machine interaction zones at the tip, drill rig, workshop or waiting area. The speed is limited to 8km/h for an LHD and 12km/h for an LDV.

Additional Notes or Comments:

It should be noted that CMS/CAS products are generally designed for set requirements as indicated above. Operating outside of these boundaries require renewed trials, testing and refining of the solution (e.g. providing CAS at higher machine velocities).

2.3. Implementation

2.3.1. Multi-faceted Approach

Nerospec commented on mine employee participation – success of this type of project is only 20% based on engineering functionality: awareness, technology, installation and maintenance. The remaining 80% of success is based on the mine operational adjustments such as traffic management, roadway conditions, employee acceptance to change/participation and implementing and maintaining discipline. The technology alone does not present a “silver bullet” solution. It must be combined with careful adjustments to operational environment and continuous training and coaching of the mining personnel, in order to achieve a successful and effective Collision Avoidance System.

Additional Notes or Comments:

Ensure operational readiness before any technology implementation.

When implementation took place at Waterval, there were no guidelines from bodies such as MOSH and the Minerals Council of South Africa. The question that may be asked in the future by an inspector is why another mine has followed Waterval’s trial and error approach, rather than relying on the guidelines now provided by these bodies. In this regard, it may be worthwhile noting that combining lessons learnt at Waterval with the newly formulated guidelines may result in a smoother commissioning phase, which could reduce the impact on productivity and result in a fully functional system in a shorter time frame.

It is then noteworthy that Nerospec and Glencore Waterval Mine has been collaborating in writing up such a guideline, incorporating the knowledge obtained in the Waterval PVDS project with the more recent guidelines from EMESRT. Part of this guideline is outlined in Section 1, which represents the phased-approach taken to achieving activation of a CAS/CMS.

2.3.2. OEM Involvement in Installation Planning

Some delays during the installation process of the project were due to the delay in delivery of materials and equipment from the OEMs. The project timeline was optimistic – it was learned that planning needed to be done according to OEM delivery schedule.

Additional Notes or Comments:

Include the OEMs in the planning process and apply Theory of Constraints thinking in planning, in order to identify and subsequently alleviate bottlenecks. Some OEMs are unfortunately not happy to sit around the same table or work together with a supplier that wishes to install a device that could exert control over their equipment or impact the integrity of their product in any way. Since no implementation can be done without OEM buy in, it is a fundamental part of the process to manage effectively.

Penalties can be imposed should an OEM not come to the table. However, this process needs to be managed correctly and carefully to avoid souring relationships. It is therefore important to create sufficient understanding of why their approval of third party equipment is required and to allow sufficient assessment to be done by the affected stakeholders. Passing on and/or accepting risks have to be carefully assessed and defined in the given context of such a project. The key to success with OEM’s was noted as identifying and making contact with the right persons, at the right locations around the world and then to drive the solutions in close working relationships with those right people. Building and maintaining respect and trust coupled with technical excellence is the only way to achieve collaborative success.

Another point to consider for future similar projects is that OEMs may increasingly start installing their own PVDS systems or use a preferred PVDS supplier (or interface supplier) on their equipment. This would also affect communications in future once OEMs decide to go this route.

2.3.3. Spares Management and On-site Maintenance Support

The consignment stock spares management needs to be in place before the project is initiated. This will prevent unnecessary downtimes and delays due to stock not being available on site. Maintenance personnel from OEMs and spares need to be arranged and planned before the commencement of the project to reduce delays and provide the required flexibility throughout the project execution. Various teams need to work together to report correctly and repair effectively any problem that arises. The “blame” culture needs to be avoided at all costs.

2.3.4. “Hot Seat” Installation of New System

The installation of the new system took place, while the previous proximity detection system was fitted on the TMM. This is necessary to ensure that the new system is fully installed on the entire fleet, to ensure that when all the tags in the lamp room is changed to the new system, the TMMs can be converted to the new system in a short period of time ensuring that effective warning and detection is maintained during the installation and commissioning process.

Additional Notes or Comments:

This approach was important in order to ensure that there is no “dark” period. The project team must ensure that the risks during the changeover period is managed. While this “hot seat” installation was done with the previous Becker system, it was noted that any previously installed system should allow for a “hot seat” changeover.

2.3.5. Change Management

It is of utmost importance that the mine team (especially production crews) need to buy into the system and take ownership. As the employees bought into the new system, they adopted a new philosophy and a drastic change in behaviour was clearly evident. In order to create buy-in and ownership, it was found that establishing goals with associated rewards (when targets were achieved) assisted in the change management process.

As anticipated by the project team, after activation, the machine operators themselves became crucial ambassadors toward the success of the project. A culture of encouraging personnel to avoid moving close to the machines was strongly adopted by the operators. Section leaders, co-ordinators, shift bosses and management personnel adopted the system as a significant improvement over the pre-existing traffic management and personnel pedestrian rules. It gave them increased peace of mind that the personnel safety, whose safety is under their charge, was enhanced by the continuous monitoring and intervention capabilities of the system.

The operators used hand signalling, verbal communication and cap lamp signalling to discourage pedestrians from coming within 10 to 5m of the machine. This was self-perpetuating since the operators naturally wanted to avoid their machines from stopping automatically, and thereby preventing them from completing their work efficiently.

Additional Notes or Comments:

A change management strategy is critical. It is also important to create shared ownership to improve successful adoption of a technological system impacting on human behaviour. It was further noted that the line supervision from top to bottom needs to drive the system. The employees working with the system need to be continuously motivated from their direct supervisors. If any of these line supervisors are not on board, adoption of the system gets hindered and implementation takes much longer.

Initially, cases of sabotage included pulling wires out and breaking off of antennas occurred. Currently, no sabotages are reported anymore. What played a role in this is that the system keeps a log of all pedestrians in the equipment vicinity and it is easy to pinpoint culprits.

At the time of this report it was around 18 months after rollout of the PVDS. The general employee feedback was noted as positive at this stage. They are seemingly more at ease with the new norm and the system further also allows for more effective traffic management, due to the fact that traffic management can now be measured. The amount of usable information obtained by the system can be used to manage an array of things.

2.3.6. Adoption through Empowerment

Empowering each of the pedestrians with the ability to stop the machines in proximity to them, simply by inverting their personal cap lamp tags, encouraged adoption by the non-operator personnel. They had intervention control of machines in their proximity for the first time in their careers, and this was well received by all personnel.

Additional Notes or Comments:

The employees have a tag in the wire from the cap lamp battery pack to the lamp. This tag must preferably be on the wearer's chest. The tag has several lights and an audible alarm. If the pedestrian enters into an unsafe area in close proximity to a TMM, the alarm will sound and the cap lamp will start flashing.

The pedestrian tag is also equipped with an emergency stop that will halt all TMMs within a pre-set radius (modifiable range) of the tag. The emergency stop is triggered by inverting the tag (180°) and keeping it in that position. When on surface or in a vehicle (areas where a hardhat is not required), it may trigger a global emergency stop if the tag hangs upside-down. Emergency stop activations are logged and malicious use thereof can be seen and addressed. However, no significant negative impact due to excessive global stops have been identified.

The system forces employees to avoid vehicles. If they want to 'make use of' or 'depend on' the system they will cause excessive stops and this will influence production, which will cause the employee behaviour to be flagged and it also will cause friction between the operator and employees with this behaviour. From the reports it could be seen that the system in fact strengthens vigilant behaviour, which can in part also be attributed to employees coaching each other not to interrupt one another's activities.

2.3.7. Operator Assistance/Training

When the TMM stops repeatedly and no one is available to assist the operator, they become frustrated with the system. It is thus important that the OEM have sufficient support staff on site and that Glencore supervisors as adequately trained to manage these situations. Additionally, the operator needs to be adequately trained to visually determine the condition of the machine from the information given on the display unit. Traffic management also plays a large role in these types of interactions and stoppages that cause frustration among operators.

Additional Notes or Comments:

The "training wheels" phase was critically important. Since this was the first site where a project like this was implemented, the phase lasted in the region of 2 months. The more time is spent with proper training the smoother the transition phase from an inactive to active system will be.

2.3.8. Lamp Room "On-the-Job" Training

During commissioning of the Comprehensive Mine Management System (CMMS), a team of occupational instructors were deployed in the lamp room providing "on the job" coaching and training that ensured employees are trained and confident to use the new system. Only after system functionality and competence was verified, was the system interlocked to start enforcing procedures and business rules. Both system specialists and instructors remained on-site to ensure there is minimum impact on production.

During commissioning and operational phase, some employees "fell through the cracks" and were blocked and not allowed to exit the lamp room due to them not correctly issuing their equipment back to the lamp room. Contractors making use of spare lamps issued to them for the shift exited the mine, upon reaching surface no lamp room personnel were on site. These contractors were stuck in the lamp room until personnel returned to receive their cap lamp and self-contained self-rescuer.

Additional Notes or Comments:
It was found that on the job training was the most effective way to ensure that everyone understands how the system works in practical conditions. The risk involved with this system necessitates effective training. It can be simplified to be self-explanatory, however, this is not an effective method of training in the current environment.

2.3.9. Full Stop Commissioning

Once TMMs were fully commissioned, they would be operational with only detection and warning active. This refers to "site readiness". The logic behind the incremental activation of crawl and stop on the TMMs was to allow flexibility and reduce the impact on production. The challenge however is that once a vehicle is only running on detection and warning, the system does not apply any self-diagnostic tools to the inactive system components. Once the section where the TMM needed to work was ready for activation, the bypass was removed resulting in the system running self-diagnostics. The system would then identify faults that needed repair before the TMM could be used, resulting in repeated rework and TMMs jumping from active to inactive stop during the production shift.

It is crucial to activate all TMMs as soon as possible during this process. In active mode the system continuously verifies the status of equipment, once some part of the system becomes unhealthy it is clearly communicated and can be repaired with the minimum amount of downtime. While TMMs are inactive, reporting on machine condition relies solely on operators who themselves are still new to the system.

2.3.10. Upgrade of Personnel Tags

The old Becker CAS system tags had to be fully replaced by the new system and tags. Double system tags on a cap lamp caused a quicker burn down of the battery, where cap lamps discharged completely within a shift. The remedy for this issue was as follows:

- Complete all hardware installations except for the installation of the new cap lamp tags.
- Make use of a long weekend or break period to complete the installation of all new tags and switch over the entire cap lamp stock.
- Spare cap lamp equipping. Ensure all spare cap lamps are equipped and that only equipped and commissioned cap lamps are issued to contractors and visitors.

2.3.11. Lamp Room Commissioning

- The instructors and trainers were on site.
- Commissioning went very well.
- Some employees fell through the cracks and were blocked and not allowed to exit the lamp room due to them not correctly issuing their equipment back to the lamp room.
- There must always be lamp room personnel present.
- Contractors making use of spare lamps issued to them for the shift exited the mine, upon reaching surface no lamp room personnel were on site.

Contractors were stuck in the lamp room until personnel returned to receive their cap lamp and self-contained self-rescuer.

Additional Notes or Comments:
Waterval changed over to a fullco three shift lamp room which addressed the issue of attendants not being present when required.

2.4. Operation

2.4.1. Standardisation of TMM Hydraulic & Electrical Standards

Every type of TMM needs to be maintained according to hydraulic and electrical drawings and kept up to standard at all times. When two TMMs of the same type are not wired according to the same drawing or hydraulically hosed according to the same drawing, it complicates the installation and fault-finding process. Ensure that all TMMs are maintained in accordance with a set standard.

Additional Notes or Comments:

This was a very important aspect to ensure effective and efficient maintenance. Every machine must be maintained to adhere to a set standard for the vehicle type.

Each OEM equipment has OEM recommended wiring, hydraulics and maintenance programmes. These need to be adhered to, to ensure the vehicles are similar and thus easy to maintain

Key Questions: Are there any other machine standards that this rule would apply to?

What about newer technology engines then? Do they come with their own OEM standard?

2.4.2. Maintenance Battery Limits

The PVDS consists of three systems to be maintained, namely:

- Glencore TMM – Auto Electrical, Hydraulic and Mechanical maintenance.
- LSC PVDS – Electronic Maintenance.
- Nerospec Interface Solution – Electronic Maintenance.

With three entities working on the same equipment, reporting of breakdowns become challenging. Various situations arise where one party blames the other and no one takes accountability. Incorrect reporting also exacerbates the situation and increases downtimes of vehicles unnecessarily. The battery limits (Figure 7) of each role player must be clearly stipulated and the team must function together and not in isolation.

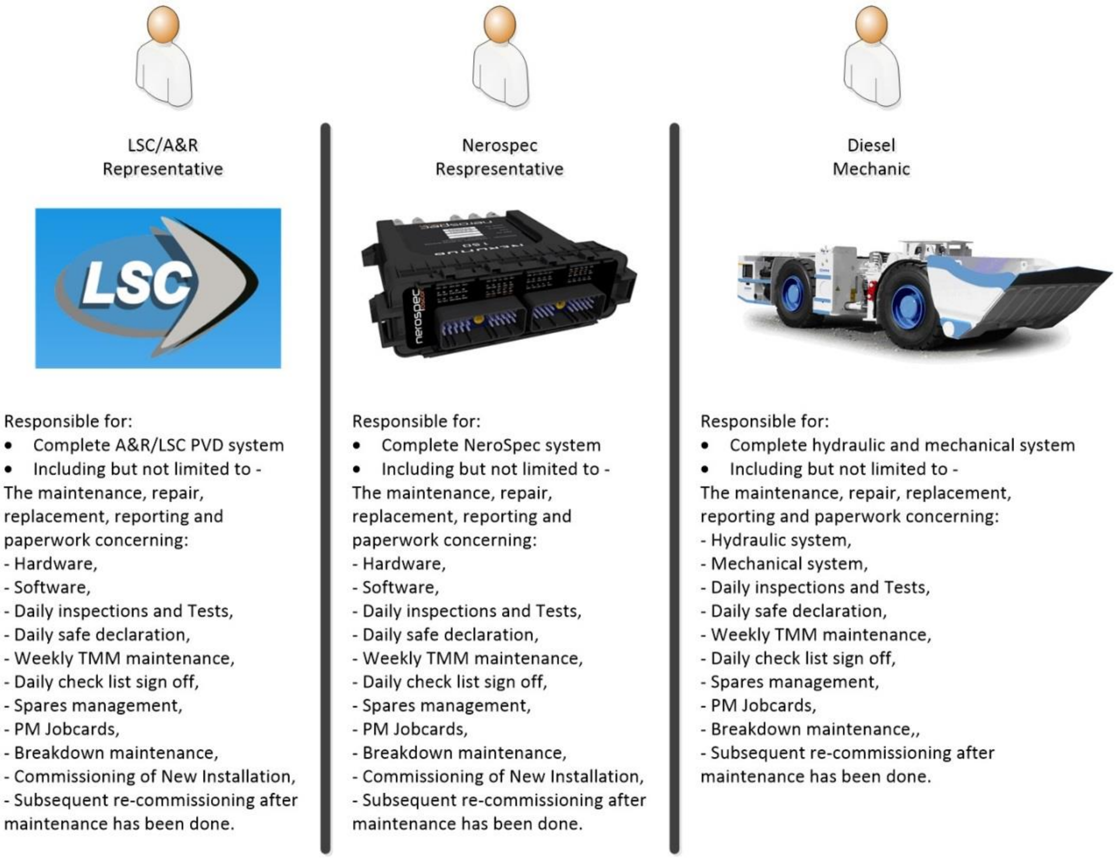


Figure 7: Maintenance Battery Limits & Responsibilities (Waterval Mine, 2017[8])

2.4.3. Management through Infringement Reports

Some employees do not adhere to the traffic management plans and refuse to leave the place where they are completing work, whether it be a safe, designated area or not. Infringement reports are generated in respect of every employee, which allows the supervisor to manage his team. Every section and shift supervisor must take ownership of their section with regards to the PVDS.

Additional Notes or Comments:

In the South African mining industry in particular, it has often been found that the labour unions oppose various initiatives relating to tracking, monitoring and reprimanding people. When questioning the reaction of the unions about the infringement reports, it was noted this was not the case at Waterval for the infringement reports. In fact, the labour unions promoted the PVDS along with management, because it improves the safety of the people they represent.

2.4.4. Operator and Supervisor Training

The focus area must be the training of the relevant operators and their supervisors. If an operator does not understand the system the supervisor must assist to ensure the correct details are reported to address site specific issues.

2.4.5. Include an effective Management System

When attempting to implement a CMS/CAS in the production environment, there are generally two outcomes – either an un-safe system or production coming to a grinding halt. On top of ensuring a well-functioning system, a management system also needs to be in place. For example, in Waterval East a person cannot proceed underground

[8] *Waterval Mine. 2017. Scope of Work – Maintenance of PVD system document.*

if he/she is not in possession of functional equipment (tested in the lamproom), and access to start/drive a vehicle is only enabled through the system whereby the driver's credentials are verified before the vehicle is allowed to start.

2.5. Testing

2.5.1. Interference

The system was verified as being unaffected by the following sources of interference close to the tag:

- Portable Handheld Radio
- Electrical power tools
- Electrical cabling

Additional Notes or Comments:

Running diesel engines could also interfere with signals. This was not confirmed to be the case or not for the PVDS. However, the Waterval team indicated that this should not be a source of interference and that the primary concern is interference through heat transmission. To avoid this, equipment/tags should not be located in close proximity of the exhaust system.

