PART 1: USER REQUIREMENTS FOR COLLISION PREVENTION SYSTEMS

(I.E. WORK PACKAGE 9)

INDUSTRY ALIGNMENT ON TMM REGULATIONS; SPECIAL PROJECT OF THE MINERALS COUNCIL SOUTH AFRICA

REV 4

CPS User Requirements Acceptance			
Name	**Signature**	**Organisation**	**Date**
Kobus Blomerus		**SECDI**	**30 May 2022**
Stanford Malatji		**Minerals Council**	20 June 2022

TABLE OF CONTENTS

1. Purpose of this document

The purpose of the CPS URS is to define the SAMI requirements for the development of a CPS that:

- Meets the MHSA TMM collision prevention regulatory requirements,

- Meets the needs of the SAMI mine types and mine working environments,
- Informs the functional specification thereby ensuring that any CPS tested in accordance with the CPS test regime is suitable for use in SAMI, and
- Meets the needs of collision prevention (V-V for surface and V-P for underground).

It is not the purpose of this URS:

- To be a functional specification,
- To define the life cycle requirements of the CPS,
- To define any SAMI CPS needs other than the MHSA regulatory requirement needs.

2. Scope

This content of this CPS URS applies to:

- The SAMI for both surface and underground mines,
- All mining types and processes as per Minerals Council South Africa document:

  MINING PROCESSES AND TRACKLESS MOBILE MACHINERY TYPES USED IN THE VARIOUS PROCESSES: Report compiled as an outcome of two industry workshops held on 15 April 2021, one for underground equipment and another for surface equipment.

The scope of this URS does not:

- Include all interaction types that may be found in the specific mining processes. These interaction types must be determined through performing a traffic flow analysis, a risk assessment and then the development and implementation of a traffic management plan in accordance with the MOSH Traffic Management Leading Practice for Surface Operations and MOSH Underground Traffic Management Technical Guide,
- Explicitly consider the capability of currently available CPS technologies, but rather defines what the user requires from a CPS.

3. Definitions and abbreviations

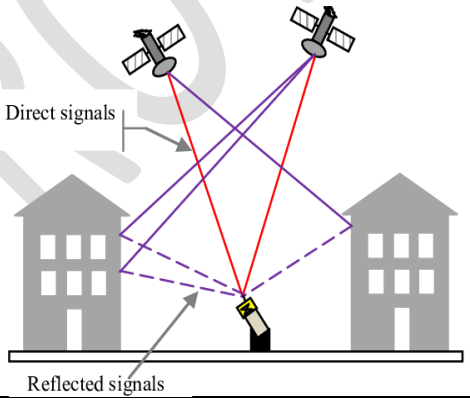
The following definitions and abbreviations will be used to create a common approach for all deliverables: (Note: The rationale for some of the terms and definitions is set out in the CMS Technical Specification Guideline Review Report)

3rd Party	An entity appointed to execute work (testing, witnessing of testing and verifying portfolios of evidence) on behalf of SAMI. Note: The purpose of 3rd party execution is to establish independence and to eliminate duplication.
Accelerated Development	Development of CPS products in a coordinated and integrated way that will require less time (for the entire SAMI need), than the previous individual mine and supplier / OEM driven CPS product development approach.
Accuracy	The degree to which the result of a measurement, calculation, or estimate conforms to the correct value, i.e. the preciseness of the measurement.
C102-F9R	C102-F9R application board Easy evaluation of ZED-F9R with sensor fusion. Application board for ZED-F9R
CMS	Collision Management System: The overall combination of preventative controls, mitigation, recovery and supporting controls, implemented by a mine site to prevent TMM collisions.
Controlled area	Area that is dedicated to testing with no interference from vehicular or pedestrian traffic. Example: Gerotek Test Facilities, section on mine isolated from any mining activity, or demarcated area at a TMM OEM assembly plant.
CPS	Collision Prevention System: A Product System that comprises the functionality and characteristics that comply with the RSA TMM collision prevention regulations. (TMM Regulations 8.10.1 and 8.10.2 and user requirements.)
CWAS/(CxD)	Collision Warning and Avoidance System device (CxD): Device with sensors providing collision warning and avoidance functions, to detect objects in the vicinity of the machine, assess the collision risk level, effectively warn the operator of the presence of object(s) and/or provide signals to the machine control system, to initiate the appropriate interventional collision avoidance action on the machine, to prevent the collision. Note to entry: Proximity Detection System (PDS) is a colloquial industry term for a physical device, providing a warning or collision avoidance functionality.
CxD	Collision warning/detection/management Device.

CxDC	CxD Controller: A sub-system of the CxD, that is typically the computer that contains the decision-making logic.
CxDI	CxD interface: A integration function between the CxD and the Machine Controller.
CxDLK	CxD Log Keeping: The function that receives, and stores CxD data.
D&T	Detect and Track: A functional group of a CxD enabling detection and tracking of TMMs and pedestrians inside the detection area of a surface TMM and an underground TMM respectively.
DAQ	Real time computer with data acquisition and control capabilities. Has ISO21815 interface. Example: DSpace MABX II.
Data scientist	Experienced person in the field of data processing and statistics. This person will analyse data collected during TRL9 pilot site roll-out testing.
Detection	Detection is sensing that an object has entered the detection area.
DMRE	Department of Mineral Resources and Energy.
Driver or operator reaction time (also known as perception response time)	The time that elapses from the instant that the driver recognises the existence of a hazard in the road, to the instant that the driver takes appropriate action, for instance, applying the brakes. The response time can be broken down into four separate components: detection, identification, decision and response. When a person responds to something s/he hears, sees, or feels, the total reaction time can be broken down into a sequence of components namely: • Mental processing time (sensation, perception / recognition, situational awareness, response selection and programming). • Movement time, and • Driver response time. Driver reaction time is also affected by several issues such as visibility, operator state of mind (fatigue), and direction or position of perceived danger.
EAV	Exposure Action Value
ELV	Exposure Limit Value
EM engineer	Qualified person (BEng, BTech) in the EMC environment, with extensive experience in EMI/EMC testing.
EMC	Electromagnetic Compatibility
EMESRT	Earth Moving Equipment Safety Round Table
EMI	Electromagnetic Interference
Employee	Employee means any person who is employed or working at a mine.

EW (Surface)	Effective Warning: For surface TMMs: The expected outcome of the operator action is that the potential collision is prevented, therefore an effective warning must inform the operators of both TMMs what the appropriate action(s) are, to prevent the potential collision.
EW (Underground)	Effective Warning: For Underground TMMs: The expected outcome of the operator and pedestrian action is that the potential collision is prevented. Therefore, an effective warning must inform the operators of TMMs what the appropriate action(s) are to prevent the potential collision and must alert the pedestrian to potential collisions, or interactions with TMMs in the vicinity.
F	Function: Indicates a function of the CPS or functional group.
F&TPR	Functional and Technical Performance Requirements
FMECA	Failure Mode Effect and Criticality Analysis
FTS	Fail to Safe: The functionality that will bring a TMM to a controlled stop
Functional Specification	Specifications that define the function, duty, or role of the product/system. Functional specifications define the task or desired result, by focusing on what is to be achieved, rather than how it is to be done.
G	General: Indicates a general requirement that is applicable to the entire CPS and all of it elements, modules, and components.
Homologation	Homologation means to sanction or "allow." Homologation refers to the process taken to certify that a TMM fitted with a CPS is manufactured, certified, and tested to meet the standards specified for critical safety related devices fitted to TMMs.
HP GNSS	High Precision Global Navigation Satellite System, capable of measuring position, with an absolute accuracy of 0.1m and velocity to within 0.2km/h with an update rate of 100Hz. Example Racelogic VBOX 3i.
ICASA	*Independent Communications Authority of South Africa*
ICMM	International Council on Mining and Metals.
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ID	Identifier.
Independent	Separate from the CPS product developer. Note: Independent does not imply an accredited 3rd party, although where required by local or international standards, it includes accredited 3rd parties.
Independent person	A person, typically a test-, software- or EM engineer, who is not affiliated with the CPS provider or TMM OEM, that can provide an unbiased assessment.

Integrated Testing Regime	A holistic method of testing, optimising existing testing facilities that are currently available irrespective of who owns them. This method ensures specific CPS tests are only done once (CxD and TMM CPS Product combinations) and verification is done as early as possible in the development process.
Interface	A boundary across which two independent systems meet and act on, or communicate with each other. Four highly relevant examples: 1. CxD-machine interface – The interface between a Collision Warning and Avoidance System Device (CxD) and the machine. This interface is described in ISO/DTS21815-2. 2. The user interface – Also sometimes referred to as the Graphic User Interface (GUI) when an information display is used. This is the interface between the user (TMM operator or pedestrian) and the CxD or pedestrian warning system. 3. V2X interface – the interface between different CxD devices. V2X is a catch-all term for vehicle-to-everything. It may refer to vehicle-to-vehicle (V-V), vehicle-to-pedestrian (V-P), or vehicle-to-infrastructure (V-E). 4. CxD-peripheral interface – This is an interface between the CxD and other peripheral systems that may be present on the TMM. Examples include a fleet management system, machine condition monitoring system, or fatigue management system. Note: An interface implies that two separate parties (independent systems), are interacting with each other, which may present interoperability and/or EMI and EMC challenges.
LO	Local Object: Denotes the TMM that is detecting other TMMs (S) or pedestrians (P)
Localization	Localization is measuring the position of the object within the detection area; it provides the local object with a map of the remote objects within the environment.
Loss of control	The uncontrolled movement of a TMM due to operator, machine, or environmental reasons. Note: Section 8.10.3 of MHS Act. Loss of control may result in several scenarios: • Machine failure – park brake, or service brake, or tyre blowout. • Operator disabled – fatigue, medical condition, inattention, distraction, or non-compliance with TMP rules (e.g., over speeding on decline, or overloading)

MBS	Machine Braking System: The physical components that makes an unintelligent TMM intelligent and enables the CPS auto slow-down and stop functionality.
MC	Machine Controller.
MCI	Machine Control Interface: The interface between the Machine Controller and the CXD interface.
MHS Act	Mine Health and Safety Act No. 29 of 1996 and Regulations.
MHSC	Mine Health and Safety Council.
Minerals Council	Minerals Council South Africa.
MLK	Machine Log Keeping: The function that receives, and stores TMM CPS data.
MOSH	Mining Industry Occupational Safety and Health.
MRAC	Mining Regulations Advisory Committee.
MRL	Manufacturing Readiness Level. A manufacturing maturity level within a manufacturing readiness framework.
MS	Machine Sensing: Sensing functionality on a TMM that enable a fully functional CPS.
Multipath	Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths, typically some direct signals, but also some reflected signals. 
OWS	Operator Warning System: The system that provides the effective warning and other warnings to the operator of a TMM.
PDS	Proximity Detection System – see CxD.
Pedestrian	A person lying, sitting, or walking rather than travelling in a vehicle.
Project	Industry Alignment on TMM Collision Management Systems Project: CAS READINESS PHASE.
PWS	Pedestrian warning System: The system that provides the effective warning to pedestrians.
Quality Assurance	Verifying a process, product, or service; usually conducted by an experienced person in the specific field.

Reasonably practicable measure	Reasonably practicable means practicable with regards to: (a) The severity and scope of the hazard, or risk concerned. (b) The state of knowledge reasonably available, concerning the hazard or risk, and of any means of removing or mitigating the hazard or risk. © The availability and suitability of means to remove or mitigate that hazard or risk, and (d) The costs and the benefits of removing or mitigating that hazard or risk.
Reliability (sensor)	Sensor reliability refers to the consistency of a measure. Achieving the same result by using the same methods under the same circumstances, is considered a reliable measurement.
RO	Remote Object: Denotes TMM(s) (S) or pedestrian(s) (U) being detected by the LO.
Robustness (sensor)	Sensor robustness is the ability of the sensing device (sensor), to remain functional in the presence of normal operating conditions of TMMs on a mine, such as electromagnetic interference, mechanical vibration, dust, adverse weather conditions, etc.
S	Surface: Indicating that a specific aspect is applicable to surface TMMs/operations.
Safe Park	A way that a TMM is parked, namely: Machine static, engine switched of and park brake applied.
Safe speed	The speed that will ensure the controlled stopping of a TMM without any immediate negative impact on the operator or machine. Note: This is a conditional variable value, depending on multiple input variables.
SAMI	South African Mining Industry.
Sensor fusion	Sensor fusion is the process of combining sensory data, or data derived from disparate sources, such that the resulting information has less uncertainty than when the sources were to be used individually.
Significant risk (of collision)	The reasonable possibility of a TMM collision, given all the controls that a mine has put in place to prevent a TMM collision.
Slow down	ISO/TS 21815-2: 2021 defines slow down as: "The SLOW-DOWN action is sent by the CxD to reduce the speed of the machine in a controlled / conventional manner, as defined by the machine control system. The intent of this command is to slow down the machine when the CxD logic determines that a collision / interaction can be avoided by reducing speed".
Software engineer	Qualified person in the communications/computer environment, with extensive experience in ISO 21815 – 2:2021 programming and testing.

