PART 2: FUNCTIONAL AND TECHNICAL PERFORMANCE REQUIREMENTS FOR COLLISION PREVENTION SYSTEMS

(I.E. WORK PACKAGE 9)

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

Rev 4

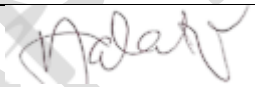
CPS F&TP Requirements Acceptance			
Name	**Signature**	**Organisation**	**Date**
Kobus Blomerus		**SECDI**	**17 Nov 2022**
Stanford Malatji		**Minerals Council**	**17 Nov 2022**

TABLE OF CONTENTS

1. Purpose 3
2. Scope 3
3. Definitions and abbreviations 3
4. Executive Summary 11
5. Context of this document 13
6. Background 13
7. Requirements Structure 14
8. Development Approach 14
9. CPS Functional Breakdown 14
10. F&TP Requirements Structure 16
11. F&TP Requirements 16
    - 11.1 CxD 16
    - 11.1.1 Detection and Tracking Functions (D&T) 17
    - 11.1.2 CxD Controller Functions (CxDC) 19
    - 11.1.3 Effective Warning Functions (EW) 28
    - 11.1.4 V2X Functions (V2X) 31
    - 11.1.5 CxD Log Keeping Functions (CxDLK) 31
    - 11.1.6 CxD Machine Interface (CxDI) 33
    - 11.2 TMM CPS 33
    - 11.2.1 Machine Interface (MCI) 34
    - 11.2.2 TMM CPS Functions (TMM CPS) 34
    - 11.3 CPS General Requirements 38
12 References 43

1. Purpose

The purpose of the Functional and Technical Performance Requirements (F&TPR) specification, is to define the technical and functional performance requirements for a CPS product that:

- Meets the MHSA TMM collision prevention regulatory requirements,
- Meets the needs of the SAMI mine types and mine working environments,
- Meets the needs of collision prevention (V-V for surface and V-P for underground).

2. Scope

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

- CPS products to be used in the SAMI for both surface and underground mines,
- CPS User Requirements as defined in Part 1 of the CPS Requirements Specification.

3. Definitions and abbreviations

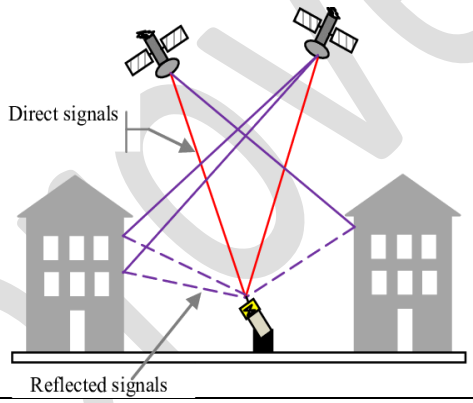
The following definitions and abbreviations will be used to create a common approach for all deliverables. (Note: The rationale for some of the terms and definitions is set out in the CMS Technical Specification Guideline Review Report)

3rd Party	An entity appointed to execute work (testing, witnessing of testing and verifying portfolios of evidence) on behalf of SAMI. Note: The purpose of 3rd party execution is to establish independence and to eliminate duplication.
Accelerated Development	Development of CPS products in a coordinated and integrated way that will require less time (for the entire SAMI need), than the previous individual mine and supplier / OEM driven CPS product development approach.
Accuracy	The degree to which the result of a measurement, calculation, or estimate conforms to the correct value, i.e. the preciseness of the measurement.
C102-F9R	C102-F9R application board Easy evaluation of ZED-F9R with sensor fusion. Application board for ZED-F9R
CMS	Collision Management System: The overall combination of preventative controls, mitigation, recovery and supporting controls, implemented by a mine site to prevent TMM collisions.
Controlled area	Area that is dedicated to testing with no interference from vehicular or pedestrian traffic. Example: Gerotek Test Facilities, section on mine isolated from any mining activity, or demarcated area at a TMM OEM assembly plant.
CPS	Collision Prevention System: A Product System that comprises the functionality and characteristics that comply with the RSA TMM collision prevention regulations. (TMM Regulations 8.10.1 and 8.10.2 and user requirements.)

CWAS/(CxD)	Collision Warning and Avoidance System device (CxD): Device with sensors providing collision warning and avoidance functions, to detect objects in the vicinity of the machine, assess the collision risk level, effectively warn the operator of the presence of object(s) and/or provide signals to the machine control system, to initiate the appropriate interventional collision avoidance action on the machine, to prevent the collision. Note to entry: Proximity Detection System (PDS) is a colloquial industry term for a physical device, providing a warning or collision avoidance functionality.
CxD	Collision warning/detection/management Device.
CxDC	CxD Controller: A sub-system of the CxD, that is typically the computer that contains the decision-making logic.
CxDI	CxD interface: A integration function between the CxD and the Machine Controller.
CxDLK	CxD Log Keeping: The function that receives, and stores CxD data.
D&T	Detect and Track: A functional group of a CxD enabling detection and tracking of TMMs and pedestrians inside the detection area of a surface TMM and an underground TMM respectively.
DAQ	Real time computer with data acquisition and control capabilities. Has ISO21815 interface. Example: DSpace MABX II.
Data scientist	Experienced person in the field of data processing and statistics. This person will analyse data collected during TRL9 pilot site roll-out testing.
Detection	Detection is sensing that an object has entered the detection area.
DMRE	Department of Mineral Resources and Energy.
Driver or operator reaction time (also known as perception response time)	The time that elapses from the instant that the driver recognises the existence of a hazard in the road, to the instant that the driver takes appropriate action, for instance, applying the brakes. The response time can be broken down into four separate components: detection, identification, decision and response. When a person responds to something s/he hears, sees, or feels, the total reaction time can be broken down into a sequence of components namely: • Mental processing time (sensation, perception / recognition, situational awareness, response selection and programming). • Movement time, and • Driver response time. Driver reaction time is also affected by several issues such as visibility, operator state of mind (fatigue), and direction or position of perceived danger.
EAV	Exposure Action Value
ELV	Exposure Limit Value

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

Independent person	A person, typically a test-, software- or EM engineer, who is not affiliated with the CPS provider or TMM OEM, that can provide an unbiased assessment.
Integrated Testing Regime	A holistic method of testing, optimising existing testing facilities that are currently available irrespective of who owns them. This method ensures specific CPS tests are only done once (CxD and TMM CPS Product combinations) and verification is done as early as possible in the development process.
Interface	A boundary across which two independent systems meet and act on, or communicate with each other. Four highly relevant examples: 1. CxD-machine interface – The interface between a Collision Warning and Avoidance System Device (CxD) and the machine. This interface is described in ISO/DTS21815-2. 2. The user interface – Also sometimes referred to as the Graphic User Interface (GUI) when an information display is used. This is the interface between the user (TMM operator or pedestrian) and the CxD or pedestrian warning system. 3. V2X interface – the interface between different CxD devices. V2X is a catch-all term for vehicle-to-everything. It may refer to vehicle-to-vehicle (V-V), vehicle-to-pedestrian (V-P), or vehicle-to-infrastructure (V-E). 4. CxD-peripheral interface – This is an interface between the CxD and other peripheral systems that may be present on the TMM. Examples include a fleet management system, machine condition monitoring system, or fatigue management system. Note: An interface implies that two separate parties (independent systems), are interacting with each other, which may present interoperability and/or EMI and EMC challenges.
LDV	Light Duty Vehicle
LO	Local Object: Denotes the TMM that is detecting other TMMs (S) or pedestrians (P)
Localization	Localization is measuring the position of the object within the detection area; it provides the local object with a map of the remote objects within the environment.
Loss of control	The uncontrolled movement of a TMM due to operator, machine, or environmental reasons. Note: Section 8.10.3 of MHS Act. Loss of control may result in several scenarios: • Machine failure – park brake, or service brake, or tyre blowout. • Operator disabled – fatigue, medical condition, inattention, distraction, or non-compliance with TMP rules (e.g., over speeding on decline, or overloading)
MBS	Machine Braking System: The physical components that makes an unintelligent TMM intelligent and enables the CPS auto slow-down and stop functionality.

