PART 1: FUNCTIONAL READINESS CRITERIA FOR COLLISION PREVENTION SYSTEMS DEVELOPMENT

(I.E., WORK PACKAGE 8)

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

REV 4

CPS Readiness Criteria Acceptance			
Name	**Signature**	**Organisation**	**Date**
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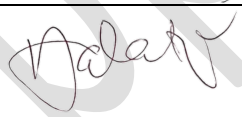
Stanford Malatji		**Minerals Council**	20 June 2022

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1. Purpose of this document

This document sets out the criteria for the progressive readiness stages for the CPS Life Cycle System including the CPS product system.

2. 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)

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.
DMRE	Department of Mineral Resources and Energy.
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.
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 pf 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	Part 1: Functional 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.
TMMP	TMM CPS Product: The product that will make a non-intelligent TMM intelligent and CxD ready.
TMM OEM	Original Equipment Manufacturer of TMMs. Original Equipment Manufacturer of a TMM may be the organisation which originally supplied, or last rebuilt or modified the TMM or the supplier per section 21 of the Mine Health and Safety Act, 1996 (Act No. 29 of 1996). [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
WP 8	Work Package 8: Readiness Criteria. One of the work packages of the Industry Alignment on TMM Collision Management Systems Project: CAS READINESS PHASE.
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.
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

3. Context of this document

This document is part of the deliverable for Work package 8 of the Industry Alignment on TMM Collision Management Systems Special Project of The Minerals Council South Africa: CAS TECHNOLOGY READINESS PHASE work.

The document will be released in 4 parts:

- Part 1 Functional Readiness
- Part 2 Manufacturing Readiness
- Part 3 Operation Readiness
- Part 4 Commercial Readiness

4. Background

TMM regulations for the SAMI have been promulgated in 2015. Some of the clauses related to diesel powered TMMs were suspended as a result of non-availability of technology to provide the functionality that is required to auto slowdown and stop the TMMs.

As described in section 5, a CPS is Product System that is complex, comprising of multiple elements (sub systems) some of the elements comprising components that are still in technology development. The range of TMM Types, brands and models in the mining industry are vast. This adds to the complexity of CPS products and especially the challenge of interoperability.

Some of the relevant challenges that the SAMI faces with regards the TMM regulations are:

- Regulations require compliance of many organisations (mines) on a specific date/period with potential negative consequences for non-compliance. (Mines can be closed).
- It requires an entire Life Cycle System (ecosystem) to be established timeously to ensure that there is sufficient supply, in order for the demand of the products to be met on the effective date of regulation.
- The Regulations dictate specific and implied functional requirements of a CPS product.
- The potential of mine closure elevates the importance of functionality and reliability significantly. In a normal commercial technology cycle, a mine can simply switch off the CPS product if it is found to be too unreliable or its functionalities are inadequate. For regulated technology this would mean a mine must stop operations or obtain temporary exemption from the regulations.
- As a safety system that ultimately takes away the control of a TMM from an operator, specific functional and system requirements are required that must be agreed upon between stakeholders and must be ensured to minimise the potential disruption of the introduction of such technology to an entire industry.
- Due to the limited window to develop the CPS ecosystem, it requires an order-of-magnitude better collaboration, co-ordination and alignment between all relevant role-players including technology providers and TMM OEMs.
- Even if mines have funds to perform all required tests on their own and at their own premises, the demand of all mines for execution of tests will be overwhelming to all suppliers whether TMM CPS Product or CxD suppliers.
- The implication of the regulations is that all mines must comply on a specific date. Many mines do not have the financial resources to procure systems, let alone funds to conduct testing of novel products that may require many iterations of retesting.

The South African TMM CPS Product development requires a CPS Life Cycle System (ecosystem) optimised approach.

As indicated above, the SAMI challenge requires the establishment of an entire ecosystem in order to have all mines compliant on the effective date.

The approach proposed for the challenge is that of a **collaborative product development and testing approach** informed by the TMM population, the number of mines, the regulatory implementation window and an optimised approach for lowest overall cost and minimum interruption of production.

This approach by implication needs a single **requirements specification** and integrated **testing** as far as practically possible.

Readiness criteria is intended to:

- Enable a logical progression of CPS product development
- Enable a logical integrated CPS Life Cycle
- Ensure a single set of minimum requirements for all CPS providers

5. The CPS Life Cycle System (Ecosystem)

The first step to readiness criteria is the definition of the CPS Life Cycle System (Ecosystem) that must be developed in order to meet the regulatory and user requirements. The CPS Life Cycle System is shown in figure 1.

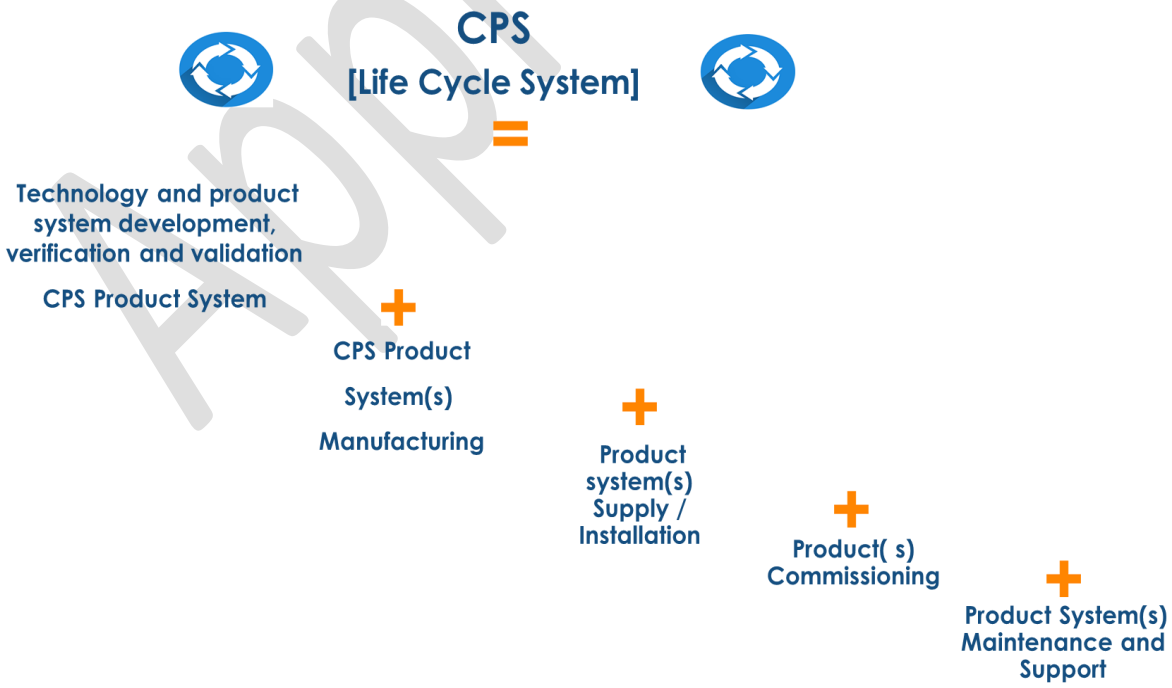


Fig 1 CPS Life Cycle System

The 1st element of the Life Cycle System is the development of the CPS Product System.

