USER REQUIREMENT SPECIFICATION FOR UNDERGROUND MINE COLLISION PREVENTION SYSTEMS

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

REV 2

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Definitions and Abbreviations

The following definitions and abbreviations will be used to create a common approach for all deliverables.

Table 1: Definitions and abbreviations

Term/Abbreviation	Definition
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.
CAS	Collision Avoidance System
CM	Continuous Miner
CMS	Collision Management System: The overall combination of preventative controls, mitigation, recovery and supporting controls, implemented by a mine site to prevent TMM collisions.
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.)
CPS Start-up	The operator has completed the pre-inspection checks as per the mine's standard operating procedure and removed the chocks or stop blocks from under the TMM's wheels. The operator has entered the cab and is preparing to start operating. During this state, the CPS is undergoing its start-up procedure, e.g. performing system health checks. The CPS is not ready to start normal operation.
CPS Slow	The state when the CxD limits the TMMs speed. The CxD instructs the TMM to slow by sending SLOW_DOWN or APPLY_PROPULSION_SETPOINTS via the ISO/TS 21815-2:2021 CAN-bus interface.
CPS Stop	The state when the CxD intervenes with the intent of stopping or keeping the TMM stationary to avoid a collision or FTSWHI. The CPS has detected a potential collision with a pedestrian and is intervening or has intervened to bring the TMM to a safe stop. Once the TMM has stopped, it remains stationary. Once stopped, the TMM is prevented from any movement, including no movement of the bucket, attachments, boom, etc. No articulation is allowed once the TMM has come to a safe stop. This state is reached by the CxD instructing the TMM to stop via the ISO/TS 21815-2:2021 CAN-bus interface.
Crawl Speed	The slowest speed a TMM can move without undue wear and tear. This speed must be slower than typical pedestrian walking speed (see Walking speed definition).
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: Proximity Detection System (PDS) is a colloquial industry term for a physical device, providing a warning or collision avoidance functionality.
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.
Detection	Detection is sensing that an object has entered the detection area.
DMPR	Department of Mineral and Petroleum Resources.

Term/Abbreviation	Definition
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.
DTS	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.
EMC	Electromagnetic Compatibility
EMESRT	Earth Moving Equipment Safety Round Table
Emergency Override	The CPS has intervened and the TMM is in the CPS Stop state. However, there is imminent danger to either the TMM operator and/or nearby pedestrians. The TMM operator engages Emergency Override, as per the mine's standard operating procedure, to move the TMM to a safe place. During Emergency Override, the TMM speed is limited and the TMM is allowed to move for a limited period of time, as determined by the mine's risk assessment. Once this period expires, the TMM returns to the CPS Stop state.
EMI	Electromagnetic Interference
Employee	Employee means any person who is employed or working at a mine.
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&TPR	Functional and Technical Performance Requirements
FMECA	Failure Modes, Effects and Criticality Analysis
FTSWHI	Fail-to-safe without human intervention The CPS has detected a critical failure that compromises the CPS functionality. The CPS brings the TMM to a safe state within a reasonable time, as defined by the mine's specific risk assessment and standard operating procedure. The CPS can only exit this state if the failure is repaired/resolved, the operator activates Emergency Override, or an authorised technician engages Maintenance Override. Critical failures are informed by the OEM or OTM Failure Modes, Effects and Criticality Analysis (FMECA).
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.
ICMM	International Council on Mining and Metals.
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.

Term/Abbreviation	Definition
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.
Intervention	See CPS Stop and CPS Slow
LDV	Light duty vehicle
Maintenance Override	An authorised technician may enable the Maintenance Override state when recovering a TMM to effect CPS repairs. TMM speed is limited as per the mine's standard operating procedure until the Maintenance Override is cancelled by the authorised technician, or the TMM is safe parked. Upon deactivation of Maintenance Override, or start-up from Safe Park, the CPS shall fail-to-safe without human intervention if the critical failure(s) has not been resolved.
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.
MHSA	Mine Health and Safety Act No. 29 of 1996 and Regulations.
MHSC	Mine Health and Safety Council.
MLK	Machine Log Keeping: The function that receives, and stores TMM CPS data.
MOSH	Mining Industry Occupational Safety and Health Initiative.
MRAC	Mining Regulations Advisory Committee.
MS	Machine Sensing: Sensing functionality on a TMM that enable a fully functional CPS.
Normal Operation	The normal state of the TMM while it is operating and there is no significant risk of collision between the TMM and pedestrians. The CPS is functioning as intended and is monitoring for potential collisions.
Operator Stop	The operator has stopped the TMM and signalled their intent to stay stopped. This may happen during the course of the shift. The Operator Stop state is typically characterised by engagement of the Park Brake by the operator. During this state, if allowed by the mine's standard operating procedure, passengers may board the TMM. The CPS is functioning normally, but the potential for collisions is limited due to the engagement of the Park Brake.
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.
PWS	Pedestrian warning System: The system that provides the effective warning to pedestrians.
Phase 2	Phase 2 of the Industry Alignment on TMM Collision Management Systems Special Project of the Minerals Council South Africa.
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. (c) 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.

Term/Abbreviation	Definition
Safe Park	The TMM is safely parked as per the mine's standard operating procedure, e.g. the operator has engaged the park brake, switched the engine off and exited the cab. The operator has placed chocks or stop blocks under the TMM's wheel(s). This state is typically encountered at the start/end of shifts when the operators are prevented from moving. The TMM is not operational.
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.
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".
Speed Limit Mode	In certain areas, the CPS may enter a Speed Limit Mode. The aim of Speed Limit Mode is to limit the TMM speed to minimize the size of the vicinity. This mode may be utilized in congested areas such as workshops, refuelling bays, waiting areas, etc.
Stop Gap	The distance between the TMM and pedestrian after the TMM has been automatically slowed down and stopped.
System	A combination of interacting elements organized to achieve one or more stated purposes (ISO/IEC/IEEE 2015).
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.
TMLP	Traffic Management Leading Practice: The MOSH Traffic Management Leading Practice for Open Cast/Cut mines in South Africa.
TMM	Trackless Mobile Machine as defined in MHSA. (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.
UG	Underground
URS	User Requirement Specification
UTC	Coordinated Universal Time.
V2X	Vehicle to everything.
Vicinity (Underground TMM and pedestrians)	The distance or time to the point of a potential collision, such that, if the operator and the pedestrian receive an effective warning to prevent a potential collision, and one or both (or all) do not take action, the CPS will still be able to prevent the potential collision.
V-P	Vehicle to pedestrian.
Walking speed	In the absence of significant external factors, the average human's walking speed is 1.4 m/s. This is included to help define the crawl speed of TMMs.
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.

1 Context

This document is one of the documents in the Mining Industry Occupational Safety and Health Initiative (MOSH) Collision Prevention Systems (CPS) guideline. During phase 1 of the project a single User Requirements Specification (URS) was developed for Underground and Surface CPS. This document is developed as part of phase 2 of the project and is now a standalone document for Underground TMMs, hence it being revision 1. Changes to it are described further on in the document.

Whilst it is developed as a stand-alone document, it is advisable to view it in the context of the other MOSH CPS guideline documents[1].

The South African mining industry (SAMI) is the only international region at the time of writing (other than Proximity Detection Systems (PDS) regulations in underground coal mines in the USA) that has regulated the installation of Trackless Mobile Machinery (TMM) safety products that can prevent collisions between TMMs and pedestrians in underground operations. This is promulgated in Regulations 8.10.1.2(a) and (b) in the Mine Health and Safety Act No. 29 of 1996 and Regulations (MHSA). Whilst the regulations make 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 readily available if a mine cannot or does not want to introduce controls that are higher up in the hierarchy of controls to address the significant risk of collisions between TMMs and pedestrians.

The availability of CPS products is an unprecedented challenge for the SAMI due to:

- Lack of maturity of the technology being used in collision warning and avoidance device (CxD) products.
- Complexity of CPS products.
- Interoperability challenges with CPS products.
- 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 in the industry.
- The large number of older TMMs in use on mines in South Africa that do not have electronic gearboxes and CAN-bus networks (referred to as legacy TMMs).
- 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.

Under the MHSA, a **mine** has the legal duty to comply with the law by introducing reasonably practicable measures to prevent persons from being injured while doing their work on the mine. One of the aspects that a mine must **ensure** is that equipment, structures and services procured for use on the mine comply with the general requirements of the MHSA, namely: it will not injure persons working on the mine when such equipment, structures or services are used as intended. Another aspect is that equipment, structures or services must comply with the specific requirements of the MHSA.

In the case of Reg 8.10.1.2(a) and (b) the mine must ensure that CPS products comply with the specifics of the relevant sub-clauses. The 2.13.1 legal appointee (in terms of the Minerals Act Regulations which remain in force and effect in terms of Schedule 4 of the MHSA) on the mine has the responsibility and accountability to **ensure such**. Since the MHSA is not a detailed, prescriptive Act that lists every single

[1] Available at https://www.mosh.co.za/transport-and-machinery/documents

requirement and design detail of each piece of equipment, structure or service, the accountability for establishing such supplementary information is that of the 2.13.1 legal appointee on a mine.

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

Since 2015 the SAMI made concerted efforts to facilitate the development of CPS products that would comply with the TMM regulations. The significant challenges that had to be overcome only became apparent during the initial years of the effort. Some of the challenges include:

- The industry wide TMM population, its types, brands, models and configurations must be known 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 to expedite the development, maturity and availability of CPS products, including:
    - Maximum collaboration between role players
    - A single set of requirements
    - A single accelerated development program
    - A single integrated test regime

In 2019 the Mining Regulations Advisory Committee (MRAC) of the Mine Health and Safety Council (MHSC), the committee responsible for facilitation of the TMM regulations, assembled a team of experts to advise it on the maturity of CPS products with a view to enforce the suspended clauses of the TMM regulations.

The MRAC task 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 would enable the upliftment of the suspended clauses of the TMM regulations as soon as possible. The key pillars of the project were:

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

The Minerals Council South Africa's investment to assist its members with regulatory readiness, demonstrates the SAMIs commitment to compliance. The MOSH CPS guideline established by the Minerals Council CPS project enables mines to comply with their duty to ensure compliance to Reg 8.10.1.2(a) and (b). This naturally only applies to those mines that adopted the MOSH CPS guideline as its requirements for CPS.

At a first glance, the most appropriate CPS product approach would be that a TMM OEM develops a CPS product for its own TMM range. This would ensure that the technical challenge for CPS products would be within the full control of TMM OEMs and a single point of liability would exist. For that approach to work, an international standard for communication between CPS products (Collision

Warning and Avoidance Devices (CxDs) from different OEMs) is a prerequisite. Such an international standard did not exist then, and still does not exist in 2025. This reality induced significant complexity to the regulatory compliance challenge and drove the functional structure and requirements of the two CPS products, namely the CxD and the TMM CPS.