MC	Machine Controller.
MCI	Machine Control Interface: The interface between the Machine Controller and the CXD interface.
MHS Act	Mine Health and Safety Act No. 29 of 1996 and Regulations.
MHSC	Mine Health and Safety Council.
Minerals Council	Minerals Council South Africa.
MLK	Machine Log Keeping: The function that receives, and stores TMM CPS data.
MOSH	Mining Industry Occupational Safety and Health.
MRAC	Mining Regulations Advisory Committee.
MRL	Manufacturing Readiness Level. A manufacturing maturity level within a manufacturing readiness framework.
MS	Machine Sensing: Sensing functionality on a TMM that enable a fully functional CPS.
Multipath	Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths, typically some direct signals, but also some reflected signals. 
Off board components	Components not fitted inside the TMM Cab.
OWS	Operator Warning System: The system that provides the effective warning and other warnings to the operator of a TMM.
PDS	Proximity Detection System – see CxD.
Pedestrian	A person lying, sitting, or walking rather than travelling in a vehicle.
Project	Industry Alignment on TMM Collision Management Systems Project: CAS READINESS PHASE.
PWS	Pedestrian warning System: The system that provides the effective warning to pedestrians.
Quality Assurance	Verifying a process, product, or service; usually conducted by an experienced person in the specific field.
RAID	Redundant Array of Independent Disks

Reasonably practicable measure	Reasonably practicable means practicable with regards to: (a) The severity and scope of the hazard, or risk concerned. (b) The state of knowledge reasonably available, concerning the hazard or risk, and of any means of removing or mitigating the hazard or risk. © The availability and suitability of means to remove or mitigate that hazard or risk, and (d) The costs and the benefits of removing or mitigating that hazard or risk.
Reliability (sensor)	Sensor reliability refers to the consistency of a measure. Achieving the same result by using the same methods under the same circumstances, is considered a reliable measurement.
RO	Remote Object: Denotes TMM(s) (S) or pedestrian(s) (U) being detected by the LO.
Robustness (sensor)	Sensor robustness is the ability of the sensing device (sensor), to remain functional in the presence of normal operating conditions of TMMs on a mine, such as electromagnetic interference, mechanical vibration, dust, adverse weather conditions, etc.
S	Surface: Indicating that a specific aspect is applicable to surface TMMs/operations.
Safe Park	A way that a TMM is parked, namely: Machine static, engine switched of and park brake applied.
Safe speed	The speed that will ensure the controlled stopping of a TMM without any immediate negative impact on the operator or machine. Note: This is a conditional variable value, depending on multiple input variables.
SAMI	South African Mining Industry.
Sensor fusion	Sensor fusion is the process of combining sensory data, or data derived from disparate sources, such that the resulting information has less uncertainty than when the sources were to be used individually.
Significant risk (of collision)	The reasonable possibility of a TMM collision, given all the controls that a mine has put in place to prevent a TMM collision.
Slow down	ISO/TS 21815-2: 2021 defines slow down as: "The SLOW-DOWN action is sent by the CxD to reduce the speed of the machine in a controlled / conventional manner, as defined by the machine control system. The intent of this command is to slow down the machine when the CxD logic determines that a collision / interaction can be avoided by reducing speed".
Software engineer	Qualified person in the communications/computer environment, with extensive experience in ISO 21815 – 2:2021 programming and testing.
SP GNSS with self-recorder	Standard Precision Global Navigation Satellite System: A system that is capable of measuring position with an accuracy of 1.5m, with an update rate of 10Hz. Can also store its own data. Example: UBlox C102-F9R.

Stage gate	A step in the testing regime / process where the CPS product system is tested against acceptance criteria, the failure of which would limit the CPS product system from moving to the next step in the regime / process.
Stop	ISO/TS 21815-2: 2021 provides for two definitions, an emergency stop, and a controlled stop, both of which are a 'Stop'. The definitions are: 1. "The EMERGENCY-STOP action is sent by CxD to instruct the machine to implement the emergency stop sequence defined by the machine control system. The intent of this command is to stop the machine motion as rapidly as possible, to reduce the consequence level, if the CxD logic determines that a collision is imminent. The equivalent of an emergency stop is the operator slamming on the brakes in an emergency." 2. "The CONTROLLED-STOP action is sent by CxD to instruct the machine to implement the controlled stop sequence, defined by the machine control system." The intent of this command is to stop the machine motion in a controlled / conventional manner, when the CxD logic determines that a collision / interaction can be avoided by slowing down and stopping. The equivalent of a controlled stop is slowing down and stopping when approaching a red traffic light.
System	A combination of interacting elements organized to achieve one or more stated purposes (ISO/IEC/IEEE 2015).
T	Technical: Indicates a technical requirement of the CPS or functional group.
Technical specification	Specifications that define the technical and physical characteristics and/or measurements of a product, such as physical aspects (e.g. dimensions, colour, and surface finish), design details, material properties, energy requirements, processes, maintenance requirements and operational requirements.
Technician	Competent person with testing experience in the mining / vehicle environment, e.g. testing technician, TMM OEM technician, CxD technician, auto electrician, etc.
Test engineer	Experienced person in the engineering/mining environment with extensive experience in CPS testing.
This document	PART 2 FUNCTIONAL AND TECHNICAL PERFORMANCE REQUIREMENTS FOR COLLISION PREVENTION SYSTEMS
TMLP	Traffic Management Leading Practice: The MOSH Traffic Management Leading Practice for Open Cast/Cut mines in South Africa.
TMM	Trackless Mobile Machine. (Machine, vehicle, etc.)
TMM CPS	The functional group comprising all TMM CPS related functions.
TMM CPS Product	The product that will make a non-intelligent TMM intelligent and CxD ready.

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

4. Executive Summary

The lack of clear functional and technical performance requirements is a major observation in the CMS Technical Requirements Guideline Review Report. As reported therein, the EMESRT approach require that, either an individual mine, or a CPS provider must develop a functional and technical performance requirements specification, using the MOSH/EMESRT CMS Technical Specification Guideline.

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 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.

The testing entities need to develop tests to validate functionality and give mines assurance that CPS products that comply with the requirements, will be fit for purpose. 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 CMS Technical Requirements Guideline Review Report and other technical reports developed in the past 6 months, the specification is the backbone of the entire accelerated development initiative.

Analysing user requirements, identifying functional and technical requirements and synthesising it to represent a fit for purpose CPS product, is a challenging task. If not for the work done since 2015, by individual mines and mining companies, EMESRT, the University of Pretoria 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, such as an area of autonomous vehicle development, the SAMI is proving that some of the erstwhile technology development capability that South Africa had before, can be re-established if enabled by the level of collaboration that is required to successfully complete the accelerated CPS development initiative.

Although the set of requirements defined in the draft specification are neither 100% complete, nor 100% correct as yet, it is a comprehensive baseline from which, with committed collaborative review and engagement from CPS providers and mines, a set of CPS requirements can be finalised that represent the best knowledge and experience in and outside of South Africa by the end of 2021.

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.

As reported in technical reports, the resolution of the small number of critical technical challenges, associated standards and specifications, must be a key focus of the supplier engagement and industry review processes.

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.
- TMM OEM specifications are key requirements for CxD development and must be made available for all TMM Types, brands and models that need CPS solutions.
- Active TMM OEM involvement and approval of specific CPS requirements are essential to the accelerated development process.
- Being safety systems, this requires CPS products to also conform with 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 resolution of the few, but important requirements in order to finalise this document are:
    - CPS requirements for roadgoing LDVs (The current specifications require all TMMs including road going LDVs, to be fitted with a fully functional CPS.)
    - Requirements for frequency spectrum management.
    - A V2X communication standard for CPS products.

The collaborative nature of the accelerated CPS development initiative requires a general agreement between collaborating parties. The following recommendations are made in this regard:

- That the specification, as well as the associated reports, be formally released for comment/review to each CPS provider individually.
- That comments are made formally and submitted to the Minerals Council South Africa.
- That SECDI collates all comments and provides formal responses to comments made by collaboration parties.
- That a formal work session be held with the members of the CM&EE TMM task team to give direction as required.
- That a formal work session be held with all CPS providers to give feedback and get alignment with CPS providers.
- That TMM OEMs make the required TMM specifications that are needed for CxD and TMM CPS product development, available to the Minerals Council, as the facilitators of the accelerated development initiative. (This is only needed if the TMM OEM is not the CPS provider).
- That the resolution of the outstanding requirements be expedited.

5. Context of this document

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

The document is released in 2 parts:

- Part 1 User Requirements.
- Part 2 Functional and Technical Performance Requirements (F&TPR this document).

