READINESS CRITERIA FOR COLLISION PREVENTION SYSTEMS DEVELOPMENT AND DEPLOYMENT

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

REV 1

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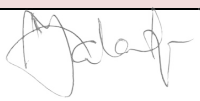
Stanford Malatji	**Minerals Council**		20/10/2025

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Definitions and abbreviations

The following definitions and abbreviations are used in this document

Table 1: Abbreviations and their definitions appearing in this document

Abbreviation	Definition
Accelerated Development	Developing of CPS products in a coordinated integrated way that will require less time (for the entire SAMI need) than the previous supplier driven CPS product development approach.
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)
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 effective warning or collision avoidance functionality.
CxDI	CxD Interface
CxDMI	CxD Machine Interface
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 decomposed 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), direction or position of perceived danger.
DMPR	Department of Minerals and Petroleum Resources
EW	Effective Warning
Effective Warning (Surface)	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.
Effective Warning (Underground)	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.
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMESRT	Earth Moving Equipment Safety Round Table
Employee	“Employee” means any person who is employed or working at a mine.

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.
FMEA	Failure Mode and Effects Analysis
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.
ICASA	Independent Communications Authority of South Africa
ICMM	International Council on Mining and Metals.
Independent	Separate from the CPS product developer. Note: Independent does not imply 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/DTS21815-2:2021 2. The user interface – Also sometimes referred to as the Graphic User Interface (GUI) if 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, 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.
Integrated Testing Regime	A holistic method of testing, optimising existing testing facilities that are currently available irrespective of who is owning them, ensuring specific CPS tests are only done once (CxD, TMM CPS Product combinations) and verification are done as early in the development process as possible.
Loss of control	The uncontrolled movement of a TMM due to operator, machine or environmental reasons. Note: Section 8.10.3 of the MHS Act. Loss of control may result in several scenarios: • Machine failure – park brake or service brake, tyre blowout, • Operator disabled – fatigue, medical condition, inattention, distraction, non-compliance with TMP rules (e.g., over speeding on decline, overloading)
MBS	Machine Braking System: The CPS module providing CPS braking functionality.
MC	Machine Controller: The TMM CPS module that provides the control functions to a non-intelligent TMM.
MCxDI	Machine Controller CxD Interface: The TMM CPS Product Module providing integration between the TMM CPS Product and the CxD.
MHS Act	Mine Health and Safety Act No. 29 of 1996 and Regulations. [1]
MHSC	Mine Health and Safety Council.
Minerals Council	Minerals Council South Africa.
MOSH	Mining Industry Occupational Safety and Health.
MRAC	Mining Regulations Advisory Committee.
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.
Quality Assurance	Verifying a process, product, or service; usually conducted by a person experienced in the specific field.
Reasonably practicable measure	Reasonably practicable means practicable having regard to:(a) the severity and scope of the hazard or risk concerned, (b) the state of knowledge reasonably available concerning that hazard or risk and of any means of removing or mitigating that hazard or risk, c) the availability and suitability of means to remove or mitigate that hazard or risk, and (d) the costs and the benefits of removing or mitigating that hazard or risk.
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.
SE	Systems Engineering: Systems engineering is an interdisciplinary field of engineering and engineering management that focuses on how to design, integrate, and manage complex systems over their life cycles.
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[2] 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.
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 15288:2015).[3])
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.
This document	Readiness Criteria For Collision Prevention Systems Development
TMM	Trackless Mobile Machine. (Machine, vehicle, etc.)
TMLP	Traffic Management Leading Practice. The MOSH Traffic Management Leading Practice for Open Cast/Cut mines in South Africa.
TMM OEM	Original Equipment Manufacturer of TMMs. Original Equipment Manufacturer of a TMM may be the organisation which originally supplied, or last rebuilt or modified the TMM or the supplier per section 21 of the Mine Health and Safety Act, 1996 (Act No. 29 of 1996). [1])

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.
TMLP	Traffic Management Leading Practice. The MOSH Traffic Management Leading Practice for Open Cast/Cut mines in South Africa.
TRL	Technology Readiness Level. A technology maturity framework for measuring and monitoring technology maturity in 9 increasing levels from TRL 1 to TRL 9.
V2X	Vehicle to Anything.
V2XI	Vehicle to Anything Interface.
VD	Vicinity Detection: The element responsible for detecting TMMs and Pedestrians to prevent TMM collisions as per TMM regulations.
Vicinity (Surface TMMs)	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
Vicinity (Underground TMM and pedestrians)	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.
Walking speed	In the absence of significant external factors, the average human's walking speed is 1.4 meters per second. This is included to help define the crawl speed of vehicles.
V2X	Vehicle to Anything
V-V	Vehicle to Vehicle
V-E	Vehicle to Infrastructure
V-P	Vehicle to Pedestrian
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

1. Purpose of this Document

The document sets out the **criteria** for the progressive maturity for collision prevention systems (CPS) product development and system deployment.

2. Context of this Document

South Africa is the **only** country in the world that has regulated automatic slow down and stop functionality for mining trackless mobile machinery (TMMs). There is not currently any other global **centre of excellence** for CPS, other than the University of Pretoria's Vehicle Dynamics Group.

CPS products exist to primarily deal with **abnormal** operational conditions where a TMM operator(s) or a pedestrian(s) has been incapacitated and a potential collision is imminent, thus putting operators/pedestrians at risk of injury. Therefore, a CPS that fails to perform its intended purpose and results in an injury to operators or pedestrians, respectively, can have very significant **legal** consequences and liabilities for the CPS product suppliers as well as the mine. Furthermore, automatically slowing down and stopping TMMs, if not executed **safely**, can have unintended consequences for the health and safety of TMM operators.

3. Approach to CPS Development

History is full of well-intended initiatives that failed after significant initial progress and even premature celebration of untested products, just to fail before the final mission of the project. Diligence, whilst often misjudged for complexity and cumbersomeness, has proven to be the fastest and cheapest way of achieving complex engineering challenges.
The Systems Engineering discipline, supported by technology maturity frameworks, have built a track-record of ensuring successful projects, especially where safety is at stake, and costs are high. The CPS Development Process is built on acknowledged standards such as ISO/IEC/IEEE 15288:2015,[3] MIL-STD-490B: Draft, 1992 [4] and ISO/FDIS 16290:2013.

Since so much is at stake for all role players, intensified by time pressure, the cutting-edge technology, the safety nature of CPS products and the complexity of the CPS product system, it is critical that unambiguous criteria are available to ensure the fastest and most effective development process for CPS products. The basic approach is: *What is to be done with regards to the CPS and its products in a progressive manner towards maturity, and what are the key criteria that demonstrate achievement of a specific level of readiness?*

The initial MOSH CPS CMS Technical Specification Guideline Review Report highlighted the need for managing the project in accordance with a Systems Engineering approach. In order to define the functional criteria for CPS product development, a maturity framework must first be defined.