6. CPS Product System

The CPS Product System is defined in full details in the CPS User Requirements Document. It is duplicated here for context only. This document should be read in conjunction with the CPS User Requirements Document

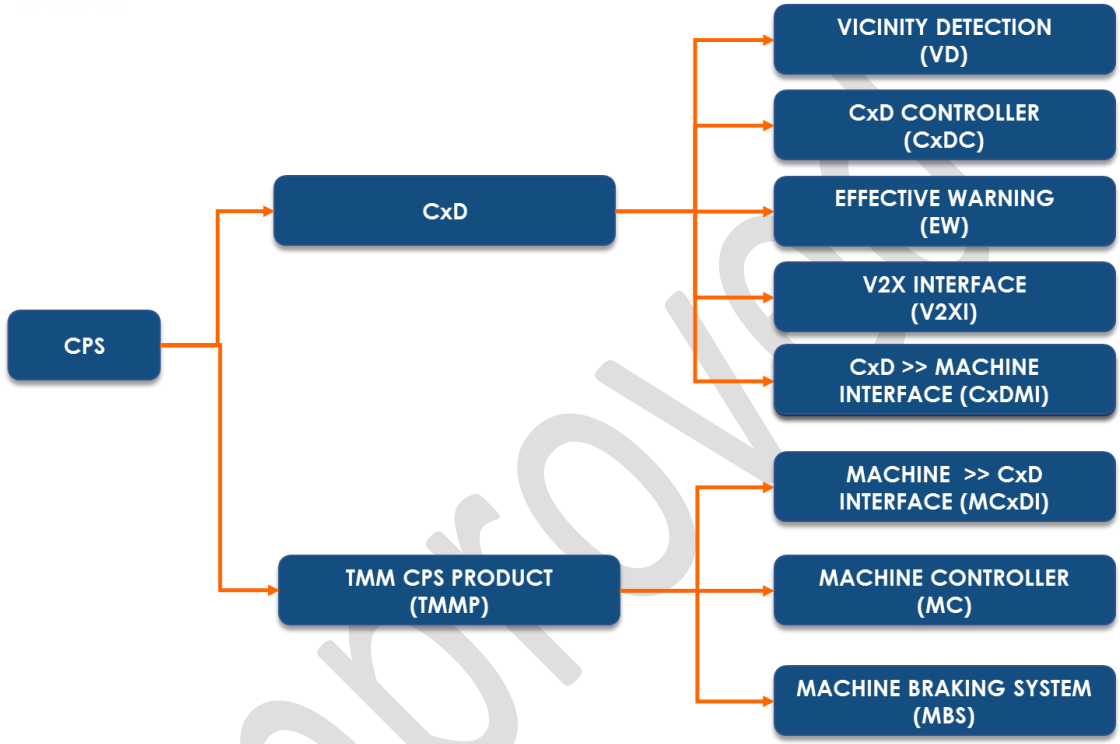


Fig 2: The CPS breakdown structure for TMMs in the SAMI (Legacy Equipment)

The CPS Product breakdown is shown in fig 2.

The **CPS** comprises **2 elements** (Products) in the case of Surface TMMs namely:

1. The TMM CPS PRODUCT (TMMP)
2. The CxD (CxD)

The **TMM CPS PRODUCT** comprises **3 modules** (sub system) namely:

1. The Machine Braking System (MBS)
2. The Machine Controller (MC)
3. The Machine CxD Interface (MCxDI)

The **CxD** comprises **5 modules** (subsystems) namely:

1. The Vicinity Detection element (VD)
2. The CxD Controller element (CxDC)
3. The Effective Warning element (EW)
4. V2X Interface (V2XI)
5. CxD Machine Interface (CxDMI)

7. CPS Product System Manufacturing

The CPS Product System Manufacturing element relates to all aspects of manufacturing of CPS products based on specific supply chain and localisation strategies. It applies both to the individual CPS supplier and CPS supply as an element of the CPS ecosystem.

The manufacturing element gives effect to national local content requirements for the SAMI as defined in the Mining Charter. It provides a vehicle for saving livelihoods for South Africans, creating meaningful jobs and even export opportunities for the country.

CPSs being safety systems, require mature and verifiable manufacturing standards from components up to the final CPS (CxD integrated to the TMM), factory acceptance testing, shipping and transportation standards, part and serial number control, proof of conformance traceability, and all other aspects required to ensure sufficient number of CPS products to ensure that all mines can comply with the TMM regulations at the time of the upliftment of the suspended clauses.

The CPS product manufacturing element of the CPS Lifecycle is a key make or break aspect of the successful introduction of CPS into SAMI. To manage the technical risks associated with CPS manufacturing a set of Manufacturing Readiness criteria are developed to govern the technical aspects of the element.

8. CPS Product System Supply and Installation

The CPS Product System Supply and Installation element relates to the commercial arrangements between mines and CPS providers. The fact that significant numbers of CPS's might be needed over a short period of time will create a peak demand. The supply and installation will therefore need to be managed as a holistic CPS ecosystem element and ideally as an integrated initiative. Aspects to be considered include:

- Geographic location of mines and proximity to suppliers
- Number of units to be supplied and installed
- Supplier capacity
- Aggregate demand

From an ecosystem perspective, the skills demand and skills requirement must be available early enough to ensure availability of sufficient installation skills to ensure timeous installation of CPS products in support of regulatory agreements.

9. CPS Product System Commissioning

The CPS Product System Commissioning element relates to the activation (switching on) of all CPS's on a mine. Again, this will need to be managed as a holistic CPS ecosystem element with similar considerations as discussed for supply and installation. CPS commissioning is part of the CPS rollout and the responsibility of the mine with support from the CPS provider.

10. CPS Product System Maintenance and Support

The CPS Product System maintenance and support element relates to the operational period of the CPS product's life. From an ecosystem perspective, the skills demand and skills requirement need to be available early enough to ensure availability of enough skills to ensure that CPS's will be maintained and supported during this life cycle element. Considerations include:

- Number of installed units
- Maintenance and support agreements between suppliers and mines
- Skills required
- Spares demand

11. CPS Operational Readiness

Whilst CPS operational readiness is not a CPS Life Cycle element, it is so important to the successful introduction of CPS products into the SAMI that specific readiness criteria must be developed to assist mines to be operationally ready to accept CPS products in a harmonised way into their operations.

Operational readiness is primarily a risk mitigation activity to ensure minimum disruption of production during the introduction of CPS products to a specific mine.

12. 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 SAMI TMM regulations by ensuring complete and unambiguous requirements. 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, to enable timeous compliance as per the regulatory requirements.
- To enable mines to purchase systems that have been proven to comply with the regulatory requirements in the RSA.

- To ensure CPS products that will have a minimum disruption of production on mines due to shortcomings in the Life Cycle System (Eco system)
- To ensure a complete set of user, functional and technical performance requirements to achieve above.
- To ensure that important functional and technical performance requirements are translated into test protocols. (3rd party testing)
- To ensure an industry integrated (Mines, TMM OEM, CxD providers) test and demonstration program that minimises time to test, cost of testing and disruption at operations.
- To ensure that CPS product conformance to requirements and readiness are witnessed and confirmed on behalf of mines.
- To ensure that technology readiness requirements for successful introduction of the regulations are verified and confirmed.

13. Approach to CPS Development

The CMS Technical Specification Guideline Review Report highlighted the need for managing the project in accordance with a Systems Engineering (SE) approach, that is different from the EMESRT approach. The EMESRT approach to "CPS" readiness, as is embedded in the CMS Technical Specification Guideline is rightly, that of **supplier** defined criteria, **supplier** defined product specifications, and **supplier** submission thereof to the mine. In order to define the functional criteria for CPS product development the actual integrated development framework must first be defined. The rest of this document defines this "different" approach to the development of CPS products, its framework and the detail criteria.

14. Accelerated CPS Development Framework

Readiness criteria will be developed using the accelerated CPS development framework as a basis. The high-level framework is shown in figure 3.

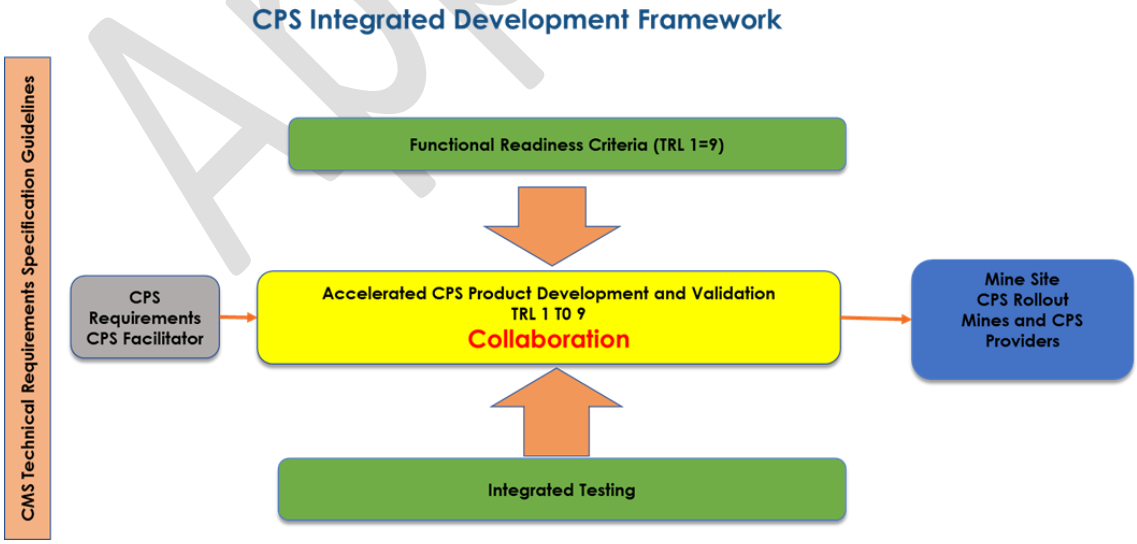


Figure 3. Accelerated CPS development framework – High level

The reference of the initiative is the CMS Technical Specification Guideline used to guide CMS development in the SAMI since 2016. The centre of the initiative is a collaborative CPS Development and Validation Process. The process is preceded by the development of CPS requirements and followed by mine site CPS rollout.