SP GNSS with self-recorder	Standard Precision Global Navigation Satellite System: A system that is capable of measuring position with an accuracy of 1.5m, with an update rate of 10Hz. Can also store its own data. Example: UBlox C102-F9R.
Stage gate	A step in the testing regime / process where the CPS product system is tested against acceptance criteria, the failure of which would limit the CPS product system from moving to the next step in the regime / process.
Stop	ISO/TS 21815-2: 2021 provides for two definitions, an emergency stop, and a controlled stop, both of which are a 'Stop'. The definitions are: 1. "The EMERGENCY-STOP action is sent by CxD to instruct the machine to implement the emergency stop sequence defined by the machine control system. The intent of this command is to stop the machine motion as rapidly as possible, to reduce the consequence level, if the CxD logic determines that a collision is imminent. The equivalent of an emergency stop is the operator slamming on the brakes in an emergency." 2. "The CONTROLLED-STOP action is sent by CxD to instruct the machine to implement the controlled stop sequence, defined by the machine control system." The intent of this command is to stop the machine motion in a controlled / conventional manner, when the CxD logic determines that a collision / interaction can be avoided by slowing down and stopping. The equivalent of a controlled stop is slowing down and stopping when approaching a red traffic light.
System	A combination of interacting elements organized to achieve one or more stated purposes (ISO/IEC/IEEE 2015).
T	Technical: Indicates a technical requirement of the CPS or functional group.
Technical specification	Specifications that define the technical and physical characteristics and/or measurements of a product, such as physical aspects (e.g. dimensions, colour, and surface finish), design details, material properties, energy requirements, processes, maintenance requirements and operational requirements.
Technician	Competent person with testing experience in the mining / vehicle environment, e.g. testing technician, TMM OEM technician, CxD technician, auto electrician, etc.
Test engineer	Experienced person in the engineering/mining environment with extensive experience in CPS testing.
This document	CPS Zone Functionality and Sensor Fusion Report.
TMLP	Traffic Management Leading Practice: The MOSH Traffic Management Leading Practice for Open Cast/Cut mines in South Africa.
TMM	Trackless Mobile Machine. (Machine, vehicle, etc.)

TMM CPS	The functional group comprising all TMM CPS related functions.
TMM CPS Product	The product that will make a non-intelligent TMM intelligent and CxD ready.
TMM OEM	Original Equipment Manufacturer of TMMs. Original Equipment Manufacturer of a TMM may be the organisation which originally supplied, or last rebuilt, or modified the TMM, or the supplier per section 21 of the Mine Health and Safety Act, 1996 (Act No. 29 of 1996).
TMP	Traffic Management Plan: A document that defines the traffic management system that a mine employs to ensure the safe movement of TMMs and pedestrians on the mine.
Tracking	Tracking is the monitoring of the progress of the objects in the detection area over time.
TRL	Technology Readiness Level: A technology maturity framework for measuring and monitoring technology maturity in 9 increasing levels from TRL 1 to TRL 9.
U	Underground: Indicating that a specific aspect is applicable to underground TMMs/operations.
UTC	Coordinated Universal Time.
V2X	Vehicle to anything.
Vicinity (Surface TMMs) Vicinity (Underground TMM and pedestrians)	The distance/time of two TMMs from the point of a potential collision, such that, if the operators of both machines are instructed to take action to prevent a potential collision, and one or both does not act, then the CPS will be able to prevent the potential collision. Note: Vicinity is a conditional, variable value, depending on multiple input variables. It is smaller than any value that is within the range of normal operation. The distance/time of a TMM from a pedestrian, such that, if the operator of the TMM and the pedestrian do not take action to prevent a potential collision, an emergency slow down and stopping of the TMM can be successfully executed, to prevent a potential collision between the TMM and the pedestrian. Note: Vicinity is a conditional, variable value, depending on multiple input variables. It is smaller than any value that is within the range of normal operation.
V-E	Vehicle to environment.
V-P	Vehicle to pedestrian.
V-V	Vehicle to vehicle.
Walking speed	In the absence of significant external factors, the average human's walking speed is 1.4meters per second. This is included to help define the crawl speed of vehicles.
WP 9	Work Package 9: Testing protocols (including legacy equipment). One of the work packages of the Industry Alignment on TMM Collision Management Systems Project: CAS READINESS PHASE.

4. Executive Summary

A key aspect of any Systems Engineering based, system or product development process is the establishment and approval of the User Requirements. As indicated in the CMS Technical Specification Guideline Review Report a formal and approved set of CPS user requirements does not exist. The absence of such almost always lead to a lengthy product development cycle, uncovering user requirements as the product is starting to be used. Following the approval of the recommendation to develop a set of user requirements for CPS this Part of this document defines the CPS User Requirements.

A specific emphasis of the URS is the definition of the CPS regulatory requirements namely; to prevent collisions involving TMMs. The integration of the regulatory requirements and the justification thereof is provided with specific attention also given to the three key aspects of vicinity, effective warning and slow down.

Technical performance management aspects such as reliability, accuracy, EMC, maintenance and support are also included in the URS.

The baseline CPS product Breakdown structure is defined using an unintelligent TMM (Legacy equipment) for reference. This is to ensure that the "worst" case legacy equipment is addressed.

Key operational scenarios are depicted defining specific requirements that the CPS products must comply with.

5. Conclusions

The development of a complete set of User Requirements that can be used to derive and develop the functional and Technical Requirement that CPS systems must comply with is a major enabler of a sound Systems Engineering based development process such as is applied for the accelerated CPS development initiative.

6. Recommendations

Given the key role that the CPS User Requirements play in the CPS development it is recommended that:

This URS be widely distributed in the SAMI and that formal feedback, inputs and acceptance is solicited to ensure that CPS products that do comply with the URS will be fit for purpose preventing the TMM collisions as intended.

7. Context of this document

This document is one part of a WP 9 deliverable of the INDUSTRY ALIGNMENT ON TMM COLLISION MANAGEMENT SYSTEMS PROJECT: CAS READINESS PHASE.

It must therefore be read in the context of:

- Data collected and collated by the Minerals Council and provided to the project. (as referenced before).
- Learnings and experience gained from SAMI where CMSs have been implemented.
- Accident and incident statistics in SAMI and other parts of the world, made available from the Minerals Council and DMRE,
- Knowledge gained from experienced mining specialists about mining processes and the V-V and V-P interactions that occur in those processes,
- Global CMS initiatives emanating from EMESRT and the ICMM.

The document will be released in 2 parts:

- Part 1 User Requirements
- Part 2 Functional and Technical Requirements

8. Background

The SAMI is the only international jurisdiction (other than PDS regulations in underground coal mines in the USA) that has regulated the installation of TMM safety products that can prevent collisions between TMMs and pedestrians in underground operations and TMMs and other TMMs in surface operations. Whilst the regulations makes provision for managing collision risks with more effective controls that are higher on the hierarchy of risk controls, there is a need to ensure that CPS products are available to timeously introduce the products if a mine cannot or does not want to introduce controls that are higher up in the hierarchy of controls.

This is an unprecedented challenge for the SAMI due to:

- The number of operations being classified as mines in South Africa.
- Most TMMs being designed and manufactured outside of South Africa.
- The many types of TMMS, brands, models and configurations.
- The large number of older TMMs in use on mines in South Africa that do not have electronic gearboxes and CAN bus controllers.
- The diversity of TMM fleets on mines.
- All mines having to ensure that on a specific date TMMs (where there is a significant risk of collision between those TMMs and other TMMs on surface operations or between TMMs and pedestrians in underground operations) are fitted with such products.
- Limited engineering and development resources and capacity in South Africa.

Although the TMM regulations have been promulgated in 2015 the two clauses requiring auto slowdown and stopping of TMMs have been suspended due to the unavailability of CPS products.

Since 2015 the SAMI made concerted efforts to develop CPS products that will comply with the TMM regulations. Significant obstacles to overcome the

challenge only became apparent during the initial years of the effort. Some of the conditions are:

- The TMM population, its types, brands, models and configurations must be available to enable a risk informed and logical development initiative
- A representative definition of relevant mining processes that involve TMMs on the different types of mines.
- Full visibility of key TMM characteristics such as deceleration rates, stopping distances and the impact of sudden stopping on operators, such as whole-body vibration.
- A fully integrated development effort between all role-players
- Maximum collaboration
- A single set of requirements
- A single accelerated development program
- A single integrated test regime

In 2019 the MHSC's Mining Regulation Advisory Committee (MRAC) convened a Task team of experts and members of mines to advise it on the readiness of CPS products with a view to recommend a date for uplifting the regulations to the board of the MHSC. The task team had several deliberations and concluded that CPS development is not at a level of maturity to uplift the regulation in the next few years.

The team identified a number of challenges that still need to be addressed and resolved. The Minerals Council South Africa took heed of the report issued by the task team and initiated a multi-million-rand project namely: Industry Alignment On TMM Regulations: Special Project Of The Minerals Council South Africa to facilitate the integrated development of not only CPS products but the required ecosystem that will enable the upliftment of the suspended clauses of the TMM regulations as soon as feasible. The key pillars of the project are:

- Collaboration
- Centralised Requirements definition
- Single integrated testing regime
- Defined development maturity criteria
- Shared verification and validation (testing)
- Ecosystem focus

The approved structure for requirements is shown in fig 1.

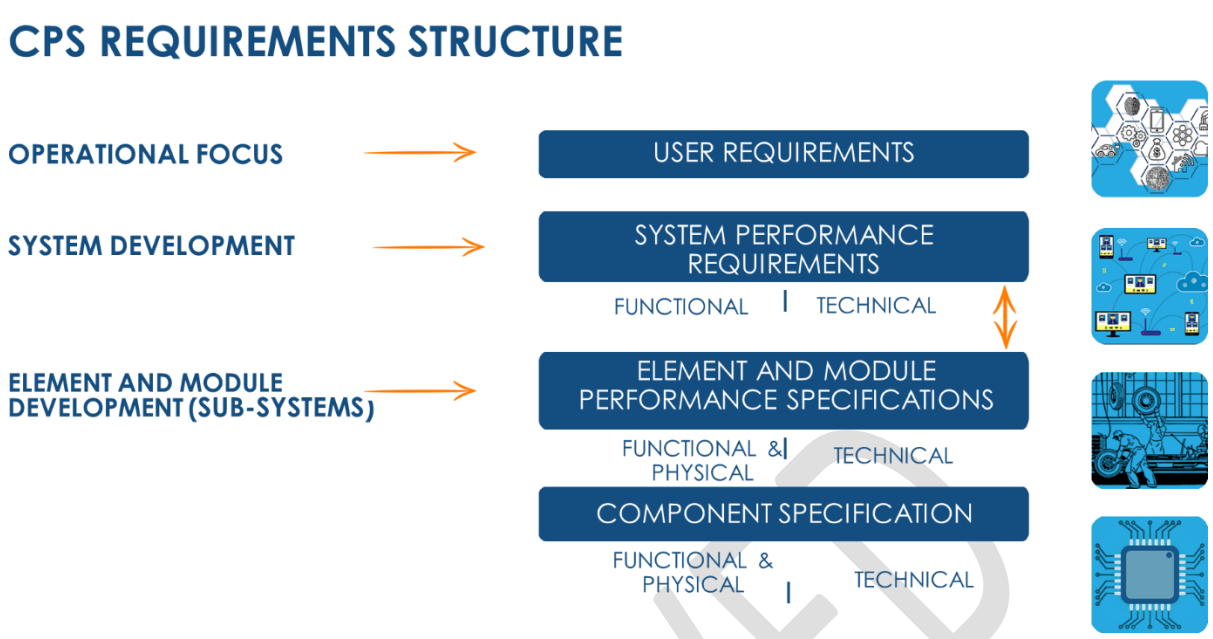


Fig 1 Requirements structure for CPS product development.

9. Competition

The Minerals Council South Africa's approach to the regulatory challenge its members face is to focus on ensuring that CPS products that are offered to the SAMI comply with the local TMM regulations. The approach is not to specify any specific technology and limit competition in the market. It does not limit any CPS product definition; it only defines the minimum regulatory requirements. CPS product providers have full freedom to provide products that provide additional functionality and features to both the local and global markets in order to differentiate its product(s).

Any CPS provider that offers a CPS product that it claims complies with the local TMM regulations will have to demonstrate that such CPS product(s) have achieved the product requirements as set out in this requirements document.

Fig 2 CPS requirements in relation to Supplier offerings

10. Approach used to develop the user requirement specification

The overall approach used to develop this document is described in the SECDI report titled: REVIEW REPORT: Collision Management Systems, Technical Specification Guideline, SME and UME, REV 5 (I.E., WORK PACKAGES 9,) OF THE INDUSTRY ALIGNMENT ON TMM REGULATIONS; SPECIAL PROJECT OF THE MINERALS COUNCIL SOUTH AFRICA.
The specific regulations that apply are defined in the above document and are included here for reference purposes:

10.1 Regulatory Requirements

For Surface Mines the regulation states: *At any **opencast** or **open pit** mine, where there is **a significant** risk of such collisions (collisions wherein persons can be injured as a result of TMM collisions) such measures **must** include:*

*8.10.2.1 Every **diesel powered trackless mobile machine** must be provided with means to automatically detect the presence of any other **diesel powered trackless mobile machine** within its **vicinity** and:*

*8.10.2.1 (a) upon detecting the presence of another diesel powered trackless mobile machine, the operators of **both** diesel powered trackless mobile machines shall be warned of each other's presence by means of an **effective warning**;*

The direct functionality requirements derived from above are:

- Detection when within each other's **vicinity**
- **Both** TMMs to detect each other
- **Both** operators to be warned
- Warnings to be **effective warnings**

Whilst bullets 2 and 3 are clear, bullets 1 and 4 require further interpretation in order to be unambiguous and needs further analysis and interpretation.

The regulations further state:

*8.10.2.1 (b) in the event where no action is taken to **prevent** a potential collision,*

This clause also provides the implied requirements with regards both **vicinity** and **effective** warning.

Vicinity:

The law expects the operators of both machines to **take action** to **prevent** a potential collision. This means that vicinity is defined as:

the distance/time of two TMMs from the point of a potential collision, such that if the operators of both machines are instructed to take action to prevent a potential collision and one or both does not take action then the CPS will be able to prevent the potential collision.

Vicinity therefore cannot be a fixed value; it is scenario dependent. It is not 50m or 30m or even 10m because we don't want operators to take **any action** if they are still 50m or 30m apart or in some instances, not even 10m, when it is necessary for normal operation as it will for example prevent TMMs from passing each other on a narrow haul roads.