The assumption on which the framework is built, is that CPS product suppliers will, as a minimum, follow the principles of ISO/IEC 15288:2008(en), systems and software engineering, if not accredited.

Technology Readiness as a method of measuring the maturity of products during development and deployment stages in a structured way, is a well-known practice for global complex technology product development. Many international standards and industry practices includes this approach. South African CPS Product development requires a CPS ecosystem optimised approach. Readiness criteria, as depicted in figure 1 below, are intended to:

- Enable a logical progression of CPS product development from individual products to the operational system.
- Minimise the development cost for product suppliers as well as mines.
- Ensure a single set of requirements for all CPS providers.

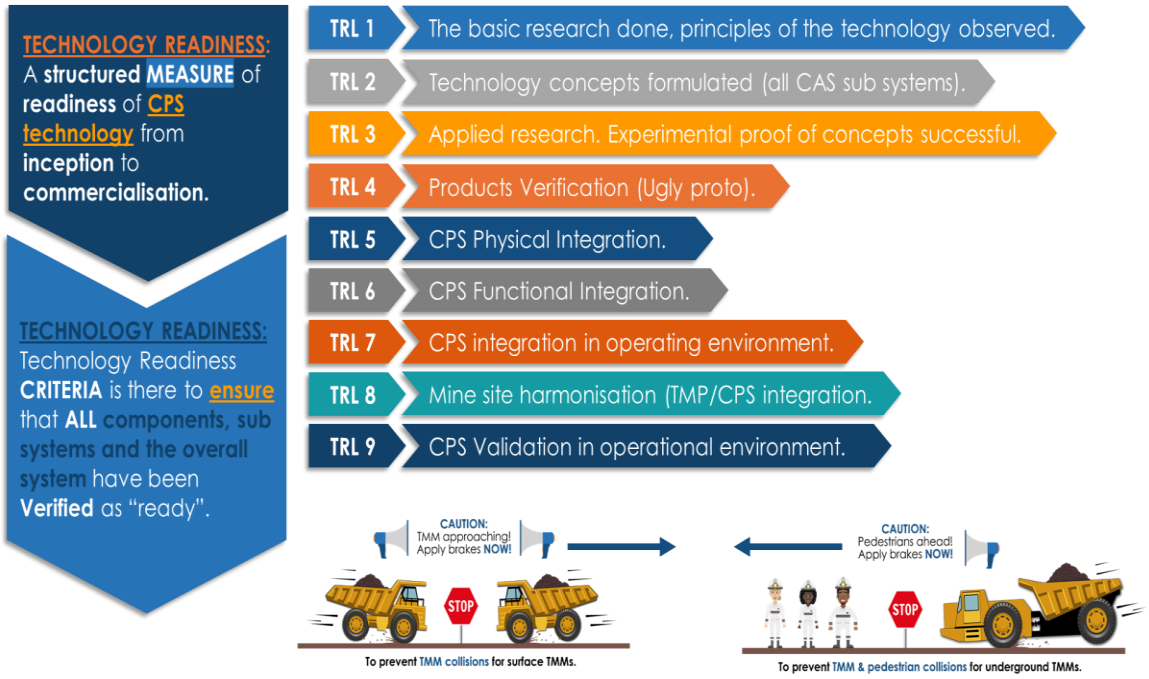

Figure 1: CPS Technology Readiness Levels

The CPS development framework, therefore, is a simple and logical process starting with what is required and ending with confirmation that the system fulfils the mines' need. To provide the reader with context, this section briefly describes the development process activities as shown in Figure 2.

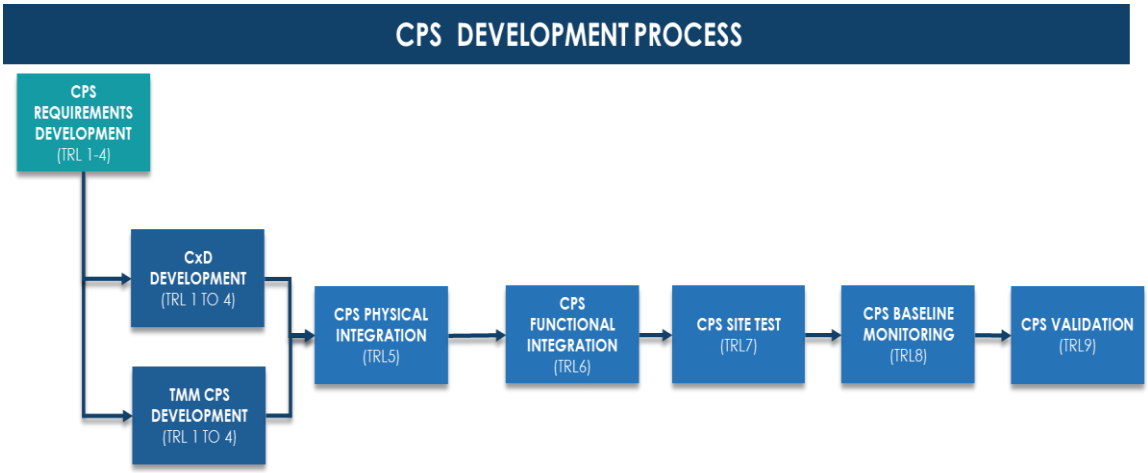

Figure 2: Basic CPS Development Process

CPS Requirements Development (TRL 1 – TRL 4)

Requirements analysis and specification is a foundational aspect of Systems Engineering. The CPS requirements are the key initiator of the process. Besides user and functional requirements, it includes two specific risk mitigation elements, namely the Independent Requirements Verification and Readiness Criteria. The following aspects are covered in CPS Requirements development work.

- Regulatory Analysis
- Alignment with international initiatives (EMESRT and ICMM)
- CPS User Requirements analysis and definition
- CPS Functional breakdown
- CPS Readiness Criteria (Functional, Operational)
- CPS Requirements Verification Regime
- CPS third party testing protocols
- CPS Interoperability challenges and documentation thereof
- CPS EMI and EMC analysis and documentation thereof
- CPS Zone functionality analysis and documentation thereof
- CPS Functional and Technical Performance Requirements

CxD and TMM CPS development (TRL 1 – TRL 4)

TMM CPS and CxD suppliers develop their products individually to fully conform with the requirements specifications.

CPS Physical Integration (TRL 5)

The CPS developer coordinates the physical Integration of the CxD with the TMM CPS and the TMM itself. (The CPS developer is the agreed party between the CxD and the TMM CPS suppliers to assume the integration responsibility).

CPS Functional Integration (TRL 6)

The CPS developer is responsible for the functional integration of the CxD with the TMM CPS. Functional integration is not testing - it can best be equated to CPS commissioning, i.e. controlled execution of basic CPS functions.

CPS Interaction Verification Testing (TRL 7)

This stage in the development is where multiple TMMs are fitted with the CPS and their interactions are tested in a controlled environment on a mine test site or on an off-mine test site. The CPS developer is responsible for the verification tests of the CPS in a representative environment.