This document was initially developed as one part of Work Package 9 (WP 9) deliverable of the INDUSTRY ALIGNMENT ON TMM COLLISION MANAGEMENT SYSTEMS PROJECT: CAS READINESS PHASE[2]. The document has been revised and updated to reflect lessons learnt and experience gained since its original publication and extensive interaction with the key role players in the SAMI. Revision 1 (this revision) is a significant update that includes a restructuring of the User Requirements Specification (URS) into separate documents for Underground TMMs and Surface TMMs. The URS must be read in the context of:

- Data collected and collated by the Minerals Council South Africa and provided to the project (as referenced before).
- Learnings and experience gained from SAMI where PDS/Collision Management Systems (CMS) has been implemented.
- Accident and incident statistics in SAMI and other parts of the world, made available from the Minerals Council South Africa and Department of Mineral and Petroleum Resources (DMPR),
- Knowledge gained from experienced mining specialists about mining processes and the Vehicle to Vehicle (V-V) and Vehicle to Person (V-P) interactions that occur in those processes,
- Global CMS initiatives emanating from Earth Moving Equipment Safety Round Table (EMESRT)[3] and the International Council on Mining and Metals (ICMM).
- Extensive CMS and CPS testing conducted by the University of Pretoria.
- Engagements with the Northern Cape Mine Managers Association Engineering Work Stream and their interactions with CPS suppliers, TMM OEMs and the Northern Cape Mine Health and Safety Inspectorate.

2 Purpose of this document

The purpose of this document is to:

- Serve as a template for 2.13.1 legal appointees for adoption or adaption as evidence of one of the reasonable steps taken to ensure compliance with Regulation 8.10.1.2.
- Serve as a SAMI requirement guideline for underground CPS product suppliers.
- Assist the SAMI with accelerated development of underground CPS products by having a single requirement set for all underground CPS products.
- Save CPS suppliers' time and money to develop conformant CPS products based on:
    - A common interpretation of the direct and indirect (implied) requirements of Reg 8.10.1 and in particular 8.10.1.2.
    - A common set of User Requirements, based on actual production processes to be executed on mines as a comprehensive basis that:
        - Meets the MHSA TMM collision prevention regulatory requirements.
        - Meets the needs of the SAMI mine types and mine working environments,
        - Informs the **CPS functional specification**, thereby ensuring that any CPS developed according to the CPS functional specification and tested in accordance with the CPS test regime will be suitable for use in the SAMI, and
        - Meets the purpose of CPS.

[2] Available from https://www.mosh.co.za/transport-and-machinery/documents

[3] Available from https://emesrt.org/wp-content/uploads/2019/09/EMESRT-PR-5A-Vehicle-Interactions_v2_20190902-1.pdf

- Common requirements for CPS development processes, that informs the Functional Readiness Criteria and will ensure that the information contained in the technical file required by Section 21 of the MHSA is produced as a natural outcome of the product development process.

It is not the purpose of this URS:

- To be the functional specification defining performance criteria (refer to CPS Functional Specification[4]).
- To be the functional readiness criteria for CPS products (refer to Functional Readiness Criteria for CPS[4]).
- To define the life cycle requirements of the CPS.
- To define any SAMI CPS needs other than the MHSA regulatory **direct and implied** CPS requirements.

The Minerals Council South Africa's approach to the regulatory challenge its members faced, was to focus on ensuring that CPS products that are offered to the SAMI conform to requirements that will allow mines to 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** requirements to ensure regulatory compliance. CPS product suppliers have full freedom to supply products with additional functionality and features to both the local and global markets in order to differentiate its product(s). It is acknowledged that CPS is not regulated in any other mining jurisdiction and therefore CPS product suppliers can supply any CAS product to those markets. Naturally where CPS requirements are more stringent and challenging than CAS products, CAS product suppliers may find it challenging to offer CPS products to such a small market.

Figure 1 depicts the relative position of SAMI CPS requirements within the local and global markets. Any CPS supplier that offers a CPS product that it claims to comply with the local TMM regulations will have to demonstrate that such CPS product has achieved the product requirements as set out in MOSH CPS requirements documents.

The role and impact of EMESRT and the ICMM Vehicle Interaction initiative is dealt with in detail in the CMS Specification Guideline Review Report Rev 7[5]. For the purposes of this URS it is important to note that (see Figure 1 for a graphical representation):

- A Collision Avoidance System (CAS) is an international term defining automatic slowdown and stop functions for mine vehicles in **general** terms.
- CAS products do not necessarily comply with the MHSA and if it does, it is best described as a Collision Prevention System (CPS). CPS is thus a subset of CAS with very specific requirements.

[4] Available from https://www.mosh.co.za/transport-and-machinery/documents
[5] Available from https://www.mosh.co.za/transport-and-machinery/documents

Figure 1:CPS requirements in relation to Supplier offerings

The CPS URS aligns with both EMESRT and ICMM Vehicle (TMM) interaction initiatives where possible, and where not in conflict with the requirements of the MHSA. EMESRT PR-5A Vehicle interaction systems dated August 2019 [1] and the Vehicle Interaction improvement Guide dated October 2020 [2] were used to support the development of this URS.

The URS also aligns with the input provided by previous guidelines most notably: "Collision Management Systems Technical Specification Guidelines for Underground Mining Operations (Rev A.6)"

The mentioned documents include a mixture of user, functional and technical requirements/specifications and where appropriate the user requirements of this document have been aligned with those in the abovementioned documents.

3 Background

The technology required to develop fit for purpose and regulatory compliant CPS products is complex. A key aspect of any systems engineering based system or product development process is the establishment and approval of the (URS). As indicated in the CMS Technical Specification Guideline Review Report, a formal and approved set of CPS user requirements did not exist in 2020. The absence of an URS almost always leads to a lengthy iterative product development cycle, uncovering user requirements as the product is starting to be used. Such an approach for a safety system in a regulated environment is highly undesirable, as it may expose legally responsible persons. This document defines the Underground TMM CPS URS, developed after extensive engagement with industry experts, facilitated by the Minerals Council South Africa MOSH Transport and Machinery (T&M) Adoption Team.

A specific emphasis of this URS is the definition of the **CPS regulatory requirements,** namely: to prevent injuries arising from collisions involving TMM operations and pedestrians in underground operations. The regulatory requirements and the justification thereof are provided with specific attention given to the key aspects of vicinity, effective warning, automatic slowdown and stop, and fail-to-safe without human intervention (FTSWHI).

Technical performance aspects such as reliability, accuracy, electronic magnetic compatibility (EMC), maintenance and support are also included in the URS as general requirements.

The URS defines the baseline CPS Product Breakdown Structure. Key operational scenarios are depicted, defining specific requirements that the CPS products must conform to. The operational scenarios represent typical use cases within which CPS products will operate.

It is reasonably foreseeable that the CPS will have significant implications on a mine's existing day-to-day operations, because the CPS can be classified as:

- A critical safety related system
- A maintenance significant system
- An operations significant system

The above classification means:

- Safety: Any fault with the system is a "NO-GO", it must fail-to-safe and be tamperproof. (Continuing operations in the presence of safety faults may expose the mine's legal appointee to liability if an injury were to occur).
- Maintenance: Since the CPS must be FTSWHI implying that a TMM with a failed CPS cannot be operated and it being a safety related system, proper, diligent maintenance of the CPS is required. Only skilled and competent employees should be allowed to work on a CPS. The CPS must support accurate fault detection and root cause analysis. Critical spares must be readily available.
- Operations: Only skilled and competent employees are allowed to operate a TMM 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, reliable and repeatable.

4 Scope

For the purpose of the scope of this document the USER is defined as **the mine** (the employer) that has the legal duty to prevent persons from being injured as a result of TMM collisions.

The Underground CPS URS applies to:

- The SAMI for TMM underground mines that adopted the MOSH CPS guideline.
- All underground mining types and processes that involve diesel powered TMMs.

The scope of this URS does not:

- Include all interaction scenarios that may be found in a specific mine's mining processes. These interaction scenarios must be determined through performing a traffic flow analysis, and risk analysis. Flowing from that work, additional/mine specific interaction scenarios may be identified.
- Explicitly consider the capability of currently available CPS products, but rather defines what the end user (the mine) requires from a CPS in order to comply with the MHSA.

5 Approach Used to Develop the URS

The overall approach used to develop this document is described in the report titled: REVIEW REPORT: Collision Management Systems, Technical Specification Guideline, SME and UME, REV 7 OF THE INDUSTRY ALIGNMENT ON TMM REGULATIONS; SPECIAL PROJECT OF THE MINERALS COUNCIL SOUTH AFRICA[6].

Figure 2 shows the CPS requirements structure. It is based on classic systems engineering practice and standards. The structure enables mines and CPS suppliers to identify the CPS products, their elements, modules and components in a holistic way, that will enable traceability from the CPS level down to a specific product/element component.

[6] Available from https://www.mosh.co.za/transport-and-machinery/documents

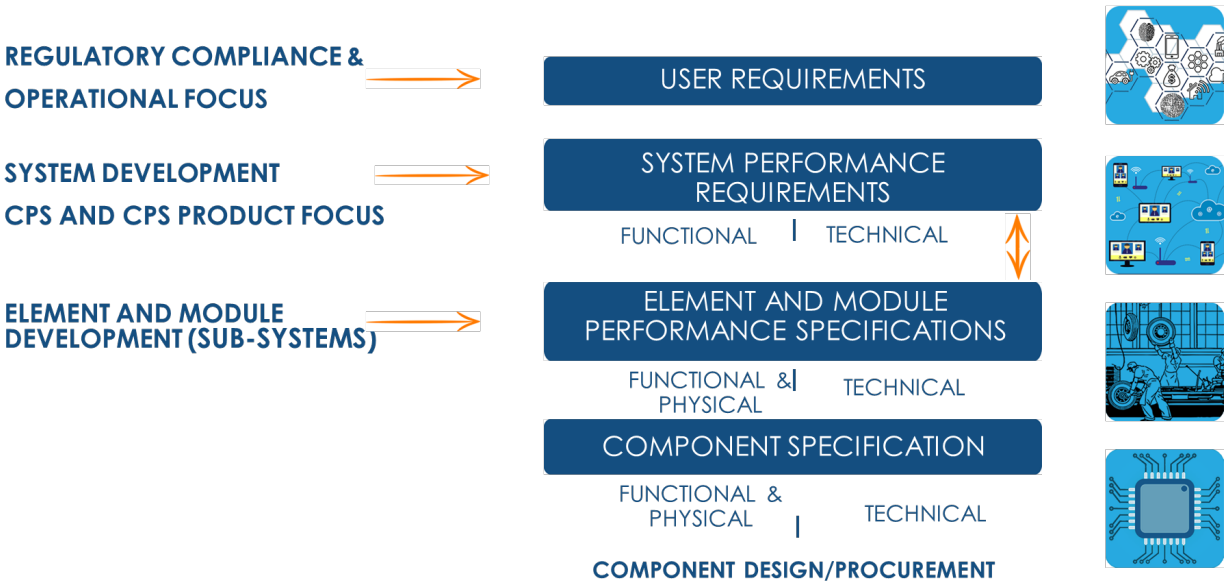


Figure 2: CPS Requirements Structure

6 Regulatory Requirements

The first step in classical systems engineering is to define all requirements **external** to the system's operational environment. The URS will therefore specifically focus on the TMM regulatory requirements. It will address the **direct as well as implied** requirements.

