FUNCTIONAL AND TECHNICAL PERFORMANCE REQUIREMENTS FOR SURFACE MINE COLLISION WARNING AND AVOIDANCE DEVICES (CxD)

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

REV 1

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Executive Summary

This document is the functional and technical performance requirement for surface mining collision warning and avoidance system devices (CxDs) in the South African mining industry (SAMI). It aims to meet the User Requirement Specification for surface mining collision prevention systems (CPS).

Clear and unambiguous performance requirements are the cornerstone of successful product development. In the absence of clear requirements, the development process is, more often than not, a costly, iterative, trial-and-error endeavour. Every single stakeholder collaborating to meet the SAMI trackless mobile machinery (TMM) regulatory requirements will benefit greatly from this document, as it defines the requirements that developers need in order to develop a compliant and working CPS. Every requirement includes acceptance criteria that are, in the case of functional performance requirements, measurable or demonstratable.

The valuable contribution that the Minerals Council South Africa is making towards industry readiness for the TMM regulations, by facilitating the development of a single set of requirements on behalf of all stakeholders, cannot be over emphasised. Considering the enormity of the challenge as has been reported in the Collision Management Systems (CMS) Technical Requirements Guideline Review Report and other CPS Technical Reports developed by the Mining Industry Occupational Safety and Health Initiative Transport and Machinery (MOSH T&M) Adoption Team, this specification is the backbone of the entire accelerated development initiative.

Analysing user requirements, identifying functional and technical performance requirements (F&TPR) and synthesising it to represent a fit-for-purpose CPS product is a daunting task. If not for the work done since 2015, by individual mines and mining companies, the Earth Moving Equipment Safety Round Table (EMESRT), the University of Pretoria (UP) and others, the compilation of requirements as documented in this specification would have taken many years to develop. Being true pioneers in a challenging technical field, the SAMI is proving that some of the erstwhile technology development capability that South Africa had, can be re-established. However, this can only be achieved through industry-wide collaboration.

This document is a revised and updated version of the original set of CPS Functional and Technical Performance Requirements released in 2022. Key learnings of the last two to three years have now been incorporated in this document.

The document structure and specification approach are function based and therefore it leaves maximum flexibility for CxD and TMM CPS product developers to develop physical modules and components of their choice.

The conclusions that can be drawn directly and indirectly from the specification are:

- CPS products must have very specific functions as derived from the TMM regulations.
- CPS products are safety systems. This requires CPS products to also conform to a number of technical requirements such as safety integrity, robustness, reliability and others. To meet these requirements will also take development time as it is part of the functional readiness criteria in the early technology readiness levels.

The collaborative nature of the accelerated CPS development initiative requires a general agreement between collaborating parties.

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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: Abbreviations and their definitions appearing in this document

Term/Abbreviation	Definition
3rd Party	An entity appointed to execute work (testing, witnessing of testing and verifying portfolios of evidence) on behalf of SAMI. Note: The purpose of 3rd party execution is to establish independence and to eliminate duplication.
Accelerated Development	Development of CPS products in a coordinated and integrated way that will require less time (for the entire SAMI need), than the previous individual mine and supplier / OEM driven CPS product development approach.
Accuracy	The degree to which the result of a measurement, calculation, or estimate conforms to the correct value, i.e. the preciseness of the measurement.
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 another TMM and is intervening or has intervened to bring the TMM to a safe stop. Once the TMM has stopped, it remains stationary. 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 maximum safe braking speed. The speed to which the TMM CPS will reduce (slow down) when the SLOW_DOWN command is received from the CxD.
CxD	Collision Warning and Avoidance System device: Device with sensors providing collision warning and avoidance functions, to detect objects in the vicinity of the machine, assess the collision risk level, effectively warn the operator of the presence of object(s) and/or provide signals to the machine control system, to initiate the appropriate interventional collision avoidance action on the machine, to prevent the collision. Note to entry: Proximity Detection System (PDS) is a colloquial industry term for a physical device, providing a warning or collision avoidance functionality.
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.
DTS	Detect and Track: A functional group of a CxD enabling detection and tracking of TMMs inside the detection area of a surface TMM.
Design Speed Limit	The maximum speed at which a CPS may operate to ensure the CxD has sufficient detection range to warn the operator(s) and to safely slow and stop the TMM CPS with sufficient stop gap.
Detection	Detection is sensing that an object has entered the detection area.
EMC	Electromagnetic Compatibility
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.
EMESRT	Earth Moving Equipment Safety Round Table
EMI	Electromagnetic Interference
EW	Effective Warning: For surface TMMs: The expected outcome of the operator action is that the potential collision is prevented, therefore an effective warning must inform the operators of both (all) TMMs what the appropriate action(s) are, to prevent the potential collision.

Term/Abbreviation	Definition
F&TPR	Functional and Technical Performance Requirements
FMECA	Failure Mode Effect 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.
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.
HME	Heavy Mobile Equipment
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ID	Identifier.
Independent	Separate from the CPS product developer. Note: Independent does not imply an accredited 3rd party, although where required by local or international standards, it includes accredited 3rd parties.
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/TS21815-2. 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 Slow and CPS Stop
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, specified in ISO/TS 21815-2:2021
MHSA	Mine Health and Safety Act No. 29 of 1996 and Regulations.
MHSC	Mine Health and Safety Council.
Minerals Council	Minerals Council South Africa.
MLK	Machine Log Keeping: The function that receives, and stores TMM CPS data.
MOSH	Mining Industry Occupational Safety and Health 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 TMMs. The CPS is functioning as intended and is monitoring for potential collisions.
Off board components	Components not fitted inside or on the TMM
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. The CPS is functioning normally, but the potential for collisions is limited due to the engagement of the Park Brake.

Term/Abbreviation	Definition
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.
PGN	Parameter Group Number
Project	Industry Alignment on TMM Collision Management Systems Project: CAS READINESS PHASE.
Reliability (sensor)	Sensor reliability refers to the consistency of a measure. Achieving the same result by using the same methods under the same circumstances, is considered a reliable measurement.
Robustness (sensor)	Sensor robustness is the ability of the sensing device (sensor), to remain functional in the presence of normal operating conditions of TMMs on a mine, such as electromagnetic interference, mechanical vibration, dust, adverse weather conditions, etc.
Safe Park	A way that a TMM is parked, namely: Machine static, engine switched of and park brake applied.
Safe speed	The speed that will ensure the controlled stopping of a TMM without any immediate negative impact on the operator or machine. Note: This is a conditional variable value, depending on multiple input variables.
SAMI	South African Mining Industry.
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	ISO/TS 21815-2: 2021 provides for two definitions, an emergency stop, and a controlled stop, both of which are a 'Stop'. The definitions are: 1. "The EMERGENCY-STOP action is sent by CxD to instruct the machine to implement the emergency stop sequence defined by the machine control system. The intent of this command is to stop the machine motion as rapidly as possible, to reduce the consequence level, if the CxD logic determines that a collision is imminent. The equivalent of an emergency stop is the operator slamming on the brakes in an emergency." 2. "The CONTROLLED-STOP action is sent by CxD to instruct the machine to implement the controlled stop sequence, defined by the machine control system." The intent of this command is to stop the machine motion in a controlled / conventional manner, when the CxD logic determines that a collision / interaction can be avoided by slowing down and stopping. The equivalent of a controlled stop is slowing down and stopping when approaching a red traffic light.
System	A combination of interacting elements organized to achieve one or more stated purposes (ISO/IEC/IEEE 2015).
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.
This document	FUNCTIONAL AND TECHNICAL PERFORMANCE REQUIREMENTS FOR SURFACE MINE COLLISION WARNING AND AVOIDANCE SYSTEM DEVICES (CxD)
TMM	Trackless Mobile Machine as defined in MHSA Regulation 8.10
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 the supplier per section 21 of the Mine Health and Safety Act, 1996 (Act No. 29 of 1996).
Tracking	Tracking is the monitoring of the progress of the objects in the detection area over time.
V2X	Vehicle to anything.
Vicinity (Surface TMMs)	The distance or time to the point of a potential collision, such that, if the operators 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.