Baseline Monitoring (TRL 8)

A key part of the development is the operational readiness and harmonisation of CPS with the specific mine site, in particular, the physical design of the site and the road networks. For CPS to function effectively on the mine the starting point/baseline must be monitored by the CPS integrator to ensure that any teething problems are identified, investigated and resolved. This requires a functional CPS mine site enabling environment. Refer to the operational readiness section for further details.

CPS Validation (TRL 9)

CPS validation is the final CPS development activity. It is the building of a statistical case that indeed the CPS is doing what it is intended to do. This includes monitoring of the technical requirements during an extended period of operation (3-6 months) to demonstrate requirements such as reliability, availability, electromagnetic compatibility and harmonisation with mining processes. It is the CPS product suppliers' final evidence of success.

4. Purpose of Readiness Criteria

Readiness criteria must be considered with reference to the objectives of the regulatory readiness project, namely:

- To ensure technology functionality that will comply to the South African Mining Industry (SAMI) TMM regulations by ensuring a systematic product maturity process. The primary purpose of the work is to ensure alignment of the mining industry stakeholders with the regulations, its direct requirements and its implications.
- To enable large scale rollout of the CPS products and enable timeous compliance as per the regulatory requirements.
- To enable mines to purchase systems that have demonstrated conformance with requirements in order to enable mines to comply with the regulatory requirements in South Africa.

- To ensure CPS products that will have minimum disruption of production on mines due to shortcomings in the Life Cycle System (Ecosystem).
- To ensure a complete set of users, functional and technical performance requirements to achieve above.
- To ensure that important functional and technical performance requirements are translated into test protocols.
- To ensure that technology readiness requirements for successful introduction of the regulations are verified and confirmed.

5. Legal Duty and Liability for CPS

Reg 8.10 only focuses on the CPS as a system to automatically slow down and stop a TMM. As a non-prescriptive and non-detailed legal framework, this is to be expected, since the MHSAct clearly defines the "employer" as the accountable party to the MHSAct. The MHSAct does not interfere with the mine's role to specify, select, contract and ensure conformance of any item of supply, other than provide a high-level functional description of how the CPS must function. Naturally, Reg 8.10 is ambiguous and/or silent when it comes to detail functional and technical performance requirements as it is not for the MHSAct to do the work of the mine and its suppliers. Section 21 of the MHSAct defines the legal duty of the CPS product suppliers.
Since a CPS comprises two distinct products supplied by different suppliers, in as far as the MHSAct is concerned, it is the engineer appointed in terms of Regulation 2.13.1 of the Minerals Act Regulations who is accountable for the CPS in as far as he/she is limited in his/her liability by contractual agreement with the CPS product suppliers.

The MOSH CPS guideline clearly and unambiguously structured the CPS products and developed requirements for the CxDs and TMM CPS' products respectively. Figure 3 depicts the CPS Legal liability structure.

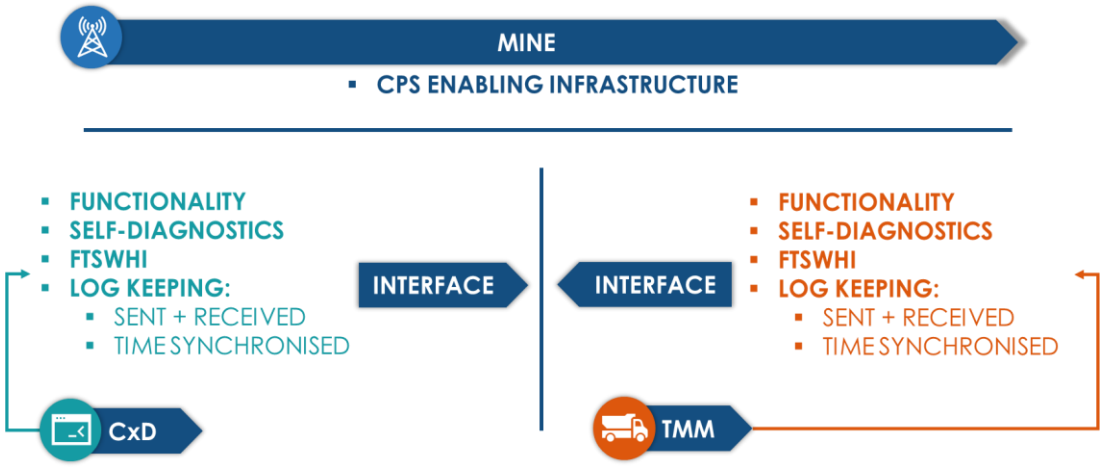

Figure 3: Legal Liability structure of a CPS

This legal structure dictated the CPS Functional and Product breakdown structure as documented in the Surface as well as the Underground CPS User requirements specifications.

6. The Mine's Role in the CPS Development Process

As the ultimate entity with legal liability for successful CPS operation, a mine has the responsibility to establish and verify the entire CPS ecosystem to either integrate with the mine's existing ecosystem or to add elements thereto.

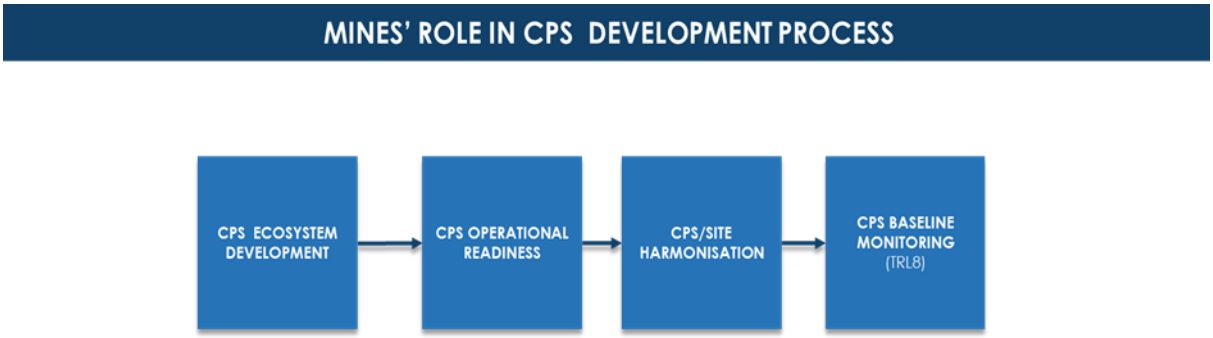

Figure 4: Mine Activities in CPS Development

a. Ecosystem Development

Figure 6 shows a typical CPS ecosystem that a mine needs to establish in order to introduce and sustain CPS on the mine, amongst others:

Figure 5: Typical CPS ecosystem

Risk Analysis

TMM collisions are Priority Unwanted Events PUEs) on mines that must be prevented. The basis of TMM collision prevention is visibility of the actual TMM potential interactions throughout all the mines' roads, operations, and operational areas.