6.1 CPS Legal Liability

Automatically slowing down and stopping a TMM, seconds before a potential collision, under the legal objective to prevent injury as a result of such collisions, bears a significant legal duty for a mine. The duty of a mine is to **ensure compliance with the TMM regulations.**

CPS falls within the accountability of the 2.13.1 legal appointee and as such he/she must be clear on the objective of the regulations, the direct requirements as well as the indirect requirements that will **ensure** compliance with the regulations. It is significant to note that Reg 8.10.1 addresses the CPS as a whole and not the sub-systems or products (CxD & TMMCPS) supplied by different suppliers.

The lack of an international standardised communication protocol between different CPS products (CxDs), implies that a mine must standardise on the CxD to be deployed on the mine. This reality has significant legal implications for the 2.13.1 appointee. If the 2.13.1 appointee is unable to bound the liability of any sub-element of the CPS, he/she will not be able to keep the suppliers of the sub-elements legally accountable for their products and hence will be exposed legally.

For a 2.13.1 appointee, it is therefore very important to define the CPS such that the requirements of the products can be unambiguously bound, to contract the products such that the product supplier bears the legal liability for the product(s) supplied.

To effectively demonstrate the reasonable measures taken to ensure compliance the 2.13.1 appointee must:

- Structure the CPS in logical elements that can be contracted with clear legal boundaries.
- Specify the Functional and Technical requirements for each of the elements.
- Specify the requirements for each of the elements' suppliers to demonstrate conformance with the requirements.

- Specify the evidence to be provided or be available (Section 21 Technical File Content).
- Ensure conformance with the requirements by either independent verification or by performing extensive inhouse testing.

Being an injury prevention safety system, comprising multiple products, implies specific functional and technical requirements that would otherwise **not** be necessary. These implied requirements are as valid as are the direct requirements. The fact that it is not directly stated in the texts does not make them optional or guidance only. These are:

- The TMM to slow down and stop without operator action when the CxD or any of the TMM CPS functions failed. This in turn implies that:
  - The CPS must have self-diagnostic capabilities
  - Automatic deceleration (retardation), service brake, as well as park brake application capabilities. This in turn implies that:
    - The deceleration must be such that it does not have any negative health impact on the operator.
    - The TMM must remain stable and controllable during such automatic slowdown.
    - The TMM must not lock wheels during such automatic slowdown. This in turn implies that the speed, load status and inclination at the time of a slowdown and stop must be considered and must be communicated to the CxD continuously or as it changes
- The CPS products must be able to give evidence of its functionality and communication with the other CPS products. This implies accurate and frequent logging of data and communication between the different CPS products.

The above implied requirements are within the context of the MHSA not being prescriptive and detailed. The onus is placed on the mine to ensure compliance and adherence to the stipulations of the MHSA. The legal duty of the mine therefore includes development of detail CPS requirements that will ensure that the mine complies with Reg 8.10.

6.2 Collisions between diesel powered TMMs and pedestrians

The specific regulations defined in the MHSA are included here for ease of reference. It is important to read Regulation 8.10.1 in its entirety, as the requirements build on the foundation laid by preceding clauses. Contextual reading is key to understanding the derived requirements of the regulations.

Since the mine has the legal duty to prevent pedestrian injuries as a result of TMM collisions, and the act says that all TMMs must be under legal duty of the engineer, it follows that it is the legal duty of the 2.13.1 appointee to **ensure compliance** with the TMM regulations. Since the regulations are not prescriptive and not specific, the first critical aspect is to interpret the high-level regulatory requirements.

8.10.1	*The employer must take reasonably practicable measures to ensure that pedestrians are prevented from being injured as a result of collisions between trackless mobile machines and pedestrians.*

The clause explicitly requires that **all** mines take reasonably practicable measures to **prevent injuries** due to collisions between diesel powered TMMs and pedestrians. The clause provides the fundamental objective of the regulation. It is not limited to specific mining types (surface or underground) and does not differentiate between types of TMMs. There is no reference to a specific type of TMM and there is also no reference to the significance of a TMM collision. A mine therefore must determine the hazards on the mine that can result in an injury due to a collision between all types of TMMs and pedestrians in all TMM related operations and introduce reasonably practicable

measures to prevent persons (operators and pedestrians) from being injured as a result of such collisions.

A critical implication of Clause 8.10. is that the regulation does not require technology products (CPS) as the **only** measure to achieve the objective. This implies that, as long as **reasonably practicable measures** are in place to prevent injuries due to diesel powered TMMs collisions with pedestrians, a mine does not need to revert to technology to prevent such collisions. The measures that are to be in place however must be **effective** in preventing persons from being injured.

Paragraph 8.10.1 then states:

8.10.1(cont.)	*At any underground mine, where there is a significant risk of such collisions such measures must include:*

This clause has two key requirements. Firstly, what follows is only applicable where there is a significant risk of such collisions (where persons can be injured). Secondly, the requirement implies that a mine must have a methodology to determine where there is a significant risk of TMMs and pedestrians to collide and have such places uniquely identified.

Clause 8.10.1 and its sub-clauses therefore are only applicable to a mine where a significant risk of these collisions **remain**, after applying the reasonably practicable measures regulated in clause 8.10.1.

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; and*

8.10.1.2 (a) requires that, where significant risk of collision exists, **all** TMMs (every) and all (every) pedestrian are to be fitted with a CPS. Detection is required within each other's vicinity.

Vicinity is not defined here; however, it can be assumed that the choice of the word implies something specific. The second direct requirement is that both the TMM operator and the pedestrian must be warned of each other's presence. The regulation uses a specific type of warning, an effective warning. Again, no further explanation or detail requirements are provided, but once more it must be assumed that the choice of words are deliberate, having a specific meaning. The clause then ends with an 'and …'

For purposes of extracting the relevant requirements, subclauses 1, a) and b) could just as well have been one single clause. This is significant in the context of the detection functionality since clause 1b indirectly defines some requirements of the detection functions.

8.10.1.2(a) defines the requirements for what must happen when the TMM and a pedestrian(s) detect each other: The direct functionality requirements derived from 8.10.1.2(a) are:

- Detection must be performed automatically for both the TMM and the pedestrian.
- Detection when within each other's **vicinity**
- **Both the TMM** operator and the pedestrian(s) must be warned
- Warnings to be **effective warnings**

Whilst bullet 1 and 3 are self-explanatory, bullets 2 and 4 require further interpretation in order to be unambiguous. Section 8.10.1.2(b) provides additional key information:

8.10.1.2 (b)	*in the event where **no** action is taken to prevent the potential collision, 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 prevent potential collision system on the diesel powered trackless mobile machine must 'fail to safe' without human intervention.*

The requirements stemming from Paragraph 8.10.1.2(b) are both direct and implied:

- Both the TMM operator and the pedestrian are expected to take action to prevent the potential collision.
- Only after the operator or the pedestrian or both fail to take action (as instructed by the effective warning), must the TMM(s) start the **automatic slowdown and stop** intervention.
- The operator and the pedestrian are to be given time to take action.
- If the TMM that is to stop automatically is travelling at a speed at which it is **unsafe** to apply the service brakes, the TMM must first **automatically slow down** to a speed at which it is **safe** to apply the **service brakes automatically**.
- Once the safe speed is reached, the **service brakes** must be applied **automatically**.
- If any of the aforementioned functionalities fail, the CPS must **fail to safe without human intervention, i.e**. operator action.

The terms **vicinity, effective warning**, **safe speed** and **fail-to-safe without human intervention** require further interpretation.

6.2.1 Defining Vicinity

Since Regulation 8.10 expects the operator and the pedestrian to only **take action** to **prevent** a potential collision 'when within each other's **vicinity**', vicinity is interpreted as follows:

*The **distance** or **time to** the point of a potential collision, such that, if the operator and the pedestrian(s) receive an effective warning to prevent a potential collision, and one or both (or all) do not take action, the CPS will still be able to prevent the potential collision.*

This requirement is implied. Vicinity therefore **cannot** be a fixed value; it is scenario dependent. It dynamically changes, based on variables such as the speed of the TMM, the direction it is travelling in, its payload, the road gradient, and importantly the rate of deceleration of each TMM, given all the other variables.

Vicinity thus depends on specific circumstances and operational scenarios. The URS (this document) therefore defines typical scenarios that may be encountered on typical South African underground mines.

It is noteworthy that the regulation only requires warning when a potential collision is imminent. Again, this is implied, however it is a critical requirement since it excludes what is called "L7" "Awareness" warnings as defined in the EMESRT approach. Lessons learned since introduction of "L7" highlights how TMM operators get conditioned to ignore "alarms" and are frustrated by the constant noise and distractions in the TMM cab.

6.2.2 Defining Effective Warning

The definition of **effective warning** can be derived from paragraphs 8.10.1.2 and 8.10.1.2(a) in conjunction with 8.10.1.2(b).

Paragraph 8.10.1.2(a) states that the operator of the TMM and the pedestrian is to receive an effective warning. Paragraph 8.10.1.2(b) implies that the operator and the pedestrian **must** take action to avoid the potential collision.

The MHSA requires that an operator of a TMM must always stay in control of his/her TMM. This requirement is fundamental to safe operation of a TMM and must be upheld even when there is a potential collision. The intention of the TMM regulation is clearly to uphold this principle.

The TMM regulations are specifying technology to enable automatic stopping of TMMs to prevent collisions, but it **upholds** the obligation of the operator to remain in control of the TMM under **normal operating conditions**. This is an important consideration as this requirement implies the provision of a delay of the time to trigger the automatic stopping of the TMM in order to give the operator an opportunity to prevent a potential collision. This requirement ensures that control is never taken away from an operator during normal operating conditions, however if an operator is incapacitated/unable to operate the TMM safely, there is a safety system to prevent the pedestrian(s) from being injured.

In order to facilitate this requirement, a CPS should not give a **general warning** or an **awareness warning**. It calls for an **effective warning,** and only at the vicinity boundary.

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

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

- Not general or an awareness mechanism
- Is only given at the vicinity boundary
- Specific, i.e. ‘Stop’ or ‘Slow’
- Considerate of a reasonable operator response time
- Anticipating an operator action

6.2.3 Defining Safe Speed

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

Various factors influence the value of the **safe speed**. Examples of these factors include the TMM type, TMM payload, road gradient, friction limit between the TMM tyre and the road, brake wear, tyre wear, etc. (note that this is not a complete list). The **safe speed** thus depends on the operational scenario and is influenced by factors the CPS designer cannot control (e.g. road surface condition). It is critical that the **safe speed** of a particular TMM is **clearly defined**, and that the **assumptions** informing that definition are clearly **documented** and **made available** to all the parties involved. This includes the mine and the CxD suppliers.

6.2.4 Defining Fail to Safe Without Human Intervention (FTSWHI)

Subsection 8.10.1.2 (b) states: The prevent potential collision system on the diesel powered trackless mobile machine must fail to safe without human intervention. In simple terms it means the CPS must do what it has been designed to do automatically – without relying on the operator. The only safe condition for a TMM with a failed CPS is a stationary TMM that does not pose a risk to the operator, the pedestrian or a person required to attend to the failed CPS. This is a fundamental and direct regulatory requirement for a CPS. FTSWHI has significant design implications for CPS. By implication a TMM that was busy with normal operations and with failed CPS will be stationary in the operational area of the mine. The implied availability, reliability and maintainability requirements are obvious,

however the self-diagnostic requirements at subassembly level must be stressed, as is the communication of the failed subassembly, correct critical sub-assemblies and repair tools. Self-diagnostic requirements for FTSWHI must not be confused with that to ensure CPS availability.

A CPS that complies with the above requirements is as unique to the South African mining industry as is the terminology for a TMM. Subsection 8.10.1.2 (b) states: “The prevent potential collision system” - This is the origin of the term Collision Prevention System (CPS).

6.3 Underground Hard Rock and Underground Coal operations

Regulation 8.10 applies broadly to all underground mining operations, making no distinction between hard rock and coal mining. It only makes two key distinctions:

- Underground versus surface mining: This is covered in Regulation 8.10.1 and 8.10.2.
- Power source of TMMs: The regulation differentiates between electrically or battery-powered TMMs and underground diesel-powered TMMs (cf. Regulation 8.10.1.1 and 8.10.1.2).

Unlike hard rock mines where diesel-powered TMMs are used for **primary production**, their use in underground coal mining is quite different. Underground coal is primarily mined by electrically powered continuous miners (CMs), which discharge coal onto electrically powered shuttle cars. The shuttle cars then transport the coal into the feeder breakers, which transfer the coal to a belt conveyor system, which moves it to the surface.

In a typical coal section, there are usually 8 to 10 workers who either walk or are transported by personnel carriers. This reality significantly impacts their exposure to collisions with diesel-powered TMMs.

This document focuses exclusively on underground diesel-powered TMMs and does not consider the likelihood of exposure. Regardless of the mining type, a collision between a TMM and a pedestrian will likely result in a serious injury or fatality.

Each mine is responsible for conducting its own risk assessment to determine the likelihood of such interactions. This assessment should be used to identify TMMs that pose a significant collision risk to pedestrians. Once identified, this document can be used to determine the requirements of the necessary CPS products to ensure compliance with Regulation 8.10.1.2 and its sub-clauses.

7 CPS Products Definition

To enable conformance with CPS direct and implied requirements, the CPS Product definition is important. The functional breakdown structure is briefly mentioned below for contextual purposes.

A key aspect of a CPS is that it will, for the foreseeable future, consist of two separate products, supplied by separate suppliers. Every TMM brand, type, model and sometimes serial number combination with a specific CxD is a unique CPS product. This is due to the diverse population of TMMs used in the SAMI. Some TMMs are electronic controlled, with CAN-bus systems and some are not. Product configurations are determined by the different CPS product providers. Products however must conform to the functional requirements for a CPS. Functional requirements are structured in a logical functional breakdown, shown graphically below.

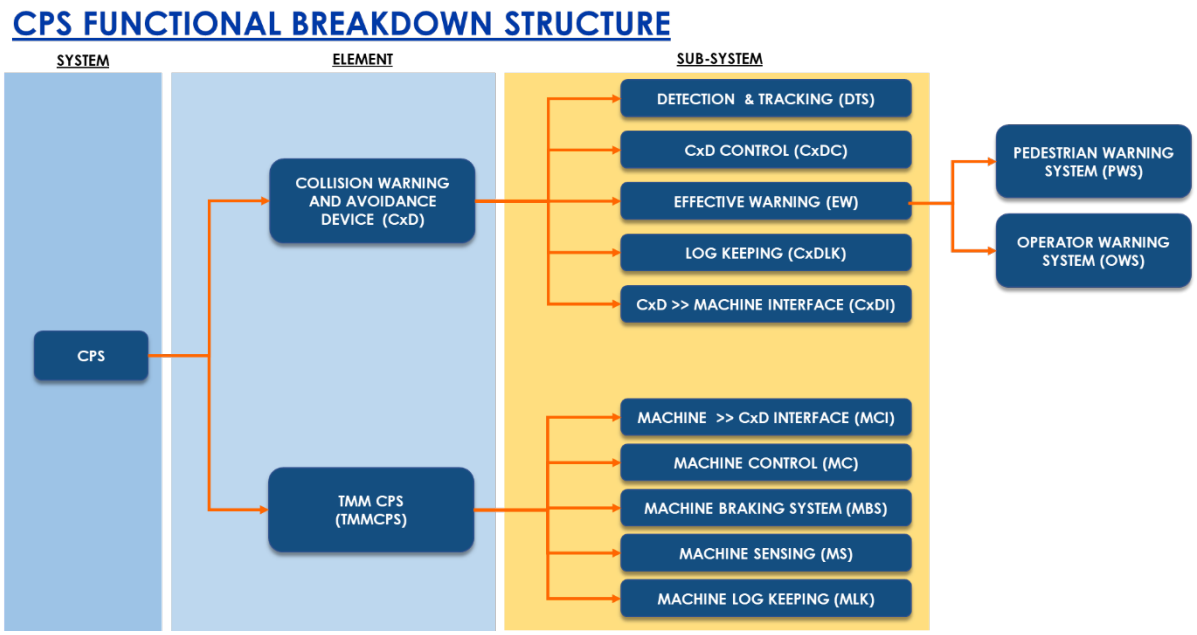


Fig 3: CPS functional breakdown structure.

The TMM CPS functions are structured in five 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 five sub-groups namely:

1. Detection and Tracking functions (DTS).
2. CxD Control functions (CxD).
3. Effective Warning functions (EWS).
4. CxD Log Keeping functions (CxDLK).
5. CxD Machine Interface functions (CxDI).

8 User Requirements Structure

The approach to define the user requirements is as follows:

- Part 1: General requirements
- Part 2: Underground mining specific requirements
- Part 3: Underground mining interaction scenarios

The Minerals Council South Africa facilitated the definition of basic TMM related mining process descriptions for different 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.

The URS are informed by the information provided by the Minerals Council South Africa.

9 Part 1: General Requirements

As highlighted before, the nature, complexity and associated liability of CPS necessitates several requirements that might otherwise not be significant.

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

General requirements include requirements related to the MHSA, the development process, design analysis and conformance verification. These requirements are the reasonable actions taken by the 2.13.1 appointee to ensure that CPS products conform to requirements that will enable the mine to comply with the regulations. Table 2 below lists the requirements.

Table 2: CPS General Requirements

Group	URS No.	Requirement
Prevent collisions	UG.G01	CPS products must prevent collisions by: • Detecting the movement of pedestrians within a detection range around the TMM • Track the movement of the TMM and pedestrians • Determine the vicinity boundary for every pedestrian as the pedestrian(s) and TMM move • Trigger an effective warning to both the TMM operator and the relevant pedestrian(s), providing both operator and pedestrian(s) time to respond • Where one or both parties do not respond appropriately, the TMM must be automatically slowed down to a safe (crawl) speed, then automatically stopped and held stationary
Conform to functional and technical requirements that will ensure mine regulatory compliance.	UG.G02	The CPS must have functional and technical performance requirements that will ensure general requirement UG.G01, as documented in the MOSH CPS guideline, that include but are not limited to: • Physical installation drawings • Operating manuals • Inspection and maintenance manuals • Post maintenance inspection test instructions
Conform to functional and technical requirements that will ensure mine operation	UG.G03	The CPS must have functional and technical performance requirements that will ensure general requirement UG.G01 as documented in the MOSH CPS guideline.
Demonstrate conformance	UG.G04	CPS conformance to requirements must be demonstrated by independent verification as defined in the CPS test regime as well as the CPS Test Specification as documented in the MOSH CPS guideline. The independent test entity(s) must demonstrate its ability to perform repeatable and accurate tests in accordance with the CPS Test Specification.
Comply with MHSA Section 21	UG.G05	Must comply in as far as: • Legal liability is unambiguously defined • Intended operation is defined • Conformance is demonstrated and traceable as per the CPS Section 21 Technical Information Framework. (produce a Sec 21 Technical File)
Have unambiguous legal boundaries	UG.G06	If the CPS is not supplied by a single supplier (as was indicated) the CPS must have clear physical and functional boundaries, as is set out in the CPS Functional and Technical Performance Requirement Specification.

Group	URS No.	Requirement
Have unambiguous formal legal agreements	UG.G07	For every mine, CPS integration supplier, CxD supplier and TMM OEM/3rd Party CPS supplier a formal signed legal agreement shall exist unambiguously defining the legal boundaries and agreements between the parties.
Prevent collisions	UG.G07.1	CPS products must prevent collisions between TMMs and pedestrians without compromising employees' health and safety due to the use of CPS.
Automatically slow down and stop	UG.G07.1.1	The TMM may not become unstable or uncontrollable due to the use of CPS,
Automatically slow down and stop	UG.G07.1.2	Limit the number of false warnings, slow down or stopping,
Automatically slow down and stop	UG.G07.1.3	CPS to limit TMM functionality to ensure that the CPS remains within its design limits (e.g. limit TMM speed to ensure there is sufficient time and/or distance to detect other TMMs, warn the operator and slow down and stop the TMM without causing a collision or resulting in TMM loss of control).
Automatically slow down and stop	UG.G07.2	Have a 100% effective detection of potential collisions
Automatically slow down and stop	UG.G07.3	Must allow normal operation of the TMM when pedestrians are outside of the vicinity boundary
Prevent collisions: Operational scenarios	UG.G07.4	Prevent collisions for all operations defined in this document.
Prevent collisions: Operational scenarios	UG.G07.4.1	Prevent TMM collisions for all reasonably foreseeable operational scenarios, including:
Prevent collisions: Operational scenarios	UG.G07.4.1.01	Machine maintenance and service support,
Prevent collisions: Operational scenarios	UG.G07.4.1.02	TMM Washing,
Prevent collisions: Operational scenarios	UG.G07.4.1.03	Brake testing,
Prevent collisions: Operational scenarios	UG.G07.4.1.04	Lubrication,
Prevent collisions: Operational scenarios	UG.G07.4.1.05	Component replacement and maintenance,
Prevent collisions: Operational scenarios	UG.G07.4.1.06	Refuelling,
Prevent collisions: Operational scenarios	UG.G07.4.1.07	Wheel changing,
Prevent collisions: Operational scenarios	UG.G07.4.1.08	Condition/health monitoring etc.,
Prevent collisions: Operational scenarios	UG.G07.4.1.09	Shift change,
Prevent collisions: Operational scenarios	UG.G07.4.1.10	Supervision/Inspection visits during operation
Prevent collisions: TMM conditions	UG.G07.4.2	Prevent collisions for all reasonably foreseeable TMM conditions and states, including:
Prevent collisions: TMM conditions	UG.G07.4.2.1	TMM accommodate current state braking system performance that may deteriorate due to wear and tear,
Prevent collisions: TMM conditions	UG.G07.4.2.2	Normal TMM operating conditions including bucket raised, TMM articulated, boom extended, as applicable to each TMM type,
Prevent collisions: TMM conditions	UG.G07.4.2.3	All normal operating speeds per TMM type,
Prevent collisions: TMM conditions	UG.G07.4.2.4	Breakdowns and recovery scenarios,

Group	URS No.	Requirement
Prevent collisions: TMM conditions	UG.G07.4.2.5	Vehicle towing and pushing,
Prevent collisions: TMM conditions	UG.G07.4.2.6	Emergency conditions (fires, ambulances, etc.)
Prevent collisions: Environment	UG.G07.4.3	All reasonably foreseeable environmental conditions, including:
Prevent collisions: Environment	UG.G07.4.3.1	Various road design and construction,
Prevent collisions: Environment	UG.G07.4.3.2	Inclines and declines,
Prevent collisions: Environment	UG.G07.4.3.3	Road surface conditions,
Prevent collisions: Environment	UG.G07.4.3.4	Weather conditions,
Prevent collisions: Environment	UG.G07.4.3.5	Day and night operation,
Prevent collisions: Environment	UG.G07.4.3.6	Poor visibility.
Prevent collisions: Vicinity	UG.G07.5	Predict potential collisions dynamically as TMMs move by continuously determining where the boundaries for vicinity are.
Prevent collisions: Effective warning	UG.G07.5.1	Ensure that operators of all TMMs within the vicinity (see definition) of pedestrian(s) receive an effective warning (see definition) of actions to be taken to prevent a potential collision. Such warnings shall:
Prevent collisions: Effective warning	UG.G07.5.2.1	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.),
Prevent collisions: Effective warning	UG.G07.5.2.2	Be provided in a way that a TMM operator(s) can clearly understand it in preferred languages ,
Prevent collisions: Effective warning	UG.G07.5.2.3	Consider all other associated attention drawing devices such as: screens, lighting or sound, if used.,
Prevent collisions: Effective warning	UG.G07.5.2.4	Be proven by human factors engineering standards and requirements to not have any distractive effect on the TMM operator as well as pedestrians or health impact and is agreed to by a representative sample of specific TMM operators and pedestrians,
Prevent collisions: Effective warning	UG.G07.5.2.5	Be the outcome of the application of a credible Human Factors and ergonomics analysis and design process,
Prevent collisions: Effective warning	UG.G07.5.2.6	Only alert to the potential collision with the highest probability, if multiple interactors are involved,
Prevent collisions: Effective warning	UG.G07.5.2.7	Ensure 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,
Prevent collisions: Effective warning	UG.G07.5.2.8	Have a standardized TMM type cab layout with regards CPS displays or have the CPS display integrated into other existing displays,
Prevent collisions: Effective warning	UG.G07.5.2.9	If the effective warning functionality is compromised, the CPS shall FTSWHI.
Interoperability	UG.G08.1	CPS products must be interoperable:
Interoperability	UG.G08.1.1	For all different types of TMMs including LDVs used in mining operations. (Mine bakkies),
Interoperability	UG.G08.1.2	For all different brands of TMMs,
Interoperability	UG.G08.1.3	For all different models of TMMs,
Interoperability	UG.G08.1.4	For all unique serialised models of TMMs.

Group	URS No.	Requirement
EMC	UG.G09.1	The CPS must be EMC with all other radio frequency-based systems used on the mine.
EMC	UG.G09.1.1	Other CPS products and electronic devices fitted to TMMs,
EMC	UG.G09.1.2	Other mine infrastructure and EMI sources,
EMC	UG.G09.1.3	The composition of the minerals mined,
EMC	UG.G09.1.4	Electronic detonation items.
Fail-to-safe	UG.G10.1	Be self-diagnostic to ensure 100% CPS functionality before starting up, during normal and emergency operation of all elements/subsystems, individually.
Fail-to-safe	UG.G10.2	Be of a fail to safe design that does not rely on any operator action, i.e. automatic. The CPS will immediately **inform** the operator and either:
Fail-to-safe	UG.G10.2.1	not start/propel the TMM if it was stationary or,
Fail-to-safe	UG.G10.2.2	bring the TMM(s) to a safe stop,
Fail-to-safe	UG.G10.2.2.1	without any negative health or safety impact on the TMM operator(s), passengers or pedestrians,
Fail-to-safe	UG.G10.2.2.2	be the outcome of the application of a credible Human Factors analysis and design process, including but not limited to the effects of:
Fail-to-safe	UG.G10.2.2.2.1	EMI,
Fail-to-safe	UG.G10.2.2.2.2	Whole body vibration.
Fail-to safe	UG.G10.3	Have a motion enabler functionality for dealing with emergency as well as recovery/repair situations
Log-keeping	UG.G11.1	Have a supervisory monitoring data collection, storage and reporting capacity that provides reports: • For analysis of interactions that are a safety concern and require urgent attention (including: test failures, trends, and heat maps of hazardous locations), • For analysis of interactions that are a production concern and require urgent attention (including trends and heat maps of production locations where interactions occur), • For summary reports of the above interactions and operating / maintenance compliance (safety, production, availability, reliability and MTTR), • For 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.
Log-keeping	UG.G11.1.1	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:
Log-keeping	UG.G11.1.1.1	Be based on the UTC time or synchronized with an easily accessible reference time,
Log-keeping	UG.G11.1.1.2	Include all machine data communicated to the CxD leading up to, during and immediately after the event,
Log-keeping	UG.G11.1.1.3	Include any actions (such as effective warning, slowdown and stop) issued by the CxD to the operator or machine,
Log-keeping	UG.G11.1.1.4	Be easily accessible to management for oversight purposes.
Log-keeping	UG.G11.1.2	With a real-time date and time stamp synchronisation of all identified system elements requiring such.
Log-keeping	UG.G11.1.3	The log keeping system shall fail to safe

Group	URS No.	Requirement
Log-keeping	UG.G11.1.4	The log keeping system must retain data logs for a minimum period of seven days on TMMs.
Log-keeping	UG.G11.1.5	Log any element/sub-system faults.
Installation, Maintenance and Repair (IMR)	UG.G12.1	The CPS shall have a modular design that shall ensure replacement of critical components/subassemblies in reasonable times.
IMR	UG.G12.2	The CPS shall have an authorized override (maintenance/recovery override) capability.
IMR	UG.G12.2.1	The CPS shall provide a means for an authorised supervisor or person to temporarily suspend an automatic intervention for maintenance and recovery reasons (To be specifically defined by the responsible person),
IMR	UG.G12.2.2	Authorised override mode to limit TMM speed (limp mode) while active,
IMR	UG.G12.2.3	Limp mode speed to be configurable as per site specific and TMM OEM requirements,
IMR	UG.G12.2.4	CPS to return to Normal Operation from Authorised Override mode as described in ISO 21815-1:2022.
IMR	UG.G12.3	Be easy to fault-find
IMR	UG.G12.4	Provide easy access for maintenance purposes by authorized and competent personnel
IMR	UG.G12.5	Provide for quick calibration
Reliability	UG.G13	Be 99% available for times required to operate
Reliability	UG.G13.1	Have identified safety critical sub-assemblies and components with operating/maintenance tactics required
Reliability	UG.G13.1.1	Have cables, sensors and antennas positioned, secured and protected against physical damage under normal operation conditions, such as stepping on, falling materials, bumping against side walls and infrastructure, etc.
Reliability	UG.G13.1.2	Vibration-induced failure to components (e.g. mounting brackets, cables passing through enclosures/panels, etc.)
Reliability	UG.G13.1.3	In harsh underground conditions of 50 °C temp and 80 % relative humidity
Reliability	UG.G13.1.4	Withstand the forces and conditions of normal vehicle high pressure washing.
Design Process	UG.G14.1	Be based on ISO 9001 or similar standard, ensure formal reviews, record keeping and independent verification
Design Process	UG.G14.1.1	Documented in a formal design quality plan,
Design Process	UG.G14.1.2	Follow an acknowledged Technology Readiness maturity process,
Design Process	UG.G14.1.3	Include independent verification by an acknowledged CPS testing entity,
Design Process	UG.G14.1.4	Keep records of evidence for the purpose of demonstrating conformance.

10 Part 2: Underground Mining CPS Technical Requirements

The CPS Regulatory Requirements for underground mines were discussed in Section 6. The technical requirements defined here are based on the definitions provided in Section 6 and the outcomes of WP 9 of the INDUSTRY ALIGNMENT ON TMM COLLISION MANAGEMENT SYSTEMS PROJECT: CAS READINESS PHASE[7].

Table 3: Underground mining specific requirements

URS no.	User requirement	Objective or purpose
UG.R01	**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 and Abbreviations). 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 expected to be between 1.5 seconds to 2.5 seconds.	To give the operator sufficient time to react to instructions from the CPS. Operator to be given reasonable opportunity to take action as instructed by the CPS.
UG.R02	**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 and Abbreviations). 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 expected to be between 1.5 seconds to 5 seconds.	To give the pedestrian sufficient time to react to TMMs in the vicinity that may lead to hazardous situations (V-P). Pedestrian to be given reasonable opportunity to take action as instructed by the CPS.

[7] Available from https://www.mosh.co.za/transport-and-machinery/documents

URS no.	User requirement	Objective or purpose
UG.R03	**User:** Operator **Requirement:** Effective warning An operator must receive an effective warning when pedestrians enter the vicinity of the TMM. Effective warning must be the result of a human factors engineering process and consider a combination of visual, audible and/or a haptic instruction including the following: • An audible warning in the operator language of choice . • A visual warning on the CPS screen or operator display. • Display to indicate the action to be taken by the operator. • Pedestrian with highest priority to be indicated on screen when multiple pedestrians are within the TMM vicinity. • Haptic instruction may be a vibrating element drawing the human's attention to the warning.	To give the operator both an audible and visual warning of the pedestrian's location and movement in the vicinity of the TMM. The warning must be effective, clearly giving the corrective action to be taken by the operator to prevent the collision.
UG.R04	**User:** Pedestrian **Requirement:** Effective warning Pedestrians must receive an effective warning when TMMs are in the vicinity. 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 audible and visual warning of TMMs in the vicinity. Pedestrian must be granted a reasonable opportunity to take corrective action to prevent a collision.
UG.R05	**User:** Pedestrian **Requirement:** Effective warning when line-of-sight obstructed (Rock penetration). Pedestrians must receive an effective warning when TMMs are in the vicinity, even when there is no direct line-of-sight to the TMM. It is reasonably foreseeable that line-of-sight will not be possible under all operational scenarios. For example, a pillar or rock wall or under/over a blind rise in a bord or haulages may obstruct the line-of-sight between the TMM and pedestrian(s). Effective warning means that URGR4 will be met when: • The pedestrian is in any position (lying, sitting, standing, or walking) • When in the vicinity of a TMM, even if line-of-sight is obstructed.	To give pedestrians both an audible and visual warning of TMMs in the vicinity and are approaching from any direction, even if line-of-sight is obstructed by a pillar or rock wall or over a blind rise.
UG.R06	**User:** Operators, pedestrians, passengers **Requirement:** No false positives or false warnings The number of false positives or false warnings must be limited to ensure that 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

URS no.	User requirement	Objective or purpose
UG.R07	**User:** Pedestrian **Requirement:** TMM safe speed When the TMM is slowing down to a safe speed, such speed must consider the average walking speed of pedestrians. This speed is expected to be 5 km/h. Underground fitness tests require pedestrians to be able to walk at 4 km/h.	Pedestrians must be able to move faster than TMMs when automatic retard or stop is active.
UG.R08	**User**: Operator and pedestrian **Requirement**: Effective warning and automatic slow and stop without disrupting production When TMMs are in the vicinity of pedestrians and vice-versa and V-P interactions 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 automatically retard to a safe speed and automatically stop. Stop gap must allow for reasonably foreseeable operating scenarios to continue without unnecessary interventions from the CPS.	Pedestrians and operators must have sufficient time to take action as instructed by the CPS. TMM must slow down and stop within the required stop gap. The zone size must auto adjust to TMM operating state and condition and interaction scenario to minimise zone sizes and impact on production and wear and tear.
UG.R09	**User:** Engineering and maintenance, OEMs **Requirement**: TMM CPS automatic slow and stop must not result in deteriorated braking performance. TMM braking systems must conform to national and international braking systems and in-service testing requirements. 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 conformance testing acceptance criteria specified by either national or international standards.	CPS initiated brake performance must comply with national and international braking system compliance in-service testing requirements.
UG.R10	**User**: Operator and pedestrian safety **Requirement:** Automatic slow down and stop final state is stationary TMM Once automatic slow down and stop has been activated by the CPS and the TMM comes to a stop, the TMM must remain stationary. The operator cannot engage any gear to put the TMM into motion whilst the pedestrian(s) is in the vicinity.	TMM to remain stationary whilst the pedestrian is in the vicinity.

URS no.	User requirement	Objective or purpose
UG.R11	**User:** Pedestrian and operator **Requirement:** Articulation and or lifting and lowering of attachments (e.g., scoop) – prevented from moving The TMM articulation and/or attachment must be prevented from moving after a pedestrian has entered the vicinity and the TMM has stopped automatically.	TMM articulation and attachments must be prevented from moving when pedestrians enter the vicinity. This is only applicable once the TMM has reached a complete stop (safe park).
UG.R12	**User:** Pedestrian **Requirements:** Pedestrian ergonomics Any CPS equipment issued to the pedestrian must be the outcome of a human-centred design process. CPS equipment must allow the wearer (pedestrian) to move freely. Pedestrian ergonomics must be considered.	Pedestrian movement should not be restricted due to CPS equipment. CPS equipment should not tire -out the wearer.

11 Part 3: Underground Mining Interaction Scenarios

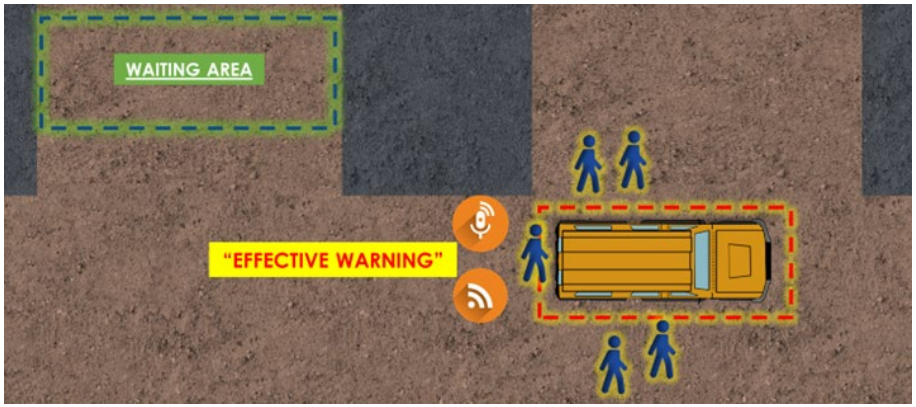
This section defines typical interaction scenarios between underground TMMs and pedestrians in underground mines in South Africa. The intent of this section is to guide the mine's legal appointees and developers of CPS products when specifying the CPS requirements. It is not an exhaustive list of all possible interaction scenarios in underground mine operations and should be used in conjunction with a site-specific risk assessment. Table 4 defines various terms to describe the state of a TMM. These states are referenced in the interaction scenarios that follow.

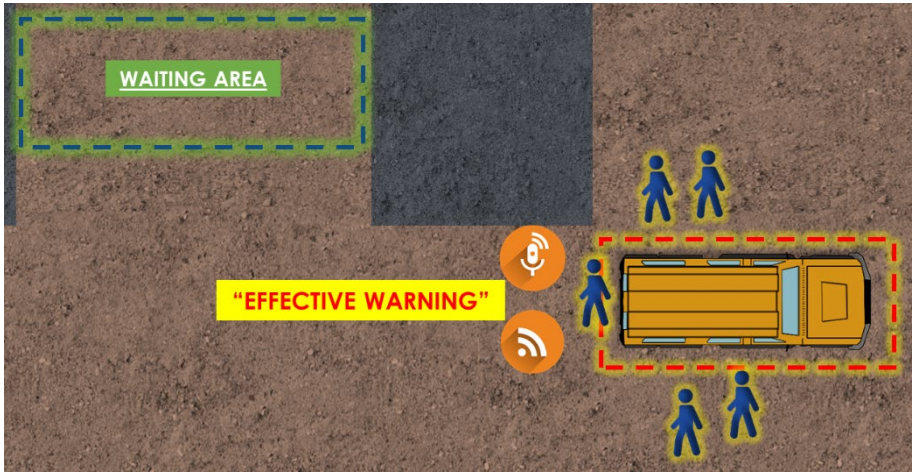
Table 4: TMM CPS states

TMM state	Description
Safe Park	The TMM is safely parked as per the mine's standard operating procedure, e.g. the operator has engaged the park brake, switched the engine off and exited the cab. The operator has placed chocks or stop blocks under the TMM's wheel(s). This state is typically encountered at the start/end of shifts when the operators are coming on or off duty. The TMM is not operational.
CPS Start-up	The operator has completed the pre-inspection checks as per the mine's standard operating procedure and removed the chocks or stop blocks from under the TMM's wheels. The operator has entered the cab and is preparing to start operating. During this state, the CPS is undergoing its start-up procedure, e.g. performing system health checks. The CPS is not ready to start normal operation.
Normal Operation	The normal state of the TMM while it is operating and there is no significant risk of collision between the TMM and pedestrians. The CPS is functioning as intended and is monitoring for potential collisions.
Operator Stop	The operator has stopped the TMM and signalled their intent to stay stopped. This may happen during the course of the shift. The Operator Stop state is typically characterised by engagement of the Park Brake by the operator. During this state, if allowed by the mine's standard operating procedure, passengers may board the TMM. The CPS is functioning normally, but the potential for collisions is limited due to the engagement of the Park Brake.
CPS Slow	The state when the CxD limits the TMMs speed. The CxD instructs the TMM to slow by sending SLOW_DOWN or APPLY_PROPULSION_SETPOINTS via the ISO/TS 21815-2:2021 CAN-bus interface.
CPS Stop	The state when the CxD intervenes with the intent of stopping or keeping the TMM stationary to avoid a collision or FTSWHI. The CPS has detected a potential collision with a pedestrian and is intervening or has intervened to bring the TMM to a safe stop. Once the TMM has stopped, it remains stationary. Once stopped, the TMM is prevented from any movement, including no movement of the bucket, attachments, boom, etc. No articulation is allowed once the TMM has come to a safe stop. This state is reached by the CxD instructing the TMM to stop via the ISO/TS 21815-2:2021 CAN-bus interface.

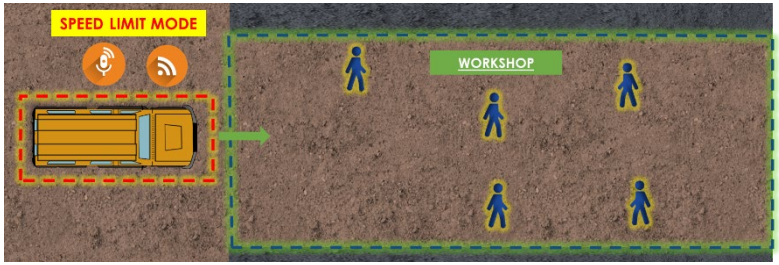
TMM state	Description
Emergency Override	The CPS has intervened and the TMM is in the CPS Stop state. However, there is imminent danger to either the TMM operator and/or nearby pedestrians. The TMM operator engages Emergency Override, as per the mine's standard operating procedure, to move the TMM to a safe place. During Emergency Override, the TMM speed is limited and the TMM is allowed to move for a limited period of time, as determined by the mine's risk assessment. Once this period expires, the TMM returns to the CPS Stop state.
Fail-to-safe without human intervention	The CPS has detected a critical failure that compromises the CPS functionality. The CPS brings the TMM to a safe state within a reasonable time, as defined by the mine's specific risk assessment and standard operating procedure. The CPS can only exit this state if the failure is repaired/resolved, the operator activates Emergency Override, or an authorised technician engages Maintenance Override.
Maintenance Override	An authorised technician may enable the Maintenance Override state when recovering a TMM to effect CPS repairs. TMM speed is limited as per the mine's standard operating procedure until the Maintenance Override is cancelled by the authorised technician, or the TMM is safe parked. Upon deactivation of Maintenance Override, or start-up from Safe Park, the CPS shall fail-to-safe without human intervention if the critical failure(s) has not been resolved.
Speed Limit Mode	In certain areas, the CPS may enter a Speed Limit Mode. The aim of Speed Limit Mode is to limit the TMM speed to minimize the size of the vicinity. This mode may be utilized in congested areas such as workshops, refuelling bays, waiting areas, etc.

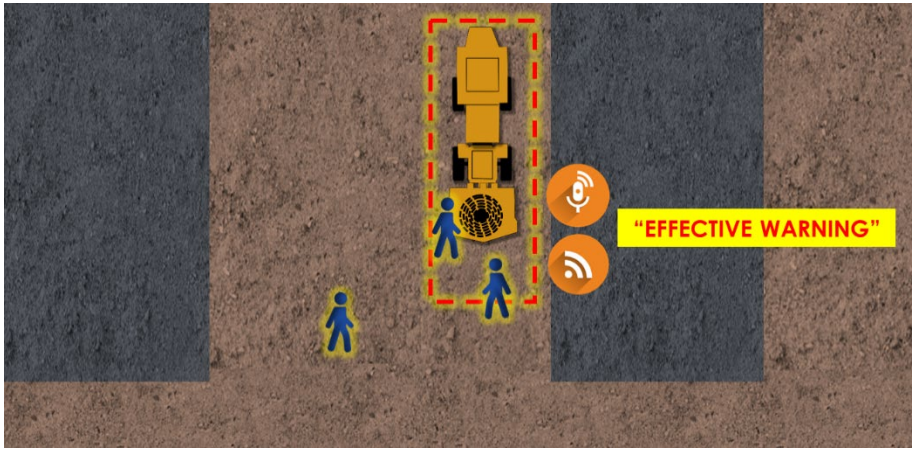
Table 5: Underground mining interaction scenarios

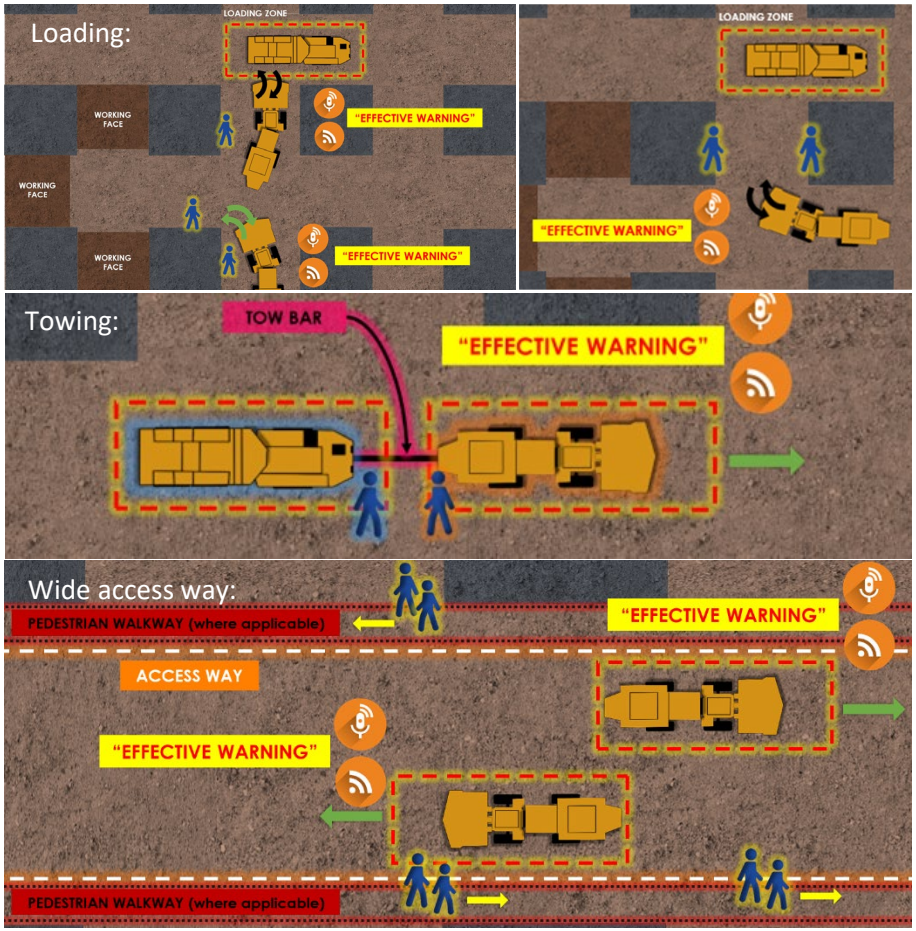
Scenario number	Scenario description	Objective
UG.S1.1	**Operator and passengers: Boarding a TMM**  • ***TMM state:*** TMM in Safe Park OR in Operator Stop. Other TMMs may be in the vicinity or inside the detection zone. • ***Pedestrians approaching and boarding vehicle:*** Pedestrians must be allowed to board a TMM in Safe Park or Operator Stop without nuisance alarms. Pedestrians must receive warnings when within the vicinity of a TMM in Normal Operation. • ***TMM CPS response:*** Operator must receive a warning of pedestrians in the vicinity if TMM not in Safe Park or Operator Stop. The operator must not be able to move the TMM while pedestrians are in the vicinity. If it is an articulated vehicle, the articulation must be prevented from moving. • ***Other TMMs in the vicinity:*** Operators must receive warnings and TMM must auto retard and auto stop when pedestrians are in the vicinity of an active TMM.	Protection for pedestrians approaching and boarding a TMM.
UG.S1.2	**Operator and passengers: Inside an active TMM** • ***TMM state*:** Normal Operation. If operator or any passenger opens any door, the TMM must automatically slow down and stop. If it is an articulated vehicle, the articulation must be prevented from moving once the TMM is stationary. No movement of any attachment or implement (e.g. boom, bucket, etc.) whilst the TMM is automatically slowing down and stopping. The operator and passengers must receive warnings from other TMMs in the vicinity that present a significant risk of collision if they exit the TMM. • ***Operator and/or passengers in TMM:*** Must be isolated from CPS and not receive warnings from TMM or other TMMs in the vicinity of the TMM when safely on-board. Operator and passengers safely paired with CPS must not give warnings to other TMMs in the detection zone. • ***Pedestrians outside TMM***: Must receive warnings and the CPS must warn operator of pedestrians in the vicinity and automatically 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 when safely inside the TMM. No false positives that cause annoyance and pedestrian disregard of response to alarms.

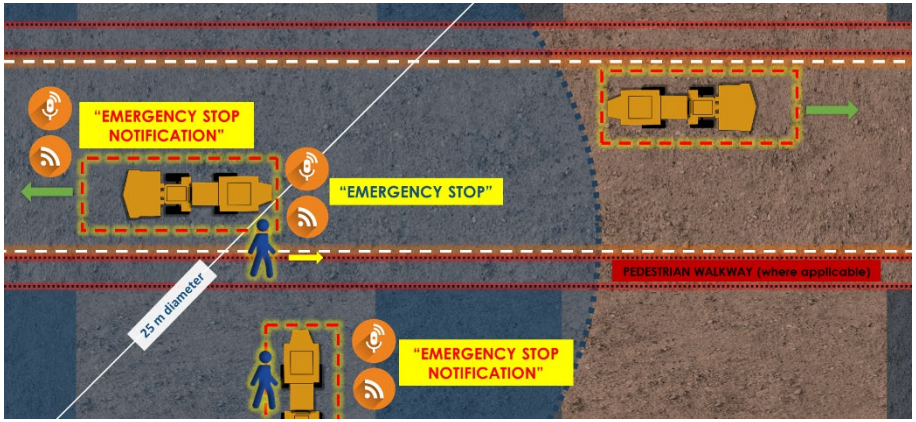
Scenario number	Scenario description	Objective
UG.S1.3	**Operator and passengers: Exiting a TMM**  • ***TMM state*:** TMM in Safe Park OR Operator Stop. • ***Pedestrians exiting TMM:*** Pedestrians must receive warnings immediately when exiting a vehicle if there is significant risk of collision with any TMM. Pedestrians to become visible to TMMs the moment they exit the TMM (unpair from TMM they have exited). • ***Exited TMM CPS response:*** When engaging gear, operator must be warned of pedestrians in the vicinity and the operator must not be able to move the TMM while pedestrians are in the vicinity. If it is an articulated vehicle, the articulation must be prevented from moving. No movement of attachments or implements (e.g. boom, bucket, etc.) if pedestrians are within the TMM vicinity. • ***Other TMMs in the vicinity's CPS response to pedestrians exiting the vehicle:*** Operators must receive warnings and TMMs must automatically retard and stop when exiting pedestrians are in the vicinity.	Immediate protection for pedestrians when exiting TMM.

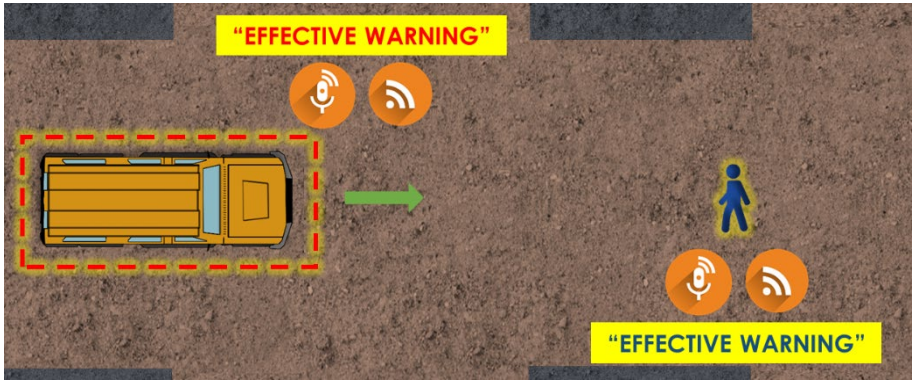
Scenario number	Scenario description	Objective
UG.S2	**Departing TMM** • ***TMM state*:** Operator Stop transitioning to Normal Operation (TMM about to move). • ***CPS action:*** ○ Whilst a pedestrian(s) is in the vicinity of the TMM, the TMM cannot move. When the TMM operator disengages the park brake, the TMM operator must receive an effective warning that a pedestrian(s) is in the vicinity. ○ When a pedestrian(s) approaches the vicinity and the TMM is in Normal Operation, the TMM operator must be given an Effective Warning. If the TMM operator does not take action, the TMM must automatically safely stop. End state is CPS Stop. ○ For TMMs with articulation, the articulation must be prevented from moving until the pedestrian moves out of the vicinity of the TMM. For TMMs with booms/attachments, booms/attachments must be prevented from moving until the pedestrian moves out of the vicinity of the TMM.	Protection for pedestrian when TMM stationery and pedestrian is within the TMM vicinity and TMM about to depart.