6. Background

The SAMI is the only international jurisdiction (other than PDS regulations in underground coal mines in the USA), that has regulated the installation of TMM safety products that can prevent collisions between TMMs and pedestrians in underground operations as well as TMMs and other TMMs in surface 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 available to timeously introduce the products if a mine cannot or does not want to introduce controls that are higher up in the hierarchy of controls.

Although the TMM regulations have been promulgated in 2015, the two clauses requiring auto slow-down and stopping of TMMs have 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 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 regulations to the board of the MHSC. The task team had several deliberations and concluded that CPS technology is 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 will enable the upliftment of the suspended clauses of the TMM regulations as soon as feasible.

The CAS Readiness Phase of the project consists of several deliverables to enable the accelerated development of CPS products. The deliverables include, a review report,

technology specific reports, and a CPS User Requirements Specification. All this work contributed to the development of a Functional and Technical Performance Requirements (F&TPR) specification (this document). The 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.

7. Requirements Structure

The approved structure for the development of CPS product requirements is shown in Figure 1. The first two layers of the structure are covered by this deliverable, part 1 and part 2 (this document). The next two layers are the responsibility of the CxD developer based on the CPS product breakdown structure.

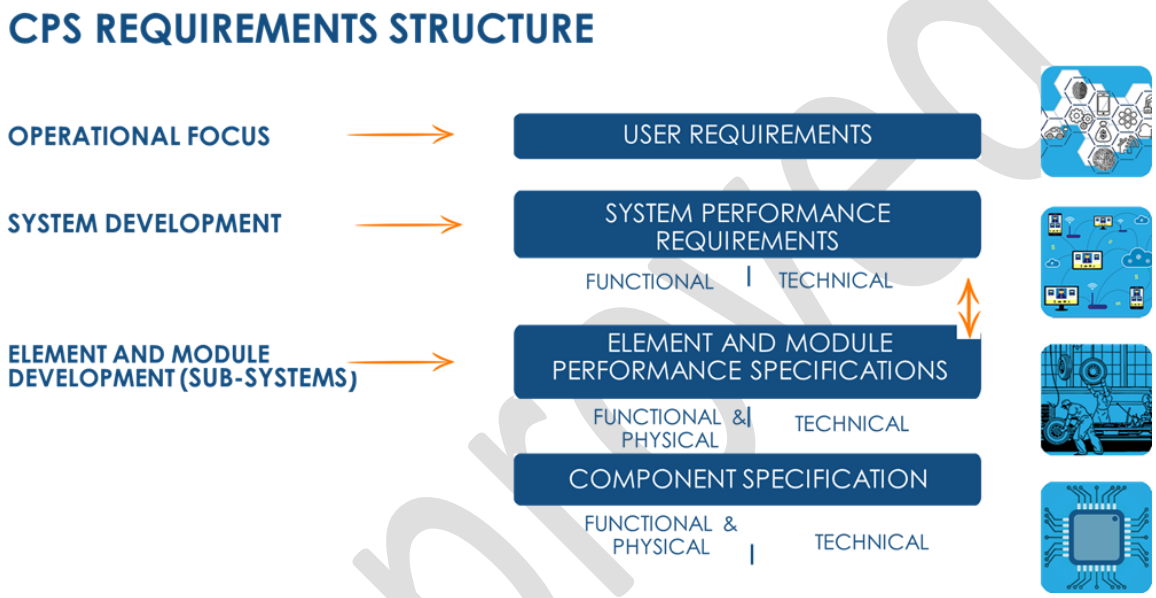


Figure 1: Requirements structure for CPS product development.

8. Development Approach

The CPS F&TPR has been developed from the following inputs:

- CPS User Requirements.
- Zone Functionality and Sensor Fusion Report.
- EMI and EMC Report.
- CPS Interoperability Report.
- International Standards.
- National Standards.

9. 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 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 Functional breakdown is shown in Figure 2.

The CPS comprises of two functional elements namely:

1. TMM CPS Functions (TMMCPS).
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.

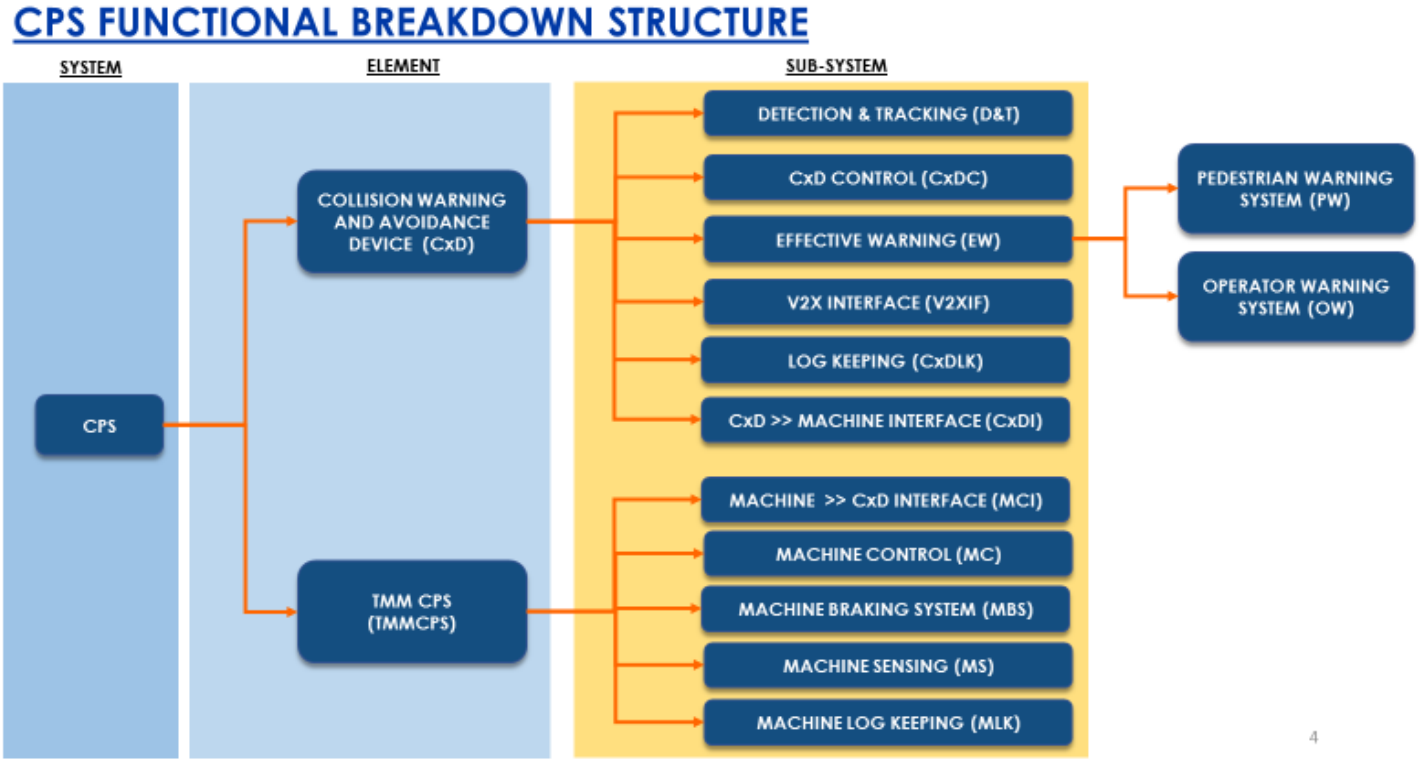


Figure 2: CPS functional breakdown structure.

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

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

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

1. Detection and Tracking functions (D&T).
2. CxD Control functions (CxD).
3. Effective Warning functions (EWS).
4. V2X Interface functions (V2XI).

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

10. F&TP Requirements Structure

The requirements structure is simple and straight forward. The specific performance requirements of every functional subgroup of the CxD element are documented in a separate table, while that of the TMM CPS, is listen in one table. This is due to the limited number of requirements specified for some of the functional subgroups. For V2X, CxDI and MCI, the functions are not tabulated, but only listed is a single paragraph. This is because the interface functions are all defined in a single international standard and does not need detail repeating and the V2X standard is still to be determined. The tables are structured as follows:

- **Column 1** is a F&TPR number.
- **Column 2** is the functional group.
- **Column 3** is an indicator for a Functional (F) or Technical (T) requirement.
- **Column 4** is the F&TPR Name.
- **Column 5** is the F&TPR Description.
- **Column 6** is the F&TPR Criteria. (S and U are used to denote Surface and or Underground TMM requirements).

Generic Technical Performance Requirements are documented under that heading with the same structure.

Specific Technical Performance Requirements related to one functional group only are listed at the end of the function group.

11. F&TP Requirements

11.1 CxD

The functional and technical requirements of the CxD are structured as per Figure 1 in the following functional groups:

- Detection and Tracking Functions (D&T).
- CxD Control Functions (CxDC).
- Effective Warning Functions (EW).
  - Operator Warning Functions (OWS).
  - Pedestrian Warning Functions (PWS).
- CxD V2X Functions CxDV2X.
- CxD Log Keeping Functions (CxDLK).
- CxD to Machine Interface Functions CxDI.

11.1.1 Detection and Tracking Functions (D&T)

The Detection and Tracking performance requirements are documented in **Table 1.**

Req No	Function group	Function Name	F/T	Function Description	Performance Criteria
0	D&T	Detect and Track	F	The DTS must detect and track TMM(s) (S) or pedestrian(s) (U)) within the detection area of the TMM. The DTS must know important characteristics of all potential interactors in the detection area	S&U: See lower level functions
1	D&T	Detect	F	Detect the presence of any TMM or Pedestrian (S & U respectively) within a predefined detection area.	S&U: latency < 0.5s 5% detection accuracy S: 99% detection of **7** machines simultaneously U: 99% detection of 10 pedestrians simultaneously S: 200m minimum U:30m minimum
1.1	D&T	Detect in all machine statuses	F	DTS must maintain full functionality in all machine statuses	S & U: bucket raised boom extended machine articulated TMM towing TMM and trailer machine drilling

1.2	D&T	Detect robustly	F	DTS must be able to detect ROs in all reasonably foreseeable environmental conditions	S&U: direct and indirect detection no blind spots blind rise dust see general requirements U: rock penetration S: rain, wind steep angle - working on dump side
1.3	D&T	Be interoperable	T	DTS must be able to detect ROs from all other CPS fitted TMMs from different OEMs. Due to unavailability of a standardised V2X communication protocol the SAMI agreed that only one CxD product will be used per site.	S: detect all CPS fitted TMMs on a particular site U: detect all CPS fitted pedestrians on a particular site U: Underground TMM to be treated as Surface TMM when exiting decline. Requirement = TBD
2.0	D&T	Track potential interactors	F	Maintain detection while RO(s) is/are moving in detection area	S: track 7 machines simultaneously no dropouts speed up to 50km/h may not identify one of the TMMs as an 8th or more TMMs must be the same object throughout U: track 10 pedestrians simultaneously also in machine footprint no dropouts may not identify one of the pedestrians as a 11th or more pedestrians must be the same objects maintained throughout
2.1	D&T	Track velocity	F	Estimate, measure or receive its LO TMM velocity and that of any other TMM (RO) within the detection area	S only: accurate to within 0.5 km/h
2.2	D&T	Determine distance	F	Measure or estimate the distance to any TMM (S) or Pedestrian (U) within the detection area	S: 200m distance, 5% accurate or 0.5m, whichever is larger U: 30m distance, 5% accurate or 0.25m, whichever is larger

2.3	D&T	Determine direction	F	Determine the direction of any RO (TMM or Pedestrian) towards the LO (TMM) within the detection area	S: accurate to within 2 deg U: accurate to within 5 deg
2.4	D&T	Determine heading	F	Estimate or measure or receive the heading of any TMM within the detection area	S only: 2deg accurate
3.0	D&T	Interface with CxDC	F	Communicate with CxDC	S&U: as per CxD developer standards
4.0	D&T	Pedestrian and beacon detection failure	F	Pedestrian (U) sensors and beacon (S&U) must communicate a failure to the CPS when failure mode is detected	S&U: off-board elements (such as cap lamps, beacons) fail to safe when a fault is detected.

Table 1: D&T functional requirements

11.1.2 CxD Controller Functions (CxDC)

The CXD Controller requirements are documented in **Table 2.**

Req No	Function group	Function Name	F/T	Function Description	Performance Criteria
0	CxDC	Quantify collision risk and intervene	F	CxDC must determine if it has enough information to determine if a collision is imminent and intervene to prevent it from happening	S&U: See lower functions
1	CxDC	Communicate/interface	F	The CxDC must receive and exchange relevant data to other LO functions as well as some RO functions. For all ROs fitted with a CxD from the same supplier.	S&U: As per CxD developer standard
1.1	CxDC	Communicate with LO DTS functions	**F**	The CxDC must receive relevant data from the DT to execute its functions effectively	as per CxD developer standards
1.2	CxDC	Communicate with LO TMM MCI	F	Communicate with MC via MCI	ISO TS 21815-2: 2021

1.3	CxDC	Communicate with ROs' CxDC	**F**	The LO CxDC must be able to receive data from all ROs within the detection area and send data to the RO CxD for all ROs fitted with a CxD from the same supplier.	S & U: As per CxD developer standard S: RO status RO state RO position data OWS instructions U: Failure report E - stop instruction RO Position data PW instruction
2	CxDC	Quantify collision risk	F	CxDC must quantify the risk of potential interaction between V-V or V-P respectively by predicting the path of all interactors within the detection area	S&U: See lower functions
2.1	CxDC	Configure stop gaps and following distances	F	The CxDC must register the stop gap for different TMM configurations as well as for pedestrians for different operational processes.	S&U: adjustable as per individual mine requirements adjustable per TMM type adjustable for specific operating processes U: 2.5 m default stop gap S: auto CPS override? When specific TMM Types are below 2km/h in specific operating process area = TBD 2 m default stop gap for "close up" operating scenarios auto CPS override of some functionality? When specific TMM Types are below 2km/h in specific operating process areas only = TBD 15m default stop gap for all non-close up operating scenarios 50m following distance for haulers
2.2	CxDC	RO CxD communication	F	The LO CxDC must interface with the RO CxDC. for CxD supplied by the same supplier.	S only As per CxD provider own standards.
2.3	CxDC	Process RO TMMs' state	F	CxDC must process ROs' TMM state as part of quantifying risk of collision.	S only CxDC takes RO state into account

2.4	CxDC	Predict ROs' (TMMs' and pedestrian's) paths	F	CxDC must calculate paths of interactors and determine vicinity boundary.	S&U: must start prediction from initial movement of ROs path prediction accuracy: 5% of stopgap value must include probability of TMM pulling away from safe-park
2.5	CxDC	Determine collision probability	F	CxDC must determine the probability of a potential collision of every detected RO. Multiple collisions must be prioritised based on the probability.	S: prioritise most likely potential collision (highest risk) of up to 7 TMMs U: prioritise most likely potential collision of up to 10 pedestrians
2.6	CxDC	Predict LO path	F	CxDC must calculate paths of interactors and determine vicinity boundary	S&U: prediction must start from initial movement of LOs path prediction accuracy: 5% of stopgap value must include probability of TMM pulling away from safe-park
2.7	CxDC	Receive TMM LO Status	F	The CxDC must receive the status of a TMM in all different operational processes Some of the data required will come from the TMM and others from the CxD solution. The following to be received from the TMM: • Towing • Broken Down • Bucket raised Boom extended	S&U: refuelling, towing, broken down, drilling, dumping, loading, bucket raised, boom extend
2.8	CxDC	Process LO TMM status	F	CxDC must know TMM status and adjust stop-gaps	S&U: adjust stopgap values as per configuration.
2.9	CxDC	Configure LO TMM type	F	CxDC must be able to configure the different TMM types	S&U: Haul Truck, LHD, Water Cart/Bowser, Diesel Bowser, grader, road roller, LDV, FEL, Excavator, Bulldozer etc. Full list to be agreed.
2.10	CxDC	Process LO TMM Type	F	CxDC must know TMM type and adjust stop-gaps	S&U: CxDC takes LO and RO type into account

2.11	CxDC	Process LO's CPS delays	F	CxDC consider all CPS sensing and computational delays as part of quantifying risk of collision	S&U: ensure stop gap tolerance 5% including all delays
2.12	CxDC	Configure TMM retardation curves	F	CxDC consider all TMM retardation curve per TMM type and model	S&U: register retardation curves (as per OEM specification)
2.13	CxDC	Process LO's retardation curves	F	CxDC consider specific TMM retardation curves as part of quantifying risk of collision	S&U: CxDC takes LO retardation curves into account
2.14	CxDC	Process RO TMMs' status	F	CxDC must process ROs' TMM status as part of quantifying risk of collision	S&U: CxDC take RO status into account
2.15	CxDC	Process ROs' TMM type	F	CxDC must process ROs' TMM type as part of intervention	S only: CxDC takes RO type into account
2.16	CxDC	Configure Operator delay	F	CxDC must facilitate operator response delay	S&U: 2.5sec
2.17	CxDC	Process operator reaction time	F	CxDC must consider operator reaction time as part of predicting stopping distance	S&U: 2.5s from effective warning ensure stop gap tolerance 5% including effective warning delay
3	CxDC	Determine EW details		CxDC must determine what the effective warning is and communicate it to OW and PW respectively	S&U: as per developer specification
4	CxDC	Decide intervention strategy	F	CxDC must decide on appropriate intervention strategy	S&U: See lower functions
4.1	CxDC	Ensure Normal Operations	F	If collision risk level is below threshold level, CxDC must allow normal operation	S&U: threshold = outside vicinity zone boundary no false interventions and warnings
4.2	CxDC	Action intervention for high risk scenarios	F	If collision risk level is above threshold, CxDC must be able to initiate appropriate intervention strategy	S&U: TMM intervention successfully initiated in all cases Intervention strategy must use TMM capability as reported by TMM during ISO21815 negotiation sequence. Intervention strategy to be consistent and repeatable
4.3	CxDC	Decide intervention strategy considering operating rules	F	Intervention strategies must consider unique parameters, rules and scenarios with regards ROs	See lower level functions
4.3.1	CxDC	Escort vehicle	F	Must allow vehicle to be escorted by CPS enabled TMM	S&U: one escorted vehicle only

4.3.2	CxDC	Priority TMMs	F	Intersections require priority TMMs not to slowdown and stop	S&U: emergency Vehicles S only: TMMs prioritized according to mine traffic management plan
4.3.3	CxDC	Overtake slow moving TMM	F	Must prevent slow moving TMM (e.g. FEL) from overtaking another slow moving TMM (e.g. grader)	S only: retain specific following distance.
4.3.4	CxDC	Overtake slow or broken down TMM	F	Must allow TMM to overtake slow or broken down TMM if safe to do so	S only: ensure specific speed restriction(s) prevent collision with oncoming TMMs
4.3.5	CxDC	Exclusion zones	F	Must allow for LDV exclusion zones to accommodate safe parking areas for LDVs in congested HME operational areas (Loading, Dumping, Hard Park, Workshops etc.)	S only: LDV can only enter area to safe park if all HMEs are in safe park HMEs can operate as normal while LDVs are parked in exclusion zone LDVs cannot exit exclusion zone unless TMMs are in safe park HMEs cannot enter exclusion zone
4.3.6	CxDC	Maintenance and support TMMs	F	If support/services TMM enters the working area (e.g. water bowser in dump/pit) all other TMMs must be in safe park	S only: allow service vehicles only to approach TMM that is in safe park prevent TMM to exit safe park while service vehicle is inside 30m radius from TMM
4.3.7	CxDC	Queuing	F	Enable queuing of TMMs (e.g. waiting at dump/pit/hard park) and prevent overtaking (jumping the queue)	S only: queuing in specific operational processes only CxDC does not allow overtaking in queue specific following distances ensured speed restriction upheld in case of breakdown in queue, mine standard operating procedure followed to allow passing of breakdown

4.3.8	CxDC	Loading	F	Enable loading of truck by excavator / shovel / FEL	S only: specific TMM types only no passing allowed engine running allowed vicinity boundary reduced to xm adjustable enable auto CPS override when specific TMM Types are approaching below 2km/h and at xm apart (Mines to decide) reset auto CPS override when specific TMM Types are above 2km/h or more that 5m apart and moving away from each other
4.3.9	CxDC	Hard park control	F	Prevent collisions in hard park	S only: prevent collisions in hard park ensure minimum following distance based on Hard park speed limit ensure hard park speed limit orderly TMM entrance and departure
4.3.10	CxDC	Brake testing	F	Prevent TMM from entering or exiting brake test ramp if occupied by another TMM	S only: TMM to enter ramp only when tested TMM exit the brake test ramp.
4.3.11	CxDC	Pit Ramp Entrance	F	Prevent collisions at pit ramp entrances	S only: ensure approaching TMM stop before turning/entering the pit ramp. ensure approaching TMM cannot enter ramp if another TMM is at ramp entrance
4.3.12	CxDC	Pit Ramp	F	Prevent collisions on pit ramps	S only: ensure no entry of TMM onto ramp when another TMM is at ramp entrance ensure TMM stops at ramp entrance, ensure TMM maintains correct gear and retarder (when fitted) down ramp, maintain speed limit down ramp, maintain following distances (xm)

4.3.13	CxDC	Underground decline	F	Prevent runaway on decline	U only: ensure no entry of TMM onto decline when another TMM is at decline entrance ensure TMM stop at ramp entrance, select correct gear, select retarder when fitted maintain speed limit maintain following distance (xm)
4.3.14	CxDC	LDV/Service Vehicle - HME proximity	F	Must prevent HME to LDV/service vehicle collisions in operational areas where HME are working, ie Pit, dump. (This requirement is not applicable to roads!)	S only: LDV/service vehicle can approach HME when HME has engaged safe park (park brake engaged, neutral, engine off) 30m radius before entry
4.3.15	CxDC	Prevent unauthorised access	F	Must be able to detect restricted areas via beacons or geo fence and prevent unauthorised TMMs from entering a restricted area based on TMM type (HMEs and LDVs segregated)	S&U: CxDC must prevent the TMM from entering restricted areas
5	CxDC	Communicate effective warnings and TMM interventions	F	CxDC must communicate effective warnings and TMM interventions to all relevant LO and RO functions	See EW functions
5.1	CxDC	Communicate effective warning to OWS	F	Communicate specific operator actions to OWS	S&U: specific warning: slow down and stop or stop
5.2	CxDC	Communicate PWS Warning	F	Communicate warning to PWS	U: specific warning: TMM alert (TBD) Continuously communicate, also during auto slow and stop
5.3	CxDC	Communicate EW and intervention instructions data to CxDLK	F	Communicate effective warning and auto slow and stop interventions to CxDLK for log keeping	S&U: log keeping must start 5s before potential interaction at a rate of 10Hz see CxDLK functions
5.4	CxDC	Communicate TMM interventions to central control room/authorised person	F	CxD must communicate all interventions to central control room/authorised person	S&U: interventions reported to central control room or cell phone communication standards
6	CxDC	Isolate operators & passengers	F	Provide effective exclusion zone to ensure operators and passengers do not trigger warnings from inside the cab;	See lower functions
6.1	CxDC	Isolate operators & passengers: Pair	F	Pair operator and passengers with TMM when inside the TMM	U only: no false warnings any number occupants

6.2	CxDC	Isolate operators & passengers: detect pedestrians	F	Upon approaching non safe-parked TMM, passengers must be protected from TMM	U only: see D&T functions
6.3	CxDC	Isolate operators & passengers: Unpair	F	Upon exiting safe parked TMM, unpair passengers	U only: <0.5 sec after door opens No false warnings
7	CxDC	Configure TMM information	F	The CxD must be able to register TMM information	S&U: See lower level functions
7.1	CxDC	Identify TMM	F	Each TMM must have a unique ID for log keeping purposes	S&U: The CxD must be able to accommodate TMM unique numbers (Alpha-numeric up to 16 characters)
7.2	CxDC	Identify operator	F	Each operator must be assigned a unique ID that can be registered when operator starts his/her shift for log keeping purposes	S&U: biometric or electronic access card
7.3	CxDC	Identify pedestrians	F	Each pedestrian must be assigned a unique ID that can be registered when operator starts his/her shift for log keeping purposes	U only: Use cap lamp function
7.4	CxDC	Register speed limits	F	The CxD must be able to demarcate operational areas and sections of roads with specific speed limits associated to it so that the CPS intervention strategies remain functional	S&U: physical location based – road sections, operational processes, operational areas variable speed limits
8	CxDC	Prohibit unauthorised use	F	CxDC must prevent unauthorised use of the TMM	S&U: TMM is prevented from operating if operator is not authorised
9	CxDC	Provide a pedestrian activated emergency stop	F	CxDC must be able to stop all TMMs in the area when a pedestrian activates an emergency button/function	U only: all machines in detection area slow down and stops when emergency function is activated
10	CxDC	Override CPS	F	Override LO CPS in emergency situations by authorised person by means of a code or an RFID card.	S&U: only overrides LO by authorised person TMM can move at predetermined "emergency" speed limit. only for limited period - variable
11	CxDC	Control maximum TMM speed	F	The CxDC must prevent the TMM from exceeding speed limits to ensure that the CxDC's intervention strategy remains effective	S&U: ensure speed restriction within 1km/h from the CPS design speed no speed limit being exceeded timeous intervention

					+- 2m accurate S: for GPS = absolute accuracy, maximum CPS design speed 40km/h
12	CxDC	Return to normal operation.	F	After collision has been successfully prevented, the CxD must allow the TMM to return to normal operation	S&U: authorised person activation only (bio metric or electronic access card) CxDC must allow system to return to normal operation repeat initiation/start-up sequence
13	CxDC	Initiate FTS	F	Upon detection or reporting of any CPS failure message, the CxD must initiate a fail to safe intervention	S&U: within 100ms from receipt of failure message warn operator – CPS failure

Table 2: CxDC performance requirements.

11.1.3 Effective Warning Functions (EW)

The Effective Warning performance requirements are documented in **Table 3.**

Req No	Function group	Function Name	F/T	Function Description	Performance Criteria
0.0	EWS	Provide effective warning		An effective warning must be provided to all operators and pedestrian(s) in case of a potential collision	See lower level functions Formal human factors and people centric design outcomes.
1.0	EWS	Provide concise warning	T	The system must avoid repetitive alarms issued for the same collision	S&U: no more than 3 repetitive alarms per vicinity detection/ continuous warning even during auto slow-down and stop intervention
2.0	EWS	Communicate only highest priority	F	Operators and pedestrians must only be warned of the collision with the highest priority	S&U: display element clearly indicates RO with highest collision priority audible warning should only address highest collision priority
3.0	OWS	OWS must be the outcome of human centred design	T	Ergonomics of operator cabin should not be compromised due to improper positioning of components	S&U: must be able to accommodate 5th percentile Female and 95th percentile Male
3.1	OWS	Simultaneous warning	F	Simultaneous warning to operators (s) or operator and pedestrians (U) of CPS fitted TMMs from the same CxD provider irrespective of type, brand or model.	S&U: communication with all other TMMs EW functions, as per CxD provider's own standards
3.2	OWS	Be audible	F	An audible warning shall be provided to all operators inside the vicinity	S&U: 10 dB above ambient. 5 x programmable language sets (TBD) programmable volume setting only (operator must not be able to turn off the volume clear voice instruction
3.3	OWS	Communicate unambiguously	F	Clearly provide the operator with the correct action to be taken to prevent the potential collision (based on instruction from the CxDC).	S&U: use verbal and visual communication use appropriate icons specific instructions: slow down and stop validated with representative sample of TMM operators

3.4	OWS	Provide visual warning indicator	F	A visual warning shall be provided to all operators in the interaction	S&U: Cab interior to be lit up with a non-intrusive but clearly visible light at the time that the operator must take action
3.5	OWS	Provide visual information display	F	A visual information display shall be provided for each CPS fitted TMM	S&U: minimum size is 150mm x150mm 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 SANS 259 (operator field of view) display location approved by TMM OEM display to be backlit automatic brightness adjustment a) bright enough to be viewed in sunlight 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 multi-mode display e.g. default, map, failure, configuration, health, shift summary, etc. display battery health on all modes display current date and synchronised time
3.6	OWS	Single CPS visual display	F	Provide one Visual display for all CPS needs.	S&U: Integrate all CPS display requirements into single visual display. Multi-mode display of types of information
3.7	OWS	Display CPS health and fault information, inform operator	F	OWS must display all CPS failure modes and CPS health information. Warn operator when system fails.	S&U: fault mode screen faults are displayed per functional breakdown standardised fault codes and icons sufficient info for quick component replacement specific warning: CPS failure

3.8	OWS	Display power supply health	F	The backup battery charge level must be displayed on the display element	S&U: battery backup charge level is displayed as a percentage operator is warned if charge level falls below 20% specific verbal warning CPS battery low
3.9	OWS	Display mini map	F	Operators must have a display element that displays all detected ROs' position and heading within the detection area	S&U: display element showing all detected ROs' position and heading highest risk RO must flash ROs must be shown on the display element in relation to the normal driving position of the operator auto map switch-off on auto slow and stop instruction
3.10	OWS	Remain functional in the presence of multiple interactors	F	Display element should function correctly independent of the number of interactors within the detection area	S&U: mini map must not be cluttered, display must not freeze up with bigger data load
3.11	OWS	Provide speed limit warning	F	OWS must warn operator when he/she is about to exceed the programmed speed limit	S&U: operator warned when speed is close to (within 2km/h) of the speed limit verbal warning: speed restriction x km/h visual warning: TBD continuous warning while above limit
4.0	PWS	Provide effective warning to pedestrian	F	Pedestrian must be effectively warned of any TMM in the vicinity	see lower level functions
4.1	PWS	Be audible	F	An audible warning shall be provided to all pedestrians in the vicinity zone	U only: 10 db. above ambient attract but not distract pedestrian attention
4.2	PWS	Be visible	F	Light on cap lamp flashes in sight of pedestrian when pedestrian inside TMM vicinity	U only: Light (LED) flashes at different speeds and different colours for TMM in vicinity.
4.3	PWS	Pedestrian mobility	T	PWS elements may not hinder the movement of any body parts of the pedestrian	U only: element design takes pedestrian ergonomics into account EN13921:2007 validate with representative sample of pedestrians
4.4	PWS	Pedestrian fatigue	T	PWS elements must be light enough that a pedestrian can carry it for an entire shift.	U: takes pedestrian ergonomics into account EN13921:2007

4.5	PWS	Pedestrian emergency stop	F	Pedestrians must have emergency stop button/function that can be used to stop all TMMs inside the detection area	U only: Emergency stop all machines in 30m detection area Button must system in place to prevent accidental activation
4.6	PWS	Unique pedestrian ID	F	PWS must have function to uniquely identify pedestrians	U only: pedestrian tag/cap lamp has unique ID number that is associated with a specific pedestrian

Table 3: EW performance requirements.

11.1.4 V2X Functions (V2X)

The standard for V2X standardisation of CPS products is still TBD.

11.1.5 CxD Log Keeping Functions (CxDLK)

The CxD Log Keeping performance requirements are documented in **Table 4.**

Req No	Function group	Function Name	F/T	Function Description	Performance Criteria
0	CxDLK	Provide CPS log keeping functionality	F	Log and provide a permanent auditable record of all specified information sets	S&U: see lower level functions
1	CxDLK	Synchronise	F	CxD and TMM logs must be synchronised with a Universal Time Frame	S&U: UTC + 2h synchronised every hour Less than 100ms discrepancy between time stamps of CxD and TMM logs
2	CxDLK	Record continuously	F	Record functions continuously at 1Hz	S&U: record data continuously at 1Hz
3	CxDLK	Store TMM ID data	F	Store the LO unique identification and configuration data	S&U: non-volatile data storage
4	CxDLK	Date and time stamp	F	Uniquely identify every data entry by date and timestamp per data type.	S&U: UTC + 2h
5	CxDLK	Receive and store CxD data	F	Receive and store data from all CxD functions	S&U:

					data receipt capability at 1Hz continuously non-volatile data storage capability of 30 days before overwriting
6	CxDLK	Data Transfer	F	Provide for periodic data transfer to mine data infrastructure	S&U: at least once per shift Wi-Fi, Local Area Network (e.g. Ethernet), Personal Area Network (e.g. Bluetooth), USB / serial, removable storage;
7	CxDLK	Data Security	F	Provide data security for stored and transfer of data	S&U: as per specialist recommendation
8	CxDLK	Store data redundantly	F	Log keeping must be done on multiple independent storage devices	S&U: at least 2 fully independent storage devices used to record and store data (RAID)
9	CxDLK	Store firmware configuration	F	Store the current version of all CPS firmware elements	S&U: unique ID and revision date installed/updated
10	CxDLK	Record unique ID for all interactors	F	The unique IDs for every interactor must be recorded during interaction	S: all TMMs inside the detection area U: all pedestrians inside the detection area
12	CxDLK	Record LO and ROs' statuses	F	The status (e.g. refuelling, drilling, etc) of the LO and all ROs within the detection area must be recorded	S: from 10s preceding the interaction, the statuses of all TMMs within the detection area must be recorded U: from 10s preceding the interaction, the status of the TMM must be recorded
13	CxDLK	Record LO system health	F	The CxD and TMM CPS system health must be recorded at every TMM start up and after health status changes	S&U: TMM health status indicators green light on Visual display functional failure red light within 1ms from detection
14	CxDLK	Record LO failure data	F	All failure modes communicated by any CxD or TMM CPS module must be recorded.	S&U: module, fault code, date and time stamp

15	CxDLK	Fail to Safe log keeping	F	CPS must fail to safe when log keeping system does not work	S&U: failure mode communicated to CxDC
16	CxDLK	Record all machine data received via MCI	F	All data communicated via the MCI must be recorded	S&U: from 5s preceding the interaction at 10Hz
17	CxDLK	Record emergency override	F	Relevant data for every emergency override must be recorded	S&U: TMM ID operator ID date and time authorised overrider unique ID duration of override
18	CxDLK	Record interactions	F	Instructions and responses to be recorded at 10Hz for later analysis	S&U: save data at 10Hz 5s before potential interaction
19	CxDLK	Record effective warning	F	All communicated warnings from the CxDC must be recorded by the CxDLK	S&U: save data at 10Hz 5s before potential interaction
20	CxDLK	Record auto slow and stop	F	All communicated auto slow and stop interventions from the CxDC must be recorded by the CxDLK	S&U: save data at 10Hz 5s before potential interaction
21	CxDLK	Record ROs' states	F	The state (e.g. gear, velocity, heading) of all TMMs in the vicinity for surface, and the state (e.g. distance, direction) of all pedestrians for underground within the vicinity must be recorded	S: save data at 10Hz 5s before potential interaction for all TMMs within the vicinity U: save data at 10Hz 5s before potential interaction for all pedestrians within the vicinity
22	CxDLK	Record LO status	F	The LO's status must be recorded at 1Hz continuously	S&U: save status data of the LO at 1Hz continuously
23	CxDLK	Store all data	T	Data gathered at each shift must be stored for a specific period before it is overwritten.	S&U: data must be stored for 30 days before overwriting

Table 4: CxDLK performance requirements

11.1.6 CxD Machine Interface (CxDI)

The CxD Machine interface functional requirements are documented in ISO TS 21815-2: 2021

11.2 TMM CPS

The requirements of the TMM CPS is structured as per figure 1 in the following functional groups:

- Machine Braking System Functions (MBS)
- Machine Sensing Functions (MS)
- Machine to CxD Interface Functions (MCI)
- Machine Controller Functions (MC)
- Machine Log Keeping Functions (MLK)

11.2.1 Machine Interface (MCI)

The Machine to CxD interface functional requirements are documented in ISO TS 21815-2: 2021

11.2.2 TMM CPS Functions (TMM CPS)

The TMM CPS performance requirements are documented in **Table 5.**

Req No	Function group	Function Name	F/T	Function Description	Performance Criteria
0	TMM CPS	TMM CPS Functions	F	The TMM CPS functions must enable an unintelligent TMM the be intelligent to the extent that a fully functional CPS will be available after CxD installation.	See lower level function See General F&T requirements
1	MBS	Provide ability to slow down and stop	F	The TMM must have the physical elements and components to slow down and stop the TMM without operator action	S&U: as per TMM OEM requirements proportional braking brake wear must not exceed OEM brake wear limits per hours of operation (MTBF must remain as per original design intent) S: ISO 3450 U: SANS 1589-3
2	S	Sense parameters	F	The TMM must have the physical elements and components to sense the parameters as is required by the TMM CPS and the CxD	S&U: as per CXD developer requirements as per TMM OEM specifications as required for ISO TS 21815-2: 2021
3	S	Sensor Interface with CxD	F	The TMM sensing data must be interfaced with the CxDC	S&U: as per CXD developer requirements as required for ISO TS 21815-2: 2021

4	MCI	Interface with CxD	F	The Machine Controller must have communication (interface) capability with CxD via MC Interface	S&U: full ISO TS 21815 -2: 2021 functionality including handshaking protocol as per the ISO TS 21815 - 2: 2021 Appendix A
5	MC	Provide auto slow down and stop	F	The TMM must have the control capabilities to control the auto slow and stop	S&U: as per TMM OEM requirements appropriate for different speed and load combinations including TMM fail to safe routine
6	MC	Execute CxD instructions	F	The TMM machine control function must be such that it can execute the CxDC commands, requests and handshaking	S&U: After successful negotiation/handshaking, TMM must be responsive to CxD commands as per CxD developer requirements intervention strategies as informed by ISO 21815 - 2
7	MC	Auto slow down	F	Decelerate TMM to a predefined speed without operator action	S&U: as per TMM OEM specifications ISO/TS 21815-2:2021 makes provision for four interventions in the CxD>>MachineCommand message to slow and/or stop the TMM. The interventions are described in Table 25 of ISO/TS 21815-2:2021. The OEM must provide information to the CxD supplier that specifies the deceleration and machine delay expected for each of these interventions. The deceleration and machine delays shall be determined under controlled conditions as specified in ISO 3450:2011 (for surface machines) and in SANS 1589-1:2022 (for underground machines). The CxD developer should be cognisant of the conditions under which these delays and decelerations are applicable and should make the necessary adjustments should machine braking performance depart from the specifications due to factors beyond the TMM OEM's control (such as a

					decline road, overloaded machine, slippery road surface, etc.).
8	MC	Retain Control	F	TMM must not veer to the left or right from direction of travel when executing CxDC commands	S&U: No wheel lock (sliding) S: ISO 3450 limits U: 10%g or width of TMM from centreline of travel
9	MC	Prevent movement	F	Prevent TMM from swivelling, articulation, boom or scoop activation after auto stop and safe park	S&U: prevent engagement of any gear while in safe park. auto lock articulation, boom movement, scoop movement.
10	MC	Auto stop	F	Stop TMM without operator action	S&U: execute CxD instruction total braking response time < 500 ms S: as per OEM specification (ISO 3450 conditions) mean deceleration, peak declaration stop gap is variable as per mining process. The functionality to be demonstratable at TRL 4. U: as per OEM specification (SANS 1589-3 with >20% variance stop gap is 2,5m default - variable
11	MC	Safe Park	F	Safe Park TMM after auto slow down and stop	S&U: auto engage and lock park brake OR propel inhibit and service brake after execution of CxD or MC initiated auto slow down and stop.
12	MC	Auto slow down and stop safely	T	Auto slow down and stop without negatively affecting operator health and safety	S&U: prevent operator from excessive jerking when stopping
13	MC	Retain operator control	F	Machine control function must allow operator action during auto slow down and stop	S&U: during CxD initiated auto slow down and stop, operator must be able to brake and steer the TMM
14	MLK	Provide TMM CPS log keeping functionality	F	Log and provide a permanent auditable record of all specified information sets	S&U: see lower level functions

14.1	MLK	Synchronise	F	CxD and TMM logs must be synchronised with a Universal Time Frame	S&U: UTC + 2h synchronised every hour Less than 100ms discrepancy between time stamps of CxD and TMM logs
14.2	MLK	Record continuously	F	Record functions continuously at 1Hz	TMM to record and save information sent & received via MI at 1 Hz for 30s prior to an auto slow and stop incident for accident investigation purposes. S&U: Save data
14.3	MLK	Date and time stamp	F	Uniquely identify every data entry by date and timestamp per data type.	S&U: UTC + 2h
14.4	MLK	Receive and store TMM CPS data	F	Receive and store data from all TMM CPS functions	S&U: data receipt capability at 1Hz continuously non-volatile data storage capability of 30 days before overwriting
14.5	MLK	Data Transfer	F	Provide for periodic data transfer to mine data infrastructure	S&U: at least once per shift Wi-Fi, Local Area Network (e.g. Ethernet), Personal Area Network (e.g. Bluetooth), USB / serial, removable storage
14.6	MLK	Data Security	F	Provide data security for stored and transfer of data	As per specialist opinion
14.7	MLK	Store data redundantly	F	Log keeping must be done on multiple independent storage devices	S &U: at least 2 fully independent storage devices used to record and store data (for e.g. RAID or similar backup and data storage redundancy)
14.8	MLK	Store firmware configuration	F	Store the current version of all CPS firmware elements	S&U: unique ID and revision date installed/updated

14.10	MLK	Record LO system health	F	The TMM CPS system health must be recorded at every TMM start up and thereafter when health status changes	S&U: TMM health status indicators green light on Visual display functional Failure red light within 1ms from detection
14.11	MLK	Record LO failure data	F	All failure modes communicated by any TMM CPS module has to be recorded.	S&U: module, fault code, date and time stamp
14.12	MLK	FTS log keeping	F	CPS must fail to safe when machine log keeping system does not work	S&U: failure mode communicated to CxDC
14.13	MLK	Record all machine data sent to CxDI	F	All data communicated via the CxDI must be recorded	S&U: from 5s preceding the interaction, all data communicated through the CxDI must be recorded
14.14	MLK	Record emergency override	F	Relevant data for every emergency override must be recorded	S&U: date and Time duration of override
14.15	MLK	Record interactions	F	Instructions and responses to be recorded	S&U: save data at 10Hz 5s before interaction
14.16	MLK	Record auto slow and stop	F	All communicated auto slow and stop interventions from the CxDC to the MC must be recorded by the MLK	S&U: from 5s preceding the interaction, all auto slow and stop interventions communicated by the CxDC must be recorded as well as the responses from the MC
14.17	MLK	Record LO status	F	The LO's status must be recorded at 1Hz continuously	S&U: the status of the LO must be recorded at 1Hz continuously
15	MLK	Store all data recorded	T	Data gathered at each shift	S&U: Data gathered must be stored for 30 days before overwriting

Table 5: TMM CPS performance requirements.

11.3 CPS General Requirements

All CPS product elements must comply with the requirements as per Table 6.

Req No	Function group	Function Name	F/T	Function Description	Performance Criteria
1	G	Risk informed	T	The CPS and all its individual modules must be informed by formal design risk assessment	S & U: mineral composition a) Coal b) Iron content operator and pedestrian health operator and pedestrian safety environment impact
2	G	Be EMC	T	The CPS must be electromagnetically compatible with other electronic systems on the mine (including detonation systems, V2X) It must not have any negative health impact on operators or pedestrians and no negative functional impact on any other sensing device used on the TMM.	S&U: SANS 13766:2013 human impact: ICNIRP S only: ICASA TA
3	G	Be Robust	T		See lower-level functions
3.1	G	Prevent dust and water ingress	T	CPS must prevent ingress of dust and water (including cap lamp)	S&U: IP67 rating
3.2	G	Survive exposure to shock	T	CPS components must be able to withstand typical vibration, shocks, etc. as normally experienced by TMMs (including cap lamps)	S&U: Mil-STD-810G shock or equivalent
3.3	G	Survive exposure to vibration	T		S&U: Mil-STD-810G vibration or equivalent
3.4	G	Operate at high and low temperatures	T	CPS components able to withstand elevated internal temperatures and external temperatures (high and low) as typically encountered on the mine (including cap lamps)	S&U: Mil-STD-810G temperatures or equivalent
3.5	G	Be intrinsically safe	T	CPS components must not be able to ignite atmospheric mixtures found in mines	U only: SANS: 60079-1
3.6	G	Survive solar radiation		CPS components must be able to withstand high temperatures and photo degradation	S&U: Mil-STD-810G solar or equivalent
4	G	Power supply			See lower-level functions
4.1	G	Out of cab functions	T	Off-board sensors as part must be supplied with suitable power supply (e.g. battery)	S&U: formal FMECA informed last at least 48 hours before recharging
4.2	G	In cab	T	In cab functions must be powered	S&U: Powered via ISO/TS 21815-2:2021 connector

4.3	G	Physical interface	T	Power cables plugs	S&U: ISO/TS 21815-2:2021 connector
4.4	G	Battery backup	T	The CPS must have a power backup capability	S&U: 48h capacity auto charged if battery able to prevent collisions when on power backup
5	G	Be self-diagnostic	F	CPS functional elements to be self-diagnostic and continuously monitor function availability	S&U: be informed by formal FMECA
6	G	Report Failure(s) to CxDC	F	All self-diagnostic functions to report failure(s) to the CxD	S&U: reporting within 100ms As per CxD developer specification ISO/TS 21815-2:2021
7	G	Data Logging	F	The CxD and TMM CPS must have separate data logging capabilities	S & U: See CxDLK and MLK functional requirements
8	G	Installation (Buildability)	T	All CPS physical components and elements to be designed for effective installation	S & U: retrofittable to existing TMMs see lower-level requirements
8.1	G	Mounting	T	Mountings not to deteriorate TMM integrity	S&U: positioned as per TMM OEM specification not be exposed to operational hazards - falling material, TMM articulation not affect structural safety ie. mountings, drilling and welding. not cause operator injury - bumping, nipping, cutting not cause EMI to other TMM systems
8.2	G	Cable routing	T	All cable routing to support TMM maintainability	S & U: positioned as per TMM OEM specification as per appropriate cable specification/standard. 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

9	G	Availability	T	All CPS modules must be designed for availability	S&U: 98% components (CxD and TMM CPS respectively) 95% CxD availability maintained
10	G	Maintainability	T	The CPS to be designed for optimal maintainability	S & U: 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 maintenance spares to be plug and play where applicable maintenance tools to be “special tools” designed for correct removal and fitment.
11	G	Operability	T	All CPS modules to be operable/configured/tested after maintenance or component replacement. CPS not to degrade TMM operating or production capability	S&U: quick reconfigurable/commissioning Not negatively impact TMM operability/production capability – as per TMM OEM specifications
12	G	Reliability	T	All CPS modules must be designed for reliability	Formal FMECA informed CPS MTBF > 2000 operating hours redundancy if required
13	G	Identification and marking	T	All CPS modules and sub systems to be uniquely identified and marked	item no item name serial number version physically marked data stored in CxDLK/MLK as relevant data displayed on OW display on request.
14	G	Firmware requirements	F	Version controlled and electronically updatable	unique identifier version date installed or last updated updatable via TBD recommissioned after update data logged specifically

15	G	Reporting	F	The CPS must have a reporting, trending and business intelligence function that is configurable by the mine	S&U: Requirements are TBD.
16	G	Safety integrity	T	The CPS must be designed for safety integrity	S&U: Comply with GMG GUIDELINE FOR APPLYING FUNCTIONAL SAFETY TO AUTONOMOUS SYSTEMS IN MINING - 18 Aug 2020
17	G	Off board components	F	Off-board components/units must initiate a fail to safe instruction when they fail.	S&U: Initiate FTS
18	G	Calibration	T	All relevant components and/or modules must be calibrated	S&U: Calibration items identified specifically Calibration specifications including frequency and calibration standards.

Table 6: CPS general performance requirements.

12 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] MIL-STD-810G: 31October 2008: Environmental engineering considerations and laboratory tests.

[3] ISO 3450:2011: Earth-moving machinery — Wheeled or high-speed rubber-tracked machines — Performance requirements and test procedures for brake systems.

[4] SANS 1589-3: 20xx: The requirements for brake systems of Underground Trackless Mobile Machines. Part 3: In-service brake testing (trailers excluded).

[5] SANS 13766:2013 Edition 1: adopted from ISO 13766: Earth-moving machinery — Electromagnetic compatibility.

[6] SANS 1717-3 (2007): The design and approval of detonator initiation systems for use in mining and civil blasting applications. Part 3: Controlled blasting systems.

[7] ICNIRP Guidelines for limiting exposure to electromagnetic fields (100 KHZ TO 300 GHZ).

[8] ISO 2631-5:2018: Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 5: Method for evaluation of vibration containing multiple shocks

[9] The Global Mining Guidelines Group (GMG) 18 Aug 2020 Publication: GMG Guideline for Applying Functional Safety to Autonomous Systems in Mining.

[10] SANS 60079-1:2015: Edition 5: IEC 60079-1:2014: Edition 7: Explosive atmospheres Part 1: Equipment protection by flameproof enclosures “d”.

[11] BS EN 13921:2007: Personal protective equipment. Ergonomic principles.

[12] ISO/IEC/IEEE 15288:2015: Systems and software engineering — System life cycle processes.

.