The mine therefore needs to know the actual movement of all TMMs and pedestrians on the mine. Knowing who is going where, when, why and with what is the first step in the process. It provides visibility of the traffic flow on the mine over a period that represents the entry and movement of all TMMs on the mine as well as entering and exiting the mine. Specific emphasis must be put on the beginning and the end of shifts.

Traffic flow analysis is part of an industry Leading Practice can typically be carried out by:

- Identifying high risk areas with mine knowledgeable personnel and planning the traffic flow count and standing at those points and recording the traffic flow.
  Hint: photographic evidence of potential high-risk interaction assists in the risk assessment.
- For surface operations, flying drones and analysing the footage.
- Installing cameras and either using the drone footage or camera video footage for artificial intelligence analysis of the footage.

The risk analysis is the next step in the process. The risk analysis is not intended as a risk grading exercise. The Minerals Council MOSH Learning Hub has facilitated a Traffic Management Leading Practice Adoption Guide for Opencast/Open Pit Operations as well as the MOSH Underground Traffic Management Technical Guide.

The practice and guideline contain extensive guidance and effective controls that a mine can introduce as controls for collision prevention. This document assumes that every mine in the SAMI has access to these guidelines/Leading Practice. It is further assumed that the introduction of the practice/guide is part of the mine's commitment to implement the so called "low hanging fruits" whilst the CPS technology matures.

Physical Collision Prevention Controls

With all the collision prevention controls identified, this phase is to establish those controls physically on the mine. It might include LDV and HME separation, one directional flow, centre berms, intersections, ramp changes, hard parks, workshop area layout changes, etc. This phase will most likely be the longest phase for the mine to get operationally ready as it might require a lot of physical construction work. This work will be the focus of a dedicated project or even projects that will require financial and human resource. Given the fact that the construction work might have to be done during operating hours it will require extensive execution risk assessment and co-ordination of resources or contractors to execute safely.

Processes, Procedures and Standards

This activity includes the updating of all CPS related standards, processes and procedures and access control rules. A specific focus of this activity is the updating of the Mine's TMM Code of Practice to include all the collision prevention controls including the CPS requirements and

references to standards and procedures. Depending on the mine's maturity with reference to traffic management, this will be a key activity, since it will embed the "new way of working" into the mines operational system.

Verification

Section 8 addresses verification in detail and the operational readiness criteria defines the outcomes of the ecosystem that is to be verified.

Proof of conformance

Proof of conformance is primarily achieved via the outputs defined in the supplier's development quality plan that must include the outputs that are defined as requirements criteria. Refer to the Section 21 Technical File Framework document for further detail.

Training

Identification of new and/or modified roles on the mine, establishing training materials & assessments and the timely training of the necessary resources is a foundational aspect of the ecosystem. Training must address operators, maintenance technicians, IT personnel as well as supervisors and managers.

Change Management

Complementary to the mine's management of change process specific attention to the human behavioural aspects of the introduction of CPS is to be given, including communication messages, means and modes as well as mechanisms to check if indeed the relevant employees have adopted the CPS as part of their daily work.

Spares, Maintenance and Support

This aspect of CPS ecosystem is to ensure that all maintenance and support arrangements and processes are in place, such that the CPS can be introduced on the mine without any negative impact on production. It includes whether to do the maintenance inhouse or outsourced.

The Minerals Council knowledge transfer framework has specific relevance to this phase and mines must ensure that they are fully aligned with what the ecosystem approach is and how they can benefit from it. This phase also includes the mines plan for establishing the required skills to support the CPS products.

b. CPS Operational Readiness

Operational Readiness is a mechanism to formally determine the readiness of the mine in terms of the CPS ecosystem. Since there will be multiple mine organisational functions involved the mine's CPS project should have periodic readiness reviews to determine the progress towards readiness for introduction. The readiness evaluation team should include cross functional members and ideally, will have established a readiness questionnaire with specific indicators, such as developed, reviewed, approved, implemented, verified, etc.

c. Site Harmonisation

Site Harmonisation can be equated to cold commissioning of a process plant. It is a period of operation of the CPS without the automatic slow down and stop function activated. The primary purpose being to activate all the CPS ecosystem elements for a specific period, with specific scrutiny of every element and its integration with other elements. This to identify teething issues to be resolved before going live. A specific aspect of the site harmonisation is a focus to identify proximity hotspots, where if the CPS was live, automatic slow down and stop interventions will happen due to physical constraints that is part of the mine's traffic management.

7. Product and Functional Breakdown Structure

As stated before, the CPS product and functional breakdown structure shown in Fig 6 is an extract from the User Requirements Specification. The structure follows the legal liability structure depicted earlier.

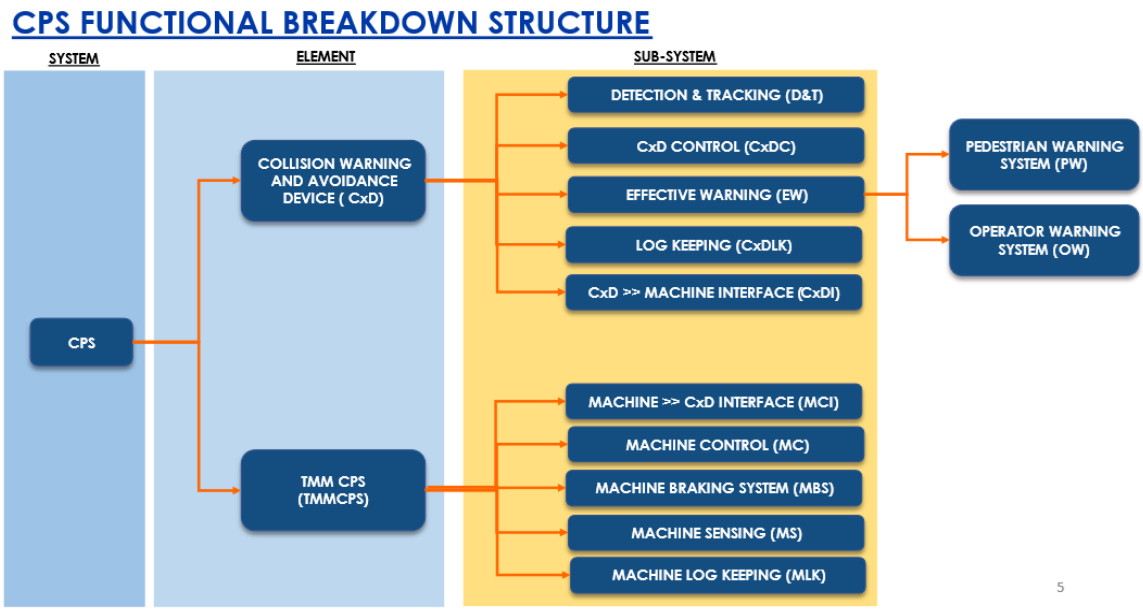

Figure 6: The CPS breakdown structure

The two CPS products are the CxD and the TMM CPS. The CxD functions are broken down into five sub-groups, namely:

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

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)

8. Verification, Validation and Demonstration Testing

For purposes of this document, the following definitions are foundational.