1 Purpose and scope

The purpose of the Surface Collision Warning and Avoidance System device (CxD) Functional and Technical Performance Requirements (F&TPR) specification is to define the technical and functional performance requirements for a Collision Prevention System (CPS) product that:

- Meets the Mine Health and Safety Act (MHSA) Trackless Mobile Machine (TMM) collision prevention regulatory requirements in accordance with Regulation 8.10,
- Meets the needs of the SAMI mine types and mine working environments as defined in the Surface Mine User Requirement Specification (URS),
- Meets the needs of collision prevention for surface mines in South Africa.

The content of this CxD F&TPR specification applies to:

- CxD products to be used in the SAMI for surface mines,
- CPS User Requirements as defined in the URS for Surface Mine CPS.

This document is a deliverable of phase 2 of the INDUSTRY ALIGNMENT ON TMM REGULATIONS PROJECT.

2 Background

The SAMI is the only international jurisdiction (other than proximity detection systems (PDS) regulations in underground coal mines in the USA), that has regulated the installation of TMM safety products that can prevent collisions between TMMs in surface mining operations. 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 to the SAMI.

Although the TMM regulations have been promulgated in 2015, the two clauses requiring automatic slow-down and stopping of TMMs had been suspended due to the unavailability of CPS products. Since 2015 the SAMI made efforts to develop CPS products that will comply with the TMM regulations. Some obstacles to overcome the challenge only became apparent during the initial years of the development effort.

In 2019 the Mine Health and Safety Council's (MHSC's) Mining Regulation Advisory Committee (MRAC) convened a TMM Task team, consisting of experts, and members of mines, to advise them on the readiness of CPS products, with a view to recommend a date for uplifting the suspended regulations to the board of the MHSC. The task team had several deliberations and concluded that CPS technology was not at a level of maturity to uplift the regulation in the next few years.

The team identified several challenges that still needed 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 feasible.

The Technology Readiness Phase of the project consisted of several deliverables to enable the accelerated development of CPS products. The deliverables include, a review report, technology specific reports, and a CPS URS. All this work contributed to the development of a F&TPR specification. This surface mine F&TPR specification forms the basis of the accelerated CPS development initiative as it provides the requirements for CPS product development that CPS developers must conform to.

On 21 December 2022, the Minister of Mineral Resources and Energy uplifted the suspended regulations with immediate effect. In the period since the Technology Readiness Phase to date, CPS products have undergone widespread testing by the UP. Additionally, extensive engagement with CPS stakeholders have been completed. The test and stakeholder engagements indicated the need to update the original F&TPR, including the following:

- Separating the surface and underground CxD and TMM CPS requirements into distinct documents.
- Improving the consistency of the requirements and cross-referencing the FTPR to the URS.
- Updating the FTPR with the lessons learnt through testing and stakeholder engagement.

3 Requirements Structure

The approved structure for the development of CPS product requirements is shown in Figure 1.

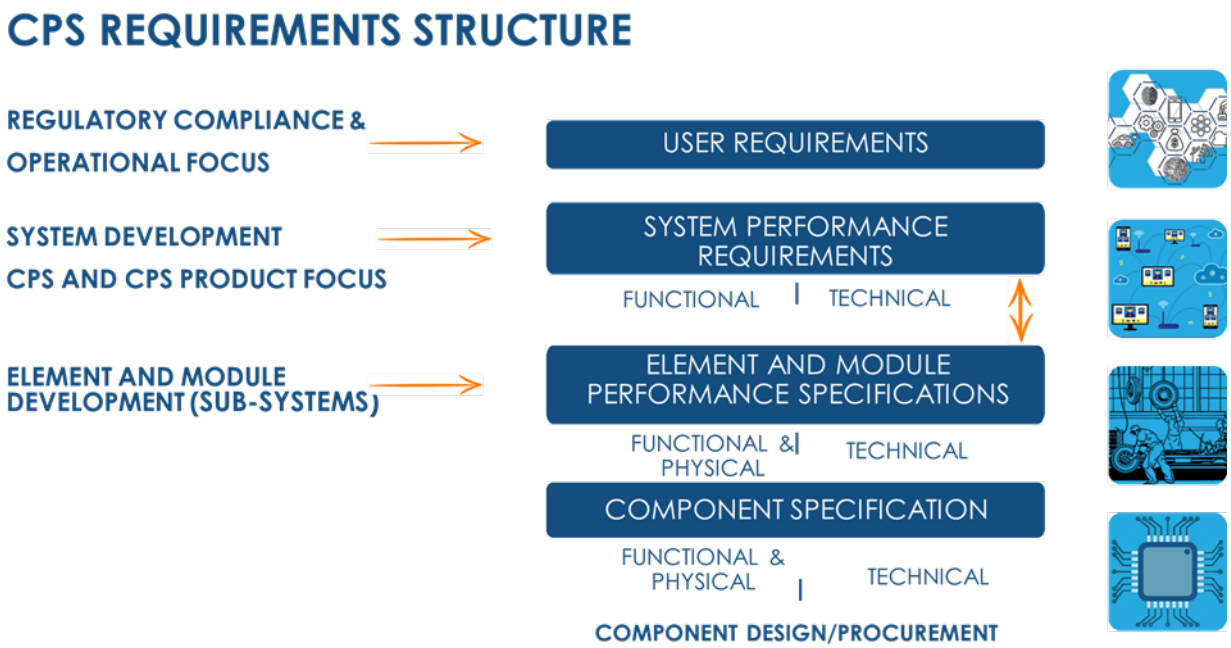

Figure 1: Requirements structure for CPS product development

4 Context

It is important to view this document in the context of the overall suite of MOSH CPS guideline documents. The document relationship with other documents provides that context.

USER REQUIREMENTS SPECIFICATION FOR SURFACE MINE COLLISION PREVENTION SYSTEMS is the higher-level document as defined in the above structure. It provides key regulatory requirements, both direct and derived for Surface CPS product suppliers as well as the surface mines using diesel powered TMMs. It is essential to read and understand the URS before studying this document. A key aspect addressed in the URS is **verification of requirements and independent verification** of requirements.

General Requirement SM.G04: Demonstrate conformance, states 'CPS conformance to user functional and technical requirements must be demonstrated by formal supplier verification as well as independent **verification,** as defined in the CPS Requirements Verification Regime, as well as the CPS Independent Verification Test Specification, as documented in the MOSH CPS guideline.'

The overall CPS Requirements Verification Regime is documented in the document titled CPS Requirements Verification Regime. All requirements as stated in this document must be verified by the TMM CPS supplier, recorded and be referenced in the specific product Section 21 Technical File.

As per the Requirements Verification Regime, all the requirements as defined herein are independently verified at TRL 4 and TRL 7 stage gates.

5 Development Approach

The CxD F&TPR has been developed from the following inputs[1]:

- CPS User Requirements.
- Zone Functionality and Sensor Fusion Report.
- Electromagnetic interference (EMI) and electromagnetic compatibility (EMC) Report.
- CPS Interoperability Report.
- International Standards.
- National Standards.

The relationship between the mentioned document is shown in Figure 2.

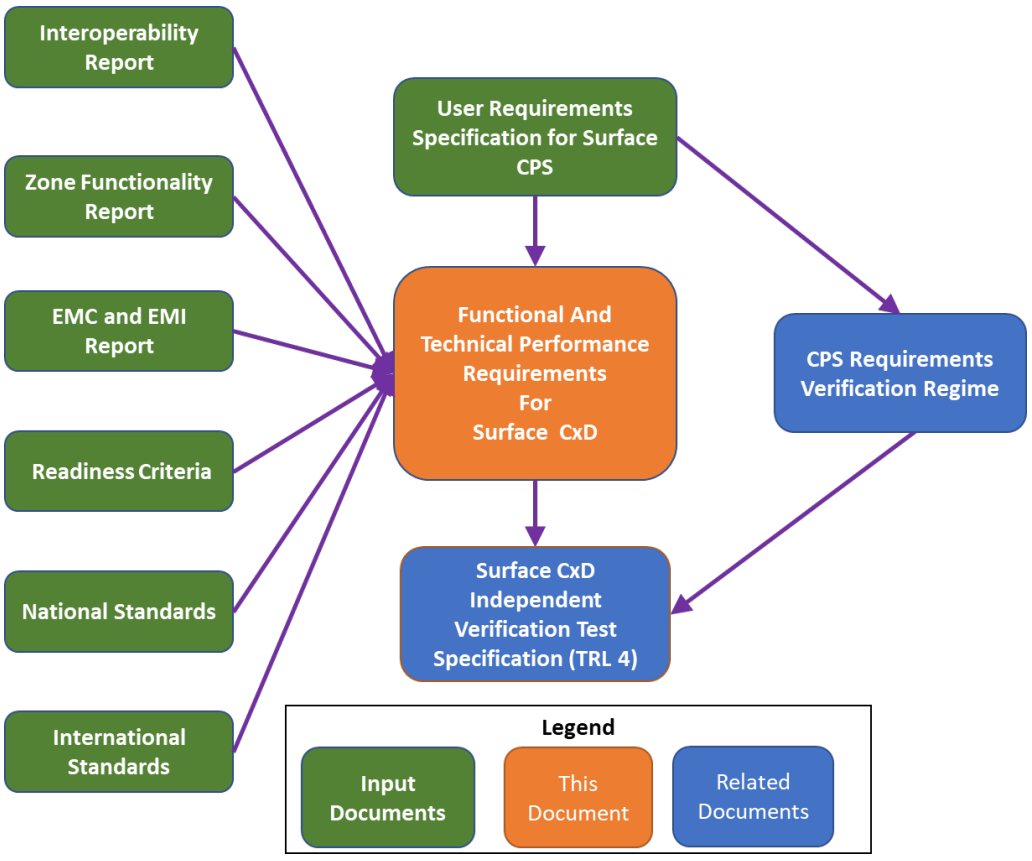

Figure 2: Relationship between various MOSH guideline documents

6 CPS Functional Breakdown

The non-homogenous population of TMMs used in the SAMI necessitates a single set of CPS functions. For a fully functional CPS, all the performance requirements must be met. The extent to which a

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

specific CPS product need to be developed will be determined by the extent to which a specific TMM (type, brand and model) is already intelligent.

The CPS comprises of two functional elements namely:

1. TMM CPS Functions (TMM CPS).
2. CxD Functions (CxD).

Each of the functional elements have a number of subgroups of functions. These groups are logically structured and do not imply that a CPS element must have a similar product breakdown structure.

The CPS Functional breakdown is shown in Figure 3.

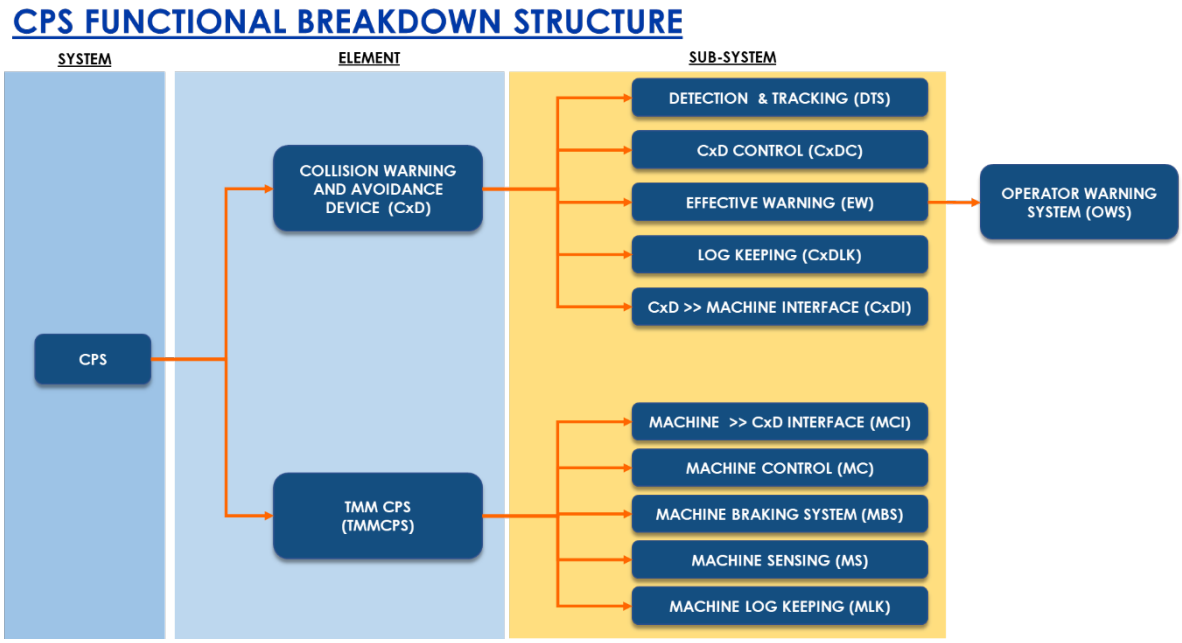

Figure 3: CPS functional breakdown structure.

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 (EW).
4. CxD Log Keeping functions (CxDLK).
5. CxD Machine Interface functions (CxDI).

7 Functional and Technical Performance Requirements

The functional and technical performance requirements of the Surface CxD are structured as per Figure 3 in the following functional groups:

- Detection and Tracking Functions (DTS)
- Effective Warning Functions (EW)
- CxD Control Functions (CxDC)
- CxD to Machine Interface Functions (CxDI)
- CxD Log Keeping Functions (CxDLK)
- General technical requirements

7.1 Detection and Tracking Functions (DTS)

Table 2 lists the Detection and Tracking functions of a surface mine CxD. Functions are uniquely identified with a number and are cross-referenced to the URS requirement that informed them.

Table 2: Surface mine CxD Detection and Tracking functions

Func. Req. No	Function Name	Functional Description	Performance criteria	URS No.
SM.DT.1	Detect	Detect the presence of any TMM within a predefined detection area.	Detection of 6 or more TMMs simultaneously 200m minimum detection range	SM.G01 SM.G07.2 SM.R13 SM.S3
SM.DT.1.1	Detect in all machine statuses	DTS must maintain full functionality in all reasonably foreseeable machine statuses such as bucket raised, boom extended, machine articulated, towing, trailer attached, etc.	Detection of 6 or more TMMs simultaneously 200 m minimum detection range ±1.5 m or ±10 % range accuracy, whichever is greater	SM.G07.4.1 (and sub-requirements) SM.G07.4.2 (and sub-requirements) SM.R01 SM.R02 SM.R13 SM.Sxx (All interaction scenarios)
SM.DT.1.2	Detect robustly	DTS must be able to detect TMMs in all reasonably foreseeable environmental conditions.	Line-of-sight No line-of-sight (e.g. blocked by infrastructure, curves, berms, etc.) Blind rise Dust Steep angles/inclines/declines	SM.07.4.3 (and sub-requirements) SM.R05 SM.S6 (and sub-scenarios)
SM.DT.2	Track potential interactors	Track TMMs while in detection area.	Track 6 TMMs simultaneously No dropouts (max 1s intervals between log entries) May not identify one of the TMMs as a new object (must be the same objects maintained throughout)	SM.G01 SM.G07.4.4 SM.Sxx (All interaction scenarios)

Func. Req. No	Function Name	Functional Description	Performance criteria	URS No.
SM.DT.3.1	Determine position	Measure or estimate the position of any TMM within the detection area.	±1.5m or ±10% range accuracy, whichever is greater	SM.G07.1.2 SM.G07.2 SM.G07.3 SM.R06 SM.R13 SM.Sxx (All interaction scenarios)
SM.DT.4.1	Be self-diagnostic	Be able to monitor the health of all DTS elements.	Detection of critical failure leads to FTSWHI response Critical faults to be based on CxD supplier Failure Mode, Effects and Criticality Analysis (FMECA)	SM.G10 (and sub-requirements) SM.G13.1
SM.DT.4.2	Off-board elements (such as beacons) detection failure	Off-board elements (such as beacons) must fail to safe without human intervention when critical failure mode is detected.	As per supplier FMECA Off-board elements (such as beacons) fail to safe when a fault is detected. FTSWHI response	SM.G10 (and sub-requirements) SM.G13.1 (and sub-requirements)

7.2 CxD Controller Functions (CxDC)

Table 3 lists the controller functions of a surface mine CxD. Functions are uniquely identified with a number and are cross-referenced to the URS requirement that informed them. For the purpose of this specification it must be assumed that the TMM CPS is fully functional.

Table 3: Surface mine CxD Controller functions

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CxDC.01	Communicate with TMM via MCI	Communicate with MC via MCI.	ISO TS 21815-2: 2021 See CxDI specifications	SM.G08 (and sub-requirements)
SM.CxDC.02	Interaction Scenario Stop Gaps	The CxDC must ensure a stop gap to the nearest TMM in all surface mine interaction scenarios.	If speed limit is ≤ 10 km/h - 1.0m - 4.0m stop gap (shortest distance between TMMs) If speed limit is > 10 km/h - 15.0 m stop gap (±5 m) (shortest distance between TMMs)	SM.G07.1 SM.G07.4 (and sub-requirements) SM.R07 SM.R08 SM.R14.5 SM.Sxx (all interaction scenarios)
SM.CxDC.03	Predict the TMM's intended movement	CxDC must estimate the TMM's motion.	CxDC must make use of available information (e.g. from information shared via the MCI to the CxD, or CxD sensing information) to predict the operator's intended course of action to determine the vicinity boundary. CxDC must be able to maintain the specified stop gap in all of the interaction scenarios	SM.G01 SM.G07.1.2 SM.G07.2 SM.G07.3 SM.G07.4 (and sub-requirements) SM.R06 SM.R08 SM.R10 SM.Sxx (all interaction scenarios)

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CxDC.04	Determine collision probability	CxDC must determine the probability of a potential collision of every detected TMM.	Prioritise most likely potential collision of up to 6 TMMs as TMMs move.	SM.G01 SM.G07.1.2 SM.G07.2 SM.G07.3 SM.G07.4 (and sub-requirements) SM.R06 SM.R08 SM.R10 SM.R13 SM.Sxx (all interaction scenarios)
SM.CxDC.05	Consider TMM Status	The CxDC must consider the status of the TMM.	TMM information shared via MCI to the CxD to be considered when determining the vicinity boundary	SM.G07.4.2 (and sub-requirements)
SM.CxDC.06	Consider TMM condition	CxDC must consider TMM condition.	TMM condition (e.g. brake wear, tyre wear) must be considered when determining the vicinity boundary	SM.G07.4.2 (and sub-requirements)
SM.CxDC.07	Configure TMM type	CxDC must be able to configure the different TMM types.	TMM specific brake performance (deceleration curves)? to be considered and configured TMM size and shape (footprint) considered and configured TMM movements & attachments considered and configured	SM.G08.1 (and sub-requirements)
SM.CxDC.08.1	Give operator reasonable time to react to EW	CxDC must give the operator reasonable time to react to EW instructions.	2.5s - 3.0s EW time before automatic slow down and stop intervention	SM.G07.5 (and sub-requirements)
SM.CxDC.08.2	Determine EW activation	CxDC must determine when to activate the EW and initiate it through OWS.	2.5s - 3.0s EW time before automatic slow down and stop intervention See EW specifications	SM.G07.5 (and sub-requirements)
SM.CxDC.09	Ensure Normal Operations	If there are no TMMs within the vicinity boundary, CxDC must allow normal operation.	No false interventions and false warnings when tested at TRL4 Stage Gate. No significant production loss when tested at TRL9 Stage Gate.	SM.G07.3 SM.R14.3

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CxDC.10	Action intervention for high-risk scenarios	If risk level is above threshold (i.e., when another TMM is within the vicinity boundary), CxDC must be able to initiate appropriate EW and automatic intervention strategy.	EW and automatic intervention successfully initiated in all cases Intervention strategy must use TMM capability as reported by TMM during ISO21815-2:2021 capability discovery. Intervention strategy to be consistent and repeatable	SM.G08.1 (and sub-requirements) SM.R14.5 SM.Sxx (all interaction scenarios)
SM.CxDC.11	Different types of TMMs	The CxDC must determine potential collisions between different types of TMMs if there is a significant risk of collision.	The CxD shall detect potential collisions between HMEs (including FELs, excavators, etc.) and LDVs in all operational areas. The CxD shall allow a LDV to approach a HME if the HME is in Safe Park or Operator Stop. The CxD shall only allow the HME to move once the LDV is out of the vicinity.	SM.S1
SM.CxDC.11.1	Speed limited area	The CxD must ensure that TMMs operate at or below the speed limit.	Speed zone demarcation Speed zone communication Time to slow down before entering speed limited area Speed limit not exceeded Speed limited area used in congested areas	SM.S2
SM.CxDC.11.2	Dovetail: Straight-line	The CxD must prevent collisions by ensuring full functionality when TMMs are following each other.	If speed limit is > 10 km/h - Minimum following distance of 15.0m (±5m) If speed limit is ≤ 10km/h - Minimum following distance of 2.5m (±1.5m)	SM.S3.1
SM.CxDC.11.3	Dovetail: Curves	The CxD must prevent collisions by ensuring full functionality when TMMs are following each other around curves.	If speed limit is > 10 km/h - Minimum following distance of 15.0m (±5m) If speed limit is ≤ 10km/h - Minimum following distance of 2.5m (±1.5m)	SM.S3.2
SM.CxDC.12	Overtaking: Slow-moving TMM	The CPS must prevent collisions between slow moving TMMs and faster TMMs approaching from the rear. CxD must allow faster moving TMM to overtake. CxD must prevent collisions with on-coming traffic. CxD must prevent near misses.	If speed limit in area is > 10 km/h - Minimum following distance of 15.0m (±5m) - Overtaking with no EW or intervention if pass gap is ≥ 6.0m - EW and intervention when pass gap < 6.0m If speed limit in area is ≤ 10km/h - Minimum following distance of 2.5m (±1.5m) - Overtaking with no EW or intervention if pass gap is ≥ 2.5m - EW and intervention when pass gap < 2.5m	SM.S4.1

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CxDC.13	Overtaking: Broken-down TMM	The CxD must prevent collisions between TMMs passing and broken-down TMMs. CxD must allow moving TMM to overtake. CxD must prevent collisions with on-coming traffic. CPS must prevent near misses.	If speed limit in area is > 10 km/h - Minimum following distance of 15.0m (±5m) - Overtaking with no EW or intervention if pass gap is ≥ 6.0m - EW and intervention when pass gap < 6.0m If speed limit in area is ≤ 10km/h - Minimum following distance of 2.5m (±1.5m) - Overtaking with no EW or intervention if pass gap is ≥ 2.5m - EW and intervention when pass gap < 2.5m	SM.S4.2
SM.CxDC.14	Head-on: Straight	The CPS must prevent head-on collisions between TMMs. The CPS must allow TMMs to pass safely. CPS must prevent near misses.	If speed limit in area is > 10 km/h - Minimum stop gap of 15.0m (±5m) If speed limit in area is ≤ 10km/h - Minimum stop gap of 2.5m (±1.5m)	SM.S5.1
SM.CxDC.15	Head-on: Curves	The CxD must prevent head-on collisions between TMMs around curves. The CPS must allow TMMs to pass safely. CPS must prevent near misses.	If speed limit in area is > 10 km/h - Minimum stop gap of 15.0m (±5m) If speed limit in area is ≤ 10km/h - Minimum stop gap of 2.5m (±1.5m)	SM.S5.2
SM.CxDC.16.1	Intersections: T-junctions	The CxD must prevent potential collisions at intersections.	If speed limit in area is > 10 km/h - Minimum stop gap of 15.0m (±5m) If speed limit in area is ≤ 10km/h - Minimum stop gap of 2.5m (±1.5m) Stop gap is the shortest distance between TMMs	SM.S6.1
SM.CxDC.16.2	Intersections: Different TMM types	The CxD must prevent collisions at intersections, including preventing collisions between different types of TMMs.	If speed limit in area is > 10 km/h - Minimum stop gap of 15.0m (±5m) If speed limit in area is ≤ 10km/h - Minimum stop gap of 2.5m (±1.5m) Stop gap is the shortest distance between TMMs	SM.S6.2

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CxDC.16.3	Intersections: Multiple interactors	The CxD must prevent potential collisions at intersections, including crossings where multiple TMMs from different directions may interact	If speed limit in area is > 10 km/h - Minimum stop gap of 15.0m (±5m) If speed limit in area is ≤ 10km/h - Minimum stop gap of 2.5m (±1.5m) Stop gap is the shortest distance between TMMs	SM.S6.3
SM.CxDC.16.4	Intersections: Designated roads/areas	The CxD must prevent collisions between all types of TMMs where a significant risk of collision exists at crossings where only one road has stops.	If speed limit in area is > 10 km/h - Minimum stop gap of 15.0m (±5m) If speed limit in area is ≤ 10km/h - Minimum stop gap of 2.5m (±1.5m) Stop gap is the shortest distance between TMMs	SM.S6.4
SM.CxDC.17.1	Congested areas: Dump	The CxD must prevent potential collisions between all types of TMMs on dumps, including during dumping process.	Dump area speed limit is not exceeded Minimum stop gap of 2.5m (±1.5m) if speed limit is ≤ 10km/h Stop gap maintained between all types of TMMs in the dump area Stop gap is the shortest distance between TMMs No use of operator override/bypass/acknowledge when performing normal mining operations and procedures	SM.S7.1
SM.CxDC.17.2	Congested areas: Pit	The CxD must prevent potential collisions between all types of TMMs in congested working areas in the pit ie. loading areas	Pit area speed limit is not exceeded Minimum stop gap of 2.5m (±1.5m) if speed limit is ≤ 10km/h Stop gap maintained between all types of TMMs in the dump area Stop gap is the shortest distance between TMMs No use of operator override/bypass/acknowledge when performing normal mining operations and procedures	SM.S7.2

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CxDC.17.3	Congested areas: Hard park	The CxD must prevent potential collisions between TMMs in congested parking areas.	Hard Park speed limit is not exceeded Minimum stop gap of 2.5m (±1.5m) if speed limit is ≤ 10km/h Stop gap maintained between all types of TMMs in the dump area Stop gap is the shortest distance between TMMs No use of operator override/bypass/acknowledge when performing normal mining operations and procedures	SM.S7.3
SM.CxDC.17.4	Congested areas: Ramp	The CxD must ensure that significant risk of injury due to collisions between TMMs in ramp areas is prevented.	Ramp speed limit is not exceeded Minimum stop gap of 2.5m (±1.5m) if speed limit is ≤ 10km/h Stop gap maintained between all types of TMMs in the dump area Stop gap is the shortest distance between TMMs No use of operator override/bypass/acknowledge when performing normal mining operations and procedures	SM.S7.4
SM.CxDC.17.5	Congested areas: General	The CxD must prevent potential collisions between TMMs in any congested area on the mine.	Congested area speed limit is not exceeded Minimum stop gap of 2.5m (±1.5m) if speed limit is ≤ 10km/h Stop gap maintained between all types of TMMs in the dump area Stop gap is the shortest distance between TMMs No use of operator override/bypass/acknowledge when performing normal mining operations and procedures	SM.S7.5
SM.CxDC.18.1	Identify each TMM uniquely	Each TMM must have a unique ID for log keeping purposes.	The Machine ID should be a unique number assigned by the end user or allocated by the machine manufacturer for a specific machine, e.g. a vehicle identification number (VIN) defined in ISO 3779 or a product identification number (PIN) as defined in ISO 10261.	SM.G11.1.1.4
SM.CxDC.18.2	Identify each operator uniquely	Each operator must be assigned a unique ID that can be registered when operator starts his/her shift for log keeping purposes.	Operator assigned unique ID Operator ID logged on CxDLK Operator training/authorization considered during start-up Interlock preventing unauthorized operation of TMM	SM.G11.1.1.4
SM.CxDC.19	Site and CPS Design Speed limit	CxDC must prevent the TMM from exceeding the CPS Design and site maximum Speed Limits.	CxDC must ensure the TMM stays at or below the CPS Design Speed Limit Design Speed Limit may not be exceeded	SM.G07.1.3 SM.R07

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CxDC.20	Return to normal operation	After collision has been successfully prevented, the CxD must allow the TMM to return to normal operation.	CxDC must allow TMM to return to Normal Operation if there is no significant risk of collision (no TMMs in the vicinity boundary) as per the mine's standard operating procedure	SM.G07.3
SM.CxDC.21	Maintenance override	CxDC to provide an Maintenance Override that can be activated by duly authorized personnel (e.g. technicians attending to breakdowns).	Credentials required to activate authorized override Maintenance override implemented as specified in ISO 21815-1:2022	SM.G12.2.1 SM.G12.2 SM.G12.2.4 SM.R14.8
SM.CxDC.22.1	Monitors CxD health	The CxDC continuously monitors the health of its elements. (Is self-diagnostic)	Critical failures of the CxDI, DTS, EW, CxDC and CxDLK must be monitored Critical faults to be based on CxD supplier Failure Mode, Effects and Criticality Analysis (FMECA)	SM.G10 (and sub-requirements) SM.G12.3
SM.CxDC.22.2	Initiate FTSWHI	Upon detection or reporting of any critical CxD failure, the CxD must initiate a FTSWHI process.	Within 500ms from critical failure detection.	SM.G10 (and sub-requirements) SM.R14.7
SM.CxDC.23	Adjust to environmental conditions affecting brake performance	CxDC must adjust for operating conditions as part of quantifying risk of collision (e.g. incline/decline/payload).	CxDC considers information shared via the MCI and CxD from sensors to determine the vicinity	SM.G07.4.3 (and sub-requirements)
SM.CxDC.24	CPS Start-up	The CxD shall prevent movement of the TMM if the CxD is not ready.	During start-up, the CxD shall prevent movement of the TMM	SM.R14.2

7.3 Effective Warning Functions (EW)

Table 4 lists the Effective Warning functions of a surface mine CxD. Functions are uniquely identified with a number and are cross-referenced to the URS requirement that informed them.

Table 4: Surface mine CxD Effective Warning functions

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.EW.01	Provide concise warning	The system must avoid continuous and repetitive alarms issued for the same collision.	OWS: - No more than 3 audible verbal alarms per incident - Visual warning to operator for duration of incident, including CxD intervention (automatic slow down and stop)	SM.G07.5 (and sub-requirements)
SM.EW.02	Communicate only highest priority	Operators must only be warned of the potential collision with the highest priority.	OWS: - Display element clearly indicates TMM with highest collision priority	SM.G07.5.2.4 SM.G07.5.2.6
SM.EW.03	OWS must be the outcome of human centred design	Ergonomics of operator cabin should not be compromised due to improper positioning of components.	Must be able to accommodate 5th percentile Female and 95th percentile Male. SANS 1610 (ISO 6011) SANS 6405 SANS 259	SM.G07.5.2.4
SM.EW.04	Be audible	An audible warning shall be provided to all operators in the vicinity.	3dB above ambient. Programmable language sets (as per mine specification)	SM.G07.5.2.2
SM.EW.05	Communicate unambiguously	Clearly provide the operator with the correct action to be taken to prevent the potential collision (based on instruction from the CxDC).	Use of verbal and visual communication, using appropriate icons Specific instructions for slow down and stop. Validated with sample of TMM operators	SM.G07.5.2.2 SM.G07.5.2.4 SM.G07.5.2.5 SM.R01 SM.R03

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.EW.06	Provide visual information display	A visual information display shall be provided to all operators.	Visual information clear and obvious to operator in normal seating position Display located taking cognisance of existing in-cab displays. Display element clearly visible from operator normal seating position. Display located not to distract operator from normal operational focus Display location not to restrict operator vision as per SANS 259 (operator field of view) Display location approved by TMM OEM Back lit display Automatic brightness adjustment a) bright enough to be viewed in sunlight, and b) dimmable to not blind operator in low light conditions Display only the current relevant information Display only the top priority information - warning and/or instructions	SM.G07.5.2.2 SM.G07.5.2.4 SM.G07.5.2.5 SM.R03
SM.EW.06.1	Single CPS visual display	Provide one visual display for all CPS needs. (CxD and TMM CPS)	Integrate all CPS display requirements into single visual display. Multi-mode display of types of information	SM.G07.5.2.2 SM.G07.5.2.4 SM.G07.5.2.5 SM.R03
SM.EW.06.2	Display CPS health and fault information	OWS must display any CPS failure mode and CPS health information.	Fault mode screen Presence of faults (including both CxD and TMM CPS faults) are clearly displayed Standardised fault codes and icons Sufficient information for quick component replacement	SM.G10.2.2.2
SM.EW.06.3	Display mini map	Operators must have a display element that displays all detected TMMs' position and heading.	Display element showing all detected TMMs' positions relative to machine	SM.G07.5.2.2 SM.G07.5.2.4 SM.G07.5.2.5
SM.EW.07	Remain functional in the presence of multiple interactors	Display element should function correctly independent of the number of interactors within the detection area.	Display to remain fully functional for a minimum of 6 TMMs in detection area	SM.R03 SM.R13

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.EW.08	Provide speed limit warning	EWS must warn operator when he/she is about to exceed the speed limit (when applicable).	Operator warned when speed is within 3km/h of the speed limit Operator to be instructed to slow down if she/he exceeds the speed limit	SM.G07.1.3 SM.R07 SM.S3

7.4 CxD Log Keeping Functions (CxDLK)

Table 5 lists the log keeping functions of a surface mine CxD. Functions are uniquely identified with a number and are cross-referenced to the URS requirement that informed them.

Table 5: Surface mine CxD Log Keeping functions

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CLK.01	Synchronise	It must be possible to synchronize TMM and CxD logs based on time.	Synchronisation can be done in post-processing (real-time synch not required) TMM time should be recorded at least once every hour of operation	SM.G11.1 SM.G11.1.1.1 SM.G11.1.2
SM.CLK.02	Record all CxDI and MCI data	Record all data shared between CxDI and MCI via the ISO 21815-2:2021 interface.	Record all messages shared via the CxDI and MCI: - CxD>>MachineStatus - CxD>>MachineCommand - Machine>>CxDReply - Machine>>CxDData - Time/Date requests and responses Data should at least be stored on change MessageID changes are not considered to be 'on-change' events	SM.G11.1.1.2 SM.G11.1.1.3
SM.CLK.03.1	Record information	Record information describing the operator, TMM CPS, CxD and all CPS peripherals at all times.	The following information must be recorded at all times - Operator ID - CxD firmware version - Machine ID and relevant information	SM.G11.1 SM.G11.1.2
SM.CLK.03.2	Record unique ID for all interactors	The unique IDs for every interactor must be recorded during interaction.	All TMMs and peripherals (e.g. beacons, geo-fences, etc. as applicable) inside the detection area	SM.G11.1
SM.CLK.04	Record all relevant data during an intervention	During interventions, all information needed to recreate interaction scenarios to be stored at a minimum resolution of 10Hz.	Information to be stored must at least include: - CxD Time - TMM IDs and positions relative to the TMM - EW status Minimum resolution of 10Hz required during interventions	SM.G11.1.1 (and sub-requirements)
SM.CLK.05	Record authorized override	Maintenance override data must be stored.	Maintenance override status Authorized person ID that activates the Maintenance Override	SM.G11.1 SM.G11.1.1.4
SM.CLK.06	Record any CxD faults	Record CxD system health information.	The presence of any CxD faults	SM.G11.1.5

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CLK.07.1	Data storage capacity	Data must be stored for at least 7 days on the TMM.	Reasonable provision made to store up to and including 7 days' worth of data on the TMM If storage capacity is full before 7 days has passed, FTSWHI response is triggered	SM.G11.1.4
SM.CLK.07.2	Store all data for 3 months	Data gathered must be stored for 3 months.	Data gathered must be stored for 3 months (on server)	SM.G11.1.1.4
SM.CLK.08	Data Transfer	Provide for periodic data transfer to mine data infrastructure.	At least once per week using an easily accessible data transfer mechanism, such as: o Wi-Fi, o Local Area Network (e.g. Ethernet), o Personal Area Network (e.g. Bluetooth), o USB / serial, o removable storage;	SM.G11.1.1.4 SM.G11.1.4
SM.CLK.09	Data Security	Provide data security for stored and transfer of data.	Reasonable steps taken to ensure that data containing sensitive information is protected	SM.G11.1
SM.CLK.10	FTS log keeping	CxD must trigger FTSWHI when CxD log keeping system does not work.	Fail to safe response is automatically triggered if CxDLK functionality is compromised (e.g. power failure, storage media unplugged) CxDLK error handling mechanisms (e.g. read/write errors) used to activate fail to safe response	SM.G11.1.3
SM.CLK.11	Data deletion	CxDLK must prevent data from being deleted without authorization.	CxDLK to provide mechanism to prevent unauthorized data deletion CxDLK to record ID of authorized person deleting data Reasonably practicable measures must be taken	SM.G11.1
SM.CLK.12	Data alteration	CxDLK must prevent data from being altered.	CxDLK to provide mechanism to prevent alteration of stored data. Reasonably practicable measures must be taken	SM.G11.1

7.5 CxD>>Machine Interface (CxDI)

Table 6 lists the CxD>>Machine interface functions of a surface mine CxD. Functions are uniquely identified with a number and are cross-referenced to the URS requirement that informed them.

Table 6: Surface mine CxD Interface functions

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CxDI.01	Physical Connection	The connection between the CxDI and the MI uses the standardised connector.	Deutsch DT-series 12 pin, part DT04-12PC-BE02 (Key C) is used for connection between CxD and TMM	SM.G08.1 (and sub-requirements)
SM.CxDI.02	Perform Negotiation	The negotiation between the CxDI and the MI is performed as per ISO21815-2:2021.	For negotiation without authentication: Perform negotiation as described in ISO 21815-2:2021 Negotiation with authentication (optional): Perform negotiation as described in ISO 21815-2:2021 Mechanism to share credentials with interfacing party(ies)	SM.G08.1 (and sub-requirements)
SM.CxDI.03	Keep connection alive	The connection between the CxDI and the MI should not disconnect and renegotiate under normal operating conditions.	Send the PROTOCOL_NOP message at least every 200 ms to maintain the connection Send the command message every 100ms to ensure the TMM consistently receives instructions.	SM.G08.1 (and sub-requirements)
SM.CxDI.04	Detect Disconnection	Disconnection between the CxDI and MI should be detected and actioned.	The CxDI should detect a broken connection Detection within 500ms of disconnection Upon disconnection, CxD may opt to: - Stay quiet, FTSWHI needed on TMM - Attempt to negotiate again - Send STAND_DOWN	SM.G08.1 (and sub-requirements) SM.G10 (and sub-requirements)
SM.CxDI.05	Discover Capabilities	The CxDI should determine the capabilities available on the TMM.	The CxDI should determine machine capabilities using one or both of the following methods: - Sending individual CxD>>MachineCommand messages - Reading the PROPULSION_MCAPS register.	SM.G08.1 (and sub-requirements)
SM.CxDI.06.1	Read Protocol Registers	The CxDI reads TMM identification information from the TMM registers.	The CxDI should attempt to read the following protocol registers: - MACHINE_ID_0 to MACHINE_ID_4 - MACHINE_SOFTWARE_REVISION	SM.G08.1 (and sub-requirements) SM.G11.1
SM.CxDI.06.2	Write Protocol Registers	The CxDI writes its own identification information to the TMM registers.	The CxDI should write to the following protocol registers: - CxD_SOFTWARE_REVISION - CxD_HARDWARE_REVISION - CxD_HARDWARE_ID	SM.G08.1 (and sub-requirements) SM.G11.1

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CxDI.06.3	Read Propulsion Registers	The CxDI reads control parameters from the TMM propulsion registers.	The CxDI should read data from the propulsion registers if available	SM.G08.1 (and sub-requirements) SM.G11.1
SM.CxDI.06.4	Reset Protocol and Propulsion Registers	The CxDI resets the registers to default values on the machine.	The CxDI should attempt to reset the data in the protocol registers to default values The CxDI should attempt to reset the data in the propulsion registers to default values	SM.G08.1 (and sub-requirements) SM.G11.1
SM.CxDI.07	Send commands	The CxDI must send commands matching the capabilities discovered during initialization.	Must conform to either or both SM.CxDI.07.1 and SM.CxDI.07.2 Must conform to SM.CxDI.07.3, SM.CxDI.07.4 and SM.CxDI.07.5	SM.G08.1 (and sub-requirements)
SM.CxDI.07.1	Send open loop commands	The CxDI sends commands used to control TMM operation in an open loop manner.	The CxDI can send the following commands to control the TMM and achieve appropriate responses: - NORMAL_OPERATION to allow the TMM to operate without restrictions on operator controls - EMERGENCY_STOP to apply all available measures to stop the TMM as quickly as possible. Reserved for use when the collision cannot be avoided and the consequences of the collision must be mitigated by reducing TMM speed - CONTROLLED_STOP to slow down and stop the TMM in a controlled manner - SLOW_DOWN to reduce the TMM's speed to a predefined crawl speed and not exceeding the crawl speed while active	SM.G08.1 (and sub-requirements) SM.R14.5 SM.Sxx (all interaction scenarios)
SM.CxDI.07.2	Use closed loop set points	The CxDI uses set point functionality to control the TMM in a closed loop manner.	The TMM may be controlled by correctly loading and applying set points using one or more of the following methods: - UPDATE_AND_APPLY to apply only a single set point at a time - MATCH_TAG to apply multiple retagged set points - APPLY_FROM_LIST to apply all set points in a list	SM.G08.1 (and sub-requirements) SM.R14.5 SM.Sxx (all interaction scenarios)
SM.CxDI.07.3	Send STAND_DOWN for FTSWHI	The CxDI must send STAND_DOWN if a critical CxD failure is detected.	STAND_DOWN to slow down and stop the TMM in a controlled manner when the CxD experiences a fault (fail to safe response)	SM.G08.1 (and sub-requirements) SM.R14.7
SM.CxDI.07.4	Provide for Maintenance Override	The CxD must provide for a CxD triggered Maintenance Override	The CxD must provide for a CxD triggered Maintenance Override in one of the following ways: - The CxDI must send BYPASS_PROPULSION, or - The override pins on the ISO/TS 21815-2:2021 connector must be used	SM.G08.1 (and sub-requirements) SM.R14.8 SM.R14.9
SM.CxDI.07.5	Inhibit motion	The CxDI must send INHIBIT_COMMAND	INHIBIT_COMMAND must be used to ensure a stationary TMM remains stationary (e.g. during CPS start-up and when one or both TMMs that was stationary want to take off while inside the vicinity boundary)	SM.G08.1 (and sub-requirements) SM.R14.2

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.CxDI.08	Message Timing	The CxDI messages are sent at the rate specified in ISO21815-2:2021.	The CxD>>MachineStatus Parameter Group Number (PGN) should be broadcast at 10 ms intervals. CxD may keep quiet between bursts of communication. PROTOCOL_NOP should be sent periodically (sent at least every 200ms) The CxD>>MachineCommand PGN should be sent every 100ms following negotiation and capability discovery	SM.G08.1 (and sub-requirements)
SM.CxDI.09	Handle Action Error	CxDI handles errors safely.	If the CxD issues an unsupported command or one that cannot be applied at the current speed, the TMM may return an ACTION_ERROR. The CxDI should handle such errors safely.	SM.G08.1 (and sub-requirements) SM.R10.1
SM.CxDI.10	Interpret Data message	CxDI interprets information from the machine correctly.	The CxDI should correctly interpret information contained in the Machine>>CxDdata PGN. If only some parameters are used, the CxDI must correctly interpret all utilised parameters.	SM.G08.1 (and sub-requirements)
SM.CxDI.11	Handle delayed status reply	CxDI can handle delayed CxD>>MachineStatus messages.	The CxDI should be able to handle the case where the TMM delays its response to the CxD>>MachineStatus message by up to 50ms	SM.G08.1 (and sub-requirements)
SM.CxDI.12	Allow time exchange in both directions	CxDI can exchange time/date information.	The CxDI should use the SAE J1939 Request PGN to request the SAE J1939 Date/Time PGN from the TMM The CxDI should respond to any SAE J1939 Request for time addressed to it with the SAE J1939 Date/Time PGN.	SM.G08.1 (and sub-requirements) SM.G11.1.1.1

7.6 CPS General Technical Requirements

Table 7 lists the general technical requirements of a surface mine CxD. Functions are uniquely identified with a number and are cross-referenced to the URS requirement that informed them.

Table 7: Surface mine CxD General Technical requirements

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.T01	Risk informed	The CPS and all its individual modules must be informed by formal design risk assessment.	Functional safety Mineral Composition Health Safety Environment Operator	SM.G02 SM.G03 SM.G07.4.3 SM.G07.5.2.3 SM.G07.5.2.4 SM.G07.5.2.5 SM.G10.2.2.1 SM.G10.2.2.2 SM.G.14.1 (and sub-requirements)
SM.T02	Be EMC	The CPS must be electromagnetically compatible with other electronic systems on the mine (including detonation systems). It must not have any negative health impact on operators and no negative functional impact any other sensing device used on the TMM.	Must consider other systems on the mine that may affect the CPS performance Must consider the effect of CPS on performance of other systems due to possible EMI SANS 61000-4-X series Comply with Electronic Communications Act 36 of 2005 ICNIRP Guidelines for limiting exposure to electromagnetic fields	SM.G09.1 (and sub-requirements)
SM.T03	Robustness	CPS must remain functional in the harsh mining environment.	See lower level functions	SM.G07.4.3 (and sub-requirements)
SM.T03.1	Prevent dust and water ingress	CPS must prevent ingress of dust and water.	IP56 for internal components (e.g. inside the cab) IP66 rating for external components (e.g. antennas mounted on the TMM)	SM.G13.1.2 SM.G13.1.5 SM.G13.1.6
SM.T03.2	Survive exposure to shock	DTS components must be able to withstand typical vibration, shocks, etc. as normally experienced by TMMs.	Mil-STD-810G shock (or similar)	SM.G13.1.4
SM.T03.3	Survive exposure to vibration	Must be able to withstand exposure to vibration.	Mil-STD-810G vibration (or similar)	SM.G13.1.4

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.T03.4	Operate at high and low temperatures	CPS components able to withstand elevated internal temperatures and external temperatures (high and low) as typically encountered on the mine.	Mil-STD-810G temperatures (or similar)	SM.G13.1.5
SM.T04.1	Out of cab functions	Off-board sensors as part must be supplied with suitable power supply (e.g. battery).	Formal FMECA informed Consider mine operations in terms of Installation, Maintenance and Repair (IMR) and reliability	SM.G10 (and sub-requirements)
SM.T04.2	Off board components	Off-board components/units must effect a fail to safe instruction.	Failure of off-board components (e.g. beacons, etc.) must result in fail to safe response automatically	SM.G10 (and sub-requirements)
SM.T05	Be self-diagnostic	All CPS functional elements to be self-diagnostic and continuously monitor function availability.	Be informed by formal FMECA Critical failures to be detected within 500ms of failure	SM.G02 SM.G03 SM.G10 (and sub-requirements)
SM.T06	Data Logging (CxDLK function)	The CxD and TMM CPS must have separate data logging capabilities.	See CxDLK and TMM CPS LK functional requirements	SM.G11.1 (and sub-requirements)
SM.T07.1	Installation (Buildability)	All CPS physical components and elements to be designed for effective installation.	Retrofittable to existing TMMs See lower level requirements	SM.G02 SM.G12.1 SM.G12.4 SM.G12.5
SM.T07.2	Mounting	Mountings not to deteriorate TMM integrity.	Positioned as per TMM OEM specification Not be exposed to operational hazards - falling material, TMM articulation Not affect structural safety i.e.. mountings, drilling and welding. Cause operator injury - bumping, nipping, cutting	SM.G02 SM.G12.1 SM.G12.4 SM.G12.5
SM.T07.3	Cable routing	All cable routing to support TMM maintainability.	Positioned as per TMM OEM specification Be protected from normal operating damage Ease of securing and removal of all CPS modules and components Protected from physical damage Not negatively impact on maintainability of other in-cab systems	SM.G02 SM.G12.1 SM.G12.4 SM.G12.5
SM.T07.4	Availability	All CPS modules must be designed for availability.	98% components (CxD and TMM CPS respectively) 95% machine availability maintained	SM.G13.1

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.T07.5	Maintainability	The CPS to be designed for optimal maintainability.	Formal maintenance and repair strategy informed Quick removal and mounting of modules Modular design to facilitate quick fault finding and lower replacement unit cost MTTR < 90min Critical spares identified	SM.G12.1 SM.G12.3 SM.G.12.4 SM.G12.5 SM.G13.1 (and sub-requirements)
SM.T07.6	Operability	All CPS modules to be operable/configured/tested after maintenance or CxD replacement.	Quick reconfigurable/commissioning	SM.G12.1 SM.G12.3 SM.G.12.4 SM.G12.5 SM.G13.1 (and sub-requirements)
SM.T07.7	Reliability	All CPS modules designed for reliability.	Formal FMECA informed CPS MTBF > 2000 operating hours	SM.G13.1
SM.T08	Identification and marking	All CPS modules and components to be uniquely identified and marked.	Item number Item name Serial number Version Physically marked Data stored in CxDLK ,TMM CPS LK as relevant Data displayed on OWS on request.	SM.G12.1 SM.G14.1 SM.G14.1.1
SM.T09	Firmware requirements	Version controlled and electronically updatable.	Unique identifier Version Date installed or last updated Recommissioned after update Data logged specifically Firmware version updated on each change	SM.G12.1 SM.G14.1 SM.G14.1.1
SM.T10	Reporting	The CPS must have a reporting, trending and business intelligence function that is configurable by the mine.	CPS performance to be monitored and used for continuous business improvement	SM.G11.1
SM.T11	Safety integrity	The CPS must be designed for safety integrity.	Comply with GMG Guideline for Applying Functional Safety to Autonomous Systems in Mining	SM.G05 SM.G10 (and sub-requirements)
SM.T12	General	Demonstrate conformance.	CxD products must demonstrate conformance to the CxD F&TPR through independent verification.	CxD tested according to MOSH CPS Test Specification by independent party

Func. Req. No	Function Name	Function Description	Performance criteria	URS No.
SM.T13	General	Unambiguous legal boundaries.	CxD must formally define its legal boundary	Legal boundary informed by functional breakdown structure shown in Figure 1

8 References

The following documents are referenced in this document:

1. ISO/TS 21815-2:2021: Earth-moving machinery — Collision warning and avoidance — Part 2: On-board J1939 communication interface.
2. ISO/TS 21815-1:2022: Earth-moving machinery – Collision warning and avoidance – Part 1: General Requirements.
3. MIL-STD-810G: 31October 2008: Environmental engineering considerations and laboratory tests.
4. ICNIRP Guidelines for limiting exposure to electromagnetic fields (100 KHZ TO 300 GHZ).
5. The Global Mining Guidelines Group (GMG) 18 Aug 2020 Publication: GMG Guideline for Applying Functional Safety to Autonomous Systems in Mining.