"Vicinity" thus depends on specific circumstances and operational scenarios.

(Note: In the absence of specific operational scenarios and the relevant circumstances it is almost impossible to develop CPS Product Systems that will comply with the regulations.)

Effective Warning:

The regulation states that the operators of both TMMs **must** take action to avoid a potential collision. The operator of a TMM must always stay in control of her/his TMM.

The intention of the TMM regulation is clearly to uphold that principle. The regulations are specifying technology to enable emergency braking of TMMs to prevent collisions, but it **upholds** the obligation of the operator to remain in control of the TMM. This is an important consideration as this requirement delays the time to trigger the automatic stopping of the TMM.

The regulations do not call for a **general warning** or an **awareness warning**, or an instruction to stop the TMM, it calls for an **effective warning**.

The expected outcome of the operator action is that the potential collision is prevented, therefore an **effective warning must inform the operators of both TMMs what the appropriate action(s) are to prevent the potential collision**.

An effective warning is conditional, depending on speed, relative position, road design, road condition, etc.

If the **operator** is expected to take action to avoid a potential collision, she/he must be granted a "fair"/reasonable opportunity to take the action. An effective warning therefore also includes the time that an operator is given to respond to the effective warning to avoid a potential collision.

8.10.*2.1 (b …….further means shall be provided to retard the diesel powered "trackless mobile machine" to a* ***safe speed*** *where after the brakes of the diesel powered "trackless mobile machine" are automatically applied. The system on the diesel powered "trackless mobile machine" must "fail to safety" without human intervention.*

A **safe speed** is a speed below which the automatic emergency stopping intervention can be initiated without increasing the risk of a collision or causing other unintended consequences that may lead to personal injury.

When considering the TMM regulations, it is important to also note that where there are "places of potential collision" that a CPS will not prevent a potential

collision or if the CPS cannot comply with the requirements of the regulations, it does not absolve the mine to introduce other preventive controls.

Two practical examples of this are where commercial LDVs are used on roads where Heavy Mining Vehicles work. If a regulatory compliant CPS does not exist for that LDV then, that LDV must be prevented from a potential collision by other reasonably practicable controls such as berm separation or separate LDV roads.

Further, if a CPS does not exist that can prevent two haul trucks moving in opposite direction on a haul road from a potential collision, then the two haul trucks must be prevented from a potential collision by other reasonably practicable controls such as a centre berm or a one directional road.

An analysis of the specific requirements for electric powered trackless mobile machines are only mentioned and not discussed since the promulgation of the regulation is not postponed due to technical difficulties.

For Electric and Battery powered machines

8.10.1.1 All electrically or battery powered trackless mobile machines, excluding shovels, bucket wheeled excavators and overburden drills must be provided with means to automatically detect the presence of any pedestrian within its vicinity. Upon detecting the presence of a pedestrian, the operator of the trackless mobile machine and the pedestrian must be warned of each other's presence by means of an effective warning. In the event where no action is taken to prevent the potential collision, further means must be provided to retard the trackless mobile machine to a safe speed where after the brakes of the trackless mobile machine are automatically applied without human intervention."

An analysis of the specific requirements for surface mines (open cast and open pit) are discussed below.

For Underground mines the regulation states: *"8.10.1.2 All underground diesel powered trackless mobile machines must be provided with means:*

*8.10.1.2.(a) To automatically detect the presence of a **pedestrian** within its **vicinity**. Upon detecting the presence of a pedestrian, the **operator** of the diesel-powered trackless machine and the **pedestrian** shall be warned of each other's presence by means of an **effective** warning;*

The direct functionality requirements derived from above are:

- Detection when within each other's **vicinity**
- **Only the** TMMs to detect the pedestrian
- **Both** the operator and the pedestrian to be warned
- Warnings to be **effective warnings**

Whilst bullets 2 and 3 are clear, bullets 1 and 4 require further interpretation in order to be unambiguous and needs further analysis and interpretation.

The regulations further state:

8.10.*2.1 (b) in the event where no action is taken to **prevent** a potential collision,*

This clause also provides the implied requirements with regards both **vicinity** and **effective** warning.

Vicinity:

The law expects the operator of the machines to **take action** to **prevent** a potential collision. This means that vicinity is defined as:

the distance/time/ of a TMM from the point of a potential collision with a pedestrian, such that if the operator of the machine are instructed to take action to prevent a potential collision and does not take action then the CPS will be able to prevent the potential collision.

Vicinity therefore cannot be a fixed value; it is scenario dependent. It is not 15m or 10m because we don't want an operator to take **any action** if a pedestrian is still within its proximity for normal operation as it will prevent TMMs from working at low speed in face areas as well as workshop areas.

"Vicinity" thus depends on specific circumstances and operational scenarios.

(Note: In the absence of specific operational scenarios and the relevant circumstances it is almost impossible to develop CPS Product Systems that will comply with the regulations.)

Effective Warning:

The regulation states that the operator of the TMMs and the pedestrian **must** take action to avoid a potential collision. The operator of a TMM must always stay in control of her/his TMM. The intention of the TMM regulation is clearly to uphold that principle. The regulations are specifying technology to enable emergency braking of TMMs to prevent collisions, but it **upholds** the obligation of the operator to remain in control of the TMM. This is an important consideration as this requirement delays the time to trigger the automatic stopping of the TMM.

The regulations do not call for a **general warning** or an **awareness warning**, or an instruction to stop the TMM, it calls for an **effective warning for both the operator and the pedestrian**.

The expected outcome of the pedestrian and the operator action is that the potential collision is prevented, therefore an **effective warning must inform the operator of the TMM what the appropriate action(s) are to prevent the potential collision** as well as the pedestrian.

An effective warning is conditional, depending on operational area/process, speed, relative position, road design, road condition, etc.

If the **operator** is expected to take action to avoid a potential collision, she/he must be granted a "fair"/reasonable opportunity to take the action. An effective warning therefore also includes the time that an operator is given to respond to the effective warning to avoid a potential collision, likewise the pedestrian must also be given a "fair"/reasonable opportunity to take the action. An effective warning therefore also includes the time that a pedestrian is given to respond to the effective warning to avoid a potential collision.

8.10*.2.1 (b …….further means shall be provided to retard the diesel powered "trackless mobile machine" to a **safe speed** where after the brakes of the diesel powered "trackless mobile machine" are automatically applied. The system on the diesel powered "trackless mobile machine" must "fail to safety" without human intervention.*

A **safe speed** is a speed below which the automatic emergency stopping intervention can be initiated without increasing the risk of a collision or causing other unintended consequences that may lead to personal injury.

10.2 EMESRT and ICMM

This project aligns with both EMESRT and ICMM TMM interaction CPS initiatives where possible and where possible these initiatives are included in this URS. EMESRT PR-5A Vehicle interaction systems dated August 2019 [1] and the Vehicle Interaction improvement Guide dated October 2020 [2] are the documents used to support this URS.

10.3 CM & EE TMM task team

This project also aligns with the input provided by previous guidelines most notably two documents titled: "Collision Management Systems Technical Specification Guidelines for Surface and Underground Mining Operations (Rev A.6)"

These two documents include a mixture of user, functional and technical specifications and where appropriate the user requirements of this document have been aligned with those in the above two documents.

11. CPS classification

The CPS is classified as:

- A critical safety related system – classification level 1,
- A maintenance significant system – classification level 1,
- An operations significant system – classification level 1.

The above classification means:

- Safety: Any fault with the system is a "NO-GO", it must fail to safe and be tamper proof,

• Maintenance: Only skilled and competent employees are allowed to work on a CPS. The CPS must support accurate fault detection and root cause analysis. Critical spares must be available,
• Operations: Only skilled and competent employees are allowed to operate a vehicle fitted with a CPS. The CPS must not receive false positives and zone sizes must be limited to lower any negative impact on production. The CPS must be accurate and reliable.

12. CPS Product Definition

The non-homogenous population of TMMs used in the SAMI necessitates multiple CPS Product definitions. Some TMMs are electronic controlled with CAN bus systems. These type of TMMs do not require a physical interface element. Product configurations are determined by the different CPS providers. Products however must comply with the functional requirements for a CPS. Functional requirements are structured in a logical functional breakdown.

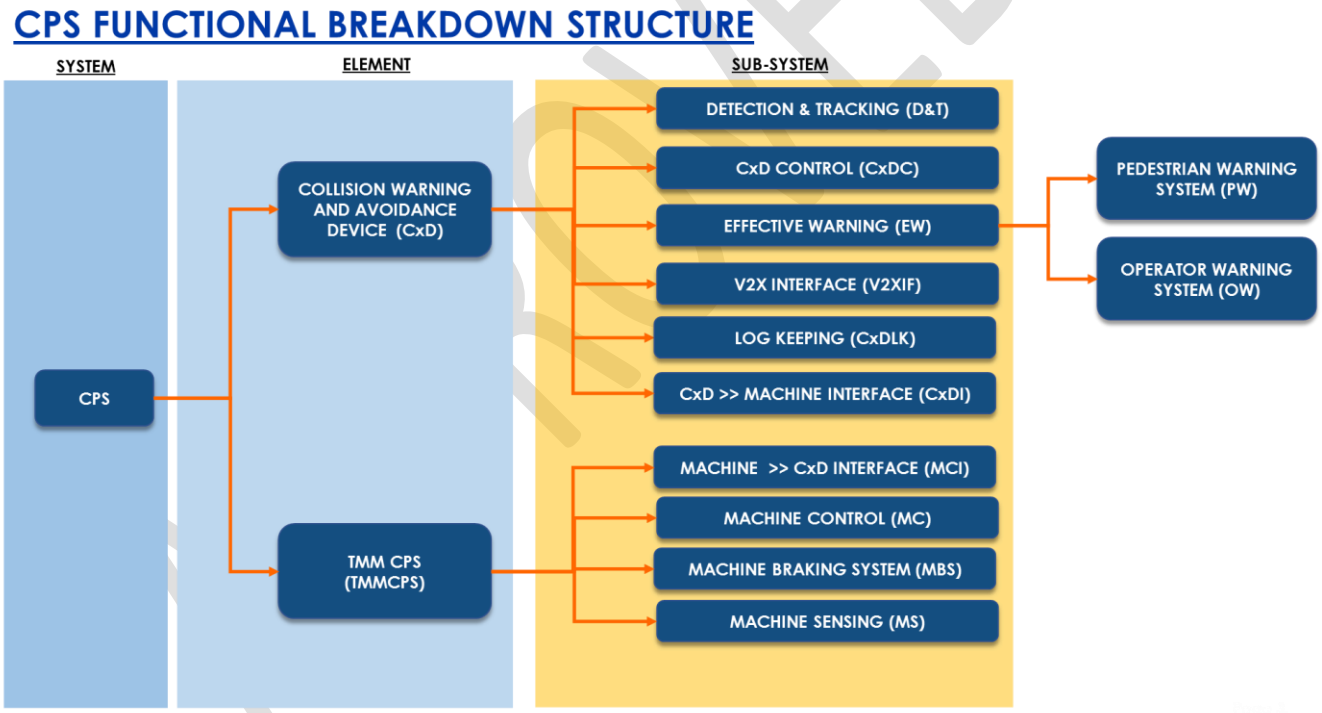


Fig 3: CPS functional breakdown structure.

The TMM CPS Functions are structured in 5 sub-groups namely:

1. Machine CxD Interface functions (MCI).
2. Machine Controller functions (MC).
3. Machine Braking System functions (MBS).
4. Machine Sensing functions (MS).
5. Machine Log Keeping functions (MLK).

The CxD Functions are broken down into 6 sub-groups namely:

1. Detection and Tracking functions (D&T).
2. CxD Control functions (CxD).
3. Effective Warning functions (EWS).
4. V2X Interface functions (V2XI).
5. CxD Log Keeping functions (CxDLK).
6. CxD Machine Interface functions (CxDI).

13. User Requirements Structure

The SAMI TMM regulations for diesel powered TMMs covers both surface and underground mines. The approach to user requirements definition is as follows:

- General requirements
- Underground Coal Mining
- Underground Hardrock Mining
- Surface Mining

The Minerals Council South Africa facilitated the definition of basic mining process descriptions for each of the above mining types also indicating equipment types involved with each type of process, the basic types of interactions, the minimum number of exposed persons and the minimum number of equipment types.

The work further includes equipment population information. This information is continuously updated as the project progresses, and more and more members of the Minerals Council South Africa report their statistics.

The User requirements will be informed by the information provided by the Minerals Council South Africa.

14. General Requirements

The user requirements that are applicable to all CPS products irrespective of the mining types and processes that they are involved in are defined below.