Testing

Testing is a technique performed onto the submitted element by which functional, measurable characteristics, operability, supportability, or performance capability is quantitatively verified when subjected to controlled conditions that are real or simulated. Testing often uses special test equipment or instrumentation to obtain accurate quantitative data to be analysed.

Verification

Verification is a cornerstone aspect of systems development based on Systems Engineering Practice. It is defined as the confirmation, through objective evidence, that specified requirements have been fulfilled. It involves activities that compare a system or its elements against requirements, design descriptions, and other properties. Verification answers the question: Is it conformant to specification?

Verification is sometimes seen as an extra or final proof that something is true. Verification can only happen if a specification exists that has observable and quantifiable criteria.

Validation

Validation is a set of activities that ensure and provide confidence that a system has accomplished its intended use, goals, and objectives. Validation answers the question: Is it effective, i.e. doing what is needed? (not only what is specified)

Verification happens before a product's release, while validation occurs after. This is because verification is typically a key part of the quality assurance process and is necessary for ensuring the functionality of a product before release (Google).

Demonstration

A technique used to demonstrate correct operation of the submitted element against operational and observable characteristics without using physical measurements (no or minimal instrumentation or test equipment).

Demonstration is sometimes called 'field testing'. It generally consists of a set of tests selected by the supplier to show that the element response to stimuli is suitable or to show that operators can perform their assigned tasks when using the element. Observations are made and compared with predetermined/expected responses. Demonstration may be appropriate when requirements or specifications are given in statistical terms (e.g. mean time to repair, average power consumption, etc.)

9. CPS Development and Verification Process

As discussed, a key aspect of CPS introduction into a regulatory environment is verification and validation. The technology readiness framework lend itself to facilitate this.

The functional readiness criteria will cover functional design, integration and testing. Since testing is specifically covered in other documents, this document will not duplicate the definition of testing work and the success criteria; it will simply refer to the testing regime.

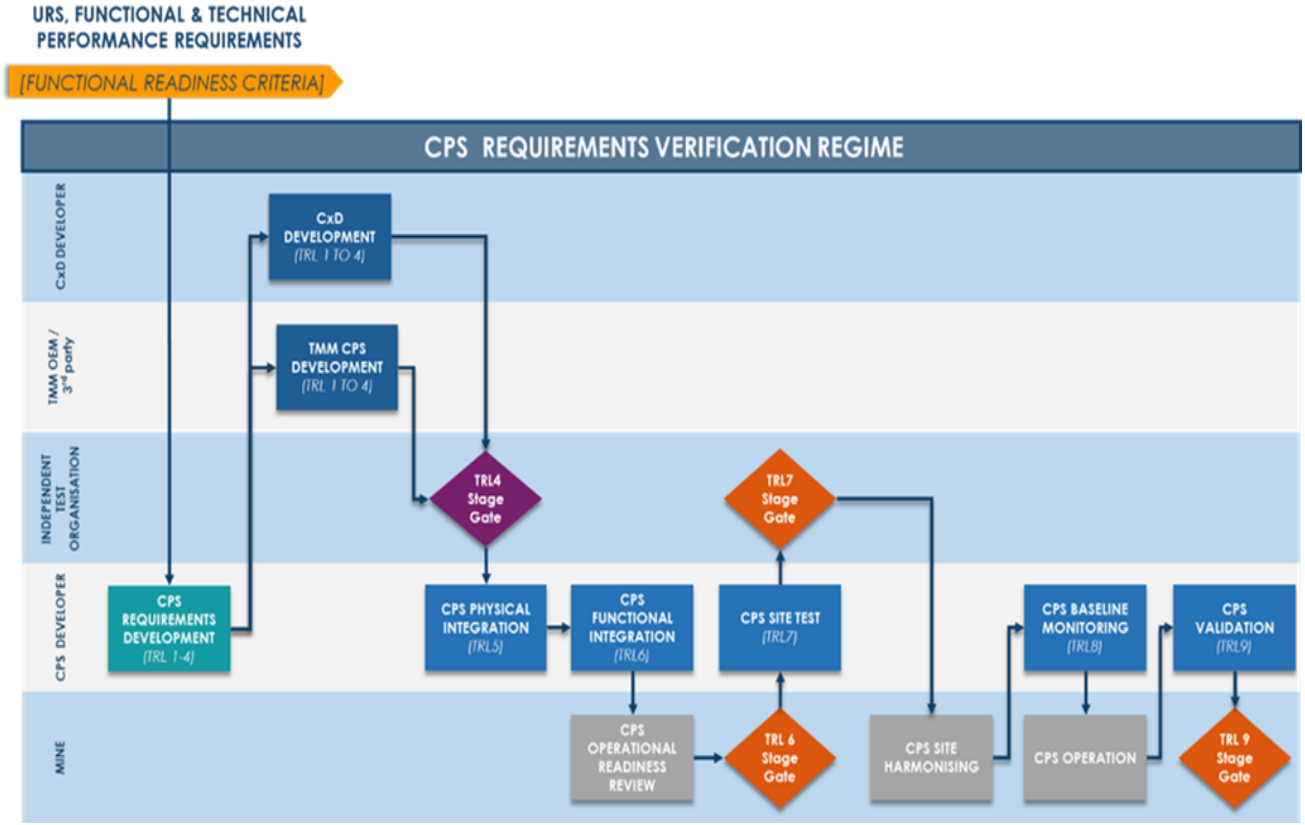

Fig 7: CPS requirements verification regime

APPENDIX 1: CPS PRODUCT SYSTEM READINESS CRITERIA

10. CPS Developer Role

The role of the CPS developer is that of the **single responsible party** for the development of every CPS i.e. the CxD and the TMM CPS Products. The practical implication therefore is that for every combination of TMM (type, brand, model and serial number) as required, the CPS developer needs to be agreed between the CxD provider and the TMM OEM. The CPS developer can be a 3rd party, the CxD provider or the TMM OEM. It is also possible that commercial agreements are made between CxD suppliers as well as TMM OEMs for the use of specific module providers. A formal agreement between the parties will have to be established that includes but is not limited to the inclusion of the criteria set out in this document.

TRL	Definition of the TRL	Description of Typical Activities	Success criteria to next maturity level (Evidence Description)
1-9	Accelerated CPS development	• Manage accelerated CPS development. • Manage Integrated Testing Arrangements. • Manage Testing Set ups. • Manage 3rd Party Testing and Validation. • Oversee and integrate inter role-player activities.	Portfolio of evidence for all elements and modules as per agreement accepted.