2.5.2. Tag Obstruction

The system was verified as being unaffected by the following tag obstructions:

- Tag inside a pipe
- Tag inside a vehicle
- Tag behind the vehicle shovel
- Tag inside an electrical enclosure (enclosure door slightly open)

2.5.3. Video Recordings

Professional video recordings were made by an out-sourced film crew, both during surface and underground testing. These video recordings were viewed after testing and used as a tool to adjust system parameters.

2.5.4. First Person Accounts and Feedback

Numerous first person accounts were initiated during surface and underground testing of the system. These first person accounts of the performance of the system were collectively used to adjust system parameters. First person accounts included the entire mine’s workforce, the CMS engineering crew, the OEM (interface) crew, senior mine management and some third party observers from other Glencore mining operations. DMR and MOSH personnel were also invited for demonstration and constructive comment during phases of the implementation.

2.6. Impacts

2.6.1. Resolving Line-of-sight Issues

Due to the limited visibility of the surrounding area from machine cabins, especially on low profile trackless machines, the operators welcomed the ability of the system to sense people in close proximity, which they may not otherwise have been able to observe and avoid.

2.6.2. Productivity Decreases

The reduction in production tonnage per shift was notable in the beginning of the system roll-out – peaking at approximately 30% impact. This was however short lived, and was resolved over a period of a few weeks through training and continuous improvements to the system.

Additional Notes or Comments:

By enforcing adherence to traffic management rules and the mining process to take place in cycle, the impact on production has been reduced. Current percentage impact has not been quantified.

2.6.3. Unforeseen Costs

There were some major unforeseen cost implications relating to the system implementation:

- Brake system wear and equipment mechanical and hydraulic maintenance costs
- Initial impact on production tonnage targets
- Required increase in the capacity of PVDS/CAS and Equipment interface maintenance personnel

Additional Notes or Comments:

Initially the impact on cost was excessive. Regarding the brake system wear, Waterval was losing in the region of four brake heads per month. This has been reduced significantly. Furthermore, there are other additional unforeseen costs that are difficult to quantify relating to the time spent on using and maintaining the system which was previously spent on production related issues. There are also six additional permanent personnel employed purely to support the PVDS (2 per shift, 1 for LSC and 1 for Nerospec). Waterval has not yet quantified the total increase in operating cost resulting from the PVDS.

2.6.4. Excessive Wear on Equipment Brakes

Brake wear per shift increased substantially after Crawl and Stop activation, due to the number of operator-intervention braking events and the nature of some of these braking events. However, this was reduced by reducing critical stops through training interventions. Excessive brake wear per equipment was due to the following:

- **LDV**: The fail-to-safe spring applied hydraulic release braking system fitted on LDVs was not designed to continuously apply the emergency stop function when a LDV receives a stop command. During the hot commissioning phase, excessive emergency stop actions were activated due to employees not adhering to traffic management plans and entering the danger zone of LDVs, causing excessive brake wear.
- **LHD**: Excessive brake wear caused by increased critical proximity and global stop events. Vehicle is subjected to repetitive "emergency stoppages", leading to an increase in wear rate and a decrease in brake life. It is suggested that the frequency of brake wear measurement should be increased – monthly by OEM and weekly by artisans. Active brake wear measurement interlocked with the TMM is currently (December 2017) being investigated for GHH LHDs (supplied by Nerospec, expected completion of concept phase for roll out – Mid Feb 2018).
- **UV**: Braking system is only capable of withstanding approx. 10 emergency stops before OEM brake wear limit is reached, with the current park/emergency brake design. It is suggested that the frequency of brake

wear measurement should be increased – monthly by OEM and weekly by artisans. R&D underway (December 2017) investigating a different OEM braking system.

Additional Notes or Comments:
Work is underway to address these challenges. However, solutions are not yet implemented or trialled. Current status unknown for the above initiatives.

2.6.5. Machine Reliability, Maintainability & Operability

The impact of the PVDS solution on reliability, maintainability & operability differs depending on many variables, such as machine type, braking mechanism, ability to crawl before braking to reduce brake wear, competency level of maintenance personnel, extent of personnel training, user/operator acceptance and so forth. There is an ongoing and consistent effort at Waterval Mine to improve in all three of these areas, and to record the failure or success of these improvements.

Additional Notes or Comments:
TMM availability is claimed to be above 90% - With minimal impact from the PVDS provided that it is managed correctly so that production can continue. Achieving this was a lengthy process.

2.7. Miscellaneous

2.7.1. Underestimation of <5m Human-Machine Interactions

The interaction statistics (between pedestrians and trackless machines) were an eye opener from the moment that the reports started to become available. This was despite the significant efforts which had previously focused the mining operation on the task of separating machines and personnel, prior to the implementation of this latest system. The reports demonstrated conclusively that sub 5m interaction statistics – not only on the Waterval East operation which was already sensitive to this – but most likely on many other Glencore operations, was far more prevalent than what had previously been imagined. This realisation caused a re-focus on the efforts, this time with the support of data acquired from live operations, on to the task of changing the behaviour and professional culture of our personnel towards avoiding moving machinery.

During the first week of implementation of the system, approximately 24000 critical proximity events were logged, which was reduced to 12000 critical proximity events within a few months. These are events that lead to equipment stoppages, or where a pedestrian entered the critical zone of a vehicle that is already stopped. The results indicated that the traffic management system at the mine needed to be reviewed. Critical proximity events are logged continuously and the latest figures can be obtained from LSC.

2.7.2. Main Purpose of System

The PVDS stops vehicles and prevents collisions. However, the main purpose of the system is to change the behaviour of the employees whereby they instinctively avoid contact with vehicles.

2.7.3. Perceived vs. Actual Proximities

Pre-system, the mine had a 5m rule in place. It was however observed that 5m as perceived by Person A was not the same as by Person B, and the necessity for an electronically demarcated 5m keep-out zone was evident.

2.7.4. Current and On-going Developments

It was noted that the PVDS at Waterval East is continuously experiencing "bug fixes" and upgrades, ranging from display and software bugs to user interface interactions/modifications, to reducing negative impacts on production and accidental global stoppages etc. (LCS plays a primary role in identifying and improving on-site requirements and maintenance for the PVDS at Waterval East).

Nerospec is active with ongoing improvements and developments as was largely indicated in Section 2.2.7.

**The following information on continuous improvement relates to EiQ, which develops the intelligence within the PVDS at Waterval East. Please note that the information provided is highly confidential and should not be shared outside of the NDA between Glencore and EiQ.*

Personnel & asset tracking

Working towards the development of a comprehensive personnel & asset tracking system based on the same time of flight technology used for vehicle proximity warning. This essentially is about the concept of using the miner's tag as a 'smart sensing platform' as well as a 'carrier of information'. The crux of this concept is to use the technology already on the tag to monitor:

1. Location – Achieved by placing fixed Reader Modules in the working area at various locations at each level (station, crosscut, waiting areas, etc.). The Reader Modules can either be networked or standalone. In the networked case, information about the location of tags is received in real time. In the standalone case, it is

received when the miner returns to the lamp room and the 'waypoint' data is download off the tag. This then shows the times the employee has visited the various areas in the mine. On top of providing management insight, in the event of an accident the last known locations of miner's are quicker to determine.
2. Activity – The level of activity of the miner is monitored / logged by the tag.
3. Temperature – The environmental temperature is monitored / logged by the tag.
4. Specialised data – The tag can be configured to store specialized data broadcast from fixed sensors located in the working environment (in line with the 'tag as carrier of information' concept). This can assist with monitoring devices that are difficult to get network connectivity to. Information such as airflow, seismic activity, stope closure rates can be stored on the miner's tag and carried out with them for dissemination on surface.

Currently, over 15000 miners are carrying this technology from EiQ in the gold mining sector in the Free State and Carletonville areas. What is valuable in this development is that the same tag is used for proximity avoidance and tracking, providing more return on investment in this technology.

Current development - Dynamic zoning for PAS1000
In the current development and revision of the dynamic zoning algorithm, elliptical zoning is rendered obsolete in favour of reducing the zone size for targets not in the potential line of travel of the vehicle. This will result in a cone shaped zone in the front of the vehicle when it is travelling forwards, with small zones to the sides and back of the machine. This shape will flip when the vehicle changes direction. The dynamic zoning would use speed, direction of travel and gradient to determine zone sizes. The zone sizes used also assume a loaded vehicle.

The aim of this initiative is to reduce false alarms and improve mine productivity when EiQ's technology is used. Essentially, the concept is to only warn miners / other vehicles that are in the current path of the vehicle, taking into account speed, pitch, roll and yaw rates of the vehicle. These are items which the sensIQ platform is estimating from its EKF model.

Better angular resolution for PAS1000
An area which is getting significant R&D attention at EIQ is the improvement of angular resolution of the system. While the distance accuracy of the system is good, the angular accuracy is a function of how widely spaced the antennas can be installed. This is due to the fact that the error increases as the antenna modules are placed closer together. "Novel techniques at the RF level and mathematical level" will be used to improve on the angular estimation of a target.

Better integration of PAS1000 tag into cap lamp system
18 months ago, EIQ purchased a cap lamp design and manufacturing tooling to allow the manufacture of their own cap lamps. The purpose of this is to provide a more suitable ergonomic solution for the miner, as well as to save the mine the cost of a separate cap lamp system and cable mount tag. They are in the final stages of the development and have modified the mechanical design and re-engineered the electrical design for their own requirements. The result will be a light weight cap lamp that integrates the tag functionality in a better way.

Vision-based AI technology
Another development in progress is for a camera based technology as an additional backup for the RF based proximity technology. As well as providing better situational awareness around the mining machine by virtue of cameras in the direction of travel, this will allow improved handling of high speed scenarios for surface proximity applications (i.e. vehicles travelling towards each other in excess of 40km/h). The crux of this technology is that a camera feed from multiple cameras is processed through a neural net which has been trained to recognise personnel and other vehicles. This net provides the AI based technology to correctly classify and give input to the proximity

system of dangerous scenarios. This technology is applicable to other scenarios in mining as well as other industrial applications.

Autonomous train control

By adding the vision-based technology with established capability of controlling electric and diesel trains remotely, will further aim to implement autonomous trains in certain areas of rail-bound mines. There may be a spill-over of this technology into the trackless TMM space with collaborations with the right vendors.

3. Proving Ground Testing

The current implementation of the PVDS was tested at Gerotek Test Facilities to the west of Pretoria. The test track is a 1km long, level concrete surface that is approximately 30m wide. The intention of the proving ground tests on surface is to evaluate the performance of the system in an objective and repeatable manner. While the surface sensing environment is not representative of the underground sensing environment, it represents the ideal sensing situation where machines and tags are not hampered by obstructions or external influences and line-of-sight is easily achieved. The proving ground tests evaluate the performance of the system's algorithm and ideal sensing accuracy. The tests also give an indication of the delays in the PVDS and the Nerospec interface. PVDS delays are varied depending on the test case. The Nerospec interface average delay was 26ms with a minimum of 15ms and a maximum of 50ms recorded on a single occasion. The Nerospec interface delay is defined as the time between the PVDS warning and the Nerospec interface actuating the crawl mode or brake application on the test vehicle. 50ms translates to an additional 10cm travel distance at a maximum speed of 8km/hr. The average of 26ms translates to an additional 5.7cm of travel distance. These distances are negligible in comparison to the 7m, 12.5m and 22m zone thresholds evaluated.

3.1. Test scenarios

The test scenarios performed were based on the observed interaction possibilities during our visit to Waterval East Mine. It was evident during the site visit that the original intention of the PVDS was to reduce machine-person interactions. Furthermore, because a Bord and Pillar mining method is employed at Waterval East Mine, the vehicle-to-vehicle (V2V) interactions were selected as head-on, reverse-on, back-up dovetailing and 90° junctions and intersections. The test scenarios were limited to machine speeds up to 8km/h. The scenarios are summarised in Table 2.

Table 2: Interaction scenarios tested

Scenario	Interaction	Reverse			Forward		Notes
		8km/h	5km/h	MI	5km/h	8km/h	
L1-Head-on	V2V	-	-		9	9	L9 crawl only
L2-Reverse-on	V2V	9	9		-	-	L9 crawl only
L3-Backup	V2V	9	9		-	-	L9 crawl only
L4-Dovetailing	V2V	9	9		9	9	L9 crawl only
T2-Crossover	V2V	-	-		9	9	L9 crawl only
T3-Junction	V2V	-	-		9	9	L9 crawl only
T4-Intersection	V2V	-	-		9	9	L9 crawl only
P1-Person (direct)	V2P	9	9	9	9	9	L9 stop
P3-Person (indirect)	V2P	9	9	9	9	9	L9 stop

Based on the guidelines recommended by the Minerals Council of South Africa, the list of interaction scenarios can be representatively tested by making use of the following test configurations:

1. Head-head (uTC3 in Figure 8)
2. Head-tail (uTC4 in Figure 8)
3. 90° intersection (uTC1 in Figure 8)
4. Take-off (person) (uTC9 in Figure 9)
5. Approach (person) (uTC10 in Figure 9)
6. Approach (person indirect) (uTC11 in Figure 9)
7. Passing (person) (uTC12 in Figure 9)

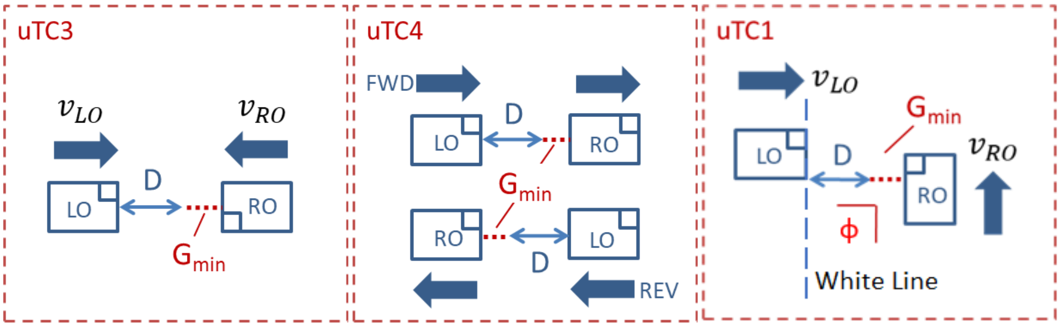


*Figure 8: Vehicle to vehicle test configurations (*LO= Local Object, RO=Remote Object)*

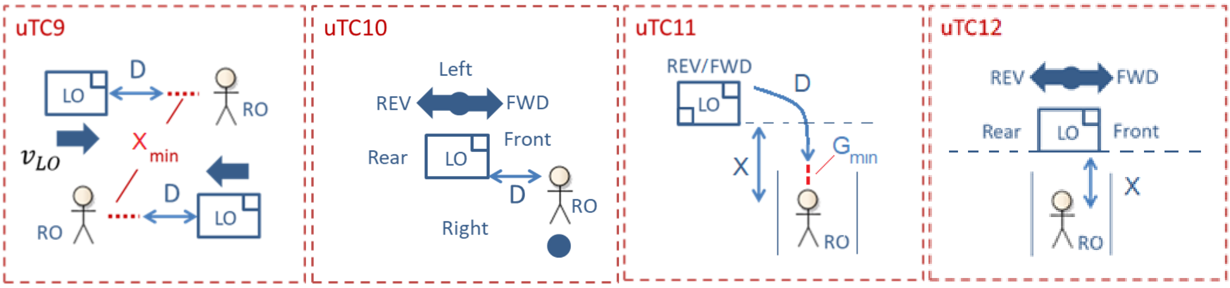


Figure 9: Vehicle to person test configurations

3.2. Experimental setup

The experimental setup makes use of two light vehicles rather than two TMMs. Both vehicles are instrumented with differential GPS. Additionally, a base station is used to remove drift from the GPS on the vehicles. This provides for an accuracy of approximately 100mm. The main vehicle (referred to as the Local Object or LO) is instrumented with a brake robot. The brake robot is used to control the deceleration of the LO. The deceleration is controlled via a feedback control loop. During the tests, the slowdown phase deceleration was set to 0.1g and the stop deceleration was set to 0.28g. The 0.1g deceleration for the slowdown phase was chosen as the lowest physically possible by the LO – this represents the worst-case scenario that can be sensibly tested. The 0.28g deceleration was based on the stopping distances required by ISO3450. ISO3450 requires an average deceleration of 0.18g on a 10% decline. For the purpose of tests on a level surface, this average deceleration was adjusted to 0.28g.

Both light vehicles were instrumented with the Embedded IQ sensors, a neroHUB and a neroVIEW. Four Embedded IQ antennas were used on each vehicle, similar to the current implementation on the LDVs at Waterval East Mine (see Figure 9). As a result, the zones were circular rather than elliptical. This was due to the limitation on the light vehicle size. As mentioned earlier in the report, the sensor location and orientation influence the zone shape. The elliptical zones could not be sensibly replicated on the two light vehicles.

In addition to the standard implementation of the PVDS system and interface, several other relay and CAN-bus connections were made between the logging system on the test vehicles and both EiQ's system and the neroHUB. This allowed for the measurement of the following delays in the system:

- Delay from the point at which the other machine or personnel tag was detected before a detection was recorded on Embedded IQ's system.
- Delay from the point when a command was issued by EiQ to the neroHUB and subsequently communicated to the 'OEM'. This delay was measured with both a relay interface and a CAN interface between the neroHUB and the test vehicle logging system, providing an indication of the delays between the Embedded IQ system and the OEM when using different interfacing strategies between the neroHUB and the OEM.

Figure 10: Positioning of antennas on Local Object

3.3. Experimental procedure

The experimental procedure is based on the guidelines provided by the Minerals Council of South Africa. The test configurations as described in Figure 8 and Figure 9 were tested. For the vehicle-to-person (V2P) test configurations, the pedestrian tag was placed on the back of the Remote Object (RO) vehicle. This is illustrated in Figure 10.

Figure 11: Pedestrian tag on the back of Remote Object vehicle (left) and Local Object shown approaching Remote Object.

The experimental procedure was as follows:

1. The vehicle is accelerated to the intended speed in the intended direction.
2. A constant speed is maintained manually by the driver.
3. When the slowdown phase is triggered, the brake robot controls the deceleration of the LO at 0.1g down to a crawl speed of 4km/h.
4. When the stop phase is triggered (only in vehicle-person scenarios), the deceleration of the LO is controlled at 0.28g by the brake robot until the vehicle comes to a complete stop.

3.4. Experimental results

The PVDS zones were set to the following sizes:

1. L7 alert at 22m
2. L8 warning and L9 crawl at 12.5m
3. L9 stop (only vehicle to pedestrian) at 7m

Figure 12 shows the gap and vehicle speed in a V2P test. The vehicle travels at a constant speed of 8km/h. It may be seen that a Level 7 alert is triggered at approximately 10s. A L8 warning and a L9 crawl are triggered almost simultaneously at approximately 12s. At this point, the speed reduces to 4km/h. The L9 stop command is triggered at approximately 15s, bringing the vehicle to a halt at a gap of 7.7m.

Figure 13 shows the gap and vehicle speed in a vehicle-to-vehicle head-on scenario. Both vehicles travel at approximately 8km/h. A L7 alert is triggered at approximately 10s. A L8 warning and L9 crawl are triggered simultaneously at 12s. The LO and RO reduce speed from this point on to 4km/h. No further interventions are triggered. The head-on test was performed with the vehicles offset at 1m. The vehicles thus eventually reach a point where a collision would have taken place if they weren’t offset. Similar graphs can be generated for all the tests performed upon request.

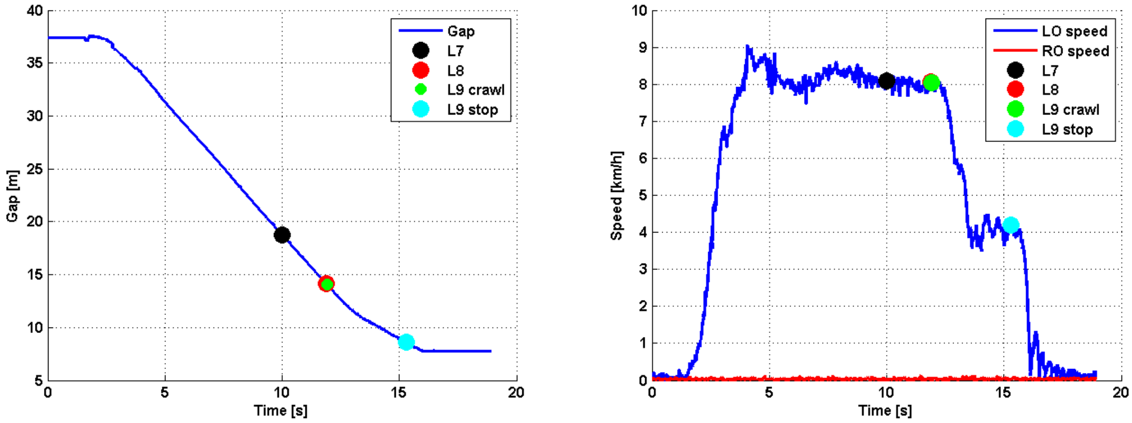


Figure 12: Vehicle to pedestrian gap (left) and speed (right)

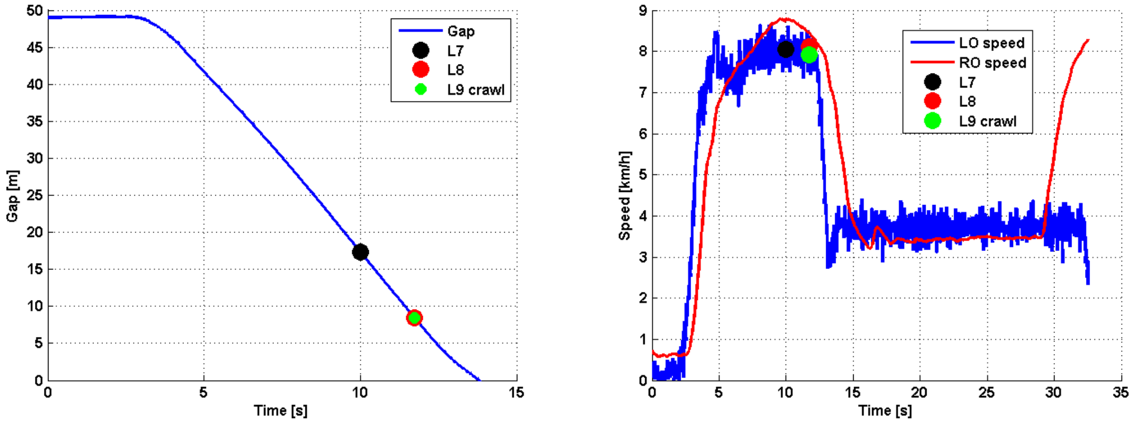


Figure 13: Vehicle to vehicle (head-on) gap (left) and speed (right)

3.5. Experimental analysis

The tested capability is given in Table 3 and is seen to agree with the claimed capability given in Table 2. The pass/fail criteria were set as follows:

1. L7 alert received between 18 and 25m from the target.
2. L8 warn and L9 crawl received between 8m and 15m from target
3. In vehicle to pedestrian scenarios, the stop gap was set at 2.5m
4. In vehicle to vehicle scenarios, the gap between the vehicles when both should have reached crawl is set at 2.5m.

A more in-depth analysis with all of the test results is available on request. Nerospec's neroHUB interface records of the individual test scenarios were offered as input to this report and are presented in chapter5. These records include the neroHUB's path trace visualization reports which were derived from the neroHUB's onboard GPS based vehicle positioning system.

Table 3: Tested capability

Scenario	Interaction	Reverse			Forward		Notes
		8km/h	5km/h	MI	5km/h	8km/h	
L1-Head-on	V-V	-	-		9	9	L9 crawl only
L2-Reverse-on	V-V	9	9		-	-	L9 crawl only
L3-Backup	V-V	9	9		-	-	L9 crawl only
L4-Dovetailing	V-V	9	9		9	9	L9 crawl only
T2-Crossover	V-V	-	-		9	9	L9 crawl only
T3-Junction	V-V	-	-		9	9	L9 crawl only
T4-Intersection	V-V	-	-		9	9	L9 crawl only
P1-Person (direct)	V-P	9	9	9	9	9	L9 stop
P3-Person (indirect)	V-P	9	9	9	9	9	L9 stop

General observations during testing

The EiQ, Nerospec and LSC team were experienced, professional and passionate about their product. The graphic interface installed on the test vehicles was clear and simple to understand. L9 Slowdown and L9 Stop interventions, when triggered, were clear and easy to understand.

During the tests, the system performed as expected every time. No false negatives were experienced during the tests. The system was however experienced as being conservative, opting to err on the side of safety. A potential problem that was identified during the tests was that the L9 Slowdown intervention failed to clear when the two vehicles had passed each other. The L9 Slowdown intervention continued to prevent acceleration up to 20m after passing the Remote Object. The Embedded IQ representative noticed this and committed to improving this feature.

It was also noticed that the zones did not take the vehicle's direction of travel into account. During the dovetail scenario, the lead vehicle (Remote Object) was also forced to crawl when the Local Object approached from the rear. It is expected that the correct application of dynamic zone sizes may prevent this false positive from occurring.

4. Underground Testing Results (Nerospec interface records)

Each of the machines at Waterval East mine are individually outfitted with Nerospec neroHUB interface/logging/reporting systems. These systems monitor the machine interaction on a 24/7 basis throughout the fleet in the real-world deployment. Nerospec contributed some of the data previously acquired in the real world underground conditions as supplementary input to this report. The reports were retrieved from the operational machines via WiFi radio interfaces and presented in the standard neroHUB Analysis software toolset as is issued to the mine personnel.

An extract from the neroHUB Analysis tool user manual introduces the main reporting screen as follows:

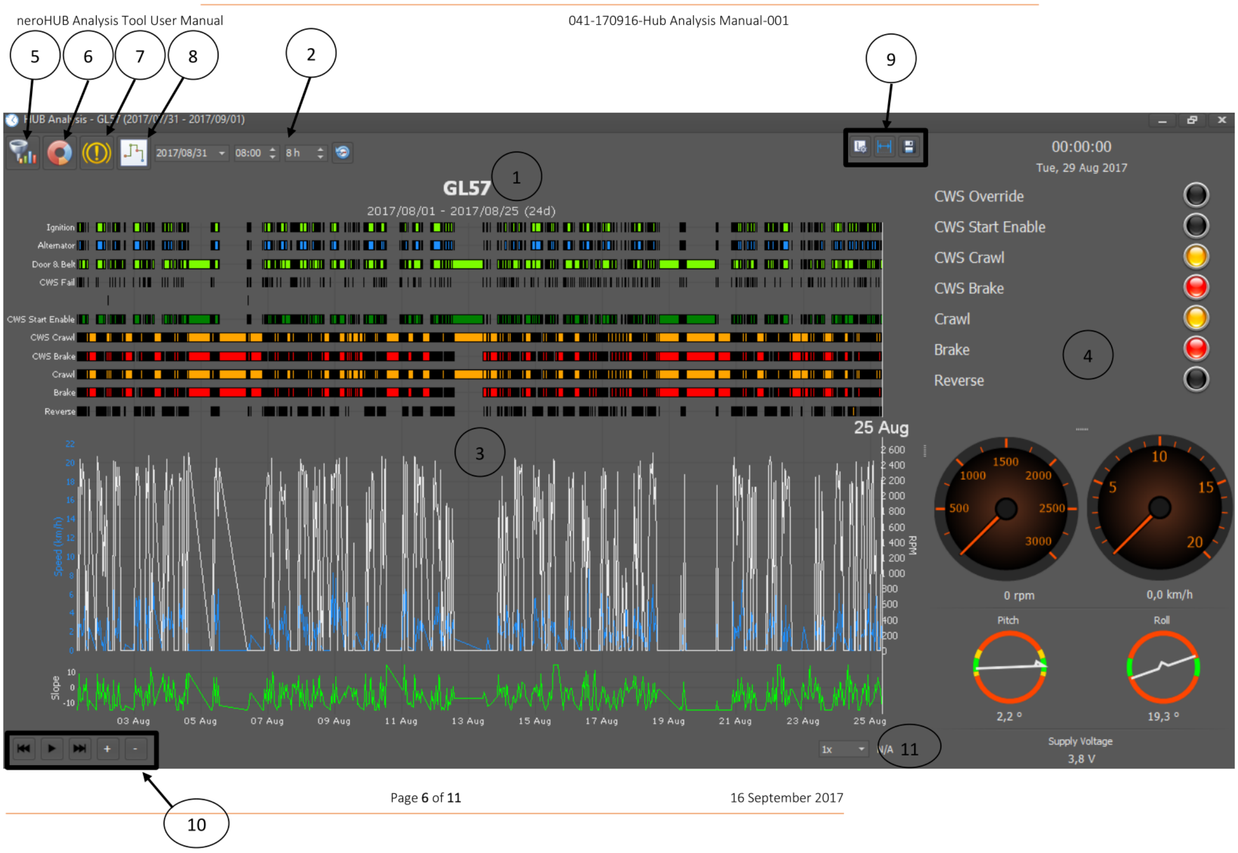


Figure 14: neroHUB Analysis Tool main screen overview (Bruno, 2018)

❶Shows the name of the machine and period of the data currently being monitored in the analysis window. Note this is not the total period of all the data imported & that the period will change according the zoom window the user is viewing. The total period of the data which was imported is visible at the top in the window title.
❷The user can set the date and time as well the hours which they want to view. Clicking on the time icon in the window frame of the data being viewed will adjust it accordingly.
❸Main view depicting the data which has being imported. Illustrating the Digital Inputs, Digital Outputs, Speed (Blue - graph), RPM (white - graph) and Slope (Pitch) of the machine.
❹Graphical representation of the data in the form of LED's for the digital inputs and outputs and a gauge for the speed and RPM. The graphical representation will change according to the time stamp of the where the cursor is currently set. It will animate when the data is being replayed in video replay mode.
❺Configuration menu, the user can choose which digital inputs and outputs they wish to view in
the main view of the analysis tool.
❻General statistics overview of the machine. Showing the engine run time, the cumulative time spent in the safe zone, crawl zone and the brake zone modes – as instructed by the PVP system.

❼Collison Warning System statistics view. Showing the time which the machine spent in the safe zone, crawl zone and the brake zone. Also charts the crawl to brake statistics to detect unsafe stopping before crawl is properly instantiated.
❽This menu allows the user to view additional digital, analog and motion values which were recorded by the neroHUB and are not visible in the main view. For example, in the figure below the front brake pressure analog value is being monitored. Note the period of the additional analog monitor screen
corresponds to the period of the main view, if the period is changed within the main view the additional graph data time stamp will change accordingly.
❾The user can save a screen shot of the data currently being viewed. There are toggle marker settings
where the markers can be used to measure the length of time a particular event occurred for (delta time).
❿These are the video controls used to playback the recorded data in animated mode.
⓫User can adjust the speed of video playback to accelerate video replay speeds up to 100x realtime.

4.1. Underground Test scenario

The purpose of this underground test was to provide input to the action plan for continuous improvement to the Personel Vehicle Protection System at Waterval Mine, after tests were conducted on 6 March 2018. Controlled tests were performed on GL34 on an underground decline with a fully loaded bucket. Multiple tests were performed with the tag in various locations, some placed in line of sight of the machine and others hidden from the view of the machine. During testing a tablet was utilized to momentarily override the system, permitting the operator to move the machine between individual tests.

4.2. Underground Test Results

The HUB Analysis tool was employed to view the logged data, represented by charts displaying digital events, measurements and statistics for given periods during the testing.

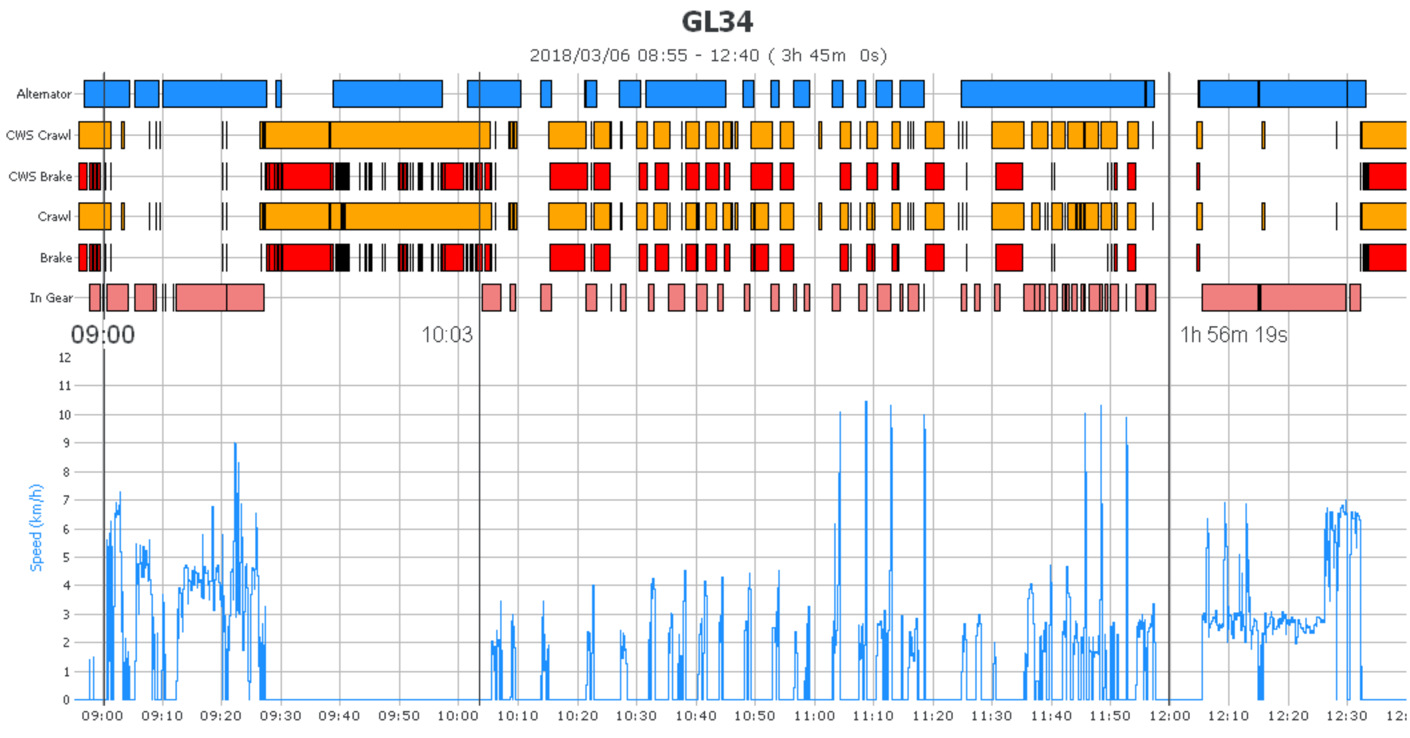


Figure 15 – Testing period full view (Bruno, 2018)

The trend view displays digital state changes and analogue values on the vertical axis with time on the horizontal axis. Time markers are used for measurement of time along the horizontal axis. The current layout is setup to display states related to the testing, with speed measurement on the blue trace and RPM measurement on the black trace.

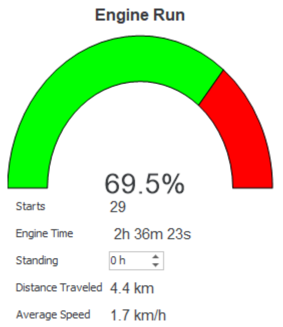


Figure 16- Operation summary (Bruno, 2018)

The engine run statistics view displays the active time of the engine, number of alternator starts, distance travelled and average speed. The method used to estimate distance travelled and average speed, is integration of the area under the velocity-time graph (speed over time).

4.2.1. Underground Low speed tests (5 km/h)

Analysis was performed on 7 braking events, between 10:31 and 10:55, for the low-speed tests conducted with GL34. Braking event 2 was not a controlled test of stopping distance and is excluded from the analysis below.

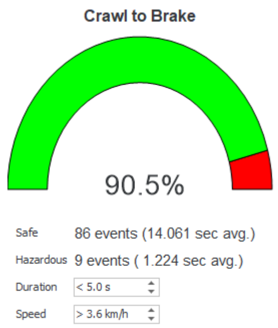
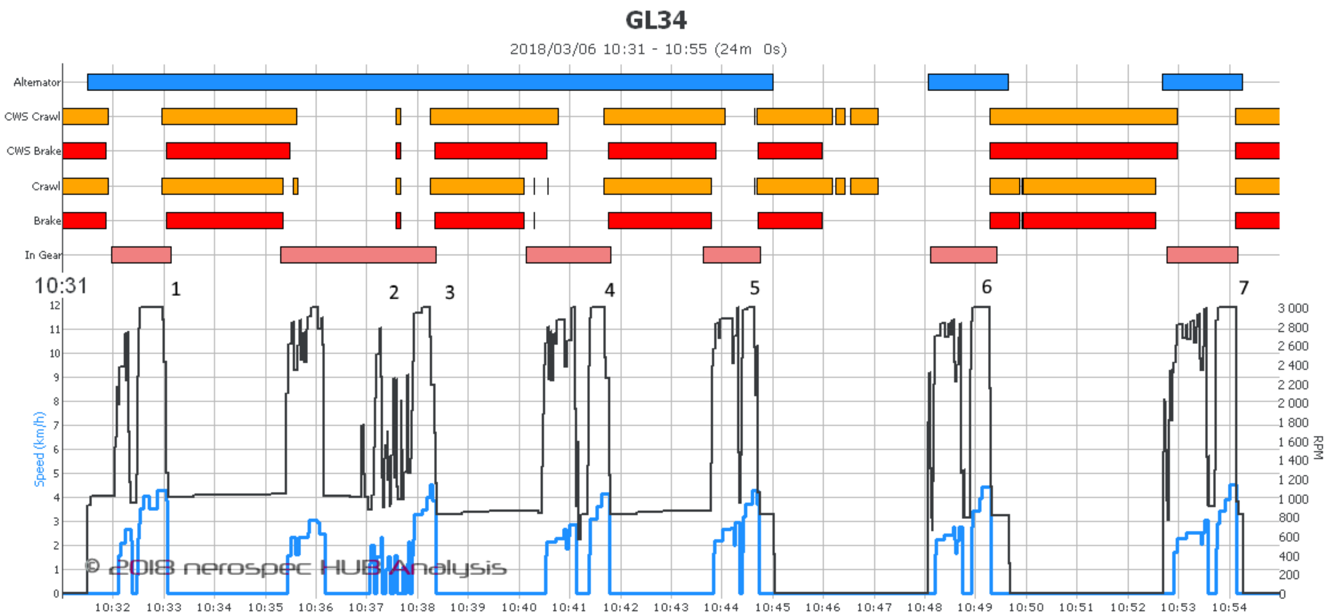


Figure 17 - Crawling mode to brake mode summary

The crawl to brake statistics view filters potential significant brake wear events using time and speed thresholds. i.e. Any event where the crawl and brake instructions are less than 5 seconds apart with a speed at braking greater than 3.6 km/h will be filtered as potential significant brake wear events, all other events are considered safe. The statistics ignore unimportant events such as events with 0 speed.

Figure 18 - Low speed testing (Bruno, 2018)



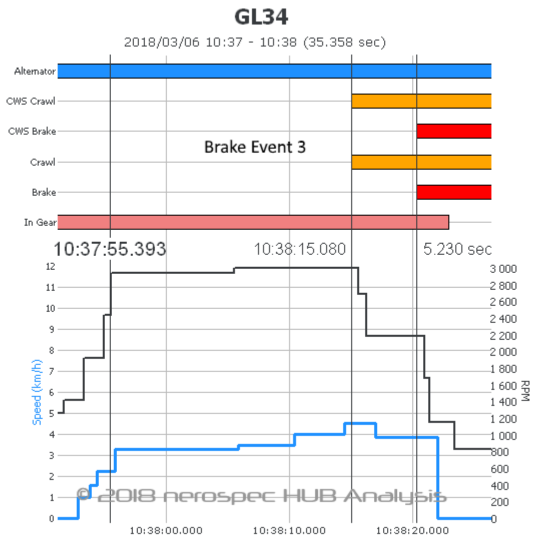


Figure 19 – Brake event 3 crawl to brake instruction measurement (Bruno, 2018)

The crawl to brake time measurement is indicated in Figure 19 above. This was achieved by measuring time elapsed between crawl instruction and brake instruction from the PVP system. The RPM and speed of the vehicle are reduced by the neroHUB by means of throttle reduction from the crawl instruction.

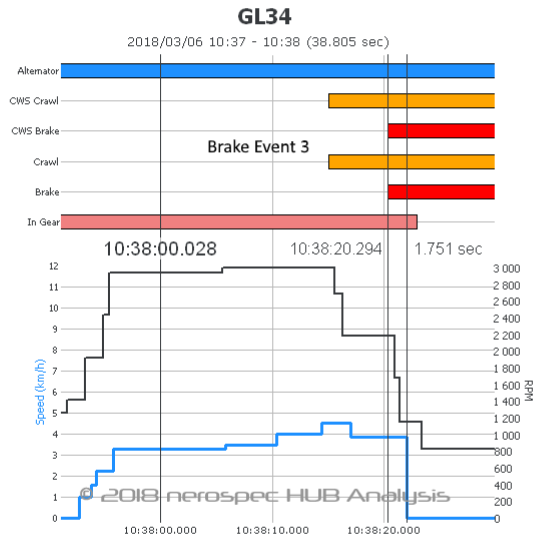


Figure 20 – Brake event 3 stopping time measurement

The brake to stop time is measured as indicated in Figure 20 above. This provides the time elapsed between brake instruction and the first logged zero speed event. The area under the speed trace is used to calculate stopping distance. The current implementation cannot account for wheel slippage. i.e. the brakes stopped the wheels turning in 1.7 seconds, however the machine may still slide before coming to a complete stop.

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The HUB analysis tool supports exporting the low speed braking events into a spreadsheet. Exported braking events for low-speed tests are listed below:

Brake Event	Time	Crawl to Brake (Seconds)	Speed at Brake (km/h)	Time to 0 Speed (Seconds)	Integrated Distance (Meters)
1	10:33:02	4.452	4.264	1.708	1.855
2	10:37:34	0	1.56	1.448	0.628
3	10:38:20	5.23	3.835	1.751	1.865
4	10:41:45	5.291	4.135	1.782	1.9
5	10:44:42	0.841	4.22	1.634	1.916
6	10:49:16	0	4.442	1.884	2.163
7	10:54:07	0	4.533	1.553	1.956
Average (excludes event 2)		**2.64**	**4.24**	**1.72**	**1.94**

Figure 21 - Exported measurements of each low speed braking event. (Bruno, 2018)

4.2.3 Underground High speed tests (10 km/h)

Analysis was performed on 4 braking events, between 11:02 and 11:20, for the high-speed tests conducted with GL34.

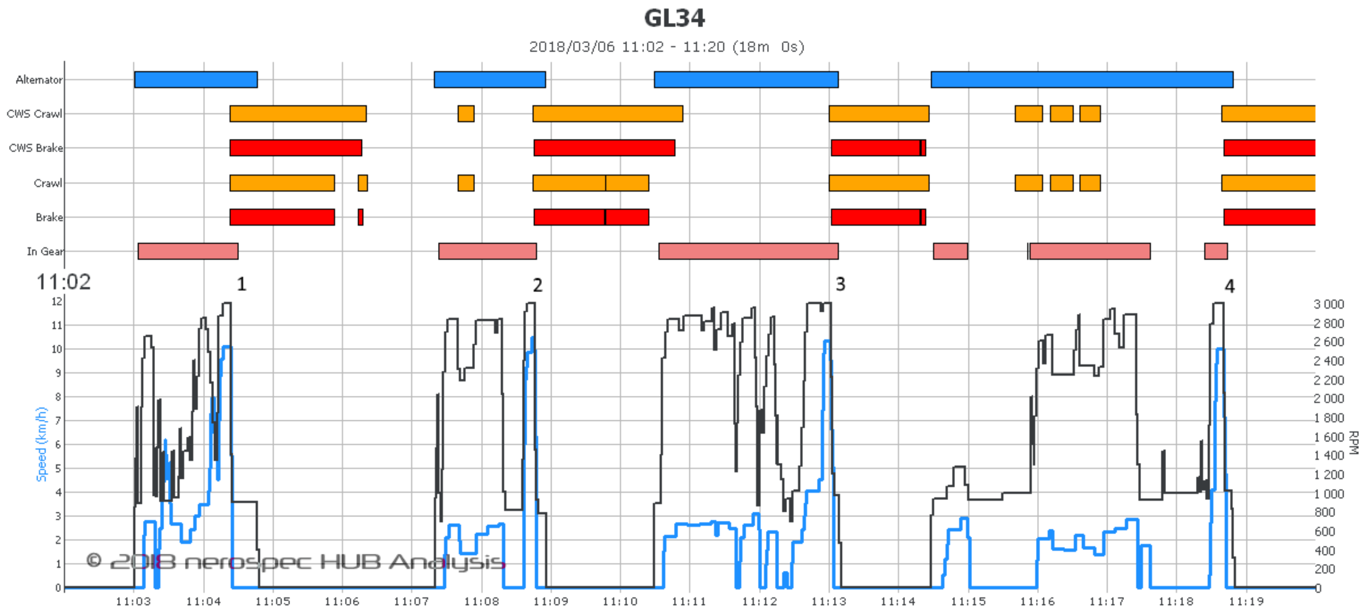


Figure 22 - High speed testing (Bruno, 2018)

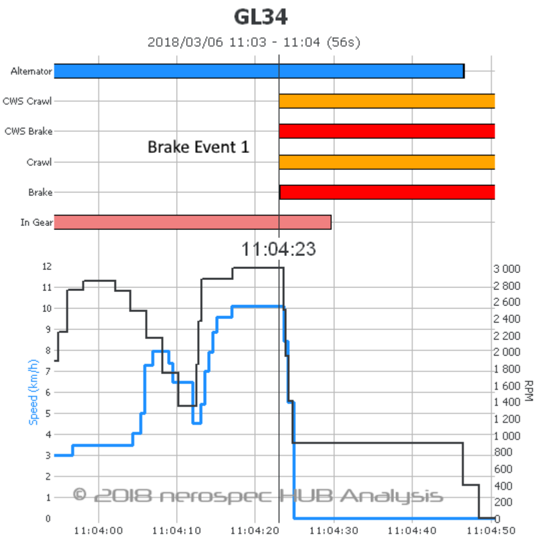


Figure 23 - Brake event 1 (Bruno, 2018)

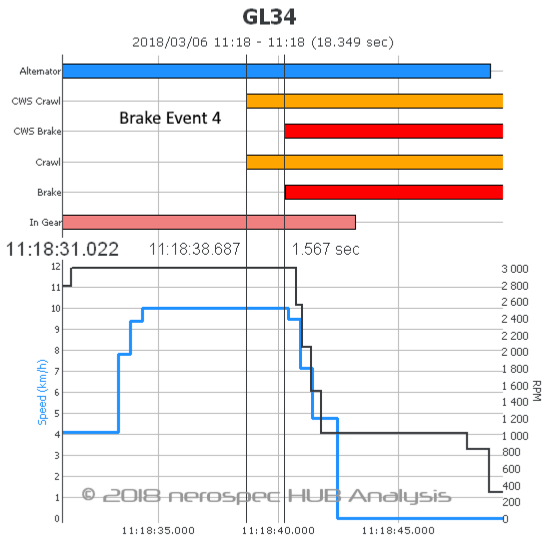


Figure 24 - Brake event 4 (Bruno, 2018)

Brake event 1 is noted as an instantaneous stop event with no measured crawl to brake duration. Reduction in RPM and speed is only observed after the brake instruction is received.

Brake event 4 showed no logged reduction in RPM or speed during the crawl to brake period. Reduction in RPM and speed is only logged after the brake instruction is received.

The HUB analysis tool exported spreadsheet braking events for high-speed tests are shown below:

Brake Event	Time	Crawl to Brake (Seconds)	Speed at Brake (km/h)	Time to 0 Speed (Seconds)	Integrated Distance (Meters)
1	11:04:22	0	10.105	2.003	4.375
2	11:08:45	0.843	9.96	1.9	4.068
3	11:13:01	1.505	9.539	1.904	3.979
4	11:18:40	1.567	10.001	2.205	4.187
Averages		**0.98**	**9.90**	**2.00**	**4.15**

Figure 25 - Exported measurements of each high speed braking event (Bruno, 2018)

4.2.4 Underground Crawl only deceleration tests

Two deceleration tests were performed one at low-speed and one at high speed, on the decline while GL34 was fully loaded, with only crawl instructions given to the neroHUB.

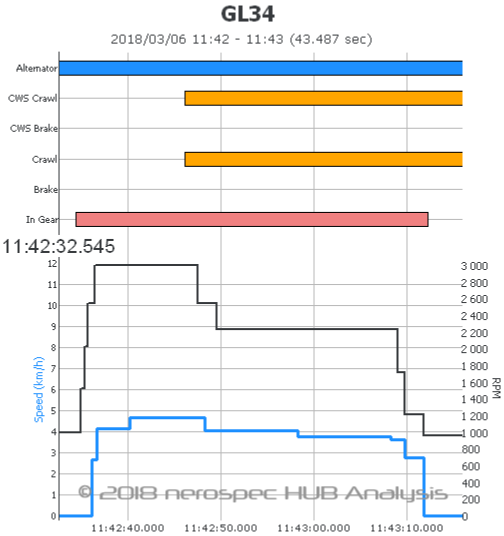


Figure 26 - Low-speed crawl only instruction (Bruno, 2018)

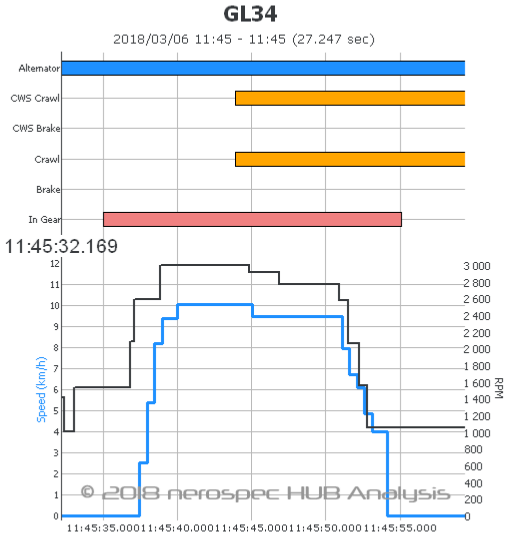


Figure 27 - High-speed crawl only instruction

The low-speed crawl only test logged a reduction from 3000 RPM to 2200 RPM over 3 seconds. The reduction of speed from 4.7km/h to 3.9km/h over the same period was logged. There is a reduction from 3.9km/h to 3.3km/h over the remaining 19 seconds before the operator stopped the vehicle.

The high-speed crawl only test logged a reduction from 3000 RPM to 2800 RPM over 3 seconds. The reduction of speed from 10.1 km/h to 9.4 km/h over the same period was logged.

4.2.5 Brake movement response times from GL36

An analysis was done on log data of GL36 neroWEAR sensors to ascertain wetbrake disk movement response times. The neroWEAR sensor's primary function is to measure brake wear over an extended period and to indicate brake calliper movement.

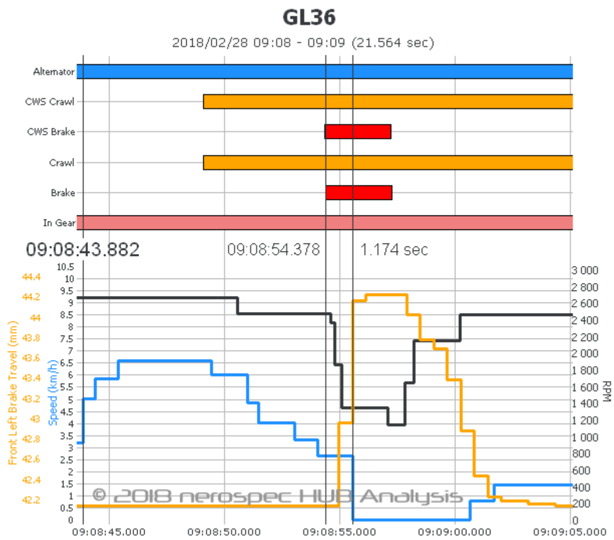


Figure 28 - Brake movement response time (Bruno, 2018)

Brake Event	First event (Seconds)	Full movement (Seconds)
1	0.253	1.165
2	0.393	1.274
3	0.409	1.289
4	0.306	1.209
5	0.531	1.381
6	0.451	1.307
7	0.291	1.109
8	0.311	1.241
9	0.565	1.485
10	0.361	1.252
Average	**0.3871**	**1.2712**

Manual analysis was done on 10 samples taken of the response times when the neroHUB Interface engaged the brakes. The measurements were conducted using the markers in the HUB Analysis application indicated above by the yellow trace showing brake movement. The measurements are from solenoid actuation until first logged wetbrake disk movement, as well as to the full movement of the wetbrake as logged by the neroWEAR sensors.

The results show a logged worse case of 0.565 seconds for first movement detection and 1.485 seconds for full movement detection. The neroWEAR sensor was currently configured for an output rate of 10 Hz and a logging rate of 2 Hz (500ms update rate). The update rate and logging rate can be readily increased to be able to provide improved timeous brake movement response measurements from the neroWEAR sensors.

The table above should be interpreted as indicative since the neroWEAR logging rate was currently coarsely set to 500ms intervals at the time of this test.

4.2.6 LHD Speed Analysis

The previous 3 months of data from the 8 most active LHDs were selected for analysis. Two recurring distinct patterns were identified alternating between day and night shifts, with afternoon maintenance shifts only showing occasional movement and static interactions (measurements and state changes while the system was powered up but had no movement)

The 2 shift patterns are categorized as slow shift and fast shift for purposes of this report. The analysis application was setup to display a 10-minute moving average and a 10-minute moving peak trace of speed during the shift. The red trace below shows the moving peak speed and the green trace shows the moving average speed.

4.2.7 Slow Shift

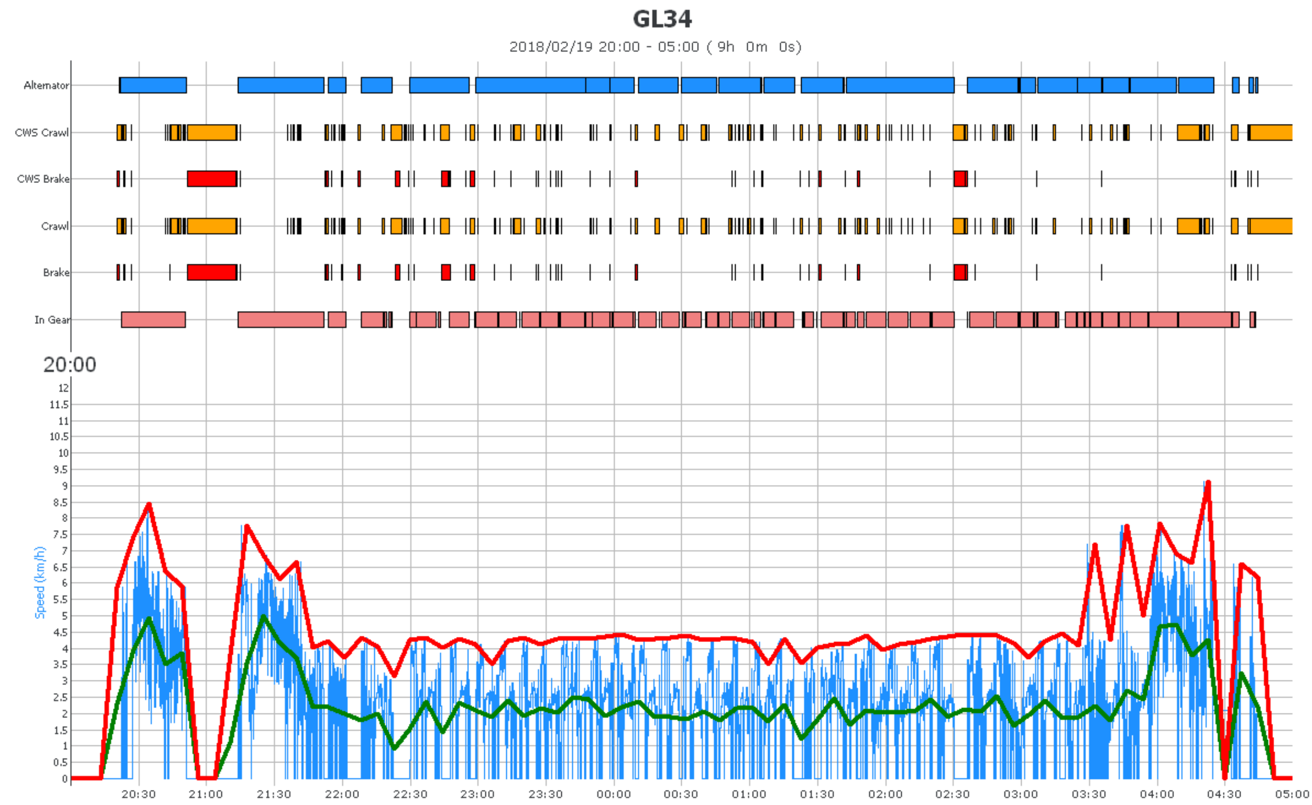


Figure 29 - LHD slow shift pattern (Bruno, 2018)

The slow shift was identified as having a consistent pattern with peaks at the beginning and end, and a plateau throughout most of the shift. Average speeds were logged at around 4.5 km/h with peak speeds around 8 km/h for the first and last hours of the shift. This was due to traveling back and forth from the underground workshop. The remainder of the shift logged an average speed of around 2.5 km/h and peak speeds of 4.5 km/h in a cyclic pattern. This is attributed to traveling back and forth to the tipping point.

The time the system spent in CWS brake state was also noted to be below 4% on average. The CWS statistics, on average, showed no crawl to brake instructions occurring above 3.6 km/h within less than 5 seconds.

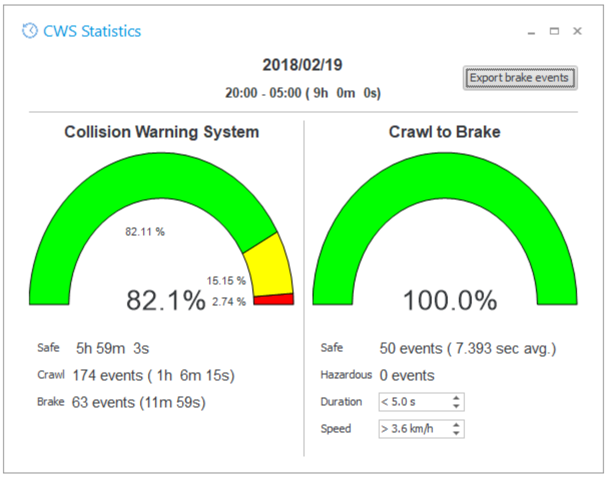


Figure 30 - CWS Statistics for a slow shift (Bruno, 2018)

4.2.8 Fast Shift

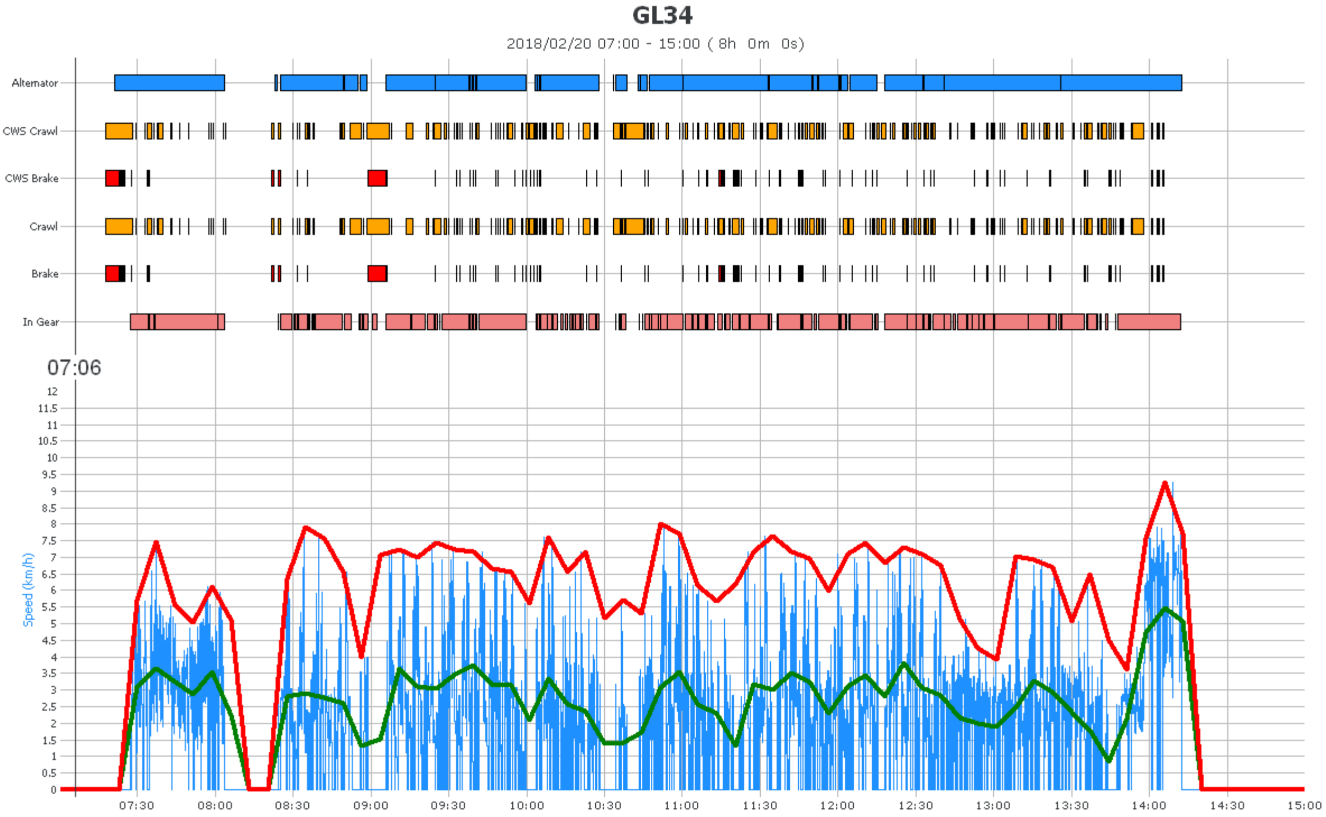


Figure 31 - LHD fast shift pattern (Bruno, 2018)

The fast shift was identified as a less uniform pattern, where the machines would generally travel faster than in the slow shift pattern. Average speeds were logged at around 3 km/h with peak speeds around 7.5 km/h for the duration of the shift.

The time in CWS brake state was also noted to be below 4% on average, but slightly higher than the slow shifts 2.74%. On average there was approximately double the CWS interaction events when compared with the slow shift pattern. The CWS statistics on average showed 14% of the CWS braking events occurring above 3.6 km/h and a crawl to brake time less than 5 seconds.

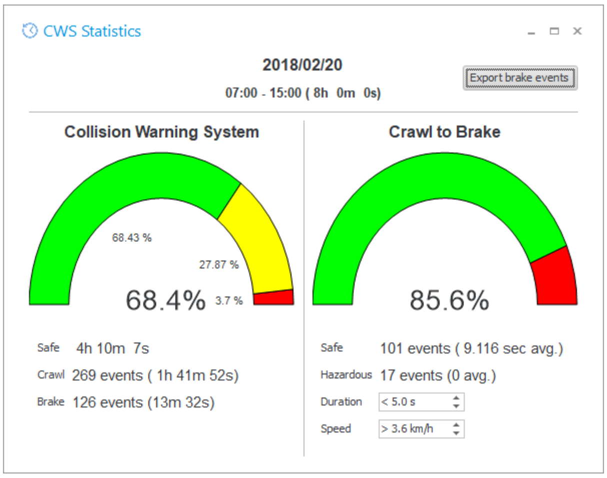


Figure 32 - CWS statistics for fast shift (Bruno, 2018)

4.2.9 neroHUB Interface Machine Stopping Distance Measurements

Further to the LHD speed analysis, all the CWS braking instructions and stopping times were exported for deeper analysis of the impact from the speed at brake instruction. The dataset used contains the speed at the time of brake instruction, the time until first 0km/hr speed measurement recorded and the calculated distance travelled after the brake instruction was received. The LHD's speed measurement is implemented with a pulsed sensor with a frequency of 4.78Hz per km/h. The neroHUB determines speed is 0km/hr by timing out pulses of less than 2Hz (500ms). This generally results in a conservative (over-estimated) stopping distance calculation. The data presented below should be interpreted as indicative:

4.2.10 Single machine stopping distance

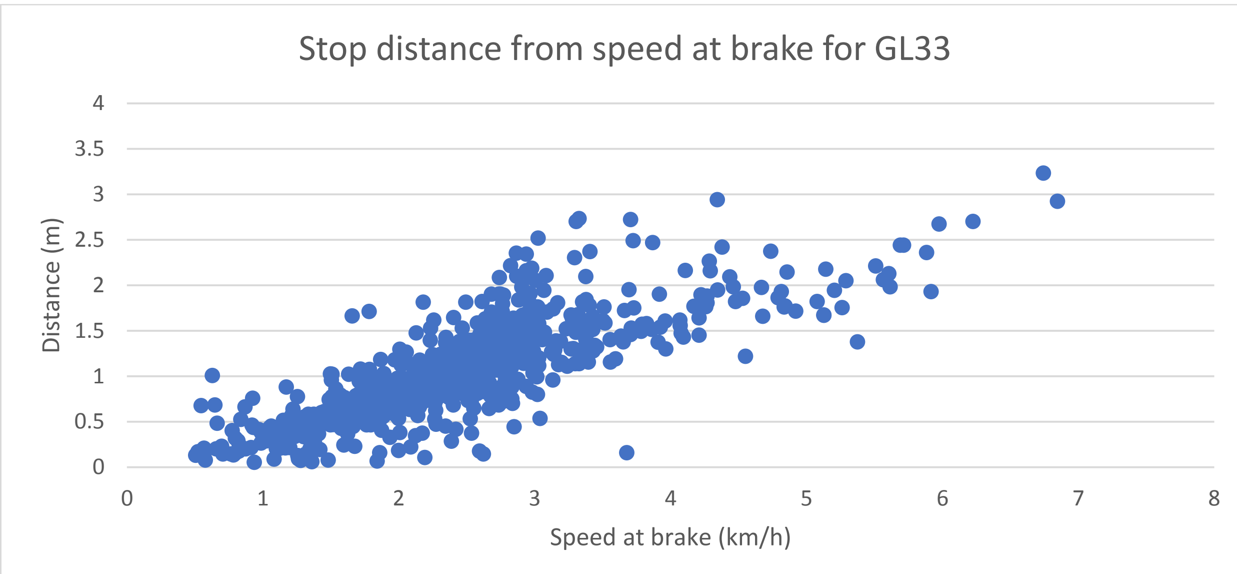


Figure 33 - Distance vs speed at brake instruction for GL33 (Bruno, 2018)

The data is represented by a X-Y scatter plot of distance versus speed at the time of brake instruction. Multiple factors influence the braking distance, such as slope, brake wear and travel way surface conditions.

4.2.11 Multiple machine overlaid stopping distance

Machine data for 3 months from 8 LHDs was overlaid to compare measurements of each machines stopping distance versus initial speed. The total amount of 10 759 events were included in the dataset. A similar pattern for each machine was observed with an expected positive correlation of increased distance versus speed at brake. Outliers such as GL33 were identified, and mine management flagged this particular machine for service in order to ascertain the cause of the occasional longer braking distances at slow speeds. The dataset clearly shows that in the last 3 months a very small percentage of events have occurred above 7 km/h.

- 31 events occurred above 8km/h, approximately **0.29%,**
- 96 Events occurring above 7km/h, approximately **0.9%**

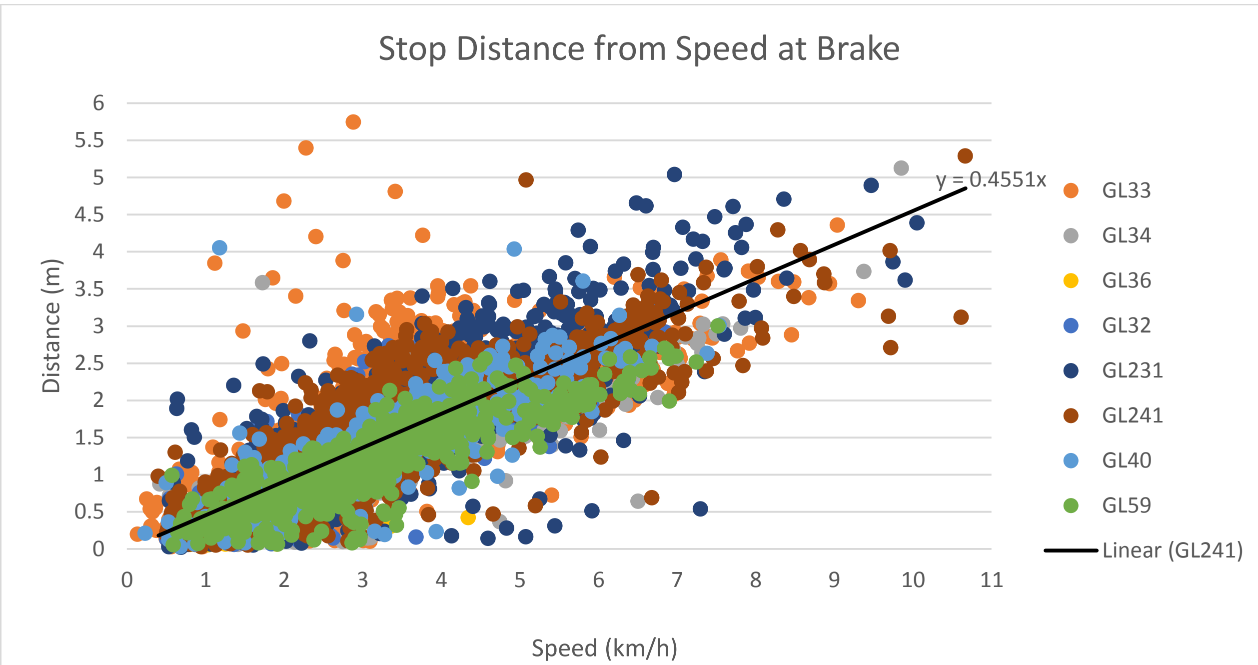
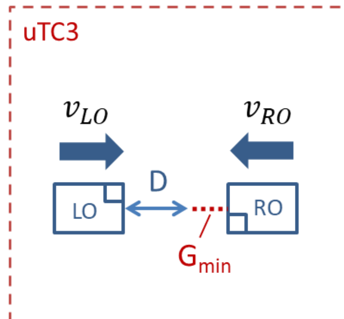


Figure 34 - Stopping Distance vs speed at brake instruction for 8 most active LHD's (Bruno, 2018)

4.3. neroHUB Recorded Data acquired during Gerotek Tests

In addition to the Mine Resilience Research Centre equipment, the two light vehicles utilized during the tests at Gerotek were also instrumented with Nerospec neroHUB Interfaces recording the PVDS instructions to the vehicles. The neroHUB Interface GPS receivers were also enabled to record the vehicle movements for visualization. Nerospec contributed some of the data acquired during the Gerotek tests as supplementary input to this report. Records are available for each of the test run. They are too numerous to include individually in this report. Instead a selection of the records are presented with a the intention of giving the reader sufficient information to visualize the nature of the tests conducted.

4.3.1. Head-head (uTC3) Crawl Only



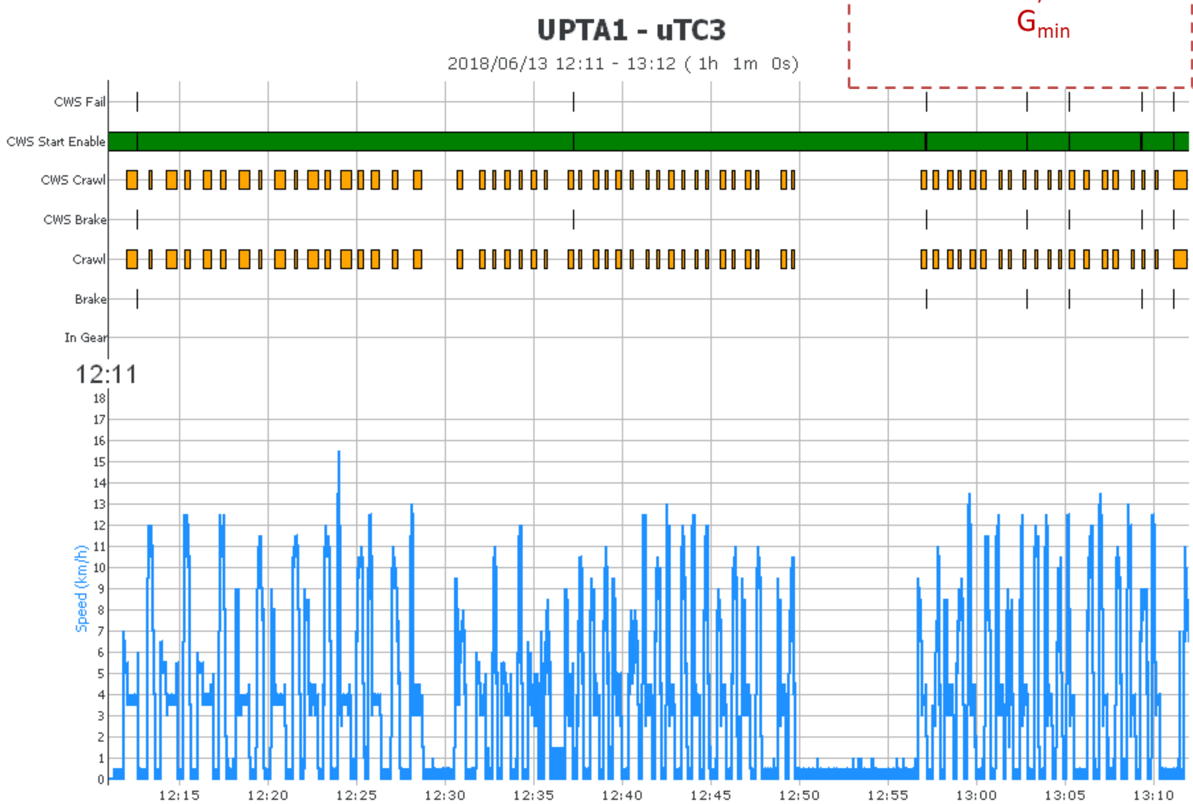


Figure 35 – uTC3 Crawl Only applications Vehicles Head to Head (Bruno, 2018)

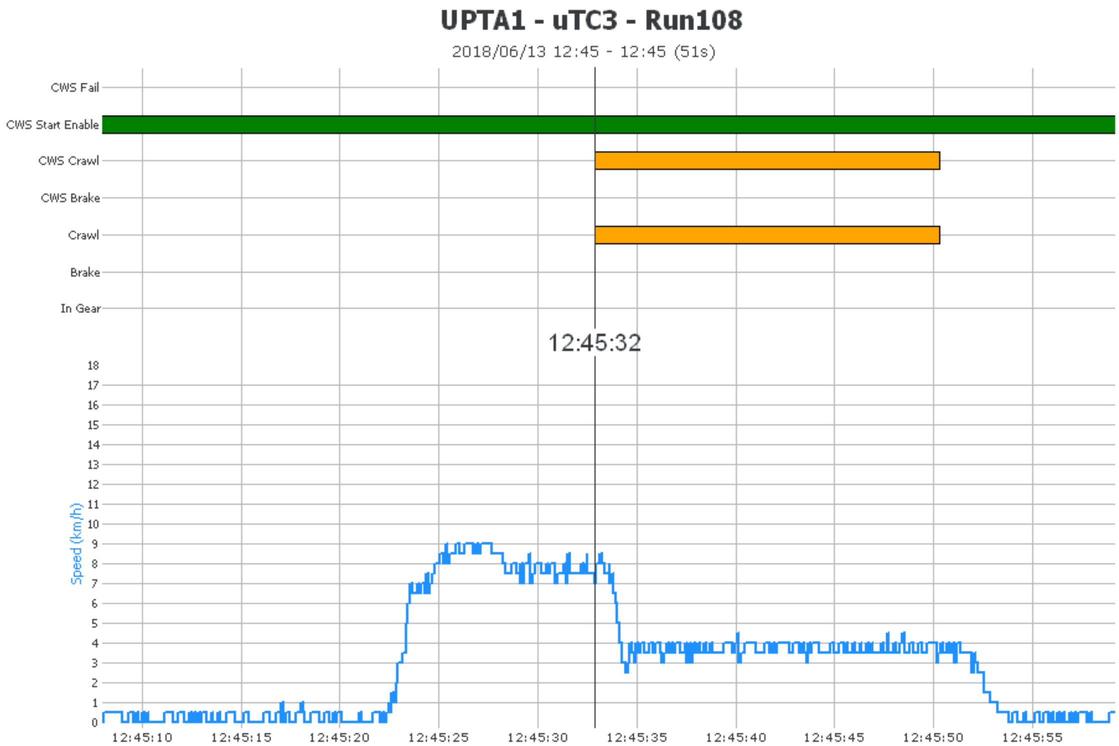


Figure 36 – uTC3 Typical Single Test Record Run 108 (Bruno, 2018)

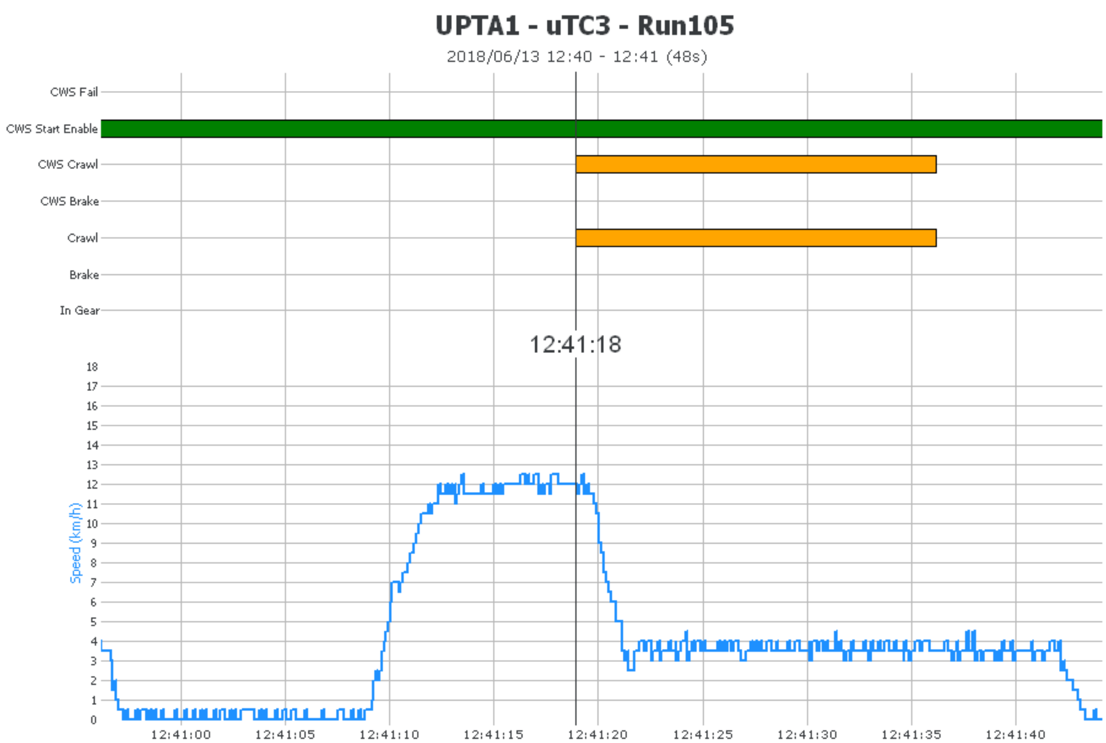


Figure 37 – uTC3 Typical Single Test Record Run 105 (Bruno, 2018)

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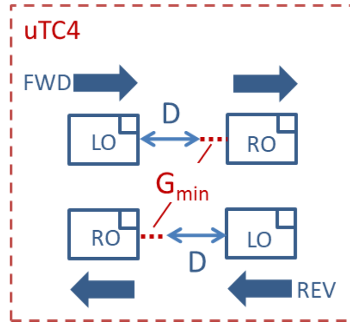
4.3.2. Head-tail (uTC4) Crawl Only



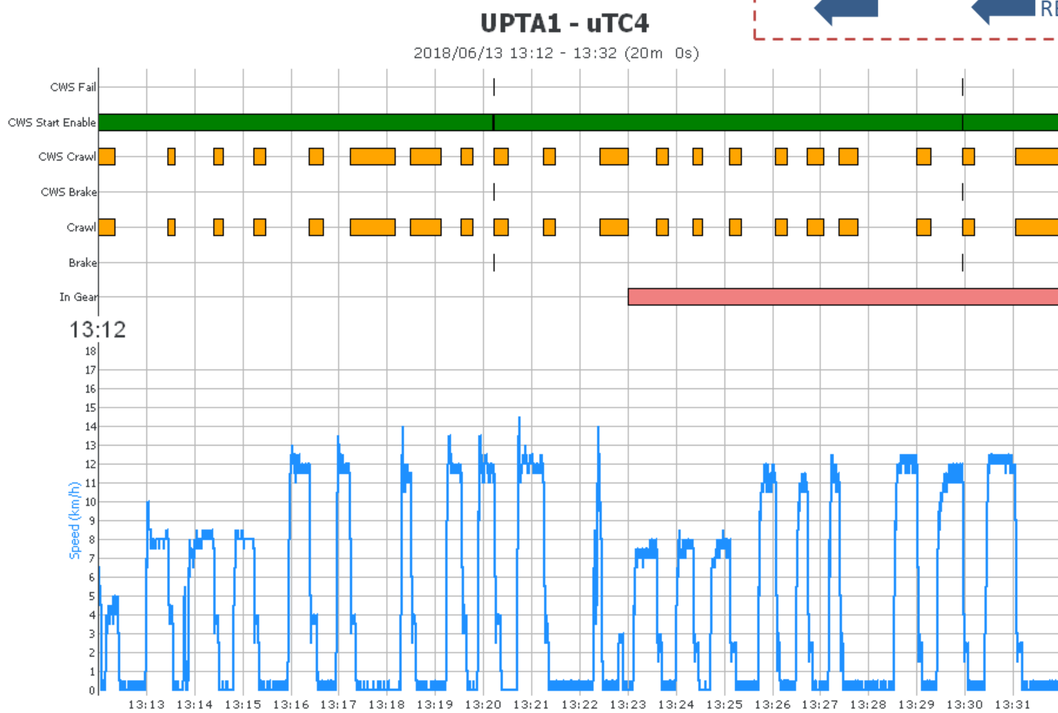


Figure 38 – uTC4 Crawl Only applications Vehicles Head-tail (Bruno, 2018)

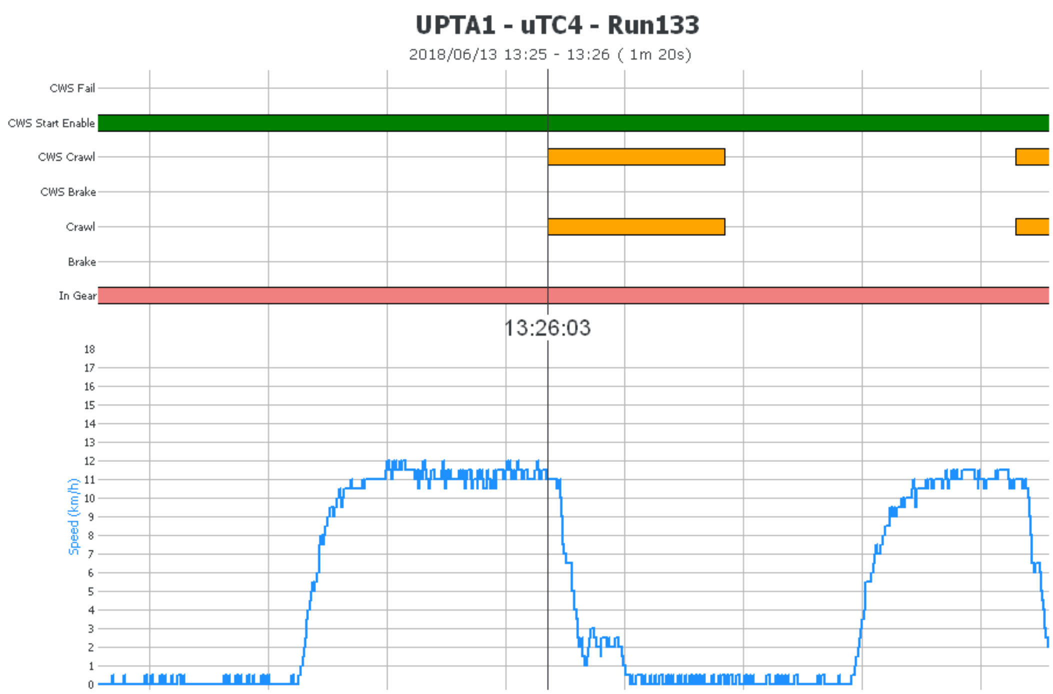
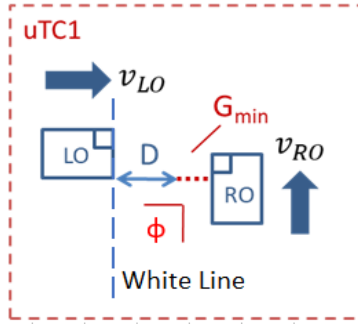


Figure 39 – uTC4 Typical Single Test record Run 133 (Bruno, 2018)

4.3.3. 90° intersection (uTC1) Crawl Only



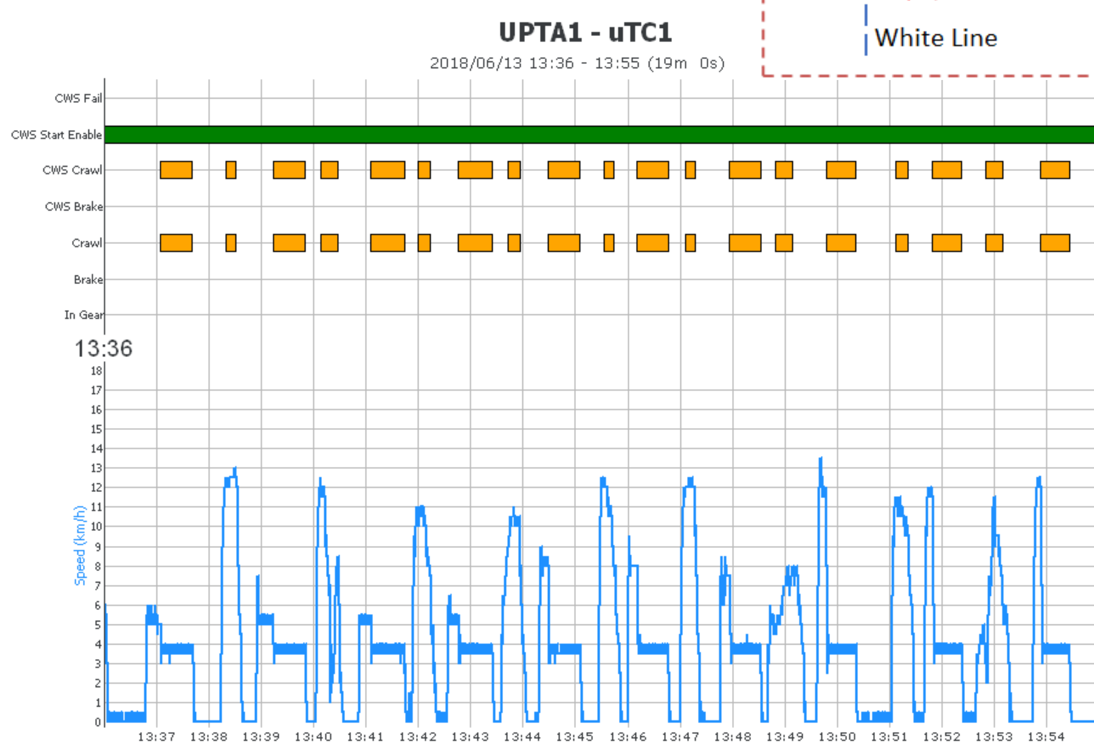


Figure 40 – uTC1 Crawl Only applications Vehicles 90° Intersection (Bruno, 2018)

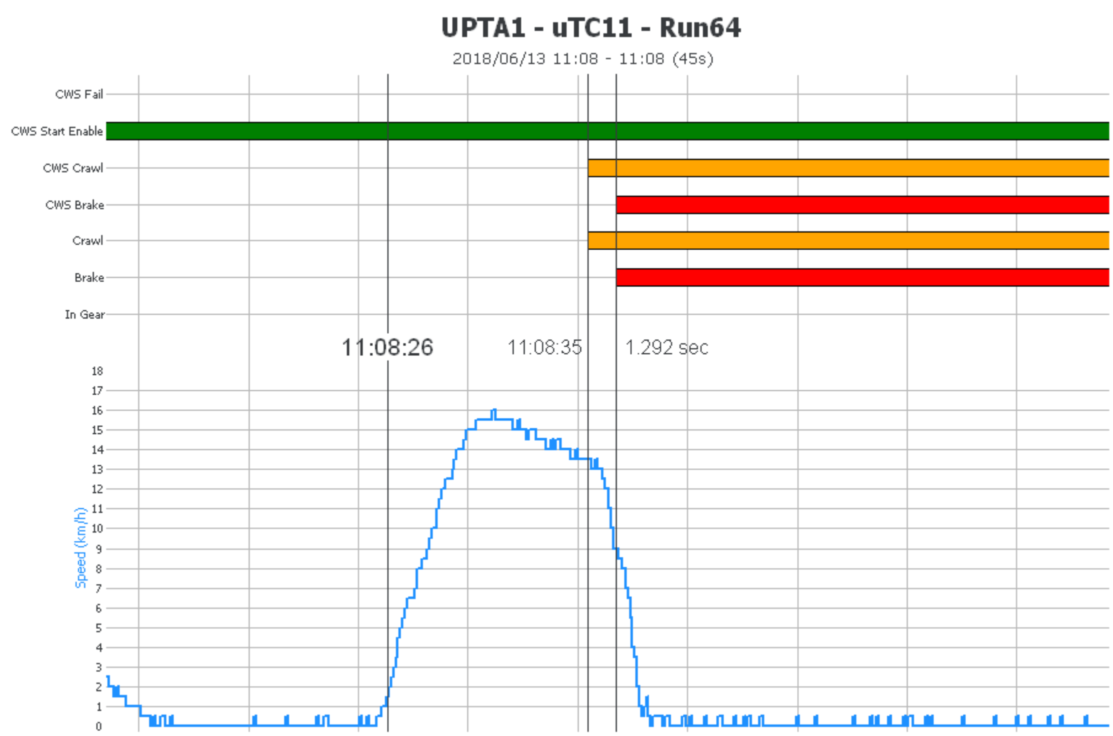


Figure 41 – uTC1 Typical single test record Run 164 (Bruno, 2018)

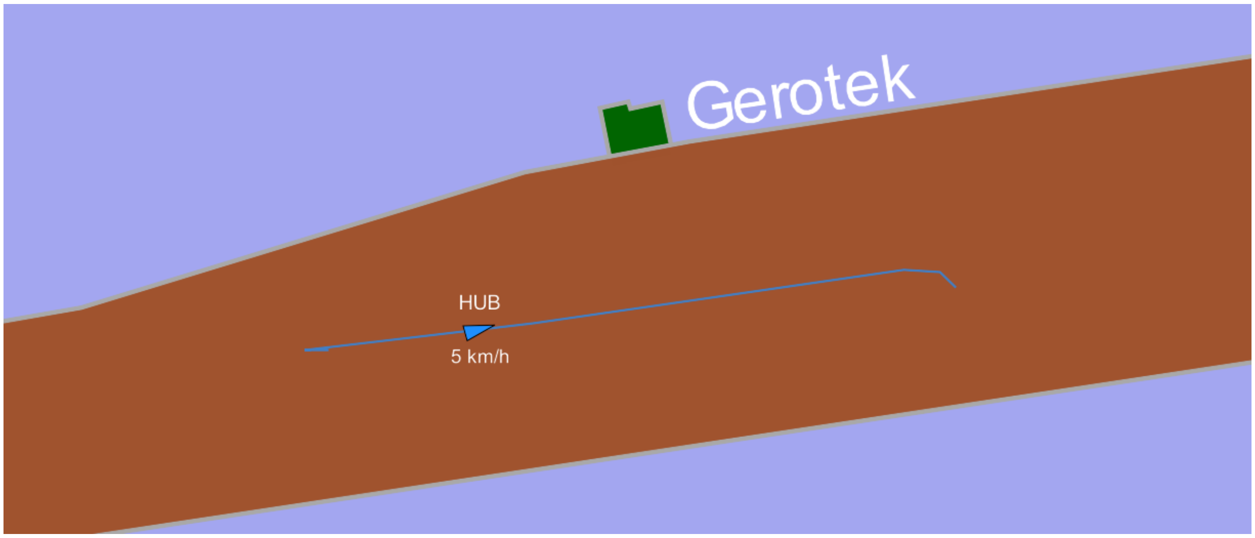


Figure 42 – uTC1 Typical Single Test record Run 164 GPS Trail (Bruno, 2018)

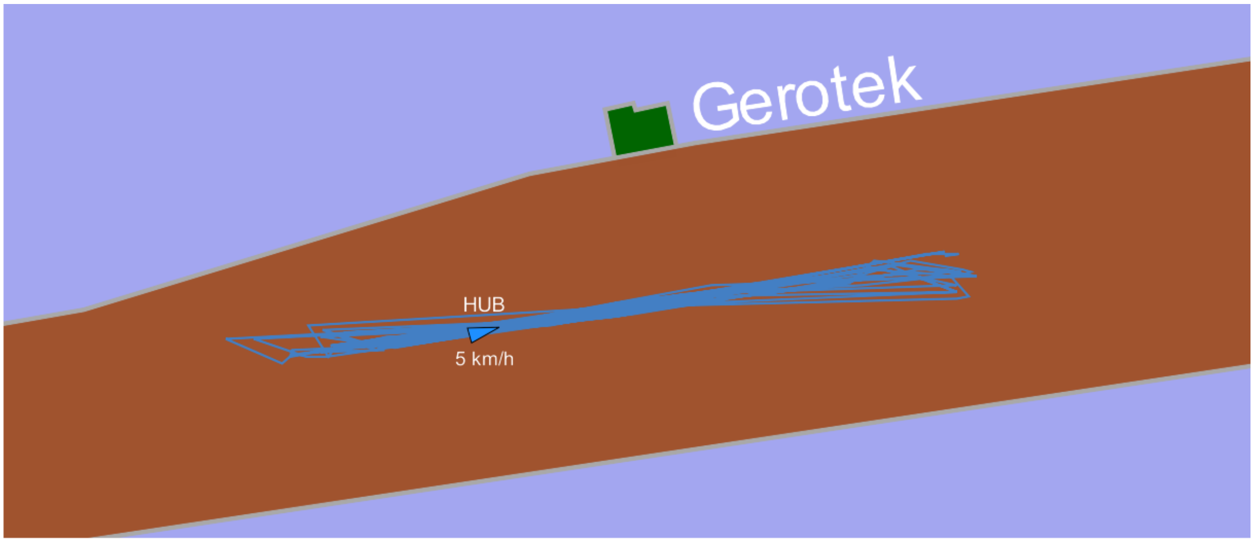


Figure 43 – Multiple uTC1 GPS Trails overlaid (Bruno, 2018)

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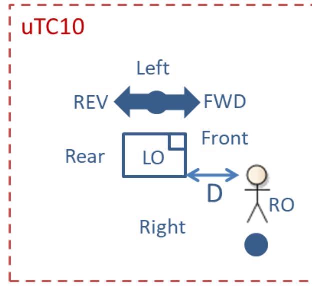


4.3.4. Approach person (uTC10) Crawl & Stop

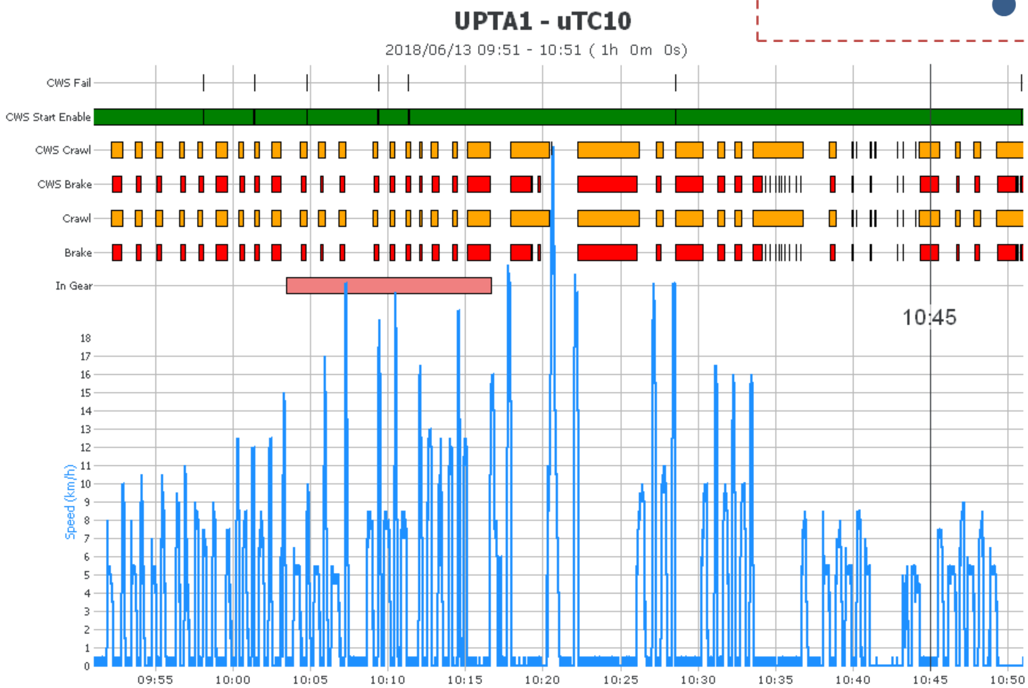


Figure 44 – uTC10 Crawl & Stop applications Approach person (Bruno, 2018)

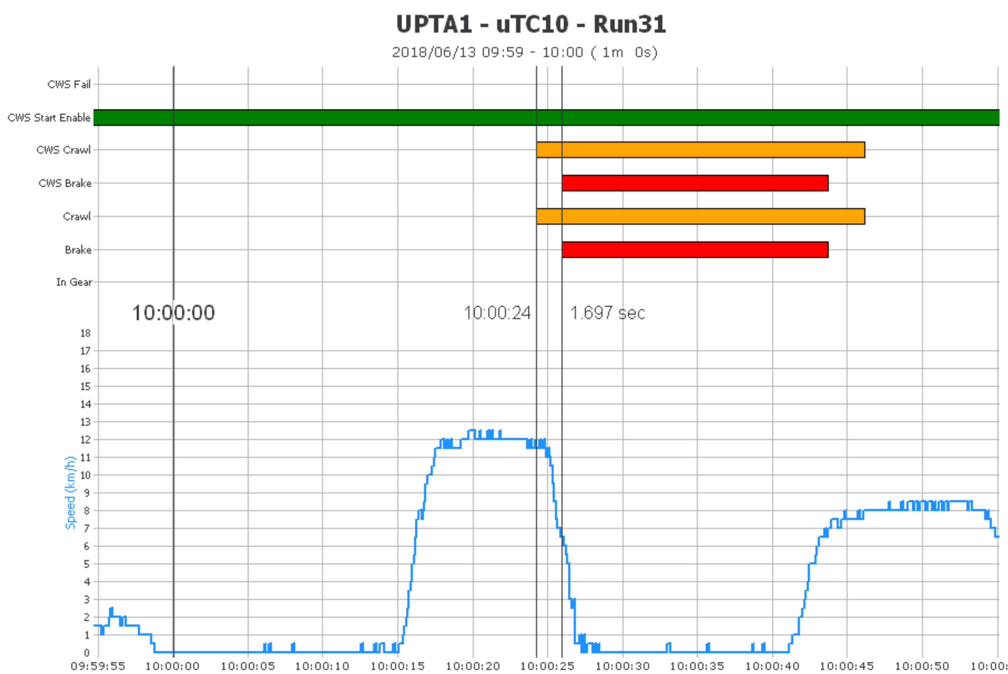
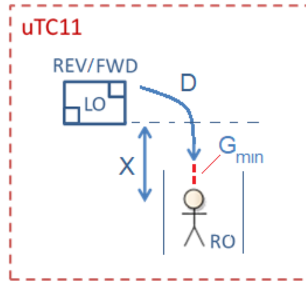


Figure 45 – uTC10 Typical single test record Run 31 (Bruno, 2018)



4.3.5. Approach person indirect (uTC11) Crawl & Stop

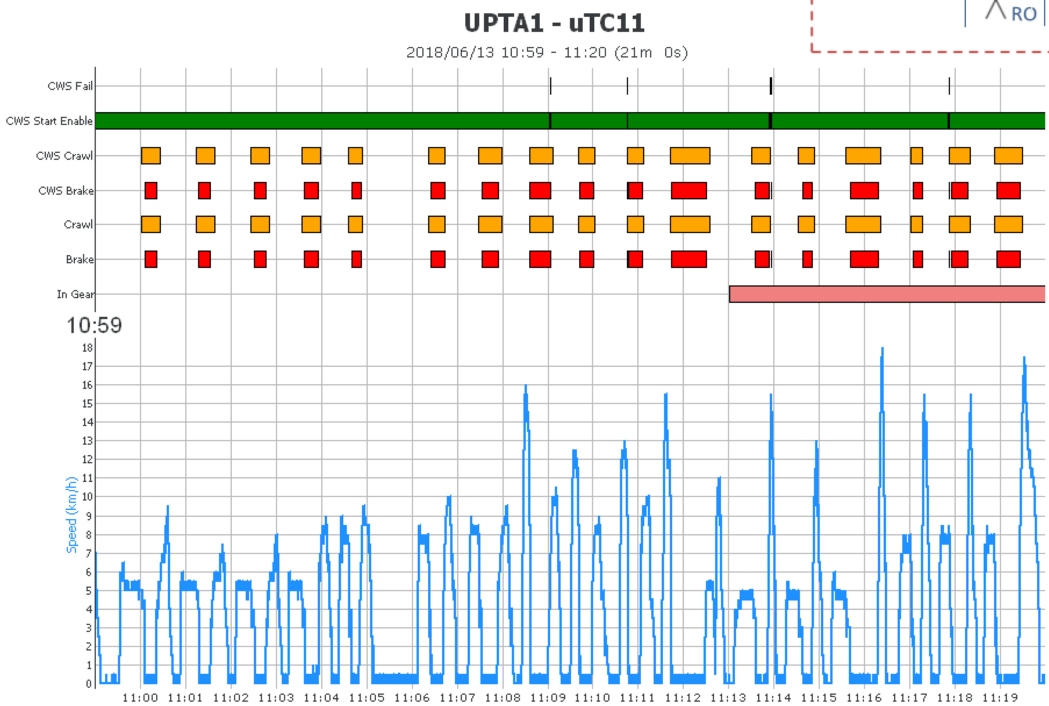


Figure 46 – uTC11 Crawl & Stop applications Approach person indirect (Bruno, 2018)