Requirement	Acceptance Criteria
CPS products must prevent collisions between TMMs for surface operations and TMMs and pedestrians for underground operations	100% collision prevention in full operational applications
a. In different mining types as defined in this document	100% collision prevention in full operational applications
b. For all operations defined in this document for every type of mine	100% collision prevention in full operational applications
CPS products must:	
• be interoperable	
a. For all different types of TMMs including LDVs used in mining operations. (Mine bakkies)	
b. For all different brands of TMMs	
c. For all different models of TMMs	

d. For all unique serialised models of TMMs	
• prevent collisions for	
a. TMM current state braking system b. normal operating scenarios	ISO 3450-1,[3] SANS 1589-3 [4]
c. All operating speeds per TMM type	
d. Breakdowns and recovery scenarios	
e. Vehicle towing	
f. Vehicle emergency conditions (fire etc)	
g. the following operating conditions:	
i. various road design and construction	
ii. inclines and declines	
iii. road surface conditions	
iv. weather conditions	
v. day and night operation	
vi. poor visibility	
• Limit the number of false warnings, slow down or stopping	Less than 2% of all warnings
• be EMC with all other radio frequency-based systems used on the mine.	
a. other CPS products and electronic devices fitted to TMMs.	Must comply with SANS 13766 [5]
b. other mine infrastructure and EMI sources	Must comply with SANS 13766 [5]
c. the composition of the minerals mined d. Electronic detonation items	SANS 1717-1 [6]
• have a 100% effective detection of potential collisions	Must always stop in in time to achieve the determined stop gap
• Be 99% reliable for times required to operate (fail to safe)	Reliability = Total time – repair time for CPS during TMM operation
• Be self-diagnostic to ensure 100% functionality before start up, during normal and emergency operation of all elements/subsystems, individually and critical components of elements including TMM braking mechanisms as well as emergency steering	• Give clear indication of CPS health on operator display. • Cap lamp self-diagnostic in cap lamp room • TMM cannot start or move if CPS is not 100% (safety interlock).
• have a supervisory monitoring data collection, storage and reporting capacity (also see user's requirements)	
a. The data / log keeping system must maintain logs when an effective warning or an automatic slowdown and stop event (the event) occurred. Such logs shall: i. Be based on the UTC time or synchronized with an easily accessible reference time. (CPS and OEM time stamps must both be UTC otherwise CPS must fail to safe)	• Drive past data acquisition point and data to appear in data base • From data verify CPS times, TMM times and interaction times. Times must be 100% the same

ii. Include all machine data communicated to the CxD leading up to, during and immediately after the event. iii. Include any actions (such as effective warning, slowdown and stop) issued by the CxD to the machine. b. With USB or Bluetooth or WiFi data download to local networks at predetermined times such as end of shift c. With real-time data download as per individual mine requirements	
d. With a real-time date and time stamp synchronisation of all identified system elements requiring such e. The log keeping system shall fail to safe f. The log keeping system must retain data logs for a minimum period of three months	• From data verify CPS times, TMM times and interaction times. Times must be 100% the same
• The ability that if any function failed (including malicious sensor obstruction) the CPS will immediately inform the operator and either not start/propel the TMM if it was stationary or	
a. bring the TMM(s) to a safe stop	
i. without any negative health or safety impact on the TMM operator(s) or passengers	
ii. be the outcome of the application of a credible Human Factors analysis and design process	
1. Including but not limited to the effects of:	ICNIRP GUIDELINES FOR LIMITING EXPOSURE TO ELECTROMAGNETIC FIELDS (100 KHZ TO 300 GHZ) [7]
a. EMI	
b. Whole body vibration	
• be of a fail to safe design	Simulate all fault conditions (including cap lamp fault)
• distinguish different types of TMMs, operating TMMs and stationary TMMs	
• Distinguish different operations with different operating rules, ie. speed of vehicles, acceptable "safe" separation distances for normal operation. (Distinguish between dumps, tips, haul roads etc.)	
• determine the movement path of every TMM in a 200 m for surface and 30 m for underground geographical area around any TMM	
• predict potential collisions dynamically as TMMs move within the area.	

• continuously determine where the boundaries for **"vicinity"** is.	
• ensure that operators of all TMMs within the **vicinity** (see definition) of other TMMs/pedestrian(s) receive an **effective warning** (see definition) of actions to be taken to prevent a potential collision	
• Determine the direction of each TMM or pedestrian	
a. such warnings shall:	
i. Not impede the normal operation of the TMM when there is no significant risk of collision (including for close interaction cases, such as hauling, loading, tipping, queueing, refuelling, parking, workshops).	
ii. Give the operator and the pedestrians sufficient time to react to the warning and take evasive action to avoid a potential collision (operator reaction time - fatigued operator, distracted operator, limited visibility, etc.)	
iii. be provided in a way that an TMM operator(s) can clearly understand it in preferred languages (To be determined)	
iv. consider all other associated attention drawing devices such as; screens, lighting or sound, if used.	
v. be proven by human factors engineering standards and requirements to not have any distractive effect on the TMM operator(s) or health impact and is agreed to by a representative sample of specific TMM operators	
vi. be the outcome of the application of a credible Human Factors and ergonomics analysis and design process	
vii. Only alert to the potential collision with the highest probability if multiple interactors are involved	
viii. entail that any devices installed in the TMM cab is positioned such that it does not impede on any visibility aspects of the design of the TMM	
ix. If TMM does not have a speed limiting device, the CPS must effectively warn the operator of any speed above the speed specified for the site or site location	

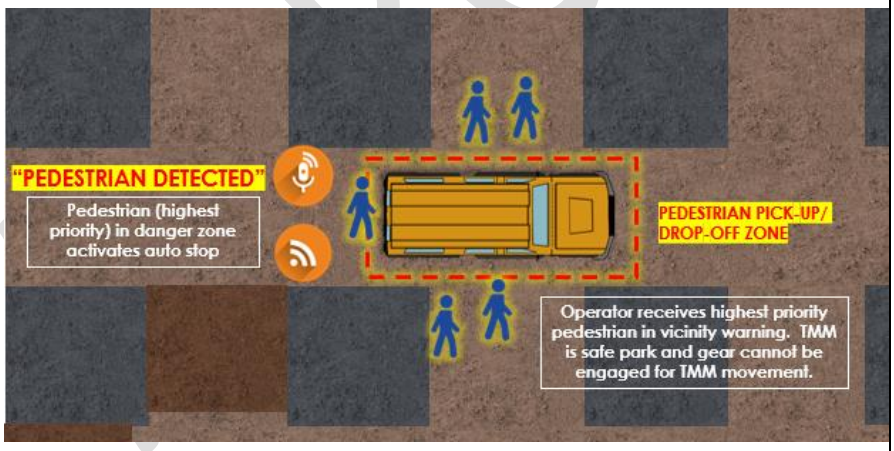
• instruct all other TMMs that are working in the operating area and that can enter into a vicinity of potential collision are instructed to stop	
• also immediately convey the instruction to a designated recipient(s) whether the mine control room or a dedicated individual	
• log proof of such instructions	
• have the ability to record response times of individual TMM operators	
• trend such response times	
• store such trends	
• present a standard dashboard with such trends (per operator)	
• have system functionality, such, that the zone(s) created around a TMM covers 100% of the special profile that is required to detect another TMM/pedestrian.	
• have a zone repeatability of at least 99,8% within a 10% tolerance of the respective nominal zone value.	• Stop gap is minimum fixed distance with >20% acceptance • >2,5 <3,0 second operator response time • CxD response time < 200 ms • Machine response time < 500 ms
• Have individually adjustable zones for the different machines without impacting the normal safe operating parameters (e.g., articulated machines and towed attachments)	
• be able to pro-actively monitor TMM and pedestrian movement (speed and direction) and monitor such movement to predict potential collisions	
• be maintainable at a time to remove and install a new module/component of:	45min
• have a modular design that shall ensure replacement of critical components/subassemblies in reasonable times.	
• self-diagnostics that can report the required component/sub assembly to a designated recipient whether a control room or individual as soon as the system has identified a fault.	Diagnostic on display or via blue tooth or USB to notepad or laptop
• be of robust design to ensure a system reliability	>2000 hours
a. cable failure	
b. cable connection failure	
c. Unit vibration failure	

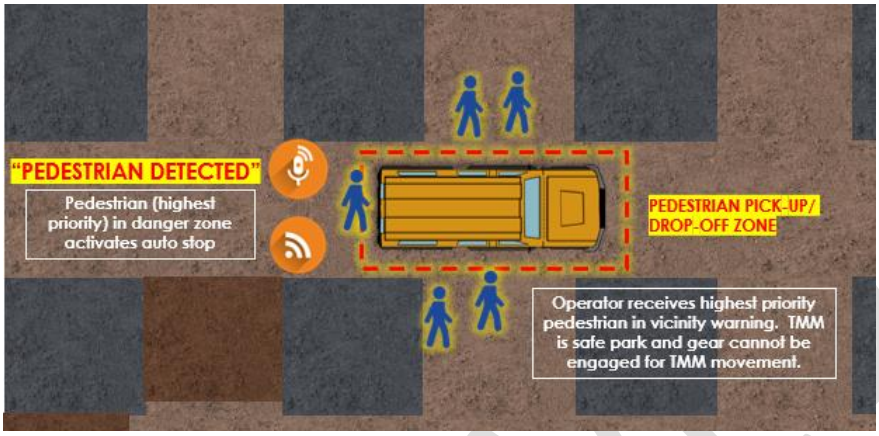
d. In harsh underground conditions of 50deg temp and 80% humidity	
e. Vehicle vibration up to 1-20 hz EAV = daily exposure action value ELV = daily exposure limit value	Vertical < 137,3 ms^{-2} (14 g)(ISO 2631-1, 5) [8] EAV <0,47 ms^{-2} A(8) ELV <0,93 ms^{-2}A(8)
f. Withstand the forces and conditions of normal vehicle high pressure washing	
• have cables, sensors and antennas positioned and protected against physical damage under normal operation conditions, such as falling materials, bumping against side walls and infrastructure.	
• be configurable to ensure that a TMM is slowed to a safe speed based on official TMM OEM requirements	Deceleration limits as defined in the ISO 3450 and SANS 1589-1
• prevent TMM collisions for all operational scenarios such as: machine maintenance and service support, washing, brake testing, lubrication, component replacement, re fuelling, cable /wheel changing, condition /health monitoring etc.	
• prevent collisions taking into consideration roads/infrastructure maintenance ie. grading, dust suppression, pumping, power lines/pipes etc.	
• prevent TMM collisions at Shift change and for Supervision/Inspection visits during operation	
• have identified safety critical components and operating/maintenance tactics required	
• have a standardized TMM cab layout with regards CPS displays or have the CPS display integrated into other existing displays	
• have and override capability: The CPS shall provide a means for an authorised supervisor or person to temporarily suspend an automatic intervention for emergency reasons, (To be specifically defined)	

Specific Mining Type User Requirements and Scenarios

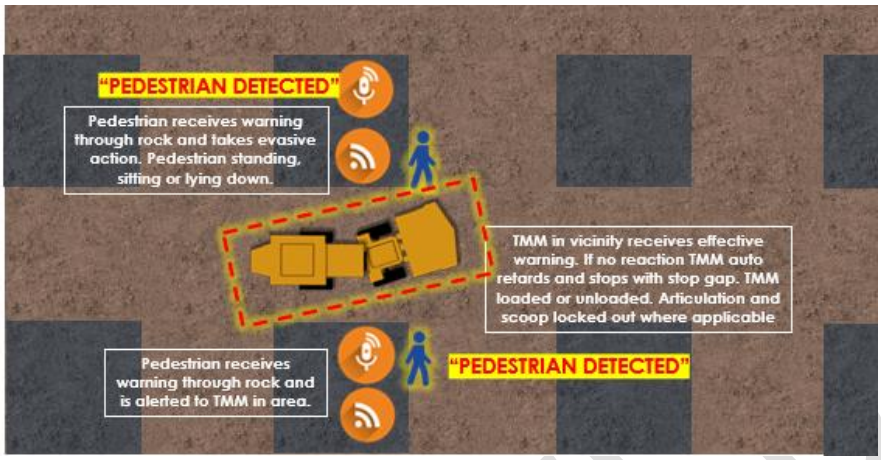
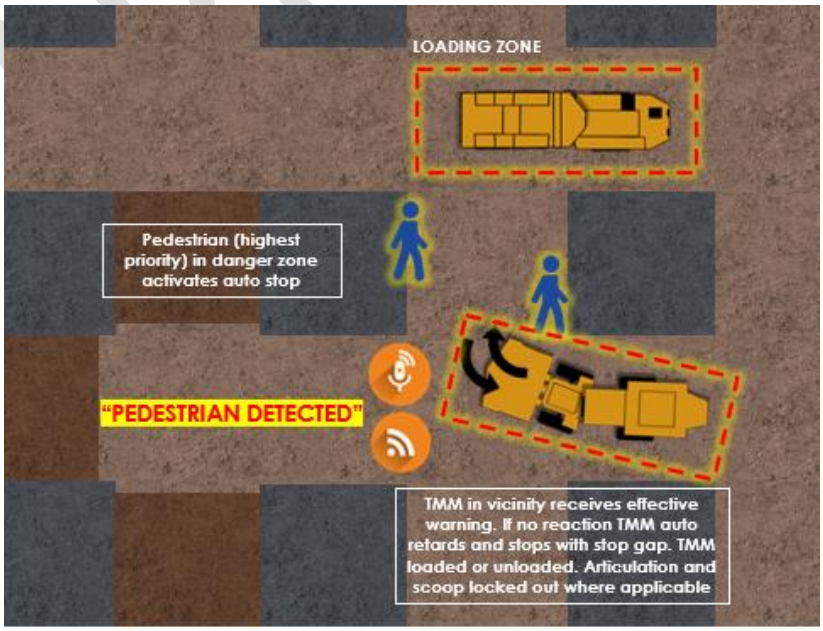
Underground Mining