11. Readiness Criteria for CxD Development (TRL 1 to 4)

TRL	Definition of the TRL	Description of Typical Activities	Success criteria to next maturity level (Evidence Description)

1	**CxD** Requirements defined, basic principles observed and reported.	**Requirements analysis**
		• CxD purpose documented.
		• MHSAct Reg 8.10 analysis
		• Section 21 legal obligation analysis.
		• Solution focus (Surface, Underground, Both).
		• CxD development strategy (Inhouse, partner, subcontracted, etc.)
		• Legal liability alignment based on selected strategy.
		• TMM OEM agreements, 3rd Party TMM CPS suppliers' agreements.
		• TMM fleet (Type, Model, Serial No) braking system characteristics analysis. (TMM CPS specification sheets)
		• CPS user requirements analyses and preliminary CxD functional requirements confirmation.
		Planning
		• CxD development plan per machine type, model, serial number as relevant.
		  ○ Safety based development process.
		  ○ Project Quality Plan.
		  ○ Time and effort.
		  ○ Human and physical resources.
		  ○ Integrated CPS testing regime including independent verification agreed.
		  ○ Test plan.
		  ○ Integration.
		Design
		• Functional analysis.
		• Relevant literature analysed.
		• Principles observed and application considered.
			• Signed off plans as per supplier development quality system ISO 9000, ISO 15288.
			• Mines' approved User Requirement
			• Mines approved Functional Specification.
			• TMM OEM agreement(s).
			• CPS developer agreement.
			• TMM characteristics available and signed off by TMM OEM. TMM specification sheets
			• CxD based on peer reviewed approaches as set out in project quality plans.
			• Target operational environment & equipment identified (surface vs. UG or both). Functional analysis completed.
			• Signed Integrated CPS Verification Regime.
			• Concepts ready to be evaluated and selected based on functional analysis.
			• Initial Sec 21 Technical File developed and populated. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

		• Functional and Technical performance of sub-assemblies/modules specified.
		• **Controller configuration – modular design:**
		  ○ Potential alternative solutions identified and documented.
		  ○ Significant benefits and challenges identified per alternative.
		  ○ Controller standardisation studies (Inter OEM and per Type and model)
		  ○ Simulation/Mockup model(s) development needs identified.
		  ○ "Research" aspects identified, research planned and started.
		  ○ Controller Module breakdown structure(s) firmed up. (Per Type, Model and Serial number) as relevant
		• CxD boundaries and interfaces identified.
		Testing
		None	

2	**CxD** concept and application formulated.
	
	1st Gen or Mockup.
		Design
		• Research completed
		• Concepts analysed
		• Solution concept selection: per Type, Model and Serial No. (including self-diagnostics and fail to safe functionality)
		• Functional design including:
		  ○ Detection and tracking, Sensor fusion
		  ○ Effective Warning
		  ○ Cap lamps (underground)
		  ○ Test stations
		  ○ Lamp rooms
		  ○ TMM conditions, speed, gear selection etc.
		  ○ Fail to Safe without human intervention
		  ○ Post failure operation
		  ○ Self-Diagnostics and CPS diagnostics
		  ○ Data recording and log keeping
		  ○ Date and Time synchronisation
			• All design and analysis documented for traceability, as per project quality plan including test results.
			• Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

		○ CxD enquiries and actions ○ Controlled deceleration ○ Controlled stopping ○ Over-speeding prevention ○ CxD integration design (physical and functional) • Controller installation position per machine type and model selected. • Simulation/Mockup model(s) development completion and verification • Robustness analysis: ○ Failure Mode Effect and Criticality Analysis (FMECA), ○ Installation analysis and optimisation ○ Component and sub assembly vulnerability analysis – Vibration/shock, Temperature, water ingress, adhesion, physical damage, installation damage. ○ EMI analysis and EMC design • Functional and Technical performance tests and test protocols designed • Sub assembly and component maintainability analysis and design • Draft manufacturing drawings **Planning** Update plans **Testing/Verification** As per supplier test plan.	
3	**CxD** proof of concept. **Next Gen item manufactured / sourced, assembled, Factory**	**Design** • **Update all design information** • Sub assembly and component maintainability analysis • Component and sub assembly inspection sheets development. • Component and sub assembly tests defined, and test instructions, test parameters and acceptance criteria developed. Factory Acceptance Tests (FAT)	• All design and analysis documented for traceability, as per project quality plan including test results. • Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

	Acceptance Tests (FAT). (Breadboard)	• Component and sub assembly installation sequence optimised, risk assessments done, and controls identified • Development of component and sub assembly fitting and routing diagrams • Installation checklist(s) development • Update manufacturing and assembly drawings **Planning** Update plan – integration focus **Testing/verification** As per CxD supplier test plan.	
4	**CxD** Functional Verification **Next generation item manufacturing, assembly and FAT** **(Verification in workshop/lab environment to verify fit form and function)**	**Design** • **Update all design information as required post-test and verification** • Update manufacturing and assembly drawings • Component and sub assembly inspection sheets updated. • Component and sub assembly tests defined and test instructions, test parameters and acceptance criteria updated. **Planning** Update plan – integration focus **Testing/verification** As per CxD supplier test plan. • **Including TRL 4 independent verification tests**	• Certificate of conformance issued for adherence to in-house design and development processes • Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document** • OEM signoff for “On TMM” testing to commence

12. Readiness criteria for TMM CPS Products (TMM OEM or 3rd Party) (TRL 1 to 4)

TRL	Definition of the TRL	Description of Typical Activities	Success criteria to next maturity level (Evidence Description)

1	Requirements defined, basic principles observed and reported.	**Requirements analysis**
		• TMM CPS purpose documented.
		• MHSAct Regulation 8.10 analysed
		• User Requirements agreed with mines.
		• Functional Requirements agreed with mines.
		• Sec 21 legal obligation analysed
		• Solution focus decided (Surface, Underground, Both)
		• CPS development strategy decided (Inhouse, partner, subcontracted, etc.) the third party must always obtain OEM input and approval.
		• Legal liability agreements based on selected strategy
		• TMM fleet (Type, Model, Serial No) braking system characteristics analysis and specification sheets developed.
		• CPS user requirements analyses and TMM CPS functional requirements confirmation. Refer MOSH documents.
		Planning
		• MC development plan per machine type, model, serial number as relevant.
		  ○ Safety based development process
		  ○ Project Quality Plan
		  ○ Time and effort
		  ○ Human and physical resources
		  ○ Test plan
		  ○ Integration
		Design
		• Functional analysis
		• Relevant literature analysed. Principles observed and application considered.
			• Signed off plans as per supplier development quality system ISO 9000, ISO 15288.
			• CxD supplier agreement(s)
			• CPS developer agreement.
			• Mines' approved User Requirement
			• Mines approved Functional Specification.
			• TMM characteristics (Specification sheets)
			• Target operational environment & equipment identified (surface vs. UG or both). Functional analysis completed. Concepts ready to be evaluated and selected based on functional analysis.
			• Initial Sec 21 Technical File developed and populated. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

		• Functional and Technical performance of sub-assemblies/modules specified. • MC configuration – modular design • Potential alternative solutions identified and documented. • Significant benefits and challenges identified per alternative. • MC standardisation studies (Inter OEM and per Type and model) • Simulation/Mockup model(s) development needs identified. • "Research" aspects identified, research planned and started. • MC breakdown structure(s) firmed up. (Per Type, Model and Serial number) as relevant • MC boundaries and interfaces identified. **Testing** None	

2	**C**oncepts and application formulated.
	