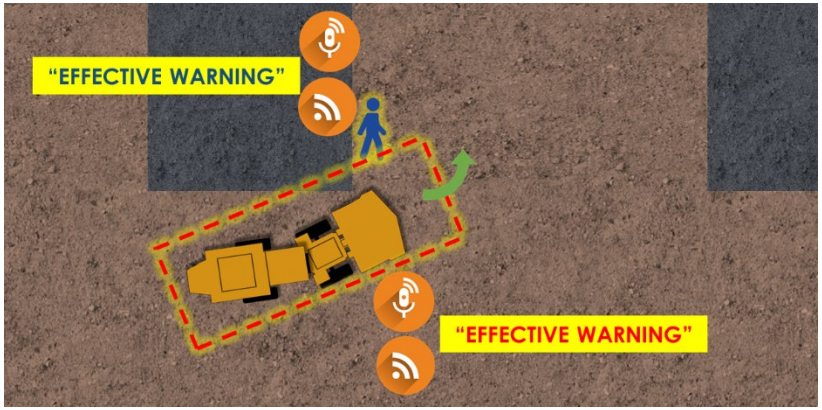
Scenario number	Scenario description	Objective
UG.S3.1	**Congested areas: Workshops (e.g. Entering/moving inside/exiting a workshop)**  • ***TMM state*:** Speed Limit Mode • **CPS action:** ○ TMM to receive Effective Warning if approaching speed limited area at a speed above the designated speed limit ○ TMM to automatically enter Speed Limit Mode before entering the speed limited area. ○ TMM may not enter the speed limited area at speeds exceeding the designated speed limit ○ TMM to be prevented from exceeding speed limit while inside the speed limited area ○ Pedestrians in the vicinity of moving TMMs must receive effective warnings and have sufficient time to move out of the TMM's way. ○ The TMM operator must receive an effective warning if a pedestrian(s) is in the vicinity. ○ If the pedestrian(s) does not move outside the vicinity, or the operator does not take action as instructed by the effective warning, the TMM must automatically stop and enter CPS Stop. ○ If TMM transitioning from Operator Stop to Speed Limit Mode (e.g. TMM about to depart, disengaging park brake), and there is a pedestrian in the vicinity, the TMM must be prevented from moving (i.e. CPS Stop).	Limiting risk of collision with pedestrians in congested areas (e.g. workshops) without preventing work from happening.

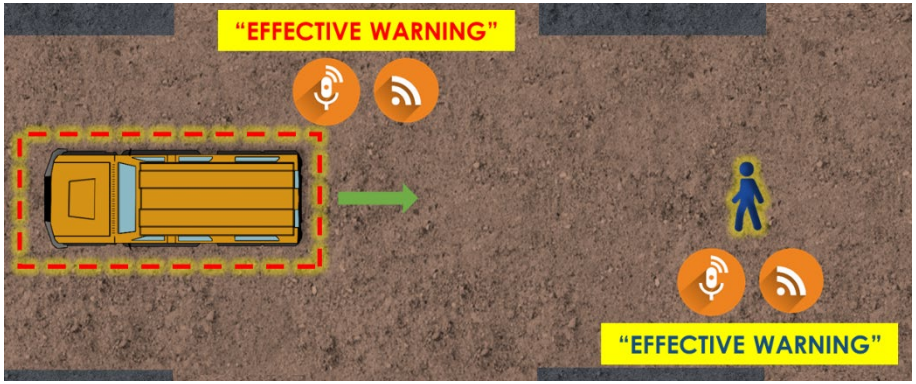
UG.S3.2	**Congested areas: Multiple pedestrians in vicinity of TMM (images are illustrative of typical TMM activities).**
	 
	
	• ***TMM state*:** Safe Park OR Operator Stop **transitioning** to Normal Operation (disengages park brake, about to depart)
	• **CPS action:**
	  ○ Pedestrians in the vicinity of a TMM must receive effective warnings and have sufficient time to move out of the TMM's way.
	  ○ The TMM operator must receive an effective warning if a pedestrian(s) is in the vicinity.
	  ○ If the pedestrians do not move outside the vicinity, or the operator does not take action as instructed by the effective warning, the TMM must automatically stop and enter CPS Stop.
	  ○ CPS to prevent accidental movement of TMM.
		Pedestrians performing tasks in the vicinity of a TMM (e.g. loading/unloading equipment, attaching cables or hoses, trying to communicate with operator) must be protected from injury due to movement of the TMM.

UG.S3.3	**Congested areas: Multiple pedestrians in vicinity of multiple TMMs (e.g. loading, towing, wide access ways)**  • ***TMM states:*** Normal Operation, Operator Stop • ***CPS action:*** When a pedestrian is in the vicinity of multiple TMMs (e.g. performing loading, towing, passing), the pedestrians and TMM operators must receive effective warnings that a pedestrian is in the vicinity of the TMMs. Should the operators or pedestrians not take appropriate action to prevent a potential collision, all the TMMs at risk of colliding with any pedestrian (inside the vicinity boundary) must slow down to a safe speed and stop. TMMs in CPS Stop must only be able to move when the pedestrians move out of the vicinity.	Pedestrians protected from all TMMs in congested areas.

Scenario number	Scenario description	Objective
UG.S4	**Breakdown in the field** • ***TMM state*:** Broken-down and has to be repaired in the field. • ***CPS action:*** When working on a TMM breakdown in the field, pedestrians must receive an effective warning of active TMMs in the vicinity. TMM operators in active TMMs must receive effective warnings when pedestrians are in the vicinity. If the TMM operator(s) do not react to the effective warnings, the TMM must automatically retard and stop and go to CPS Stop.	Pedestrian protected from TMM interaction when working on a breakdown.
UG.S5	**Pedestrian activated emergency stop of TMMs**  • ***TMM state*:** Normal Operation. • ***CPS action:*** When pedestrians notice or enter an area where TMMs could pose a V-P collision risk, a pedestrian must be able to protect all pedestrians and automatically stop the TMMs in the area.	Pedestrian able to auto stop TMMs in the detection area.

Scenario number	Scenario description	Objective
UG.S6.1	**Operating TMM: Line-of-sight to pedestrian**  • ***TMM state:*** Normal Operation**.** • ***CPS action:*** When the pedestrian is in the vicinity of a TMM travelling at any speed in any direction, under any reasonably foreseeable TMM condition (e.g. fully loaded) and any reasonably foreseeable environmental condition (e.g. down a decline, wet road surface, etc.), both the pedestrian and TMM operator must receive an effective warning of the potential collision. Should the operator or pedestrian not take appropriate action to prevent the potential collision, the TMM must slow down to a safe speed and stop. The minimum stop gap distance must be 2.5m (such that if a pedestrian walking on the side of a TMM loses his/her footing he/she shall not be run over). • If the pedestrian is to the side of the TMM (more than 3.0m), the TMM may crawl past the pedestrian in Crawl Speed. • TMMs fitted with attachments (e.g., a drill boom, or LHD scoop), the safe stop gap must be from the closest hard point of the TMM (extremity). • Provision will be made for variable distances of vicinity 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 TMM must be able to operate normally when the pedestrian is not within the of vicinity of the TMM.	Pedestrian protected from TMM travelling without unnecessarily impacting production for all reasonably foreseeable TMM conditions and environmental conditions.

Scenario number	Scenario description	Objective
UG.S6.2	**Operating TMM: Pedestrian around corner**  • ***TMM state:*** Normal Operation • ***CPS action:*** When a TMM goes around a corner (e.g. to turn into a bord), either moving forward or reverse, where a pedestrian is either walking, sitting, or lying, both the pedestrian and TMM operator must receive an effective warning. Should the operator and/or pedestrian not take appropriate action to prevent a potential collision, the TMM must automatically slow down to a safe speed and stop. • Provision should be made for any reasonably foreseeable TMM condition (e.g. fully loaded, driving at or below the speed limit) and for any reasonably foreseeable environmental condition (e.g. down a decline, slippery road). • For TMMs with articulation and booms, the articulation and the boom must be prevented from moving until the pedestrian moves out of the vicinity of the TMM. For non-articulated TMMs, the boom must be prevented from moving until the pedestrian moves out of the vicinity of the TMM. • The TMM must be able to operate normally when the pedestrian is not within the of vicinity of the TMM.	Pedestrian protected from TMM turning into bord where pedestrian is located, and pedestrian is unseen/obscured (limited or no line-of-sight) for all reasonably foreseeable TMM conditions and environmental conditions.

Scenario number	Scenario description	Objective
UG.S6.3	**Operating TMM: TMM reversing**  • ***TMM state:*** Normal Operation • ***CPS action:*** When a pedestrian is behind a TMM and the TMM is reversing towards the pedestrian, both the pedestrian and TMM operator must receive an effective warning that a pedestrian is in the vicinity of the TMM. • If the TMM is fully loaded and automatically slows down and stops, the stop gap must make reasonable allowance for the load falling from the TMM onto the pedestrian. • Provision must be made for any reasonably foreseeable TMM condition and reasonably foreseeable environmental condition. For TMMs with attachments, gaps must be from the attachment edge. • The TMM must be able to operate normally when the pedestrian is not within the of vicinity of the TMM.	Pedestrian protected from reversing TMM, including provision made for load falling off of TMM for all reasonably foreseeable TMM conditions and environmental conditions.
UG.S6.4	**Operating TMM: Blind rise** • ***TMM state***: Normal Operation • ***CPS action:*** When a TMM crests a blind rise and there is a pedestrian within the TMM vicinity, both the pedestrian and TMM operator must receive effective warning. If the operator or pedestrian does not take corrective action, the TMM must automatically retard and stop within a safe stop gap. • The TMM must be able to operate normally when the pedestrian is not within the of vicinity of the TMM.	Pedestrian protection when TMM crests a blind rise for all reasonably foreseeable TMM conditions and environmental conditions.