The CPS requirements are the key initiator of the initiative, with two specific risk mitigation elements, namely the **Integrated Testing Regime** and the **Functional Readiness Criteria.**

Since so much is at stake for all role players, intensified by time pressure, the cutting-edge technology used in CPS products, the safety nature of CPS products and the complexity of the CPS product system it is key that **unambiguous criteria** are available to ensure the fastest and most effective development process for CPS products.

History is full of well-intended initiatives that failed after significant initial progress and even premature celebration of untested successes, 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 Accelerated 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. [5]

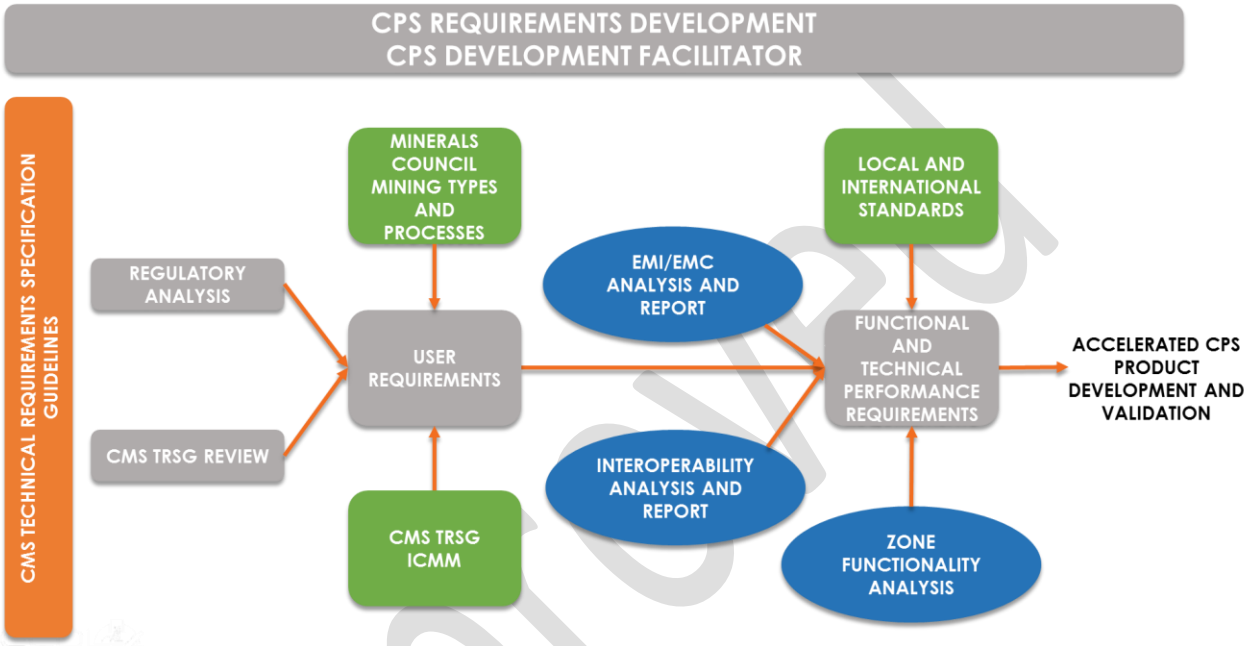
With the CPS development work having started in 2015, it is impractical to introduce a puristic SE process at this stage. The approach for Readiness as defined in this document is pragmatic and the criteria is more important than naming conventions.

A clear distinction between CPS System Level, CPS Elements and CPS modules criteria is made. This will ensure that suppliers have full visibility of all the criteria that must be conformed with in the different readiness stages.

The basic approach is: **What is to be done with regards to the CPS, its elements and its modules in a progressive manner** towards maturity and **what are the key criteria** that demonstrates achievement of a specific level of readiness?

15. CPS Requirements Development Process

As indicated in the background section, the accelerated and integrated approach, unlike the CMS Technical Specification Guideline process, by implication, needs a single **requirements specification** and integrated **testing** as far as practically possible. The process therefore needs to include the development thereof, as well as all the requirements related aspects that informs the requirements specification and testing protocols, for example; user -



, interoperability -, EMI and EMC,- zone functionality requirements.

Since the development initiative is an integrated one, the CPS requirements development had to be facilitated by the Minerals Council South Africa through its INDUSTRY ALIGNMENT ON TMM REGULATIONS; SPECIAL PROJECT.

Figure 4: CPS Requirements Development Process

The CPS Requirements Development Process is shown in fig. 4

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 Life Cycle System breakdown and definition
- CPS Product System breakdown (preliminary)
- CPS Readiness Criteria (Functional, Manufacturing, Operational and Commercial)
- CPS Integrated Testing Regime

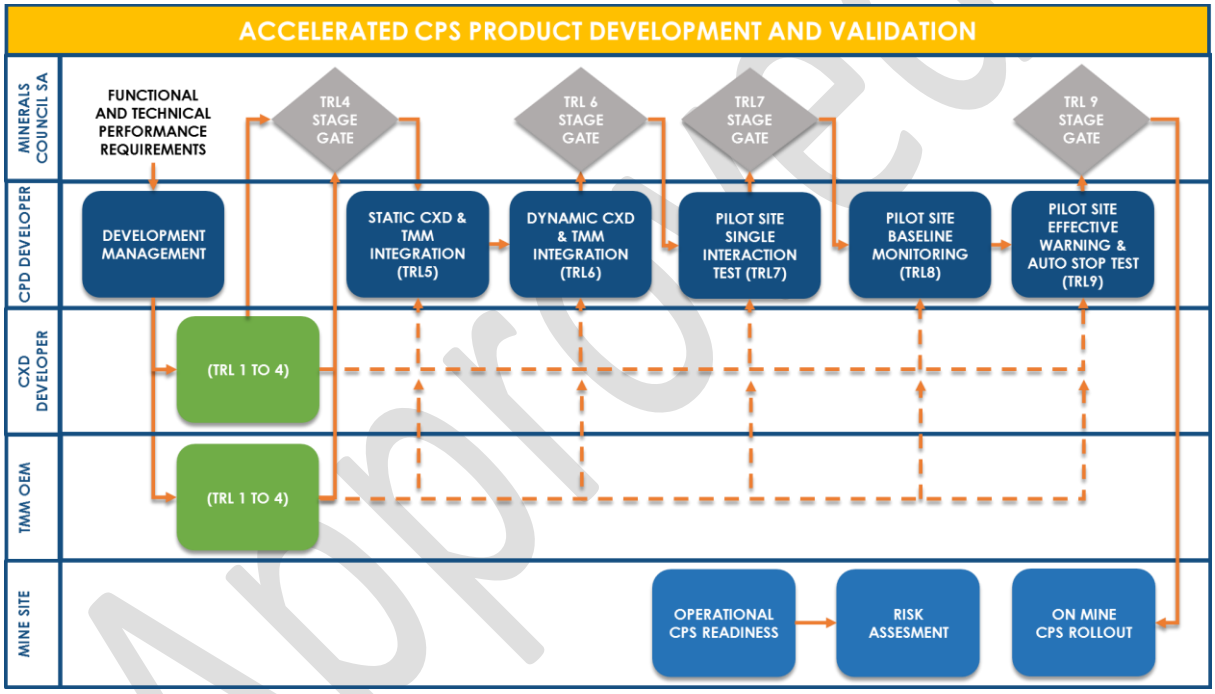
- CPS 3rd party testing protocols
- CPS Interoperability challenges and specification
- CPS EMI and EMC analysis and specification
- CPS Zone functionality analysis and specification
- CPS functional and technical performance requirements

With the availability of the CPS functional and technical performance requirements, the accelerated CPS product development will be able to start.

16. Accelerated CPS Development and Validation Process

The accelerated CPS Product Development Process is shown in further detail in figure 5.

Figure 5: Accelerated CPS Product Development Process (High level)



The level of collaboration in the initiative is clearly visible in the different "swimlanes" showing the role of the different participating role-players. The CxD and TMM CPS Product Development (TRL 1 to 4) are shown in further detail in figures 6 and 7.

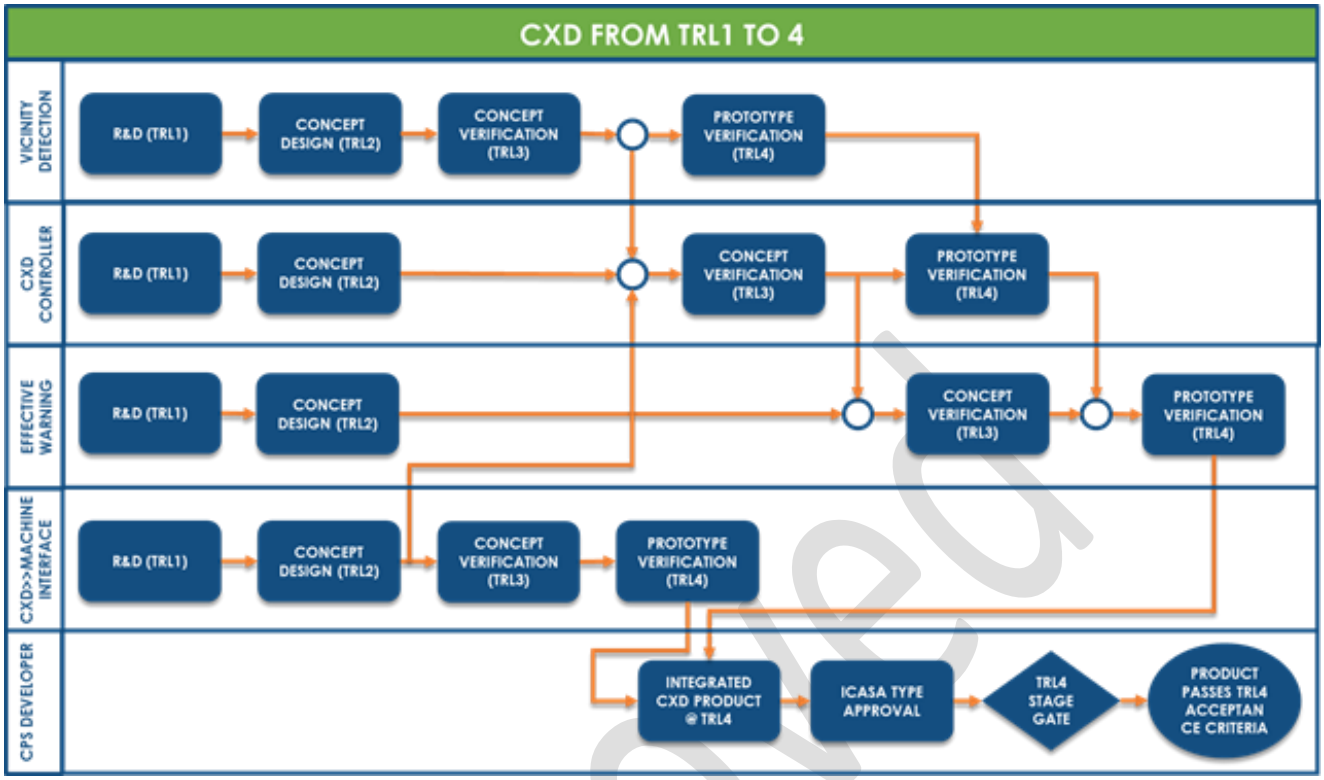


Figure 6: Accelerated CXD Product Development Process

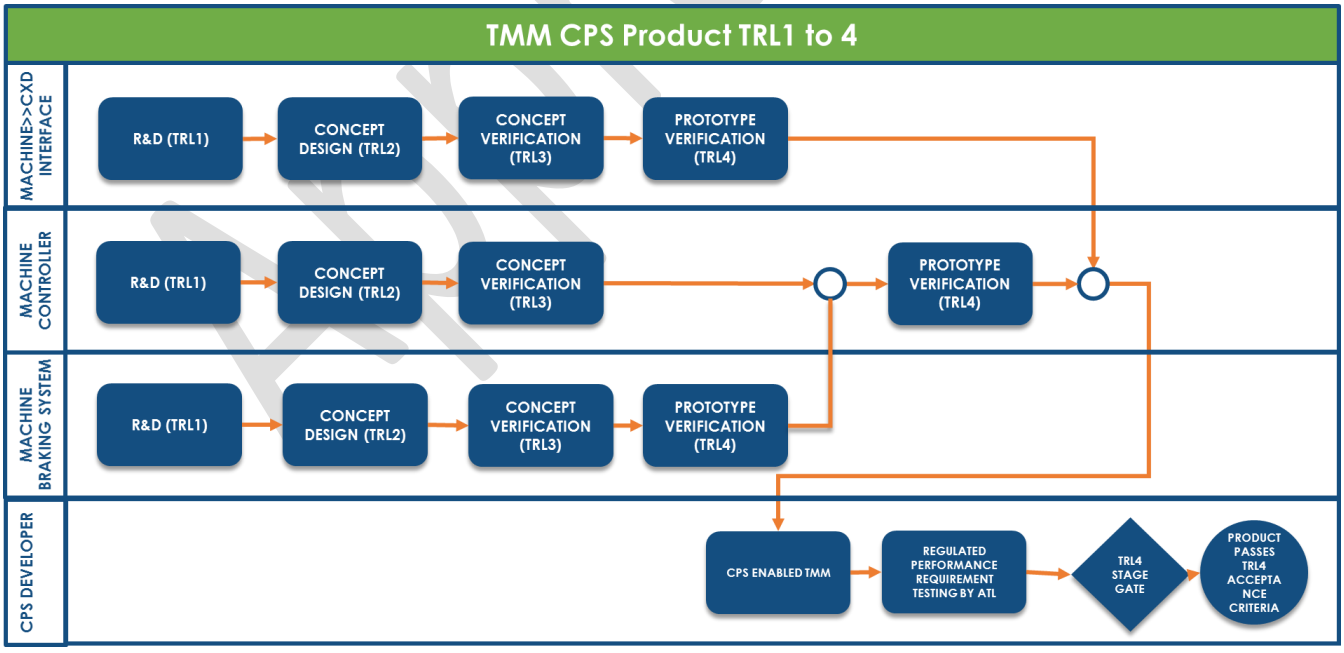


Figure 7: Accelerated TMM CPS Product Development Process

For the sake of completeness, the on-mine CPS rollout process is also shown, although there are no specific functional readiness criteria associated with it. Operational readiness criteria will be addressed in future revisions of this document.

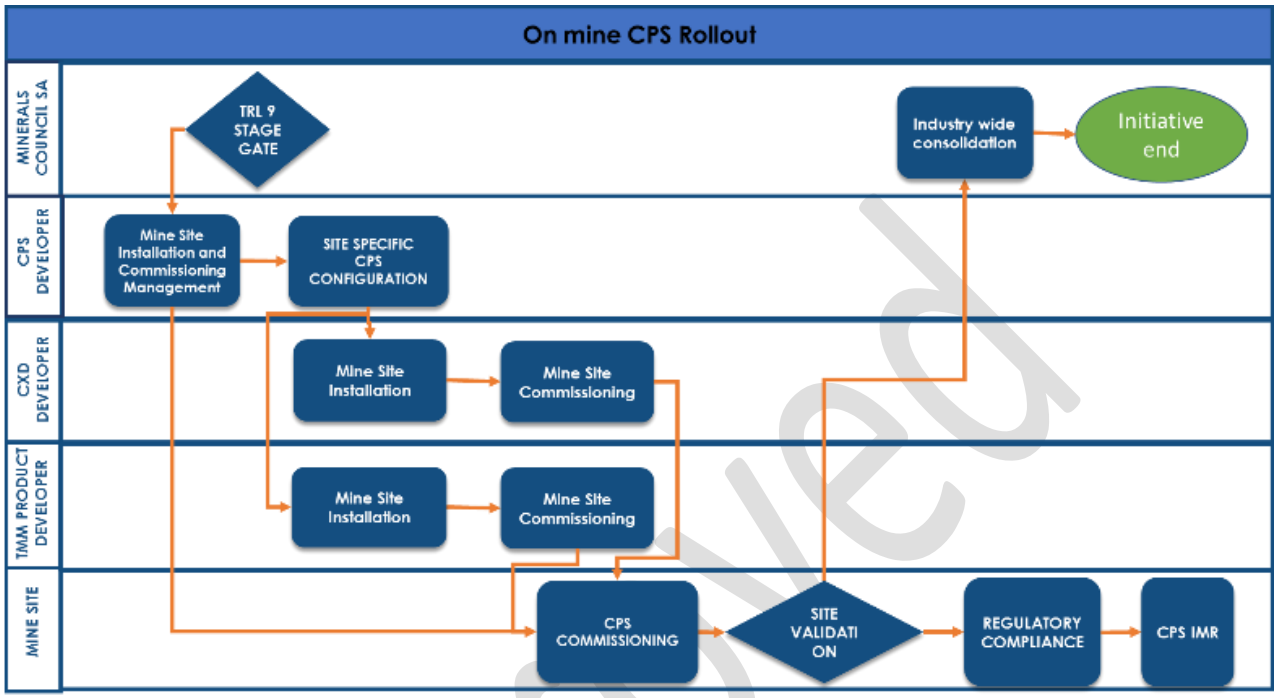


Figure 8: On mine CPS Product Rollout Process

The functional readiness criteria will cover functional design, integration and testing. Since testing is a particularly important aspect of collaboration, an integrated testing regime for CPS product has been developed. This document will not duplicate the definition of testing work and the success criteria, it will simply refer to the testing regime. From TRL 5 onwards the **functional** criteria relate to integration and testing only, and the criteria is therefore defined in the Integrated CPS Testing Regime document and not repeated here.

PART 1 CPS PRODUCT SYSTEM FUNCTIONAL READINESS CRITERIA

17. CPS Development Facilitator (Minerals Council South Africa)

TRL	Definition of the TRL	Description of Typical Activities	Success criteria to next maturity level (Evidence Description)
N/A	CPS Product System User **Requirements**	• System purpose documented. • TMM direct and related regulations analysed and functional and technical requirements documented and signed off. • CPS scope determination • User requirements definition (Including operational scenarios).	• TMM direct and related regulations analysed and functional and technical requirements signed off. • CPS scope signed off. • User requirements signed off. (Including. operational scenarios)

		• Preliminary CPS Product System breakdown structures development. (Legacy and interim scenarios). • CPS Life Cycle system analysis and definition. • User requirements analysed and allocated to CPS product elements.	• Preliminary CPS Product System breakdown structures signed off by end users. • CPS Life Cycle system definition signed off. • CPS product elements requirements signed off.
N/A	CPS Product System **Functional baseline**	• Functional analysis and allocation. • System Functional and Technical Requirements definition. • Interoperability analysis and specification. • EMI analysis and EMC specification. • Zone Functionality analysis and specification.	• CPS Functional and Technical Performance Requirements signed off. • Interoperability challenges resolved.
N/A	CPS Product System **Verification baseline**	• CPS integrated test regime development. • Test facility analysis and development recommendations. • TMM population estimate defined. • Risk Informed approach signed off. • 3rd Party Functional Testing Protocol development.	• Testing Protocols signed off. • TMM Population estimate signed off. • Risk Informed approach signed off.

18. CPS Developer

The role of the CPS developer as defined in the CMS Technical Requirements Guideline Review Report is that of the **single responsible party** for the development of every CPS ie. 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 are 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.	Portfolio of evidence for all elements and modules as per agreement accepted.

		• Oversee and integrate inter role-player activities.	

19. Readiness Criteria for CxD Development

Vicinity Detection Module (VD)

TRL	Definition of the TRL	Description of Typical Activities	Success criteria to next maturity level (Evidence Description)
1	**VD** requirements defined, basic principles observed and reported.	**Requirements analysis** • VD purpose documented. • Sec 21 legal obligation analysed. • Solution focus decided (Surface, Underground, Both). • VD development strategy (Inhouse, partner, subcontracted, etc.) Note: the third party must always obtain OEM input and approval. • Legal liability alignment based on the specific strategy chosen. • TMM fleet (Type, Model, Serial No) braking system characteristics analysis. • CPS user requirements analyses and preliminary VD functional requirements confirmation. **Planning** VD development plan per machine type, model, serial number as relevant, including the following criteria: • Safety based development process. • Project Quality Plan. • Time and effort. • Human and physical resources. • Test plan. • Integration. **Design activities** • Functional analysis. • Relevant literature analysed. Principles observed and application considered. • Functional and Technical performance of sub-assemblies/modules specified.	• Signed off plans. • TMM OEM agreement(s). • TMM characteristics available and signed off by TMM OEM. • VD based on peer reviewed approaches. Target operational environment & equipment identified (surface vs. UG or both). Functional analysis completed. Concepts ready to be evaluated and selected based on functional analysis.

		• VD configuration defined, including modular design • Potential alternative solutions identified and documented. • Significant benefits and challenges identified per alternative. • VD standardisation studies (Inter OEM and per Type and model) • Simulation/Mock-up model(s) development needs identified. • "Research" aspects identified, research planned and started. • VD Module breakdown structure(s) firmed up. (Per Type, Model and Serial number) as relevant • VD boundaries and interfaces identified. **Testing** None	

2	**VD** concept and application formulated.
	
	1st Gen or Mockup.
		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:
		  ○ Fail to safe analysis and design
		  ○ Self-diagnostic design
		  ○ VD integration design (physical and functional)
		• VD installation position per machine type and model selected.
		• Simulation/Mockup model(s) development completion and verification
		• Robustness analysis
		  ○ FMEA,
		  ○ Installation analysis and optimisation
		  ○ Component and sub assembly vulnerability analysis – vibration/shock, temperature, water
			All design and analysis documented for traceability, as per project quality plan.

		ingress, adhesion, physical damage, installation damage. o EMI analysis and EMC design • Functional and Technical performance tests and test protocols design. • Sub assembly and component maintainability analysis and design. • Draft manufacturing drawings development. **Planning** Update plans. **Testing/Verification** See Integrated Testing Regime.	
3	**VD** proof of concept. **Next Gen item manufactured/sourced, assembled, FAT. (Breadboard)**	**Design** • Sub assembly and component maintainability analysis. • Component and sub assembly inspection sheets documented. • 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 defined. • Component and sub assembly fitting and routing diagrams development. • Installation checklist(s) development. • Manufacturing and assembly drawings updated. **Planning** Update plan – integration focus. **Testing/verification** See Integrated Testing Regime.	• All design and analysis documented for traceability, as per project quality plan. • Certificate of conformance issued by module developer.
4	**VD** Functional Validation **Next generation item manufacturing, assembly and FAT**	**Design** • Update manufacturing and assembly drawings. • Component and sub assembly inspection sheets updated.	• Certificate of conformance issued for: o Adherence to inhouse design and development processes.

	(Validation in workshop/lab environment to verify fit, form and function)	• 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** See Integrated Testing Regime.	○ Test and verification results. • OEM signoff for "On TMM" testing to commence.
4	**VD, - CxD** integration **(Fit and function verification in relevant environment)** **Final VD installed on actual TMM** **(TMM OEM Site)**	**Installation** • Time and motion studies. • Tools required finalised. • Skills required finalised. • Installation documentation verified. • Commissioning documentation verified. **Testing** See integrated testing regime.	• Integrated VD certified to conform to requirements. • Portfolio of evidence available. • Skills requirements published • TMM OEM signed off.

CxD Controller (CxDC)

TRL	Definition of the TRL	Description of Typical Activities	Success criteria to next maturity level (Evidence Description)
1	**CxDC** Requirements defined, basic principles observed and reported.	**Requirements analysis** • CxDC purpose documented. • Sec 21 legal obligation analysed • Solution focus (Surface, Underground, Both). • CxDC development strategy (Inhouse, partner, subcontracted, etc.) the third party must always obtain OEM input and approval. • Legal liability alignment based on selected strategy. • TMM fleet (Type, Model, Serial No) braking system characteristics analysis. • CPS user requirements analyses and preliminary CxDC functional requirements confirmation. **Planning** • CxDC development plan per machine type, model, serial number as relevant. o Safety based development process. o Project Quality Plan. o Time and effort. o Human and physical resources. o Test plan. o Integration. **Design** • Functional analysis. • Relevant literature analysed. Principles observed and application considered. • Functional and Technical performance of sub-assemblies/modules specified. • Controller configuration – modular design o Potential alternative solutions identified and documented. o Significant benefits and challenges identified per alternative.	• Signed off plans. • TMM OEM agreement(s). • TMM characteristics available and signed off by TMM OEM. • CxDC 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. • Concepts ready to be evaluated and selected based on functional analysis.

		○ 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 • CxDC boundaries and interfaces identified. **Testing** None	
2	**CxDC** 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: ○ Sensor fusion ○ TMM conditions, speed, gear selection etc. ○ Post failure operation ○ Self-Diagnostics and CPS diagnostics ○ Data recording and log keeping ○ Date and Time synchronisation ○ 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 ○ CxDC integration design (physical and functional) • Controller installation position per machine type and model selected.	All design and analysis documented for traceability, as per project quality plan

		• Simulation/Mockup model(s) development completion and verification
		• Robustness 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
		See Integrated Testing Regime	

3	**CxDC** proof of concept. **Next Gen item manufactured / sourced, assembled, FAT. (Breadboard)**	**Design** • 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 **Testing/verification** See Integrated Testing Regime	• All design and analysis documented for traceability, as per project quality plan • Certificate of conformance issued by module developer.

4	**CxDC** Functional Validation **Next generation item manufacturing, assembly and FAT** **(Validation in workshop/lab environment to verify fit form and function)**	**Design** • 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 assessment done and controls identification. • Installation checklist(s) development. **Testing** See Integrated Testing Regime	Certificate of conformance issued for: • Adherence to inhouse design and development processes • Test and verification results • OEM signoff for "On TMM" testing to commence
4	**CxDC, - CxD** integration **(Fit and function verification in relevant environment)** **Final CxDC installed on actual TMM** **(TMM OEM Site)**	**Installation** • Time and motion studies • Tools required finalised • Skills required finalised • Installation documentation verified • Commissioning documentation verified **Testing** See integrated testing regime	• Integrated CxDC certified to conform to requirements • Portfolio of evidence available • Skills requirements published • TMM OEM signed off

Effective Warning (EW) Module

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

1	**EW** Requirements defined, basic principles observed and reported.	**Requirements analysis**
		• EW purpose documented.
		• Sec 21 legal obligation analysed
		• Solution focus decided. (Surface, Underground, Both)
		• EW development strategy decided. (Inhouse, partner, subcontracted, etc.) Note: the third party must always obtain OEM input and approval.
		• Legal liability alignment based on selected strategy
		• TMM fleet (Type, Model, Serial No) braking system characteristics analysis.
		• CPS user requirements analyses, and preliminary EW functional requirements confirmed.
		Planning
		• EW 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.
		• Functional and Technical performance of sub-assemblies/modules specified.
		• EW configuration – modular design
		• Potential alternative solutions identified and documented.
		• Significant benefits and challenges identified per alternative.
		• EW standardisation studies (Inter OEM and per Type and model)
			• Signed off plans
			• TMM OEM agreement(s)
			• TMM characteristics available and signed off by TMM OEM
			• EW based on peer reviewed approaches. Target operational environment & equipment identified (surface vs. UG or both). Functional analysis completed. Concepts ready to be evaluated and selected based on functional analysis.

		• Simulation/Mockup model(s) development needs identified. • "Research" aspects identified, research planned and started. • Human interface analysis • Effective Warning analysis – Human interface • EW Module breakdown structure(s) firmed up. (Per Type, Model and Serial number) as relevant • EW boundaries and interfaces identified. **Testing** None	
2	**EW** concept and application formulated. **1st Gen or Mockup.**	**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: o Human factors design. (Operator and pedestrian centric design) Human interface o Post failure operation o Self-Diagnostics o Data recording and log keeping o Fail to safe analysis and design o EW integration design (physical and functional) • EW installation position per machine type and model selected. • Simulation/Mockup model(s) development completion and verification • Robustness analysis o FMEA, o Installation analysis and optimisation o Component and sub assembly vulnerability analysis – Vibration/shock, Temperature, water ingress,	All design and analysis documented for traceability, as per project quality plan

		adhesion, physical damage, installation damage. o EMI analysis and EMC design • Functional and Technical performance tests and test protocols designed and documented • Sub assembly and component maintainability analysis and design completed • Draft manufacturing drawings done **Planning** Update plans **Testing/Verification** See Integrated Testing Regime	
3	**EW** proof of concept. **Next Gen item manufactured/sourced, assembled, FAT. (Breadboard)**	**Design** • Sub assembly and component maintainability analysis • Component and sub assembly inspection sheets documented • 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 • Component and sub assembly fitting and routing diagrams documented. • Installation checklist(s) development. • Update manufacturing and assembly drawings **Planning** Update plan – integration focus **Testing/verification** See Integrated Testing Regime	• All design and analysis documented for traceability, as per project quality plan • Certificate of conformance issued by module developer.
4	**EW** Functional Validation **Next generation item manufacturing, assembly and FAT** **(Validation in workshop/lab**	**Design** • 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.	Certificate of conformance issued for: • Adherence to inhouse design and development processes • Test and verification results

	environment to verify fit form and function)	**Installation** • Component and sub assembly installation sequence optimisation, risk assessment done, and controls identified • Installation checklist(s) updated **Testing** See Integrated Testing Regime	• OEM signoff for "On TMM" testing to commence
4	**EW, - CxD** integration **(Fit and function verification in relevant environment)** **Final EW installed on actual TMM** **(TMM OEM Site)**	**Installation** • Time and motion studies • Tools required finalised • Skills required finalised • Installation documentation verified • Commissioning documentation verified **Testing** See integrated testing regime	• Integrated EW certified to conform to requirements • Portfolio of evidence available • Skills requirements published • TMM OEM signed off

V2X Interface (V2XI) Module

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

1	**V2XI** Requirements defined, basic principles observed and reported.	**Requirements analysis**
		• V2XI purpose documented.
		• Sec 21 legal obligation analysed
		• Solution focus decided. (Surface, Underground, Both)
		• V2XI development strategy decided (Inhouse, partner, subcontracted, etc.)
		• Legal liability alignment based on chosen strategy
		• CPS user requirements analyses and ISO/TS 21815-2:2021 analysis.
		Planning
		• V2XI development plan
		  ○ Safety based development process
		  ○ Project Quality Plan
		  ○ Time and effort
		  ○ Human and physical resources
		  ○ Testing (FAT and Integration)
		  ○ Integration
		Design
		• Functional analysis
		• Potential alternative solutions identified and documented.
		• Significant benefits and challenges identified per alternative.
		• Simulation/Mockup model(s) development needs identified; development starts. CxD emulator.
		• "Research" aspects identified, research planned and started.
		• V2XI Module Breakdown Structure(s) firmed up. (Per Type, Model and Serial number) as relevant
		• Cab layouts available for installation design.
			• Signed off plans
			• TMM OEM agreement(s)
			• TMM characteristics available and signed off by TMM OEM
			• V2XI based on peer reviewed approaches.
			• Target operational environment & equipment identified (surface vs. UG or both).
			• Functional analysis completed.
			• Concepts ready to be evaluated and selected based on functional analysis.

2	**V2XI** concept and application formulated. **1st Gen or Mockup manufactured**	**Design** • Concepts analysis. • Solution concept selection: per Type, Model and Serial No. (including self-diagnostics and fail to safe functionality).	All design and analysis documented for traceability, as per project quality plan.

		• Sub assembly and components characterised (functional and physical).
		• V2XI integration design: (physical and functional), Installation.
		• Fail to safe design.
		• EMC design.
		• Sub assembly and component design.
		• Sub assembly and component draft manufacturing drawings.
		• Simulation model(s).
		• Sub assembly and component robustness analysis
		  ○ FMEA,
		  ○ Component and sub assembly vulnerability analysis – Vibration/shock, Temperature, water ingress, adhesion, physical damage, installation damage
		  ○ Maintainability analysis
		• Sub assembly and component maintainability analysis.
		Planning
		Update plans.
		Testing and Validation
		As per inhouse testing plan and protocols.	

3	**V2XI** proof of concept. **Next Gen components manufactured/sourced and assembled. (Breadboard)**	**Design** • Update manufacturing and assembly drawings. • Component and sub assembly inspection sheets documented. • Component and sub assembly tests defined and test instructions, test parameters and acceptance criteria documented. • Installation sequence optimised, risk assessments completed, and controls identified. • Installation checklist(s) documented. • Certificate of conformance defined. **Planning** Update plan – integration focus. **Testing and Validation** See integrated test regime.	• All design and analysis documented for traceability, as per project quality plan. • Certificate of conformance issued by module developer.

4	**V2XI** functional validation **Next generation item manufacturing, assembly and FAT** **(Validation in workshop/lab environment to verify fit form and function)**	**Design** • 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** See Integrated Testing Regime.	Certificate of conformance issued for: • Adherence to inhouse design and development processes. • Test and verification results. • OEM signoff for "On TMM" testing to commence.
4	**CxD** Integration **(Fit and function verification in relevant environment)** **Final V2XI components manufactured, assembled, FAT**	**Installation** • Time and motion studies. • Tools required finalised. • Skills required finalised. • Installation documentation verified. • Commissioning documentation verified. **Testing** See integrated testing regime.	• Integrated TMM Product certified to conform to requirements. • Portfolio of evidence available. • Skills requirements published. • TMM OEM signoff.

CXD >> Machine Interface (CXDMI) Element

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

1	**CxDMI** Requirements defined, basic principles observed and reported.	**Requirements analysis**
		• CxDMI purpose documented.
		• Sec 21 legal obligation analysed
		• Solution focus decided. (Surface, Underground, Both).
		• CxDMI development strategy (Inhouse, partner, subcontracted, etc.)
		• Legal liability alignment based on selected strategy.
		• CPS user requirements analyses and ISO/TS 21815-2:2021 analysis.
		Planning
		• CxDMI development plan
		  ○ Safety based development process.
		  ○ Project Quality Plan.
		  ○ Time and effort.
		  ○ Human and physical resources.
		  ○ Testing (FAT and Integration)
		  ○ Integration.
		Design
		• Functional analysis.
		• Potential alternative solutions identified and documented.
		• Significant benefits and challenges identified per alternative.
		• Simulation/Mockup model(s) development needs identified; development starts. CxD emulator.
		• "Research" aspects identified, research planned and started.
		• CxDMI Module Breakdown Structure(s) firmed up. (Per Type, Model and Serial number) as relevant.
		• Cab layouts available for installation design.
			• Signed off plans.
			• TMM OEM agreement(s).
			• TMM characteristics available and signed off by TMM OEM.
			• CxDMI based on peer reviewed approaches.
			• Target operational environment & equipment identified (surface vs. UG or both).
			• Functional analysis completed.
			• Concepts ready to be evaluated and selected based on functional analysis.

2	**CxDMI** concept and application formulated.
	
	1st Gen or Mockup manufactured
		Design
		• Concepts analysis.
		• Solution concept selection: per Type, Model and Serial No. (including self-diagnostics and fail to safe functionality).
		• Sub assembly and components characterised (functional and physical).
		• CxDMI integration design (physical and functional) Installation.
		• Fail to safe design.
		• EMC design.
		• Sub assembly and component design.
		• Sub assembly and component draft manufacturing drawings.
		• Simulation model(s) for ISO/TS 21815-2:2021 available.
		• Sub assembly and component robustness analysis
		  ○ FMEA,
		  ○ Component and sub assembly vulnerability analysis – Vibration/shock, Temperature, water ingress, adhesion, physical damage, installation damage
		  ○ Maintainability analysis
		• Sub assembly and component maintainability analysis.
		Planning
		Update plans.
		Testing and Validation
		As per inhouse testing plan and protocols.
			All design and analysis documented for traceability, as per project quality plan.

3	**CxDMI** proof of concept. **Next Gen components manufactured/sourced and assembled. (Breadboard)**	**Design** • Update manufacturing and assembly drawings. • Component and sub assembly inspection sheets documented. • Component and sub assembly tests defined and test instructions, test parameters and acceptance criteria documented. • Installation sequence optimised, risk assessments done, and controls identified.	• All design and analysis documented for traceability, as per project quality plan. • Certificate of conformance issued by module developer.

		• Installation checklist(s) documented. • Certificate of conformance. **Planning** Update plan – integration focus. **Testing and Validation** See integrated test regime.	
4	**CxDMI** functional validation **Next generation item manufacturing, assembly and FAT** **(Validation in workshop/lab environment to verify fit form and function)**	**Design** • 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 defined. • Installation checklist(s) documented. **Testing** See Integrated Testing Regime.	Certificate of conformance issued for: • Adherence to inhouse design and development processes. • Test and verification results. • OEM signoff for "On TMM" testing to commence.
4	**CxD** to machine Integration **(Fit and function verification in relevant environment)** **Final CxDMI components manufactured, assembled, FAT**	**Installation** • Time and motion studies. • Tools required finalised. • Skills required finalised. • Installation documentation verified. • Commissioning documentation verified. **Testing** See integrated testing regime.	• Integrated TMM Product certified to conform to requirements. • Portfolio of evidence available. • Skills requirements published. • TMM OEM signoff.

20. Readiness criteria for TMM CPS Products (TMMP) (TMM OEM or 3rd Party)

Machine > CxD Interface (MCxDI) Module

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

1	**MCxDI**
	Requirements defined, basic principles observed and reported.
		Requirements analysis
		• MCxDI purpose documented.
		• Sec 21 legal obligation analysed.
		• Solution focus decided (Surface, Underground, Both).
		• MCxDI development strategy decided. (Inhouse, partner, subcontracted, etc.)
		• Legal liability alignment based on selected strategy.
		• CPS user requirements analyses and ISO/TS 21815-2:2021 analysis.
		Planning
		• MCxDI development plan
		  ○ Safety based development process
		  ○ Project Quality Plan
		  ○ Time and effort
		  ○ Human and physical resources
		  ○ Testing (FAT and Integration)
		  ○ Integration
		Design
		• Functional analysis.
		• Potential alternative solutions identified and documented.
		• Significant benefits and challenges identified per alternative.
		• Simulation/Mockup model(s) development needs identified; development starts. CxD emulator.
		• "Research" aspects identified, research planned and started.
		• MCxDI Module Breakdown Structure(s) firmed up. (Per Type, Model and Serial number) as relevant
		• Cab layouts available for installation design.
			• Signed off plans
			• TMM OEM agreement(s)
			• TMM characteristics available and signed off by TMM OEM
			• MCxDI based on peer reviewed approaches.
			• Target operational environment & equipment identified (surface vs. UG or both).
			• Functional analysis completed.
			• Concepts ready to be evaluated and selected based on functional analysis.

2	**MCxDI** concept and application formulated.
	
	1st Gen or Mockup manufactured
		Design
		• Concepts analysis
		• Solution concept selection: per Type, Model and Serial No. (including self-diagnostics and fail to safe functionality)
		• Sub assembly and components characterised (functional and physical).
		• MCxDI integration design (physical and functional), installation.
		• Fail to safe design.
		• EMC design.
		• Sub assembly and component design.
		• Sub assembly and component draft manufacturing drawings.
		• Simulation model(s) for ISO/TS 21815-2:2021 available.
		• Sub assembly and component robustness analysis.
		  o FMEA,
		  o Component and sub assembly vulnerability analysis – Vibration/shock, Temperature, water ingress, adhesion, physical damage, installation damage
		  o Maintainability analysis
		• Sub assembly and component maintainability analysis.
		Planning
		Update plans.
		Testing and Validation
		As per inhouse testing plan and protocols.
			All design and analysis documented for traceability, as per project quality plan.

3	**MCxDI** proof of concept. **Next Gen components manufactured/sourced and assembled. (Breadboard)**	**Design** • Update manufacturing and assembly drawings. • Component and sub assembly inspection sheets documented. • Component and sub assembly tests defined and test instructions, test parameters and acceptance criteria documented. • Installation sequence optimised, risk assessment done, and controls identified.	• All design and analysis documented for traceability, as per project quality plan. • Certificate of conformance issued by module developer.

		• Installation checklist(s) documented. • Certificate of conformance development. **Planning** Update plan – integration focus. **Testing and Validation** See integrated test regime.	
4	**MCxDI** functional validation **Next generation item manufacturing, assembly and FAT** **(Validation in workshop/lab environment to verify fit form and function)**	**Design** • 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** See Integrated Testing Regime.	Certificate of conformance issued for: • Adherence to inhouse design and development processes. • Test and verification results. • OEM signoff for "On TMM" testing to commence.
4	**MCxDI**, **MC and MBS** Interface Integration **(Fit and function verification in relevant environment)** **Final MCxDI components manufactured, assembled, FAT and installed on actual TMM**	**Installation** • Time and motion studies. • Tools required finalised. • Skills required finalised. • Installation documentation verified. • Commissioning documentation verified. **Testing** See integrated testing regime.	• Integrated TMM Product certified to conform to requirements. • Portfolio of evidence available. • Skills requirements published. • TMM OEM signoff.

Machine Controller (MC) Module Criteria (TMM OEM or 3rd Party)

What's in the box: A black box with mountings and a female cable socket.
Note: for CAN bus

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

1	**MC** Requirements defined, basic principles observed and reported.	**Requirements analysis**
		• MC purpose documented.
		• Sec 21 legal obligation analysed
		• Solution focus decided (Surface, Underground, Both)
		• MC development strategy decided (Inhouse, partner, subcontracted, etc.) the third party must always obtain OEM input and approval.
		• Legal liability alignment based on selected strategy
		• TMM fleet (Type, Model, Serial No) braking system characteristics analysis.
		• CPS user requirements analyses and preliminary MC functional requirements confirmation.
		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.
		• 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)
			• Signed off plans
			• TMM OEM agreement(s)
			• TMM characteristics available and signed off by TMM OEM
			• MC based on peer reviewed approaches. Target operational environment & equipment identified (surface vs. UG or both). Functional analysis completed. Concepts ready to be evaluated and selected based on functional analysis.

		• 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	**MC** concept 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: o CXD enquiries and actions o Wheel locking and steering stability o Controlled deceleration o Controlled stopping o Over speeding prevention o Brake actuation characteristics o Fail to safe functionality (CXD and/or MBS unavailability). o Fail to safe analysis and design o Self-diagnostic design o MC and MBS integration design (physical and functional) • MC installation position per machine type and model selected. • Simulation/Mockup model(s) development completion and verification • Robustness analysis o FMEA, o Installation analysis and optimisation o Component and sub assembly vulnerability analysis – Vibration/shock, Temperature, water ingress, adhesion, physical damage, installation damage. o EMI analysis and EMC design	All design and analysis documented for traceability, as per project quality plan

		• 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** See Integrated Testing Regime	
3	**MC** proof of concept. **Next Gen item manufactured/ sourced, assembled, FAT.** **(Breadboard)**	**Design** • 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 development. (FAT) • Component and sub assembly installation sequence optimised, risk assessments done, and controls identified • Component and sub assembly fitting and routing diagrams drawn. • Installation checklist(s) documented • Update manufacturing and assembly drawings **Planning** Update plan – integration focus **Testing/verification** See Integrated Testing Regime	• All design and analysis documented for traceability, as per project quality plan • Certificate of conformance issued by module developer.
4	**MC** Functional Validation **Next generation item manufacturing, assembly and FAT** **(Validation in workshop/lab environment to verify fit form and function)**	**Design** • 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** See Integrated Testing Regime	Certificate of conformance issued for: • Adherence to inhouse design and development processes • Test and verification results • OEM signoff for "On TMM" testing to commence

4	**MC, MBS and CxDI** integration **(Fit and function verification in relevant environment)** **Final MC installed on actual TMM** **(TMM OEM Site)**	**Installation** • Time and motion studies • Tools required finalised • Skills required finalised • Installation documentation verified • Commissioning documentation verified **Testing** See integrated testing regime	• Integrated TMM Product certified to conform to requirements • Portfolio of evidence available • Skills requirements published • TMM OEM signed off

Machine Braking System (MBS) Module (TMM OEMs or a 3rd party)

(What is in the box (kit): Proportional hydraulic Valve(s), Valve mounting brackets, Valve to controller cable with connector, throttler, retarder switch, speed sensor, gear selection unit, probes and sensors

TRL	Definition of the TRL	Description of Typical Activities	Success criteria to next maturity level (Evidence Description)
1	**MBS** Requirements defined, basic principles observed and reported.	**Requirements analysis** • MBS purpose documented. • Sec 21 legal obligation analysed • Data requirements to support legal liability identified. • Establish a Safety engineering approach • Solution focus decided (Surface, Underground, Both) • MBS development strategy decided (Inhouse, partner, subcontracted, etc.) the third party must always obtain OEM input and approval. • Legal liability alignment based on selected strategy. • TMM fleet (Type, Model, Serial No) documented with braking system characteristics of each (at least a drawing of the braking system layout). (Note: Braking systems components and layouts may be found in the OEM manuals) • CPS user requirements analyses and initial MBS functional requirements confirmation. • Testing requirements to ensure brake compliance after modification (Back to original standard SANS 1589-1, ISO 3450 etc certification)	• Signed off plans • TMM OEM agreement(s) • TMM characteristics available and signed off by TMM OEM • MBS based on peer reviewed approaches. Target operational environment & equipment identified (surface vs. UG or both). Functional analysis completed. Concepts ready to be evaluated and selected based on functional analysis.

		Planning
		• MBS development plan.
		  o Safety based development process
		  o Time and effort
		  o Project Quality plan
		  o Human and physical resources
		  o Testing Plan
		  o Integration with machine.
		Design
		• Functional Analysis
		• Functional and Technical performance requirements of all components specified.
		• Relevant literature analysed, principles observed, and application considered.
		• Potential alternative solutions identified and documented including self-diagnostics and fail to safe functionality)
		• Significant benefits and challenges identified per alternative.
		• "Research" aspects identified, research planned and started.
		• Simulation/Mockup model(s) development needs identified.
		• MBS breakdown structure(s) firmed up. (Per Type, Model and Serial number)
		• MBS boundaries and interfaces identified.	

2	**MBS** concept and application formulated.
	
	1st Gen or Mockup.
		Design
		• Concepts analysis and risk assessment
		• Solution concept selection: per Type, Model and Serial No.
		• Sub assembly and components characterised (functional and physical)
		• Functional design including:
		  o CXD enquiries and actions
		  o Wheel locking and steering stability
		  o High friction deceleration
		  o High friction stopping
		  o Over speeding prevention
		  o Brake actuation characteristics
			• All design and analysis documented for traceability, as per project quality plan
			• If third party, signed off by OEM

		○ Fail to safe functionality (CXD and/or MBS unavailability ○ Fail to safe analysis and design ○ Self-diagnostic design ○ MBS and MC integration design (physical and functional) • Functional and Technical performance tests and test protocols designed • Human factors analysis and engineering ○ Operator exposure from deceleration ○ Effective communication modes of actions to be taken, including not introducing any distractions ○ Cab layout optimisation ○ Operator interface • Braking mechanism mock-up design • Simulation models completed and validated. • Mock-up completed and instrumented. • Sub assembly and component robustness analysis ○ FMEA, ○ Installation analysis and optimisation ○ Component and sub assembly vulnerability analysis – vibration/shock, temperature, brake mechanism overheating, water ingress, adhesion, physical damage, installation damage • Sub assembly and component maintainability analysis and design • Draft manufacturing drawings development. **Planning** Update plan **Testing/Verification** • Component testing/functionality verification to ensure validity of assumptions. • Human factors analysis and related design requirements	

3	**MBS** proof of concept. **Next Gen item manufactured/ sourced, assembled, FAT.** **(Breadboard)**	**Design** • Sub assembly and component maintainability analysis • Sub assembly and component draft manufacturing drawings • Component and sub assembly inspection sheets documented • Component and sub assembly tests defined and test instructions, test parameters and acceptance criteria development. • Component and sub assembly installation sequence optimised, risk assessments done, and controls identified • Installation checklist(s) documented • Component and sub assembly fitting and routing diagrams updated **Planning** Update plan – integration focus **Testing** See integrated test regime	• All design and analysis documented for traceability, as per project quality plan • Certificate of conformance issued by module developer.
4	**MBS** Functional Validation **Final items manufacturing and assembly to verify fit form and function** **(Validation in workshop/lab environment to verify fit form and function)**	**Design** • Build mock-up(s) • Update manufacturing and assembly drawings • Component and sub assembly inspection sheets updated • Component and sub assembly, test parameters and acceptance criteria updated • Factory acceptance testing design, test instructions/protocols development **Installation** • Component and sub assembly installation sequence refined, MBS risk assessments done, and controls identified. • Installation checklist(s) documented • Commissioning acceptance criteria documented **Testing** See integrated test regime	Certificate of conformance issued for: • Adherence to inhouse design and development processes • Test and verification results • OEM signoff for "On TMM" testing to commence • Brake test compliance

4	**MBS, MC and CxDI** integration **(Fit and function verification in relevant environment)** **Final MBS installed on actual TMM** **TMM OEM site.**	**Installation** • Time and motion studies • Tools required finalised • Skills required finalised • Installation documentation verified • Commissioning documentation verified **Testing** See integrated testing regime	• Integrated TMM Product certified to conform to requirements • Portfolio of evidence available • Skills requirements published • TMM OEM signed off

21. 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 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: Draft, 1992 MILITARY STANDARD PROGRAM-UNIQUE SPECIFICATIONS, PREPARATION OF

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