	1st Gen or Mock-up.
		Design
		• Research completed
		• Concepts analysis
		• Solution concept selection: per Type, Model and Serial No. (including self-diagnostics and fail to safe functionality)
		• Functional design including:
		  ○ CXD enquiries and actions
		  ○ Wheel locking and steering stability
		  ○ Controlled deceleration
		  ○ Controlled stopping
		  ○ Over speeding prevention
		  ○ Brake actuation characteristics
		  ○ Fail to safe functionality (CXD and/or MBS unavailability).
		  ○ Fail to safe analysis and design
		  ○ Self-diagnostic design
		  ○ MC and MBS integration design (physical and functional)
		• MC installation position per machine type and model selected.
			All design and analysis documented for traceability, as per project quality plan.
			Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

		• Simulation/Mockup model(s) development completion and verification
		• Robustness analysis
		  ○ Failure Mode and Effects Analysis (FMEA),
		  ○ Installation analysis and optimisation
		  ○ Component and sub assembly vulnerability analysis – Vibration/shock, Temperature, water ingress, adhesion, physical damage, installation damage.
		  ○ EMI analysis and EMC design
		• Functional and Technical performance tests and test protocols designed
		• Sub assembly and component maintainability analysis and design
		• Draft manufacturing drawings
		Planning
		Update plans
		Testing/Verification
		As per supplier test plan	

3	**P**roof of concept. **Next Gen item manufactured/ sourced, assembled, FAT. (Breadboard)**	**Design** • **Update all design information as required post-test and verification** • Sub assembly and component maintainability analysis • Component and sub assembly inspection sheets development. • Component and sub assembly tests defined and test instructions, test parameters and acceptance criteria developed. (FAT) • Component and sub assembly installation sequence optimised, risk assessments done, and controls identified • Development of component and sub assembly fitting and routing diagrams • Installation checklist(s) development • Update manufacturing and assembly drawings **Planning** Update plan – integration focus	• All design and analysis documented for traceability, as per project quality plan including test results. • Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

		Testing/verification As per product testing plan	
4		**Design** • **Update all design information as required post-test and verification** • Update manufacturing and assembly drawings • Component and sub assembly inspection sheets updated • Component and sub assembly tests defined and test instructions, test parameters and acceptance criteria updated. **Installation** • Component and sub assembly installation sequence optimised, risk assessments done, and controls identified • Installation checklist(s) documented **Testing** As per product testing plan but including TRL4 Independent verification tests.	• Certificate of conformance issued for adherence to in-house design and development processes • Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document** • OEM signoff for "On TMM" testing to commence

13. Readiness criteria for CPS Physical Integration (TRL5)

As per the CPS Requirements Verification Regime, the CPS developer coordinate and ensure all the activities of TRL 5. Refer the CPS Requirements Verification Regime.

TRL	Definition of the TRL	Description of Typical Activities	Success criteria to next maturity level (Evidence Description)

5	**Physical integration of a CxD onto a CXD ready TMM (TMM CPS)**	• Time and motion studies
		• Tools required finalised
		• Skills required finalised
		• Installation documentation verified
		• Commissioning documentation verified
		• Physical Installation of a TRL 4 Stage Gate Passed CxD onto a TMM that passed the TMM CPS TRL4 Stage Gate Independent verification test.
		• Installation happening exactly as per the installation instruction and installation drawings.
		• Specific activities to confirm that the positioning of the CxD hardware (kit) is the result of:
		  ○ Ergonomic design
		  ○ Integrated Cab layout
		  ○ Ease of access for maintenance and repair
		• Specific activities to confirm the fault finding and testing manual(s)
		• Specific activities to confirm the maintenance and repair instructions and establish the baseline Time to Repair data.
		• These activities to cover both the CxD and TMM CPS products
		• Formal signoff by TMM OEM
			• Signed off Cab layout drawings.
			• Signed off installation drawings (CxD and TMM CPS)
			• Signed off installation instructions (CxD and TMM CPS)
			• Signed off fault-finding manual/procedure
			• Signed off TMM OEM CPS physical integration certificate
			• Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

14. Operational Readiness Criteria (TRL 6)

Operational readiness for introduction of CPS is a significant endeavour for a mine. Reg 8.10 requires a mine to ensure that employees are not injured as a result of TMM collisions. It states that the mine must implement reasonably practicable measures to do this. Section 6 (a) of this document defines the ecosystem elements that the mine must establish.

Traffic Flow and Risk Analysis (TFRA)

Description of Activities	Success criteria (Evidence Description)
• Demarcation of mining processes and process boundaries • Identification of TMM and pedestrian movement • Identification of potential collision hotspots. • Identification of the reasonably practical measures (controls) to be implemented. • Identification of work areas where significant risk of TMM collisions will remain even after introducing the new controls. • Identification of all TMMs working in these operational areas. • Selection of the preferred CxD provider that the mine wants to use for its fleet of CPS TMMs. This is needed to ensure that CxD providers know what TMMs their products must support. The mine must do the selection in conjunction with the relevant TMM OEMs.	• Updated mining lease area survey plans indicating process areas and boundaries. • Redline survey plans indicating hazards and TMM interaction points (people and TMMs as well as TMMs and TMMs). • Redline survey plans showing potential concepts for separation of TMMs (V-P and V-V). • Process area and road survey plans with TMM types that operate in the areas listed – primary, secondary and auxiliary TMMs (haul trucks, loaders, drill rigs, personnel carriers, LDVs). • TFRA formal report signed off by 2.13.1 and 3.1(a) appointees. • List of TMM types, models and numbers requiring CPS. • Collision prevention controls plan signed off. • CxD supplier chosen.

Such measures include traffic management. Traffic management is defined in the following MOSH documents:

- TRAFFIC MANAGEMENT LEADING PRACTICE FOR OPEN PIT/CAST OPERATIONS IN SOUTH AFRICA
- TRAFFIC MANAGEMENT TECHNICAL GUIDE FOR UNDERGROUND TRACKLESS OPERATIONS IN SOUTH AFRICA

Physical Collision Prevention Controls

Road Network

Description of Activities	Success criteria (Evidence Description)
• Haul Road and operational area improvement schedules • Detail designs for haul roads, intersections, curves, berms etc. • Construction risk assessments • Physical construction of roadways, intersections, berms, access control and all other effective controls as per the updated risk analysis.	• New/ revised Traffic Management Standards including haul road design and construction design standards. • "As designed" survey plans incorporating all the detail standards as applied on the mine. • All work as per plan completed and signed off by project manager. • Survey department signoff of build to design reports. • "As built" survey plans, and workshop area block plans signed off by 3.1(a) legal appointee and all other relevant role-players.