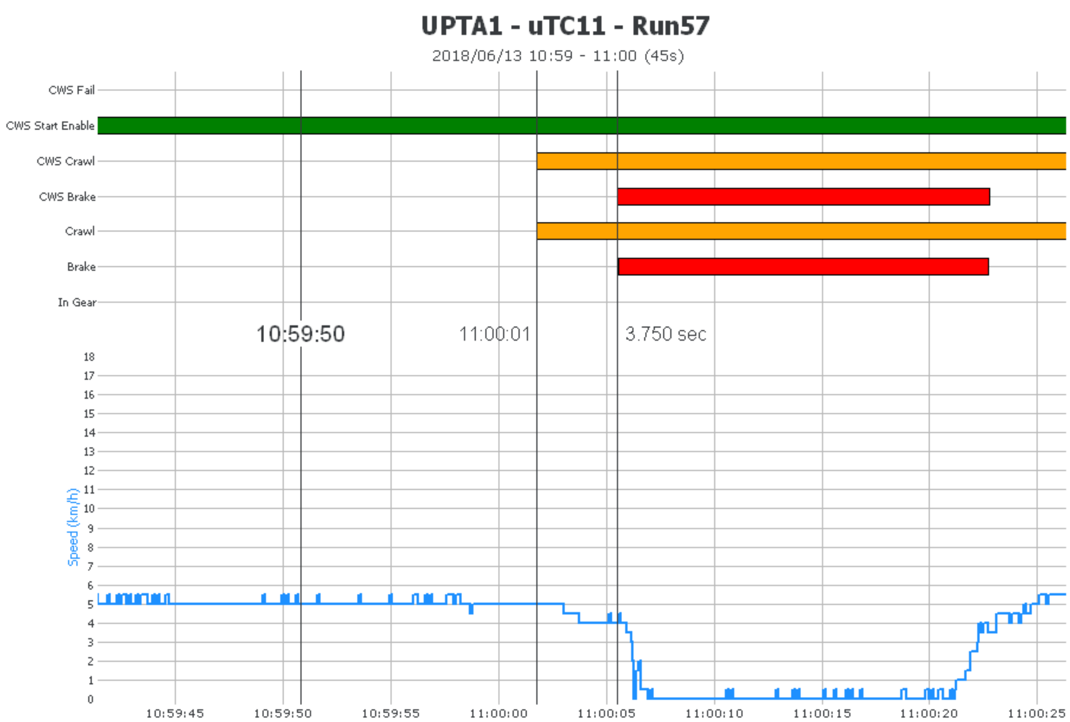


Figure 47 – uTC11 Typical single test record Run 57 (Bruno, 2018)

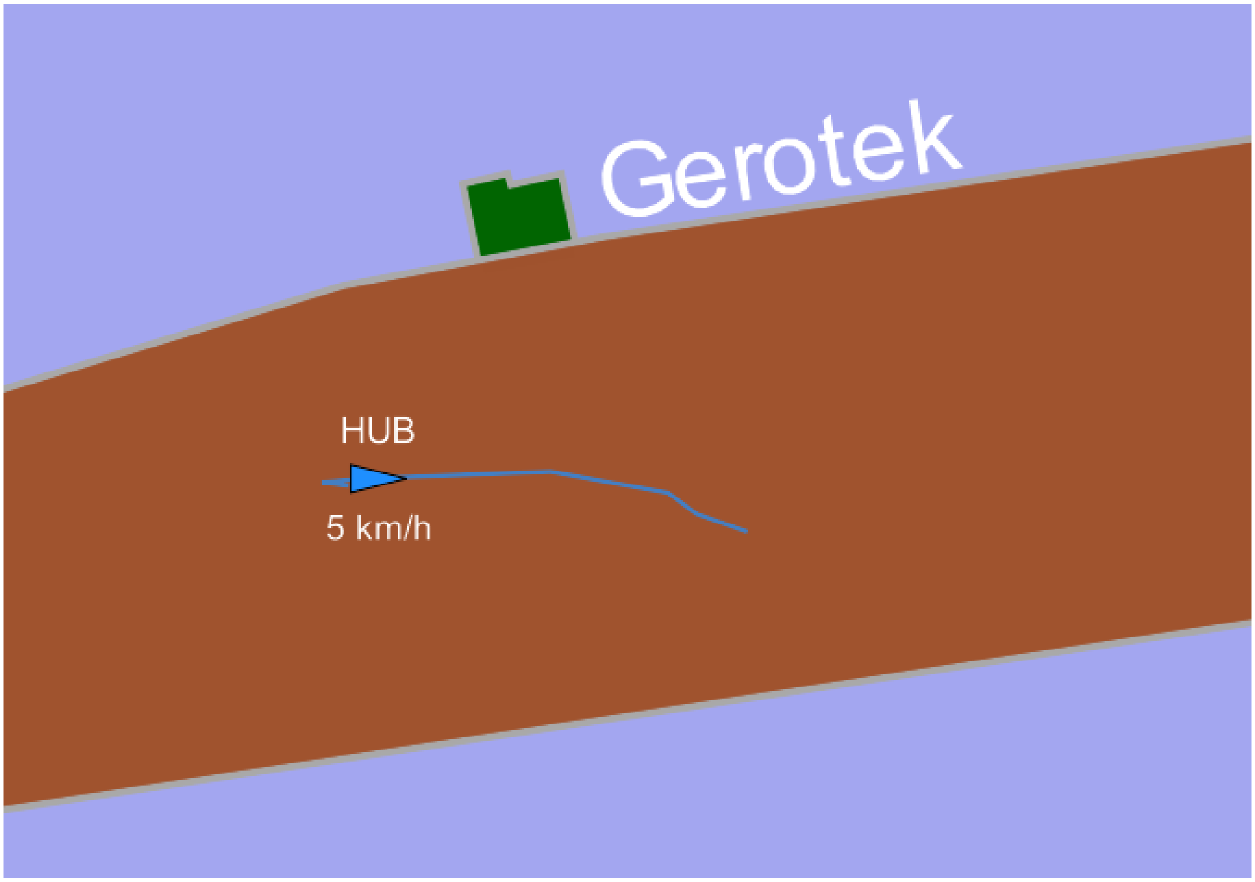


Figure 48 – uTC11 Typical Single Test record Run 57 GPS Trail (Bruno, 2018)

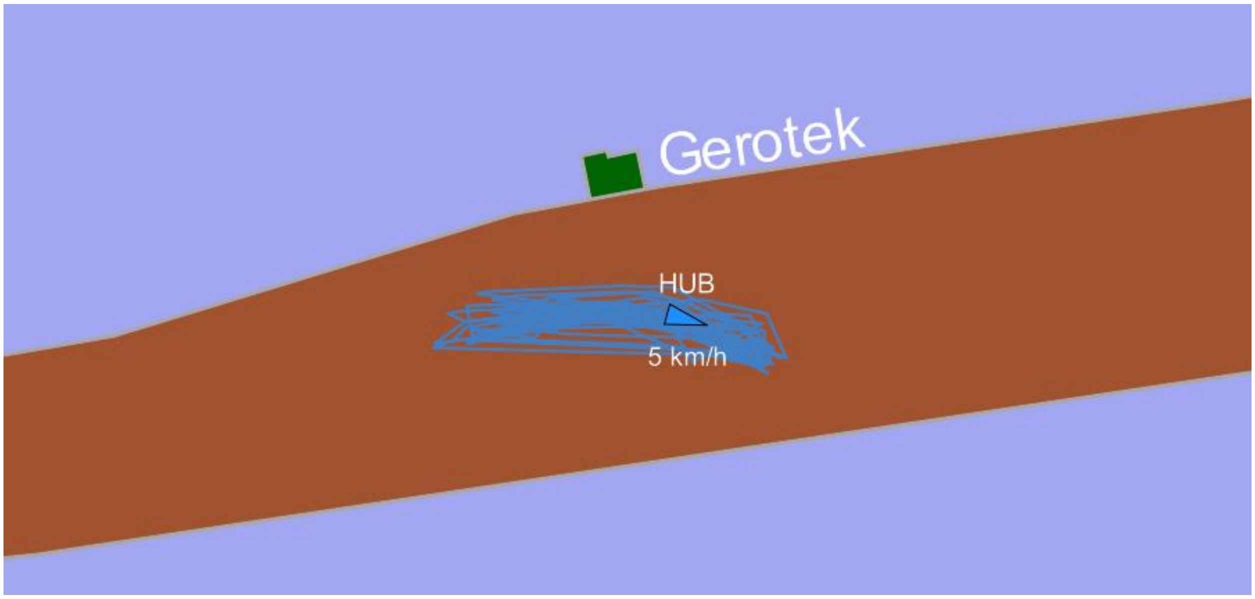


Figure 49 – uTC11 Multiple uTC11 GPS Trails overlaid (Bruno, 2018)

5 Technology Capability Assessment Framework

A capability assessment framework was created for CAS/CMS implementation, as shown in Table 4. This table highlights the components applicable for the assessment toward commercialisation or roll-out. The table represents components applicable to the PVDS. The relevant sections within this report that cover or add to some of these components, are indicated within the table.

The “vertical axis” indicates the Technology Capability Components, laid out in the sequential order that drive the eventual technology capability, as well as what aspects underlie this capability (i.e. people and knowledge requirements). As seen from this framework, it is important to understand which factors in the user environment drive, and lead to, the user requirements. The user requirements were divided into factors that affect successful user adoption (end-user requirements), the safety specifications (stakeholder requirements), and the corresponding or resulting technical requirements (developmental requirements).

Following the user requirements are the technical specifications that then drive the product design to achieve the user requirements within the given user environment description. For the PVDS it is then important to map the system of how the product is designed and interlinked by the various suppliers. Following this, when assessing the capability of a technology product it is also vital to map the underlying technology (components and equipment) that it consists of – as well as the technology readiness of these components (e.g. sensor technologies, software, hardware etc.), in order to understand the constraints and benefits and the effect of these on the initial user requirements. Similarly, the knowledge and people required for the successful production as well as the eventual operation and maintenance of the product should also be mapped.

The “horizontal axis” indicates the Technology Readiness Components that align with the technology’s lifecycle. For the PVDS, these were split into two categories. The first being the functional criteria (which are in an evolving order of increasing requirements and complexity, i.e. from L7 to L9 as applicable to the scope of the PVDS). The second category is the criteria for capability and readiness, which are listed in order of priority as well as transition along the lifecycle. These can be broadly described as the safety implications criteria, i.e. what implications the technology capability will have on safety; system implications, i.e. what impact the technology will have on the system it acts upon, such as productivity, increased brake wear, process management etc.; continuous improvement, i.e. what improvements and further developments are necessary to address the requirements on the “y-axis” in order to move to the next stage in the technology’s lifecycle; which is the roll-out to another user environment (mining operation).

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Table 4: CAS/CMS Capability Assessment Framework

Glencore Waterval East PVDS – Technology Capability Map									
			Technology Readiness Components						
			Functional Criteria			**Capability & Readiness Criteria**			
			a Operator Awareness (EMESRT L7)	b Advisory Controls (EMESRT L8)	c Intervention Controls (EMESRT L9)	d Safety implications	e System Implications	f Continuous Improvement	g Commerciali sation / Roll-out
Technology Capability Components	**1. User Environments**	1.1 Description of the environment of the user / systems architecture, that drives the requirements				Briefly touched on in Section 3			
	2. User Requirements	2.1. User Adoption	Overview provided throughout Section 2						
		2.2. Safety Specifications	Overview provided throughout Section 2						
		2.3. Technical Requirements				Section 2.2			

Glencore Waterval East PVDS – Technology Capability Map									
			Technology Readiness Components						
			Functional Criteria			Capability & Readiness Criteria			
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	3. Technical Specifications	3.1 Technical Specifications				Section 2.2			
	4. Product	4.1. LSC	Section 3	Section 3	Section 3	Section 3	Section 2.6	Section 2.7.4 (Not exhaustively covered)	
		4.2. EiQ	Section 3	Section 3	Section 3	Section 3	Section 2.6	Section 2.7.4	
		4.3. NeroSpec	Section 3	Section 3	Section 3	Section 3	Section 2.6		
		4.4. OEMs (Interface with controls enabling Control Level 9)							

Glencore Waterval East PVDS – Technology Capability Map									
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	5. Technology	5.1. Components & Equipment							
	6. Knowledge	6.1 Knowledge requirements for the Technology							
	7.1 People	7.1 People requirements for the Technology							

6 Conclusions

The general conclusions for the assessment of the PVDS at Waterval East Mine can be summarised as follows:

- The PVDS project team obtained valuable knowledge over the past few years through a trial and error approach to the successful implementation and acceptance of the CMS/CAS system.
- This report highlighted the key learnings (both technical and human based) from this team that were identified as relevant to other similar initiatives.
- The PVDS implemented at Waterval Mine was tested on a proving ground (at Gerotek, Pretoria, South Africa) and the system was found to be consistent and repeatable in achieving its requirements. These included collision mitigation (in V2V interactions) and collision avoidance (in V2P interactions) measures, which are in line with the EMESRT Level 9 requirements.
- Although the PVDS functions sufficiently and greatly improves TMM related safety, it should be noted that this system came at great cost – in terms of capital and operating cost, as well as in production impacts (the latter was gradually decreased although the current impact was not quantified).
- A few nuisance inefficiencies were also highlighted in the report that negatively affect production. In this regard it should be noted that a complex technology system implementation will inevitably require after-care to improve efficiencies. In the case of a CMS/CAS initiative, the focus will largely be on balancing optimal safety requirements with minimal negative impacts on production.
- The suppliers of the PVDS also demonstrated a high degree of professionalism and continuous improvement of their products to achieve this balance as optimally as possible.
- The previous points highlight a few aspects. Firstly, the Waterval Mine team possess great amounts of tacit knowledge that may be leveraged in order to achieve a smoother and more efficient CAS or CMS implementation. Secondly, the financial feasibility and technical requirements for such a system should be investigated on an individual, per operation, basis.
- It should be noted that other technical documents, written up by Waterval East and by the suppliers (Nerospec, EiQ, LSC), are available for additional and substantiating information on top of the content within this report. Furthermore, if additional information is required, direct engagements with the PVDS project team would yield valuable insights.
- Combining these learnings with official CAS implementation guidelines would allow the creation of a more efficient implementation plan – Something that Waterval Mine in collaboration with its suppliers is currently working on.

Main key learnings:

- Successful implementation of a technology system that aims to monitor, or that functions by monitoring, the activities and behaviour of people often have difficulty being accepted by the workforce. Successful implementation of a CAS system, like the PVDS, is 80% worker acceptance and change management, and 20% technological development and engineering implementation.

- As such, it is crucial to start by identifying factors and approaches that would improve successful end-user adoption – a change management initiative needs to run top-down and in parallel with technology development and implementation.
- A system that addresses the majority of TMM related hazards is better than having no system in place – Plan the safety and technical requirements by analysing the user environment of the system to target priority needs.
- When referring to EMESRT guidelines, it should be noted that the EMESRT Level 9 is classified as the employment of intervention controls. These intervention controls may be either a forced (regardless of operator control or interaction) crawl of the TMM or a forced stop. It should be noted then that a forced crawl would allow improved collision management, but not necessarily collision avoidance as a forced stop would. In this regard, the PVDS at Waterval East currently provides L9 collision mitigation (crawl) for vehicle-to-vehicle interactions and L9 collision avoidance (stop within the critical one) for vehicle-to-person interactions.
- In developing the PVDS, other spin-off benefits were also realised. Firstly, the neroWEAR makes it possible to monitor brake wear electronically and in real time. This can be implemented on mining equipment irrespective of CMS/CAS initiatives. Secondly, poor or sub-optimal practices may be identified from suppliers and service providers when improved monitoring is implemented. In case of the PVDS brake wear was monitored due to increased cost resulting from the system. As a result, it was found that other system components were not replaced as needed during maintenance which caused uneven brake wear.
- In implementing the PVDS it also came to light that various aspects were not as well defined or in-place as previously thought. Traffic management at Waterval was one such an example. As such, implementing the PVDS led to other benefits as well, such as improved traffic management as well as a positive change in employee behaviour where a more considerate, aware and safe approach is now taken toward TMMs.

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