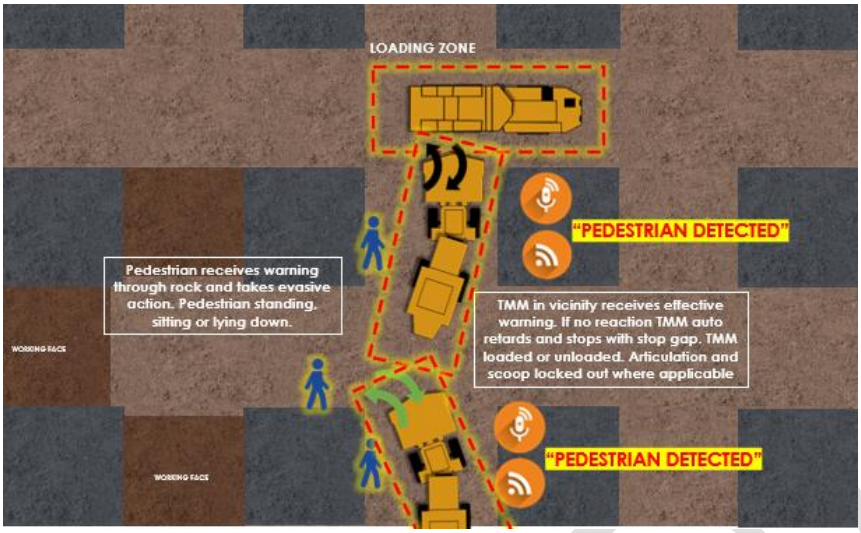
15. Interactions underground

Scenario number	Scenario description	Objective or purpose
S1	**Operator or passengers isolated from all vehicles CPS.** • ***Vehicle state:*** Engine running whether in safe park or TMM is moving. If operator opens the operator door, the TMM must auto safe park with engine auto switched off. If it is an articulated vehicle, the articulation must be isolated and locked. As soon as the vehicle engine is switched off, the vehicle CPS must not issue warnings, but both the operator and passengers must receive warnings from other vehicles in the vicinity whose engines are running. • ***Operator or passengers in vehicle:*** Must be isolated from vehicle CPS and not receive warnings from vehicle or other vehicles in the vicinity of the vehicle. • ***Pedestrians outside vehicle***: Must receive warnings and the vehicle CPS must warn operator of pedestrians in the vicinity and auto retard and auto stop if pedestrians move into the vicinity of the TMM.	Operator and passengers must not cause warnings of the CPS and cause the vehicle to stop. No false positives that cause annoyance and pedestrian disregard of response to alarms.
S2	**Operator or passengers warning activation when exiting a vehicle:**  ***Vehicle state:*** Engine running and TMM in safe park. • ***Pedestrians exiting vehicle:*** Pedestrians must receive warnings immediately (and without delay) when exiting a vehicle since it is in the vicinity of the TMM and in the vehicle danger zone. This warning can be from either the parked vehicle or other vehicles in the vicinity. • ***Exited vehicle CPS response:*** Operator must be warned of pedestrians in the danger zone and the TMM must not be able to engage any gear while pedestrians are in the danger or warning zones. If it is an articulated vehicle, the articulation must be isolated and locked.	Immediate protection for pedestrians outside vehicle.

	• ***Other vehicles in the vicinity CPS response to pedestrians exiting the vehicle:*** Operators must receive warnings and vehicle must auto retard and auto stop when exiting pedestrians are in the warning and danger zones.	
S3	**Operator or passengers warning activation when boarding a parked vehicle:**  • ***Vehicle state:*** Engine running and vehicle in safe park. • ***Pedestrians approaching and boarding vehicle:*** Pedestrians must receive warnings when entering the warning and danger zones. • ***Parked vehicle CPS response:*** Operator must be warned of pedestrians in the warning and danger zones. The vehicle must remain in safe park and the operator must not be able to engage any gear while pedestrians are in the danger or warning zones. If it is an articulated vehicle, the articulation must be isolated and locked. • ***Other vehicles in the vicinity CPS response to pedestrians exiting the vehicle:*** Operators must receive warnings and vehicle must auto retard and auto stop when pedestrians are in the warning and danger zones.	Protection for pedestrians approaching and boarding a vehicle whose engine is running.
S4	**Vehicle movement when vehicle is stationary with engine running and pedestrians in vicinity:** While pedestrian is in the vicinity of the TMM, the vehicle cannot pull off in any direction and remains in safe park. The vehicle operator must also receive an effective warning that a pedestrian or pedestrians are in the vicinity and when a pedestrian or pedestrians approach the danger zone and the operator has not engaged safe park, the vehicle must safely park. For TMMs with articulation and booms the articulation and the boom must be locked and isolated until the pedestrian moves out of the vicinity of the TMM. For non-articulated vehicles the boom must be locked and isolated until the pedestrian moves out of the vicinity of the TMM.	Protection for pedestrian when vehicle stationary and is in the vicinity.

S5	**Workshop: Pedestrians working on vehicles.** Pedestrians / artisans in the vicinity of moving vehicles must receive effective warnings and have sufficient time to move out of vehicles way. Vehicles must drive at a slow speed with very small warning and danger zones in workshops. The vehicle operator must also receive an effective warning that a pedestrian or pedestrians are in the vicinity and when a pedestrian or pedestrians approach the danger zone the vehicle must auto stop.	Limiting impact speed in workshops without preventing work from happening.
S6	**Breakdown anywhere:** When pedestrians are working on a breakdown, pedestrians must receive an effective warning of vehicles in the area. Vehicle operators must effective warnings when pedestrians are in the vicinity. Should the vehicle not react to the pedestrians in the danger zone the vehicle must auto retard and stop and go to safe park. Any type of movement thereafter must only be allowed when pedestrians have moved from the danger zone.	Pedestrian protected from vehicle interaction during a breakdown.
S7	**Pedestrian stop of TMMs in vicinity** When pedestrians notice or enter an area where TMMs in the vicinity could pose a V-P collision risk, the pedestrians must be able to protect all pedestrians and auto stop the vehicle or vehicles in the area.	Pedestrian ability to auto stop TMMs in the vicinity
S8	**Vehicle driving or tramming with pedestrian visible in the road:** When the pedestrian is in front or on the side of the vehicle travelling at maximum speed in either forward or reverse gear, fully loaded on maximum gradient, both the pedestrian and vehicle operator must receive effective warning of the approaching vehicle. Should the pedestrian not take appropriate action to prevent a potential collision the vehicle must slow down to a safe speed and stop. The TMM must be able to accelerate to full speed when the pedestrian is in out of the vicinity of the TMM. TMMs fitted with attachments (a drill boom, or LHD scoop), the safe stop gap must be from the edge (extremity) and not from the vehicle outer perimeter. Provision will be made for variable distances of "vicinity" (zones) in front of, at the back, or on the sides of the TMM depending on the direction of travel and the speed of travelling. The minimum stop gap distance must be 2,5m (such that if a pedestrian walking on the side of a TMM loses her/his footing he/she shall not be run over.	Pedestrian protected from vehicle travelling in board without impacting production.

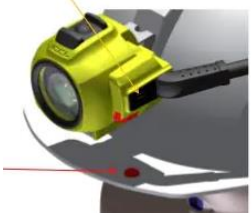
S9	**Vehicle driving or tramming in straight line and turning into approaching pedestrian positioned behind a pillar: Vehicle not visible.**  When a vehicle turns into a bord, either moving forward or reverse, where a pedestrian is either walking, sitting, or lying, both the pedestrian and vehicle operator must receive an effective warning. Should the pedestrian not take appropriate action to prevent a potential collision the vehicle must slow down to a safe speed and stop. The vehicle can be fully loaded at maximum speed on maximum decline. For TMMs with articulation and booms the articulation and the boom must be locked and isolated until the pedestrian moves out of the vicinity of the TMM. For non-articulated vehicles the boom must be locked and isolated until the pedestrian moves out of the vicinity of the TMM.	Pedestrian protected from vehicle turning into bord where pedestrian is positioned, and pedestrian is unseen.
S10	**Vehicle loading:**  	Pedestrian protected from both vehicles when vehicles are loading.

	 When a pedestrian moves into the vicinity of a vehicle being loaded, both the pedestrian and vehicle operators must receive an effective warning that a pedestrian is in the vicinity of the TMMs. Should the pedestrian not take appropriate action to prevent a potential collision both the vehicle must slow down to a safe speed and stop. Both vehicles must only be able to move when the pedestrian moves out of the vicinity of the TMMs.	
S11	**Vehicle reversing: Vehicle driving or tramming in straight line: Articulating vehicle. Vehicle and Pedestrian in same bord.** When a pedestrian is behind a TMM and the TMM is reversing towards the pedestrian, both the pedestrian and vehicle operator must receive an effective warning that a pedestrian is in the vicinity of the TMM. If the vehicle is fully loaded and auto stops, the stop gap must make allowance for the load falling from the vehicle onto the pedestrian. The vehicle must be fully loaded at maximum speed (crawl speed) on maximum decline. No slow down if the pedestrian is in front of front bumper. For attachment zones it must be from the attachment edge. Note: ADT load can fall on pedestrian.	Pedestrian protection when in line with vehicle fully loaded and reversing.
S12	**Vehicle tramming over a blind rise when the pedestrian is unseen.** When the pedestrian is in front or side of the vehicle travelling at maximum speed and above the blind rise, fully loaded on maximum gradient, both the pedestrian and vehicle operator must receive effective warning of the approaching vehicle and the vehicle must auto retard and stop within a safe stop gap. The vehicle must be able to accelerate to full speed when the pedestrian is out of the vicinity of the TMM.	Pedestrian protection when vehicle approaches from above the blind rise with vehicle fully loaded and at maximum speed on maximum decline.

16. Underground user's requirements

The CPS requirements from individual user groups within the mine is defined in the table below. This provides further details to be considered during the functional analysis.

Req. number	User requirement (V-P)	Objective or purpose
R1	**User: Operator** **Requirement: Sufficient time to react** Effective warning (warning zone sizes) must allow for sufficient time for the operator to react to the effective warning. Each operator will react differently and in different times depending on a variety of factors that confront the operator at the time (see Definitions: Driver or Operator reaction times). For the purposes of the URS, this reaction time must allow for the worst-case scenario with the operator in the worst state. This reaction time is between 1,5 seconds to 2,5 seconds. Operator reaction time = 2,5 seconds	To give the operator sufficient time to react to pedestrians in the vicinity to avoid hazardous situations (V-P).
R 2	**User: Pedestrian** **Requirement: Sufficient time to react** Effective warning (warning zone sizes) must allow for sufficient time for pedestrians to react to the warning. Each pedestrian will react differently and in different times depending on a variety of factors that confront the pedestrian at the time (see Definitions: Driver, can be read pedestrian or Operator reaction times). For the purposes of the URS, this reaction time must allow for the worst-case scenario with the pedestrian in the worst state. This reaction time is between 1,5 seconds to 2,5 seconds. Pedestrian reaction time = 2,5 seconds	To give the pedestrian sufficient time to react to vehicles in the vicinity that may lead to hazardous situations (V-P).

R 3	**User: Operator** **Requirement: Effective warning** An operator must receive an effective warning when pedestrians enter the vicinity of the vehicle whose engine is running and or the vehicle is in motion. Effective warning must be the result of a human factors engineering process and considers a combination of visual, audible and or a haptic instruction including the following: • An audible warning in the operator language of choice (To be determined) • A visual warning on the CPS screen or operator display. • Display to indicate the alert, alarm, or advisory message with the highest priority when multiple warnings are received. • Haptic instruction may be a vibrating element drawing the human's attention to the warning.	To give the operator both an audio and visual warning of the pedestrian's location and movement in the vicinity of the vehicle. 
R 4	**User: Pedestrian** **Requirement: Effective warning** Pedestrians must receive an effective warning when TMMs are in the vicinity and the vehicle's engine is running and is stationary or is in motion. Effective warning must be the result of a human factors engineering process and must consider the following: • An audible warning • A visual warning to appear in or around the pedestrian line of sight	To give pedestrians both an audio and visual warning of vehicles in the vicinity. For illustration only  
R 5	**User: Pedestrian** **Requirement: Effective warning when behind a pillar or rock wall. (Rock penetration)** Pedestrians must receive an effective warning when TMMs are in the vicinity. The vehicle's state: The engine is running, and vehicle is stationary, or the vehicle is in motion and the vehicle is unseen because it is behind a pillar or rock wall or under / over a blind rise in a bord or haul road. Effective warning means the following:	To give pedestrians both an audio and visual warning of vehicles in the vicinity and are approaching unseen from behind a pillar or rock wall or over a blind rise.

	• That R 4 will be enabled and work when: ○ The pedestrian is in any position (lying, sitting, standing, or walking) ○ In all warning zones (advisory, auto retard and auto stop zones – green, yellow, and red)	
R 6	**User: Operators, pedestrians, passengers** **Requirement: No false positives or false warnings** The number of false positives or false warnings must be limited (<2%) to ensure that all employees do not become complacent and ignore warnings of potential collisions in their vicinity.	To limit the number of false warnings, auto retards or auto stops for all employees
R 7	**User: Pedestrian** **Requirement: Vehicle safe speed** When the TMM is slowing down to a safe speed, such speed must consider the average walking speed of pedestrians. This speed on average is 5 km/hr. Underground fitness tests require pedestrians to be able to walk at 4 km/hr. Safe speed = 3 km/hr	Pedestrians must be able to move faster than vehicles when in the crawl zone.
R 8	**User: Operator and pedestrian** **Requirement: Effective warning without disrupting production** When TMMs are in the vicinity of pedestrians and vise-versa and V-P interaction may occur, operators and pedestrians must have sufficient time to react and move away from the TMM by being effectively warned. Should the operator and or pedestrians not react to prevent the potential V-P collision then the TMM must auto retard to a safe speed and auto stop. Stop gap = 2,5 m	Pedestrians and operators must have sufficient time to react to V-P and vehicle must slow down and stop within the required stop gap. The zone size must auto adjust to vehicle speed to minimise sizes and impact on production.
R 9	**User: Engineering and maintenance, OEMs** **Requirement: Vehicle braking systems must comply with national and international braking systems and testing requirements when activated by the CPS.** Braking systems (service braking, retarder, regenerative braking, hydrostatic braking, emergency braking, park brake) must be used to ensure the best proportional braking option to minimise any negative impact on operator and machine life cycle and maintenance costs. Machine braking performance must not deteriorate the braking system to such an extent that it cannot meet the compliance testing acceptance criteria specified by either national or international standards.	CPS initiated brake performance must comply with national and international braking system compliance testing.

R 10	**User: Operator and pedestrian** **Requirement: Auto-stop final state is safe park** Once auto-stop has been activated by the CPS and the vehicle comes to a stop, the vehicle must enter a state of safe park which means that the park brake is activated with the engine running and that the operator cannot engage any gear to put the vehicle into motion until the pedestrian has moved out of the danger zone.	Vehicle to remain in safe park while the pedestrian is in the danger zone.
R 11	**User: Pedestrian and operator** **Requirement: Articulation and or lifting and lowering of attachments (e.g., scoop) – isolation / lock out** The vehicle articulation and or attachment must be isolated and locked out (prevented from moving) should a pedestrian enter the danger zone when the vehicle engine is running.	Vehicle articulation and attachments must be isolated or locked out when pedestrians enter the danger zone.
R 12	**User: Operator, maintenance, engineering** **Requirement: CPS fail to safe** The CPS must fail to safe automatically when any fault is detected on the CPS. The fail to safe state of the vehicle shall be safe park and engine off. The CPS must have a self-diagnostic that checks the CPS health continuously and should it detect a fault, have both an audio and visual alarm to warn the operator and bring the vehicle to a safe park state with the engine off. When a vehicle is started, the CPS self-diagnostic shall run and confirm that the CPS system is healthy with a confirmation on the CPS screen or display. If the diagnostic detects a fault the operator must be unable to engage any gear and the machine must shut down in safe park. Typical fail to safe states may be: • no power on the system, • the connected antennas are not functional, • any system faults are detected, • a communication error is detected, • any battery required by the system fails to maintain a minimum operating voltage or power to enable proper operation, • a faulty machine or pedestrian component is detected, or • any component failure.	CPS fail to safe

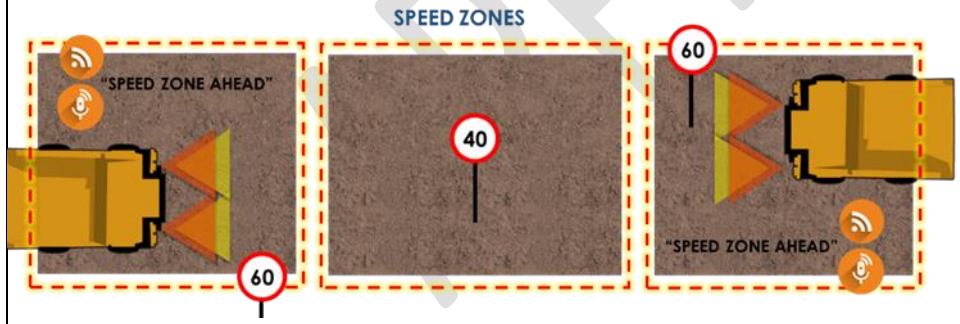
R 13	**User: Authorised Supervisor or person (Operations, maintenance, engineering)** **Requirement: CPS override** The CPS shall provide a means for an authorised supervisor or person to temporarily suspend an automatic intervention for emergency reasons only. (must be specifically defined.)	Provision of CPS override in emergency
R 14	**User: Operations, engineering** **Requirement: CPS Data logging, storage, and data retrieval** The CPS must time stamp, log and provide a permanent auditable record of potentially hazardous interactions (including near misses) and machine response recorded by the CPS. The CPS storage capacity for interaction data shall be for a minimum of six months and must be able to be retrieved through any of the following means, and this list is not exhaustive: • USB connection, • Blue tooth, • WiFi, • GSM network (5G), • Local area network.	Accurate data storage and retrieval through many means
R 15	**User: Operations, engineering, SHEQ, maintenance** **Requirement: CPS reports from interaction data** The CPS must provide management information reports based on interaction data for the following needs: • Daily analysis of interactions that are a safety concern and require urgent attention (including: test failures, trends, and heat maps of hazardous locations), • Daily analysis of interactions that are a production concern and require urgent attention (including trends and heat maps of production locations where interactions occur), • Weekly summary reports of the above interactions and operating / maintenance compliance (safety, production, availability, reliability and MTTR), • Incident detail reporting when required, • The reporting system must have an up-time of 24/7 x 98% and be configurable for each mine site and must be able to run in the cloud and on typical SAMI mining local area networks, • The reporting system must be secure.	Management information reports

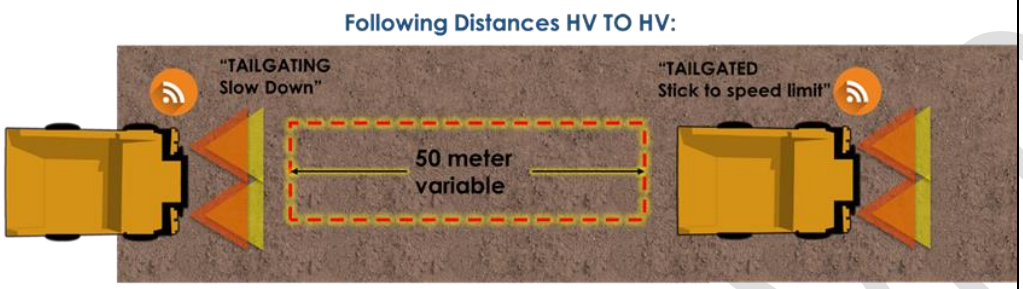
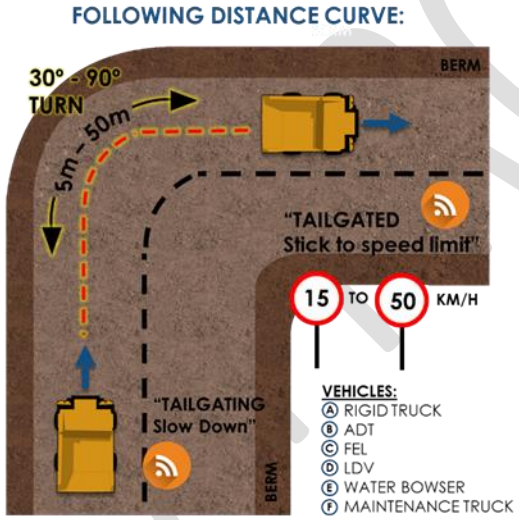
R 16	**User: Operations, maintenance, engineering** **Requirement: CPS operational and maintenance reliability** The CPS must be: • Reliable >99%, • Easy to fault find – fault finding on screen, • Installed such that it facilitates ease of access for maintenance • Provide for quick changeout of components including cables. • Installed on the TMM for optimum system performance, • Provide for quick calibration	Operation and Maintenance of the CPS to be in accordance with critical safety related system.
R 17	**User: All employees** **Requirement: CPS EMI, EMC** The CPS interface must not interfere with other electronic systems on the mine and must not be affected by other electronic or electrical systems or ore body contents. These systems can be: • Radio systems, • Fuel filling systems, • Electronic detonation systems, • WiFi, • Local instrumentation (plant operating equipment), • High voltage areas, • Ore bodies containing high ferritic (iron ore) content, • The CPS must not have any negative effect on humans and limit human exposure to electromagnetic fields.	No interference with or by other electromagnetic fields in the radio frequency (RF) spectrum that is caused by another electronic device.
R 18	**User: Operator** **Requirement: Visibility** **Operator display:** The operator's visibility should not be obstructed or restricted due to improper positioning of equipment: • Operation of the CPS solution controls should be evaluated through design risk assessments (by the CxD supplier and by the OEM) and an operational risk assessment (by the end user) to ensure unintended risks or consequences are not introduced, • Ergonomics of the operator cabin should not be compromised due to improper positioning of components,	Operator visibility not to be impeded by CPS location in cab

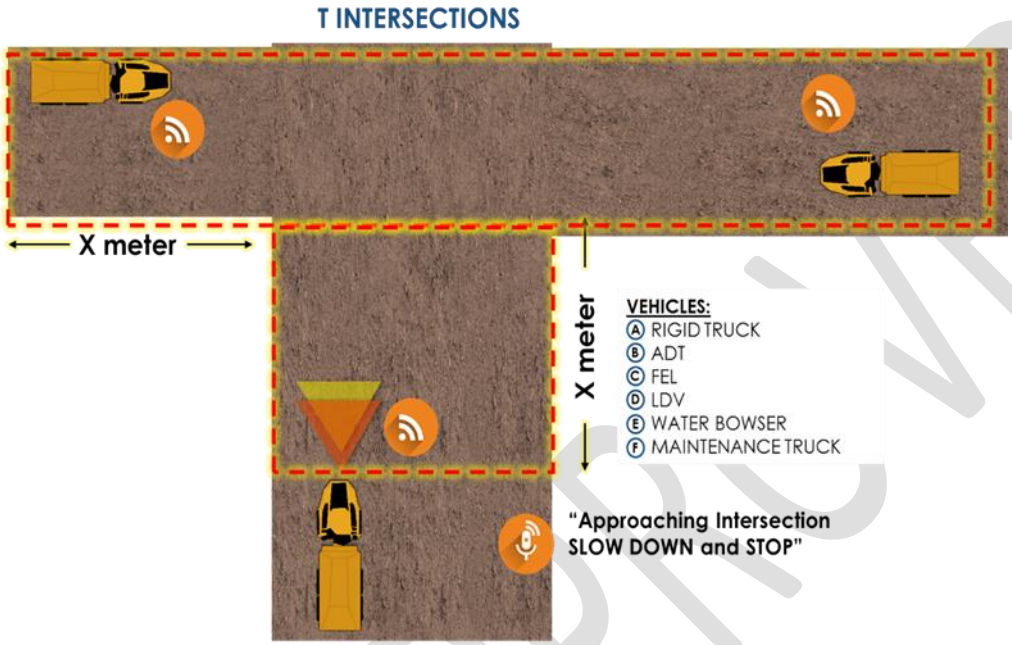
	• Warning or diagnostic display units should be positioned so that the operator is always made aware of an alarm regardless of direction of travel or driving position. • Display units should be positioned in the operator's field of vision to allow alarms or advisory messages to be seen by the operator without unnecessary distraction and confirmed by design and operational risk assessments, • Display units should function effectively in bright daylight and in fully dark / unilluminated conditions underground, • Display units should function effectively independent of the number of vehicles or personnel around the machine, • Display units should indicate the standby battery power availability (if an independent battery power supply has been specified), • Display units should show the current date and time if an internal real-time clock is used for time stamping of data, • Display units should clearly indicate the operating status of any radio communication or positioning links (e.g. vehicle-to-person, vehicle-to-vehicle or vehicle-to-fixed infrastructure communications links); • Colours used by display units should be different to other existing warnings on the machine to avoid operator confusion.	

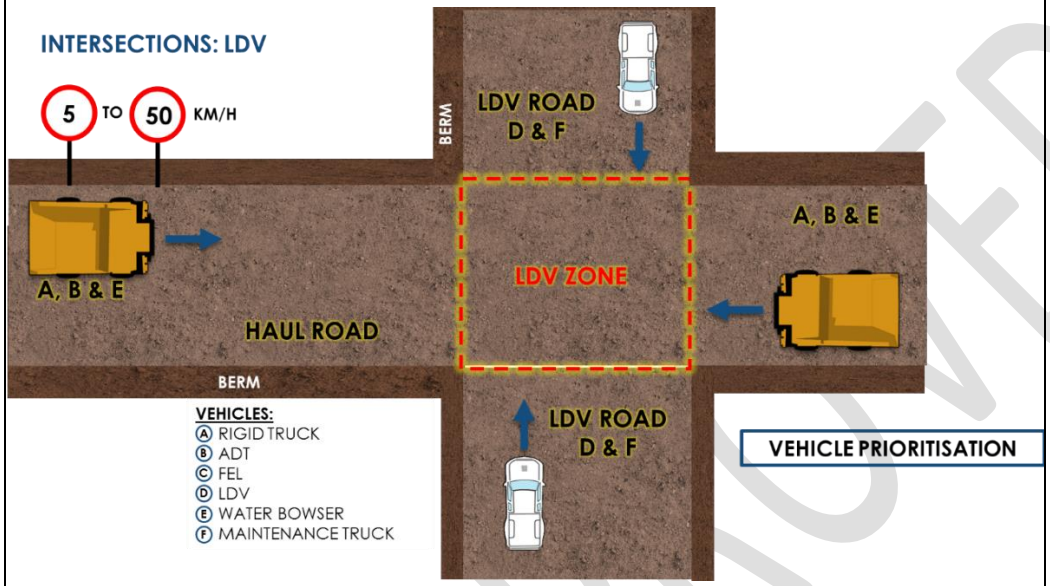
Surface Mining

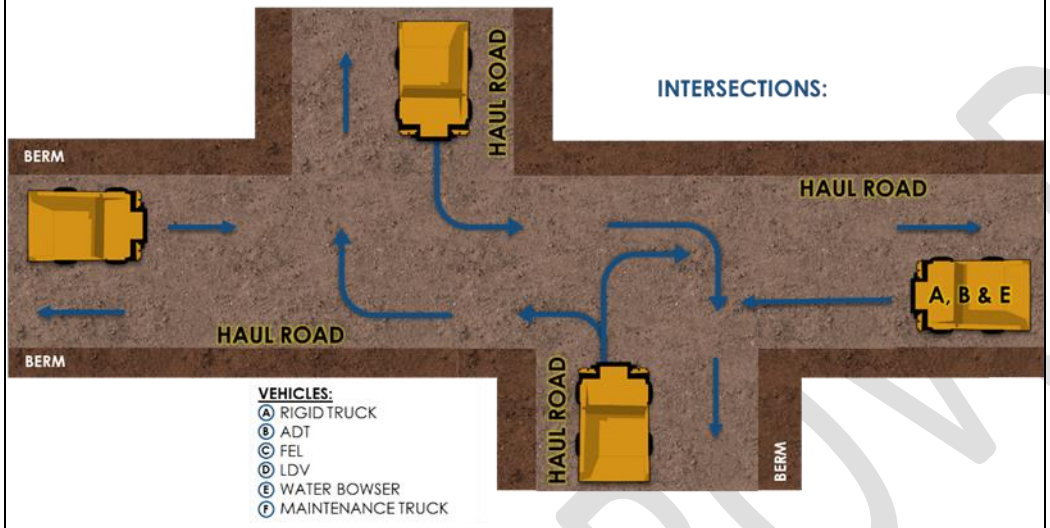
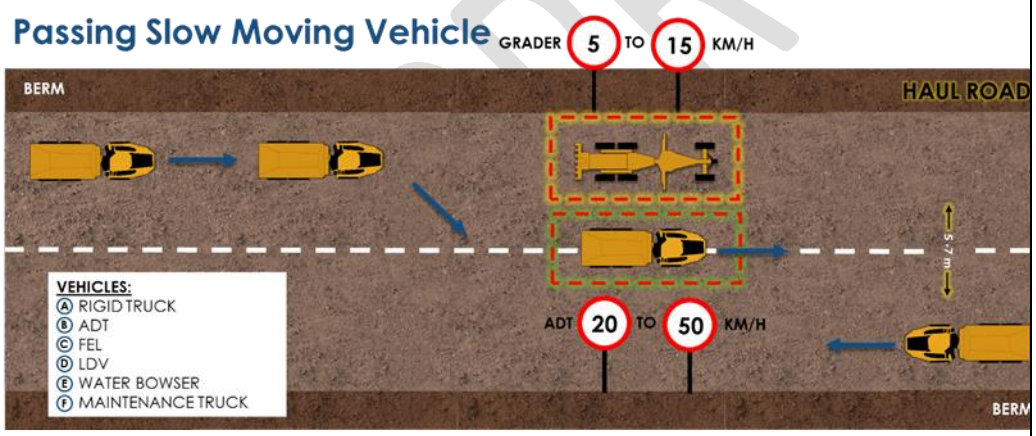
17. Interaction scenarios

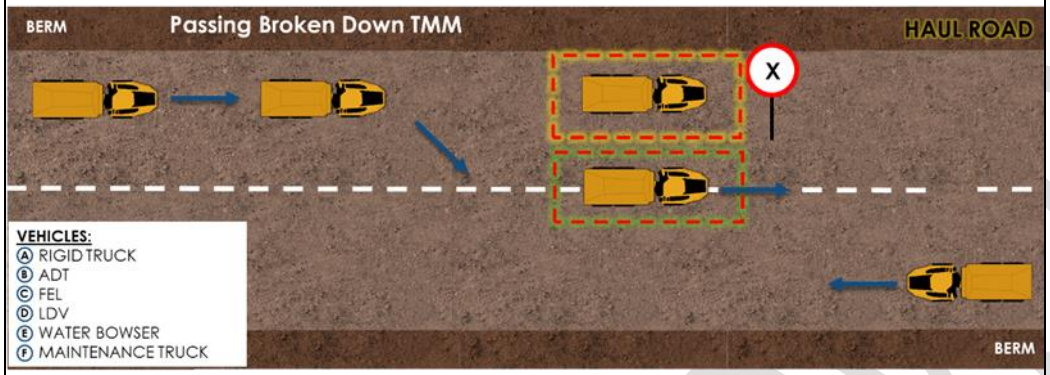
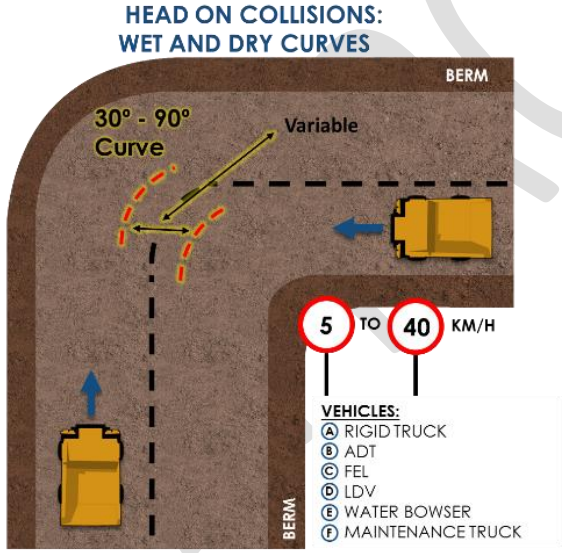
Scenario number	Scenario description	Operating Rules/Requirement
S1		• The CPS must prevent potential TMM collisions by ensuring that TMMs of specific types can only move on roads specifically dedicated for them. (Road zones) The system must ensure "no access" at road and area boundaries for predetermined TMM Types. • The CPS must be able to identify TMMs that are not fitted with a CPS that might have entered an CPS area or road. (Lost vehicle) (Boom gate with sensor) • TMMs like delivery vehicles, mobile cranes and the like must be escorted by TMMs fitted with CPS and specific speed restrictions are enforced.
S2		• The CPS must prevent potential collisions by ensuring that the speed restrictions on different areas on the mine are maintained. This to ensure that the CPS will remain within its design limits. Examples of such areas are: Dumps, stockpiles, hard parks, workshop areas etc. Similar for specific sections of roads such as: ramps, curves, intersections, proximity to infrastructure and the like.

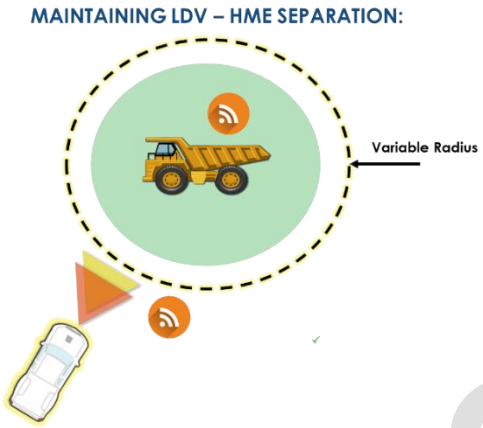
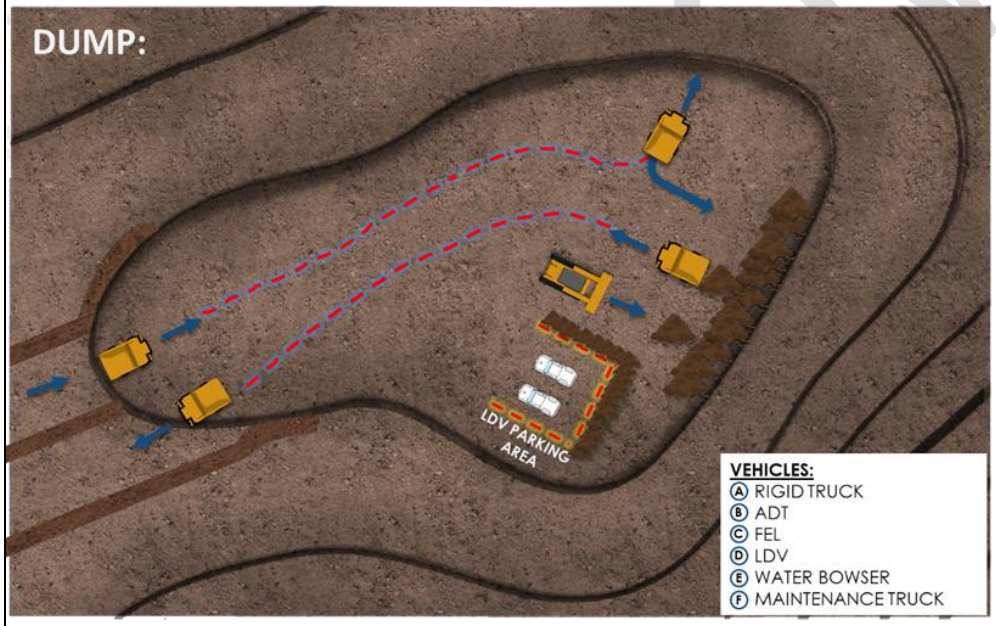
S3		• The CPS must prevent potential TMM collisions by ensuring safe following distances of TMMs. Following distances can be variable depending on the area of the mine (a ramp, a loading area etc.) and the specific place on a road (a curve, etc.) and also variable based on the specific speed restriction on roads. • The system must allow for a variable safe distance between TMMs when a TMM is slowing down to stop at an intersection and another TMM is also approaching the intersection from behind the front TMM.
S4		• The CPS must ensure detection of a TMM by another TMM on curves/bends or when the TMMs are not in line of sight but close enough to be "monitored" • The CPS must be able to adjust following distances based on weather and road conditions.

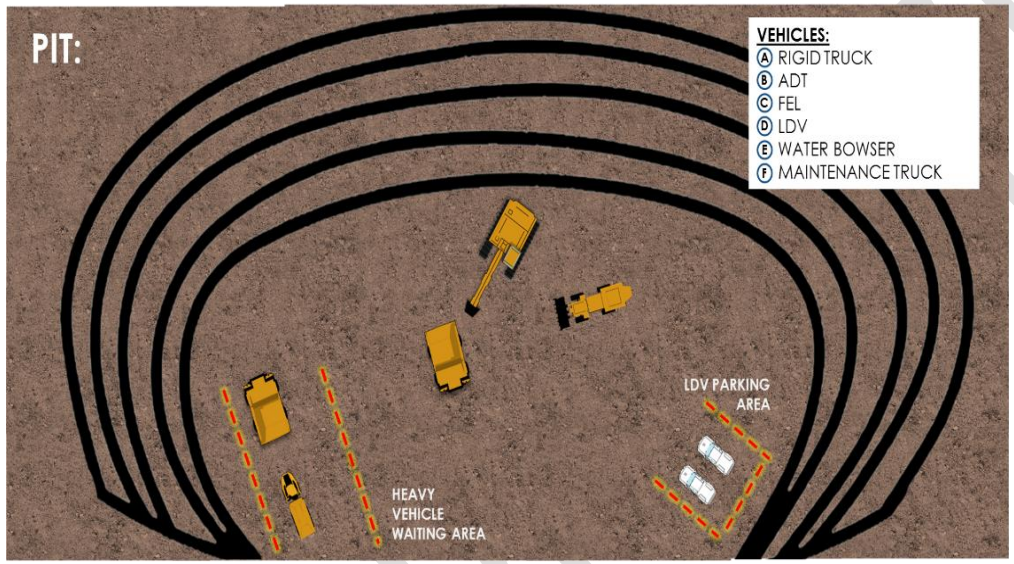
S5		• The CPS must prevent potential collisions by ensuring that intersections can be zoned for priority directions. At a T intersection the CPS will give priority to any TMM on the " main" road and ensure that the TMM that stopped can only start moving when there is no TMM on the main road close enough that the TMM that will be turning will require the TMM on the main road to reduce speed. • The CPS must provide correct functioning despite the presence of berms as per the mines Traffic Management Plan. • The CPS must provide for HME berms and LDV berms as well as intersection berms • The CPS must ensure that TMMs approaching the T intersection slow down and stop if the operator does not adhere to the traffic rules (Slowdown and stop)

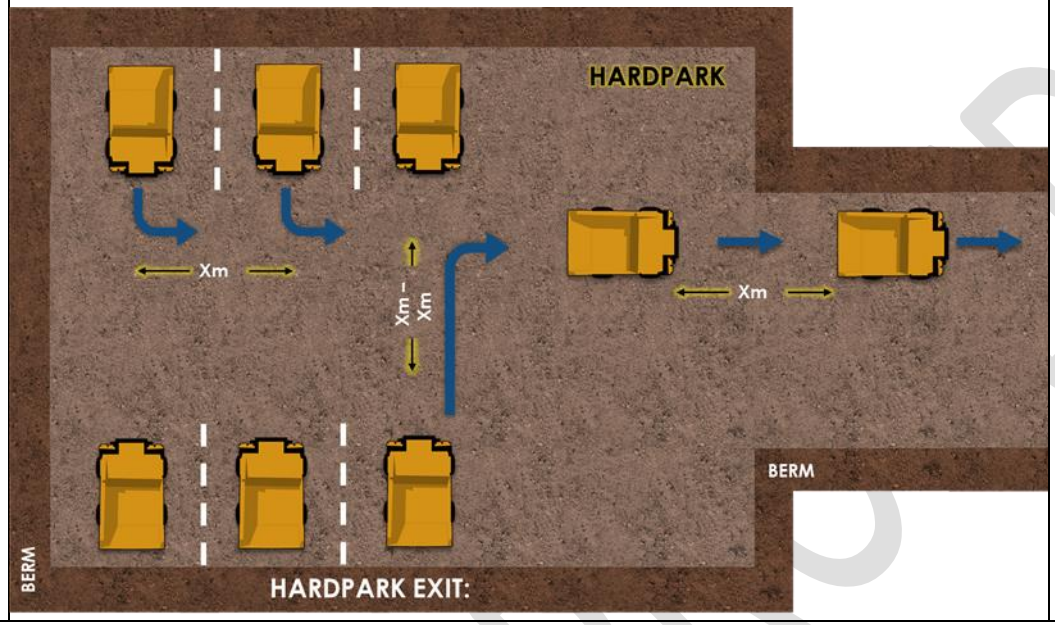
S6		• The CPS must prevent potential collisions by ensuring that intersections can be zoned for priority directions. • At a crossover LDV intersection with a TMM road, the CPS will give priority to haulers and ensure that the LDVs come to a complete stop and can only start moving when there is no TMM on the TMM (haul) road close enough that the LDV will require a TMM on the haul road to reduce speed. • At an LDV / TMM intersection potential collisions will be prevented by not allowing the LDV to turn onto the TMM road. • At a ✚ HME intersection the CPS will give priority to priority TMMs and ensure that the other TMMs came to a complete stop and can only start moving when there is no TMM on the main road close enough that the TMM will require a TMM on the main/haul road to reduce speed.

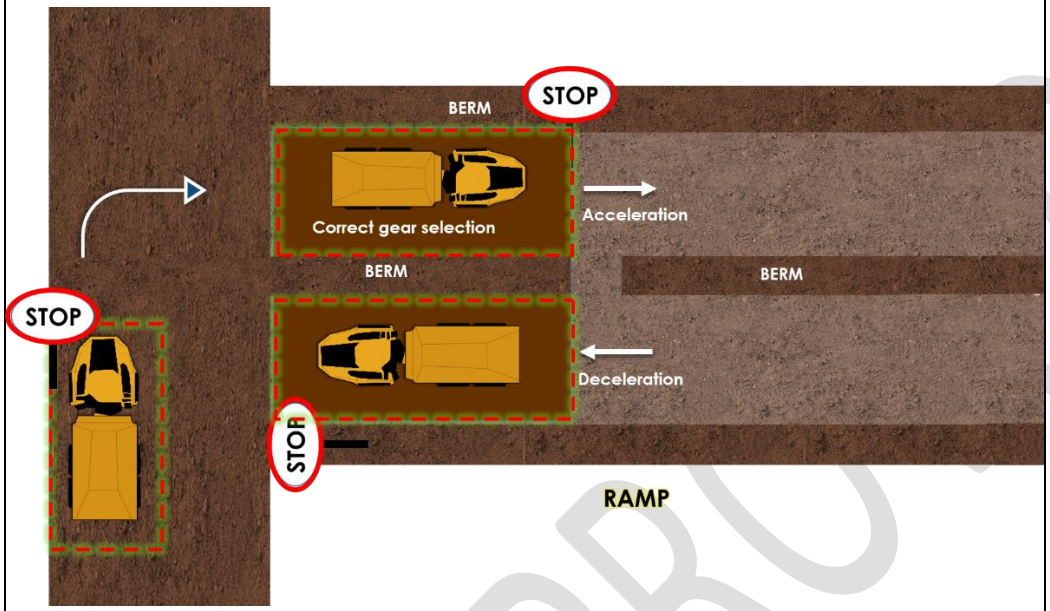
S7		• The CPS must prevent potential collisions by ensuring that intersections can be zoned for priority directions. • At a crossover HME intersection the CPS will give priority to priority TMMs and ensure that the other TMMs come to a complete stop and can only start moving when there is no TMM on the priority road, close enough that the turning TMM will require a TMM on the priority road to reduce speed.
S8		• The CPS shall prevent TMM collisions when faster moving TMMs must pass a slower moving TMM. • The CPS shall prevent specific types of TMMs to pass other slow moving TMMs eg. FEL passing Grader The CPS shall provide for passing bays where the passing TMM can pass a slow moving TMM, eg. FEL passing Grader

S9		• The CPS shall prevent potential collisions between TMMs when a TMM has broken down on a road. • The CPS shall give all TMM operators within 200m from the broken down TMM an effective warning to deal with the breakdown.
S10		• The CPS shall prevent potential head on collisions between approaching TMMs on straight stretches of road and on curves in wet and dry conditions • Safe passing distance between passing TMMs must be variable depending on size and speed of TMMs • Curved areas must be able to be speed zoned in accordance with the speed restrictions on the mine such that the CPS stays within its design limits

S11		• The CPS shall prevent potential collisions between HMEs (including FELs, Shovels, etc.) and LDVs in all operational areas by ensuring a minimum distance between LDVs, service trucks and operating TMMs (HME). • The CPS shall provide a digital lockout functionality ensuring the HME is in safe park before allowing an LDV or service truck to move inside the safe radius. The CPS shall only allow the TMM to start and move once the LDV is out of the set distance (variable)
S12		• The CPS shall prevent potential TMM collisions during dumping operations by ensuring a minimum "xm (variable)" distance between TMMs. • Maintaining S11 between all HME and LDVs on the dump, unless a dedicated bermed LDV parking area is dedicated for LDV parking. • A variable minimum distance of xm (variable) between all vehicle sides will be maintained (including dozer) • When any TMM other than dump truck is entering the dump ramp all TMMs on the dump must be parked in safe parked and electronically locked out. (Diesel Bowser, Maintenance Truck, Water Bowser) • Variable speed limits for different types of TMMs will be ensured on the dump ramp and dump itself.

S13		• The CPS shall prevent potential TMM collisions during all loading operations by ensuring a minimum (variable) distance between TMMs and maintaining S11, unless a dedicated bermed LDV parking area is demarcated for LDV parking. • Trucks waiting to be loaded will be kept a minimum (variable) distance of xm in front and behind each other. • Trucks in the waiting area will not be able to pass each other. • An excavator will be allowed within xm (variable) from a dump truck while loading. • Any TMM used for cleaning will be kept a minimum xm (variable) from loading machines and haul trucks • The boom of an excavator will be prevented from swinging over any part of a dump truck cab. • When any TMM other than dump truck is entering the dump ramp all TMMs on the dump must be parked in safe parked and electronically locked out. (Diesel Bowser, Maintenance Truck, Water Bowser) • To ensure that the CPS functions within its design limits variable speed limits for different types of TMMs will be ensured on the dump ramp and dump itself.

S14		• The CPS shall prevent TMM collisions inside of hard parks by ensuring the maximum (variable) speed limit inside the hard park and maintain a prioritisation sequence for the movement of TMMs who's engines are running. • It will maintain a x m (variable) following distance between TMMs leaving the hard park. • If an LDV needs to enter the hard park, then the S11 scenario must be maintained

S15		• The CPS will prevent TMM collisions by ensuring that TMMs wanting to turn onto the ramp cannot do so if a TMM is in the ramp entrance. A TMM in the ramp entrance, must come to a complete stop, select the correct gear (CPS ensure) and only then take off. • The CPS shall ensure a TMM coming up the ramp will start deceleration only once it reached the top of the ramp and come to a complete stop before turning onto the haul road. • Ensuring the S6 scenario.
S16	TMM congested areas.	• The CPS shall prevent collisions in TMM congested areas by maintaining the S12 scenario in all areas of the mine.

18. Surface user's requirements

The CPS requirements from individual user groups within the mine is defined in the table below. This provides further details to be considered during the functional analysis.

Req. number	User requirement (V-V)	Objective or purpose
R1	**User: Operator** **Requirement: Sufficient time to react** Effective warning (warning zone sizes) must allow for sufficient time for the operator to react to the effective warning. Each operator will react differently and in different times depending on a variety of factors that confront the operator at the time (see Definitions: Driver or Operator reaction times). For the purposes of the URS, this reaction time must allow for the worst-case scenario with the operator in the worst state. This reaction time is between 1,5 seconds to 2,5 seconds. Operator reaction time = 2,5 seconds	To give the operator sufficient time to react to TMMs in the vicinity to prevent TMM collisions.
R 2	**User: Operator** **Requirement: Effective warning** An operator must receive an effective warning when other TMM(s) enter the vicinity of her/his TMM. Effective warning must be the result of a human factors engineering process and considers a combination of visual, audible and or a haptic instruction including the following: • An audible warning in an operator language of choice (To be decided) • Screen brightness auto adjustment to brightness of the interior of the cab. • Screen or operator display indicating the alert, alarm, or advisory message with the highest priority when multiple warnings are received. • Haptic instruction may be a vibrating element drawing the human's attention to the warning.	To give the operator both an audio and visual warning of a TMM's location and movement in the vicinity of the vehicle. 
R 3	**User: Operators** **Requirement: No false positives or false warnings** The number of false positives or false warnings must be limited (<2%) to ensure that operators do not become complacent and ignore warnings of potential collisions in their vicinity.	To limit the number of false warnings, auto retards or auto stops.

R 4	**User: Engineering and maintenance, OEMs** **Requirement: Vehicle braking systems must comply with SANS 1589 when activated by the CPS.** Braking systems (service braking, retarder, regenerative braking, hydrostatic braking, emergency braking, park brake) must be used to ensure the best proportional braking option to minimise any negative impact on operator and machine life cycle and maintenance costs. Machine braking performance must not deteriorate the braking system to such an extent that it cannot meet the compliance testing acceptance criteria.	CPS initiated brake performance must comply with national and international braking system compliance testing.
R 5	**User: Operator** **Requirement: Auto-stop final state is safe park** Once auto-stop has been activated by the CPS and the TMM comes to a stop, the TMM must enter a state of safe park which means that the park brake is activated with the engine running and that the operator cannot engage any gear to put the TMM into motion until the other TMM has moved out of its vicinity.	TMM to remain in safe park while the other TMM is in its vicinity.
R 6	**User: Operator, maintenance, engineering** **Requirement: CPS fail to safe** The CPS must fail to safe automatically when any fault is detected on the CPS. The fail to safe state of the TMM shall be safe park and engine off. The CPS must have a self-diagnostic that checks the CPS health continuously and should it detect a fault, have both an audio and visual alarm to warn the operator and bring the vehicle to a safe park state with the engine off. When a TMM is started, the CPS self-diagnostic shall run and confirm that the CPS system is healthy with a confirmation on the CPS screen or display. If the diagnostic detects a fault the operator must not be able to engage any gear and the TMM must shut down in safe park. Typical fail to safe states may be: • no power on the system, • the connected antennas are not functional, • any system faults are detected, • a communication error is detected,	CPS fail to safe

	• any battery required by the system fails to maintain a minimum operating voltage or power to enable proper operation, • a faulty machine component is detected, or • any component failure.	
R 7	**User: Authorised Supervisor or person (Operations, maintenance, engineering)** **Requirement: CPS override** The CPS shall provide a means for an authorised supervisor to temporarily suspend an automatic intervention that must be specifically defined.	Provision of CPS override in certain circumstances
R 8	**User: Operations, engineering** **Requirement: CPS Data logging, storage, and data retrieval** The CPS must time stamp, log and provide a permanent auditable record of potentially hazardous interactions (including near misses) and machine response recorded by the CPS. The CPS storage capacity for interaction data shall be for a minimum of six months and must be able to be retrieved through any of the following means, and this list is not exhaustive: • USB connection, • Blue tooth, • WiFi, • GSM network (5G), • Local area network.	Accurate data storage and retrieval through many means
R 9	**User: Operations, engineering, SHEQ, maintenance** **Requirement: CPS reports from interaction data** The CPS must provide management information reports based on interaction data for the following needs: • Daily analysis of interactions that are a safety concern and require urgent attention (including: test failures, trends, and heat maps of hazardous locations), • Daily analysis of interactions that are a production concern and require urgent attention (including trends and heat maps of production locations where interactions occur), • Weekly summary reports of the above interactions and operating / maintenance	Management information reports

	compliance (safety, production, availability, reliability and MTTR), • Incident detail reporting when required, • The reporting system must have an up-time of 24/7 x 98% and be configurable for each mine site and must be able to run in the cloud and on typical SAMI mining local area networks, • The reporting system must be secure.	
R 10	**User: Operations, maintenance, engineering** **Requirement: CPS operational and maintenance reliability** The CPS must be: • Reliable >99%, • Installed such that it facilitates ease of access for maintenance • Provide for quick changeout of components including cables. • Installed on the TMM for optimum system performance, • Provide for quick calibration	Operation and Maintenance of the CPS to be in accordance with critical safety related system.
R 11	**User: All employees** **Requirement: CPS EMI, EMC** The CPS interface must not interfere with other electronic systems on the mine and must not be affected by other electronic or electrical systems or ore body contents. These systems can be: • Radio systems, • Fuel filling systems, • Electronic detonation systems, • WiFi, • Local instrumentation (plant operating equipment), • High voltage areas, • Ore bodies containing high ferritic (iron ore) content, • The CPS must not have any negative effect on humans and limit human exposure to electromagnetic fields.	No interference with or by other electromagnetic fields in the radio frequency (RF) spectrum that is caused by another electronic device.

R 12	**User: Operator** **Requirement: Visibility** **Operator display:** The operator's visibility should not be obstructed or restricted due to improper positioning of equipment: • Operation of the CPS solution controls should be evaluated through design risk assessments (by the CxD supplier and by the OEM) to ensure unintended risks or consequences are not introduced, • Ergonomics of the operator cabin should not be compromised due to improper positioning of components, • Warning or diagnostic display units should be positioned so that the operator is always made aware of an alarm regardless of direction of travel or driving position. • Display units should be positioned in the operator's field of vision to allow alarms or advisory messages to be seen by the operator without unnecessary distraction and confirmed by design and operational risk assessments, • Display units should function effectively independent of the number of vehicles or personnel around the machine, • Display units should indicate the standby battery power availability (if an independent battery power supply has been specified), • Display units should show the current date and time if an internal real-time clock is used for time stamping of data, • Display units should clearly indicate the operating status of any radio communication or positioning links (e.g. vehicle-to-person, vehicle-to-vehicle or vehicle-to-fixed infrastructure communications links); • Colours used by display units should be different to other existing warnings on the machine to avoid operator confusion, if possible.	Operator visibility not to be impeded by CPS location in cab.

19. References

The following documents are referenced in this document

1. EMESRT PR-5A Vehicle interaction systems dated August 2019
2. EMESRT Vehicle Interaction improvement Guide dated October 2020
3. ISO 3450-1, Earth-moving machinery — Wheeled or high-speed rubber-tracked machines — Performance requirements and test procedures for brake systems
4. SANS 1589-3: The braking performance of trackless mobile mining machines.
5. SANS 13766 adopted from ISO 13766
6. SANS 1717-3 (2007) "The design and approval of detonator initiation systems for use in mining and civil
7. ICNIRP GUIDELINES FOR LIMITING EXPOSURE TO ELECTROMAGNETIC FIELDS (100 KHZ TO 300 GHZ)
8. ISO 2631-1, 5 Mechanical Vibration and Shock