Operational Area Separation Design

Description of Activities	Success criteria (Evidence Description)

• Detail design of operational areas to ensure TMM separation during operations, including:
  ○ Loading Areas
  ○ Dumps
  ○ Ramps
  ○ Workshops
  ○ Refuelling area
  ○ Etc. as identified by TFRA
	• Detail design layout drawings/survey plans showing all the flows and routes of TMMs and pedestrians demonstrating separation.
	• All work as per plan completed and signed off by project manager.
	• "As built" survey plans, and workshop area block plans signed off by 3.1(a) legal appointee and all other relevant role-players.

Processes, procedures, infrastructure and Standards

CPS Infrastructure

Description of Activities	Success criteria (Evidence Description)
Mine to establish/upgrade • CPS server and network with sufficient capacity • GPS/Wi Fi Network coverage analysis • GPS / WiFi Network • Geo Fence Architecture – Hardware (beacons) • CPS Configuration Architecture – Hardware • CPS Functional Test infrastructure (Cap Lamps HR UG) and (TMM CPS HR UG and S) • Lamp Room(s) UG	• CPS IT infrastructure and data capacity report • CPS IT hardware available • CPS Geofence establishment and maintenance process tested

Procedures and Standards

Description of Activities	Success criteria (Evidence Description)

• Traffic Flow and Risk Analysis procedure development.
• Traffic Flow and Risk Analysis checklist
• Standards updated to include all collision prevention controls and provisions.
• CPS URS
• CPS F&TPRS
• CPS Section 21 Technical File information requirements document
• Operational Readiness Review procedure and checklist
• Operational Procedures harmonised with any new collision prevention controls including CPS products, including:
  ○ In-Pit refuelling, Maintenance and Lubrication
  ○ In-Pit queuing with CPS installed TMMs
  ○ Operating on the mine with geofences
  ○ Refuelling TMMs at refuelling bays
  ○ TMM operation in workshop areas
• Safe CPS operations procedures for:
  ○ CPS TMM FTSWHI procedure
  ○ CPS collision prevention interventions
  ○ Post CPS maintenance, testing procedure
  ○ Procedure to establish and manage CPS configurations
• COP updated, reviewed and approved including new or changed operator visibility diagrams as required by COP guideline.
• Mine specific user requirement specification
	• Collision Prevention related documentation list available and complete.
	• All related documents reviewed and approved.
	• All documents available.
	• TMM register updated to include CPS on each TMM.
	• Operator visibility diagrams updated to include any visibility improvement as a result of the introduction of CPS.
	• CPS Products selected
	• Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

• Technology selection scope of work document development • Mine's standard commercial process activities • SLA development	

Technology Introduction

Description of Activities	Success criteria (Evidence Description)
• CPS product procurement and installation • Underground mines only: If new technology is selected, lamp room changeover plan and risk assessment. DMPR approval for the high-risk running period. • Change Management plan • Section 21 files • Upgrading of unintelligent machines • Installation of CPS, commissioning, and testing • Effective reporting and follow up actions	• CPS acceptance certificate • DMPR record of approval for high risk running period • Change Management implemented • Section 21 files in place • Hot spot analysis and resolution • Effective reporting on interactions and overrides

Verification

See section 8 of this document.

Description of Activities	Success criteria (Evidence Description)
• Inhouse and Independent verification by competent 3rd parties. This document provides minimum criteria.	• Verification and Independent Verification Reports and actions closed out. Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

Proof Of Conformance

The criteria for proof of conformance are defined in the Sec 21 Information Framework for Collision Prevention Systems document

Training

Description of Activities	Success criteria (Evidence Description)
Identification of Training Needs: • Technology • Change Communication • Maintenance and Fault Finding • Procedures and Processes	• Training needs report signed off • Training materials • Train the trainers or training contracts established • Training provided • Competence verified by assessment

Change Management

Description of Activities	Success criteria (Evidence Description)
• Change Management needs identified in Reg 8.10 Management of Change (MOC) and Change Management (CM) process • Stakeholder Engagement • Training and Communication Materials development • Training and Change interventions • Change effectiveness monitored	• Reg 8.10 MOC and CM plan documented • Stakeholder engagements and outcomes records • Training and Communication materials registered • Training and communication intervention records • Change effectiveness reports.

CPS Spares Maintenance and Support

Description of Activities	Success criteria (Evidence Description)
• Maintenance strategy, maintenance support agreements where relevant • Spares supply agreements	• Evidence of agreements and arrangements.

15. CPS Functional Integration and Operational Readiness Independent Verification (TRL 6 Stage Gate)

As stated, this stage gate must be independently verified by organisations with the necessary knowledge and expertise as required. The mine can contract specific aspects of the verification to different suppliers

Description of Activities	Success criteria (Evidence Description)
• Reg 8.10 Independent Verification plan(s) based on the criteria as set out in this document as a minimum requirement. • Verification checklists	• Independent verification reports and action closeout Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

16. CPS Verification Testing (TRL7) and CPS Independent Verification Testing (TRL7 Stage Gate)

Refer to the COLLISION PREVENTION SYSTEMS REQUIREMENTS VERIFICATION REGIME and the INDEPENDENT VERIFICATION TEST SPECIFICATION FOR SURFACE COLLISION PREVENTION SYSTEMS (CPS): TRL7 STAGE GATE

17. CPS Baseline Monitoring (Stage Gate 8)

As stated, this stage gate must be independently verified by an organisation(s) with the necessary knowledge and expertise as required. The CPS developer must play a key role in the stage gate to ensure that all technology and physical road aspects that must be resolved before going "live" is identified and resolved.

Description of Activities	Success criteria (Evidence Description)
• Hotspot analysis and action plans • Firmware configuration management system	• Independent verification reports and action closeout Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

18. CPS Validation (Stage Gate 9)

As stated, this stage gate must be independently verified by organisations with the necessary knowledge and expertise as required. The mine can contract specific aspects of the verification to different suppliers

Description of Activities	Success criteria (Evidence Description)
• Analyse data and reports to determine if the CPS is fulfilling the needs of a CPS and the URS.	• CPS validation report • Updated Sec 21 Technical File. Refer: **Sec 21 Information Framework for Collision Prevention Systems document**

19. References

The following documents are referenced in this document:

[1] Mine Health and Safety Act No. 29 of 1996 and Regulations

[2] ISO/PRF TS 21815-2:2021 Earth-moving machinery — Collision warning and avoidance — Part 2: On-board J1939 communication interface

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

[4] MIL-STD-490B:1992 Draft Military Standard Program-Unique Specifications.

[5] ISO/FDIS 16290:2013. Space systems — Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment