INTEGRATED COLLISION PREVENTION SYSTEMS

TESTING REGIME

(I.E., WORK PACKAGE 9)

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

REV 4

Integrated CPS Testing Regime Acceptance			
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TABLE OF CONTENTS

1. Purpose of this document 3
2. Definitions and abbreviations 3
3. Executive Summary 9
4. Conclusions 10
5. Recommendations 10
6. Context of this document 12
7. Background 12
8. Principles of the Integrated CPS Test Regime 13
9. Alignment of the Integrated CPS Testing Regime with CPS Readiness Criteria .. 14
10. Proposed Integrated CPS Testing Regime 14
    7.1 End-state CPS testing regime 15
    7.2 Interim state CPS testing regime 16
8. Accelerated CPS Development Process 17
9. Stage Gate Testing 20
10. CxD Testing: TRL 1 to 4 22
11. TMM CPS Product Testing: TRL 1 to 4 25
12. CxD-TMM CPS Product integration Testing: TRL 5 to 9 26
    12.1 CxD-TMM CPS Product integration Testing: TRL 5 and 6 testing 26
    12.2 CPS Pilot Site Testing: TRL 7 to 9 27
13. Operational Readiness 29

1. Purpose of this document

This document defines the proposed Integrated Testing Regime for Collision Prevention Systems for Trackless Mobile Machines (TMM) in the SA Mining Industry (SAMI).

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.
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.
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, 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)
Minerals Council	Minerals Council South Africa.
MHS Act	Mine Health and Safety Act No. 29 of 1996 and Regulations.
MHSC	Mine Health and Safety Council
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, © 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.
SAMI	South African Mining Industry
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.
Significant risk (of collision)	The reasonable possibility of a TMM collision given all the controls that a mine has put in place to prevent a TMM collision.
Slow down	ISO/TS 21815-2: 2021 defines slow down as: The SLOW_DOWN action is sent by the CxD to reduce the speed of the machine in a controlled / conventional manner as defined by the machine control system. The intent of this command is to slow down the machine when the CxD logic determines that a collision / interaction can be avoided by reducing speed.
Stop	ISO/TS 21815-2: 2021 provides for two definitions, an emergency stop, and a controlled stop, both of which are a 'Stop'. The definitions are: 1. The EMERGENCY_STOP action is sent by CxD to instruct the machine to implement the emergency stop sequence defined by the machine control system. The intent of this command is to stop the machine motion as rapidly as possible to reduce the consequence level, if the CxD logic determines that a collision is imminent. The equivalent of an emergency stop is the operator slamming on the brakes in an emergency. 2. The CONTROLLED_STOP action is sent by CxD to instruct the machine to implement the controlled stop sequence defined by the machine control system.

	The intent of this command is to stop the machine motion in a controlled / conventional manner when the CxD logic determines that a collision / interaction can be avoided by slowing down and stopping. The equivalent of a controlled stop is slowing down and stopping when approaching a red traffic light.
System	A combination of interacting elements organized to achieve one or more stated purposes (ISO/IEC/IEEE 2015)
Technical specification	Specifications that define the technical and physical characteristics and/or measurements of a product, such as physical aspects (e.g., dimensions, colour, and surface finish), design details, material properties, energy requirements, processes, maintenance requirements and operational requirements.
This document	Integrated CPS Testing Regime. A document that defines the proposed integrated testing of CPS, its elements and modules.
TMM	Trackless Mobile Machine. (Machine, vehicle, etc.)
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)
TMM CPS Product	The product that will make a non-intelligent TMM intelligent and CxD ready
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.
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.
V2X	Vehicle to anything
V-V	Vehicle to Vehicle
V-P	Vehicle to pedestrian
Walking speed	In the absence of significant external factors, the average human's walking speed is 1.4meters per second. This is included to help define the crawl speed of vehicles.
WP 9	Work Package 9: Testing protocols (including legacy equipment). One of the work packages of the Industry Alignment on TMM Collision Management Systems Project: CAS READINESS PHASE.
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. Executive Summary

The regulatory nature of Collision Protection Systems for the SAMI requires that:

1) Enough CPS products are available for all TMMs working in mining processes where there is V-V (Surface) and V-P (underground) interaction inside a short window of time.
2) All CPS's comply with a set off minimum requirements (functional and technical) that will ensure compliance to the TMM regulations.

These requirements necessitate:

1) A single set of CPS requirements.
2) A collaborative and coordinated development process.
3) Traceability of conformance to requirements.

The development of CPS products for the SAMI started out by piggybacking on the EMESRT Collision Management System approach. The approach is:

1) Individual mine or mining company driven, using a generalised collision avoidance system functionality and technical requirements guideline to develop individual mine or mining company requirements.
2) CMS supplier performance based, ie. "this is what my system can do" as opposed to: "this is what my system can do including compliance to the CPS functional and technical performance requirements"
3) One where CMS suppliers set their own acceptance criteria and mines then decide if these criteria is acceptable.

The challenges with this approach are set out in detail in the CMS Technical Specification Guideline Review Report. The challenges include:

1) The development process is iterative, slow and does not produce traceable evidence of compliance to SAMI TMM regulatory requirements.
2) Every mine must prove due diligence in verification and validation of the CMS system that it will introduce to its mine. This will result in many similar or almost exact tests being conducted over and over on many mines.
3) Significant risk that noncompliance to the SAMI TMM regulations (direct and implied requirements) will only by discovered during the piloting or even rollout of the CMS and at a time when a mine cannot afford to change supplier. Inevitable the mine must then individually "sponsor" the resulting development needed.

With the increasing pressure from the DMRE to uplift the suspended TMM regulatory clauses the minerals council on behalf of its members initiated the INDUSTRY

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

The project's objectives include to ensure:

1) Enough CPS products are available for all TMMs working in mining processes where there is V-V (Surface) and V-P (underground) interaction at the time of upliftment of the suspended clauses of the TMM regulations.
2) That all the CPS Life Cycle System (Eco system) elements are developed to achieve the objective. This includes:
    a. Availability of testing capability and capacity
    b. Supply and/or manufacturing capability and capacity
    c. Installation and commissioning capability and capacity
    d. Operational and maintenance support capability and capacity
3) All CPS's comply with a set off minimum requirements (functional and technical) that will ensure compliance to the TMM regulations.
4) The quickest and most cost-effective CPS development process.

4. Conclusions

The following conclusions are made:

- It is not feasible to continue with the current approach given the challenges
- Successful CPS development will require extensive collaboration between TMM OEMs, Mines and CPS Providers.
- Availability of TMMs for testing must be well coordinated.
- Since a homologised CPS testing regime is not available the Integrated CPS Testing Regime must be embedded into the CPS development process.
- The Integrated CPS Testing Regime and its associated test protocols, if packaged in a guideline will be of significant benefit to the ICMM Vehicle Interaction initiative.

5. Recommendations

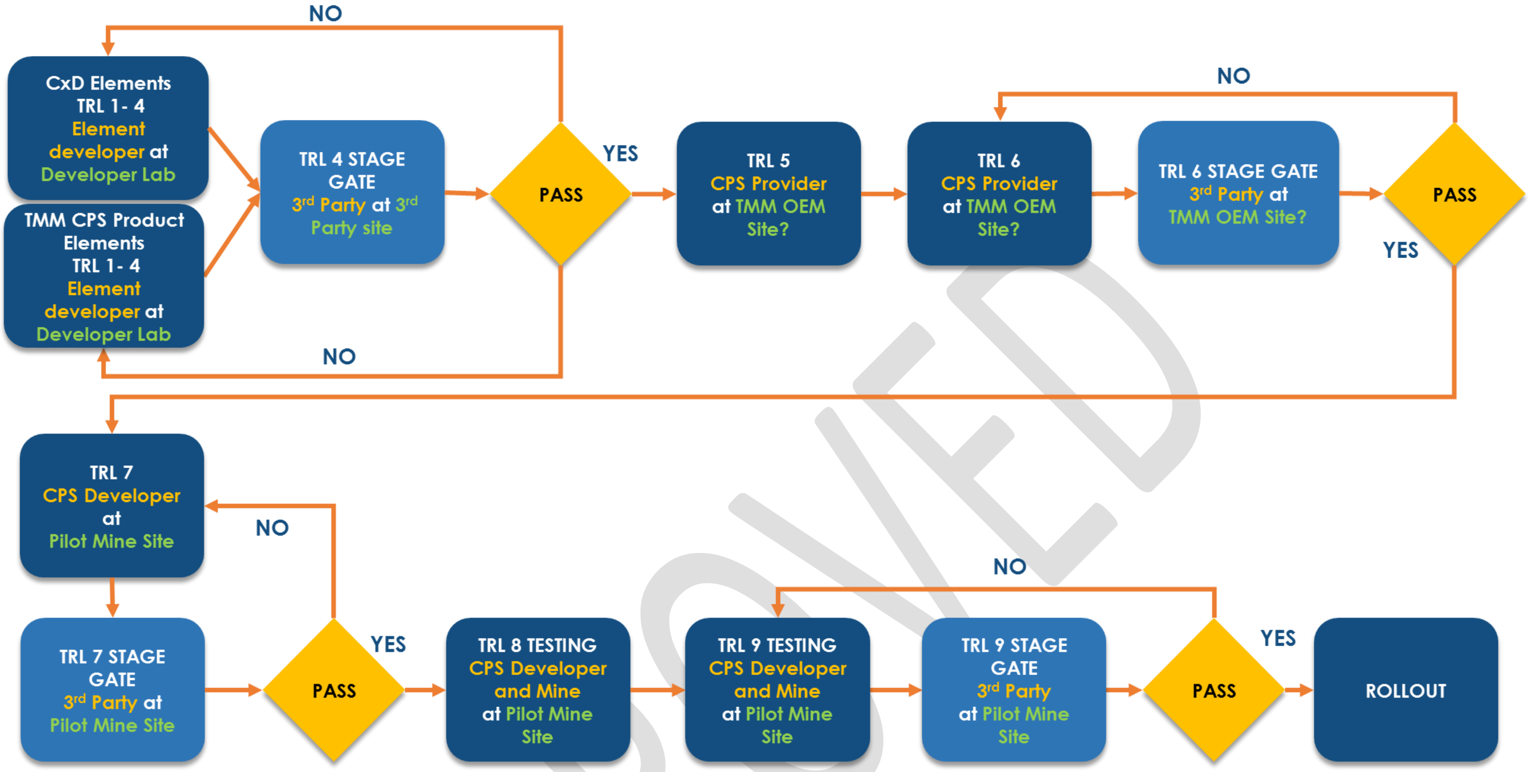
Following the approval of the development of the Integrated CPS Testing Regime in the CMS Technical Specification Guideline Review Report, this document defines the Integrated CPS Testing Regime in detail. The following recommendations are the principles of the proposed Integrated CPS Testing Regime set out in this document:

- A single set of User Requirements, Functional and Technical performance requirements, and testing criteria for CPS products are essential to an integrated testing regime.
- As much as possible testing to be done at the lowest level of component, module, or element.

- All Stage Gate testing to be done by an independent 3rd party testing entity, except for TRL 6 where only a portion of the testing is done by a 3rd party. This does not preclude any CPS product developer to use their own appointed independent 3rd party testing entities for any or all of the TRL 1 to 9 testing.
- A single set of test protocols for Stage Gate testing with clear acceptance criteria.
- Minimizing of the total number of tests to be done on mines by using pilot mines to facilitate specific CPS configurations for testing on behalf of all mines using such configurations.
- Sharing of test facilities and capabilities between TMM OEMs and CxD providers to minimize the cost of testing facilities, testing infrastructure and TMMs to perform tests.
- Sharing of the cost to establish testing capability by all parties (mines, CxD providers and TMM OEMs) as well as executing the 3rd party testing.
- Rigorous CPS development criteria that CxD providers, CxD and TMM CPS Product providers have to demonstrate in a structured ecosystem readiness framework.
- Proof of conformance to all CxD and TMM CPS Product tests criteria to be performed by suppliers themselves.
- 3rd party witnessing of testing and verification of portfolios of evidence of conformance to development and testing requirements and criteria in order to ensure traceability of conformance.
- Initiate a CPS homologation (testing guideline) project within 18 months.

A simplified Integrated testing process is shown in the figure below. It shows the testing logic, the stage gates and the responsible party as well as the ideal location of the testing. Finalisation of the testing locations is dependent on agreements between TMM OEMs, SAMI and CPS providers.

INTEGRATED CPS TESTING PROCESS FLOW:



6. Context of this document

The document is one of the deliverables of Work Package 9: Testing protocols (including legacy equipment) of the CAS Readiness Phase work of the *INDUSTRY ALIGNMENT ON TMM REGULATIONS; SPECIAL PROJECT OF THE MINERALS COUNCIL SOUTH AFRICA*.

7. Background

Regulations: TMM regulations for the SAMI were 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.

Product System Complexity: A CPS is a Product System that is complex, comprising multiple elements (sub systems) with some comprising components that are still in technology development.

TMM types: The range of TMM types, brands and models in the mining industry is vast. This adds to the complexity and the challenge faced by the SAMI.

History: In 2019, the MRAC of the MHSC (the committee responsible for facilitation of

the TMM regulations) assembled a task team made up of experts to advise it on the readiness of technology with a view to uplift the suspended clauses of the TMM regulations. The Task Team concluded:

- That the technology is not ready yet and that a few but significant technology challenges are still to be overcome.
- That the current approach is based on every mine developing its own set of unique CPS requirements and criteria based on the CMS Technical Specification Guidelines. Furthermore, specific performance criteria are **not** defined but are specified by CPS providers based on their unique CPS designs.

Collaborative approach: SECDI proposed a collaborative approach for the accelerated CPS product development and testing as documented in REVIEW REPORT: Collision Management Systems Technical Specification Guideline: SME and UME REV 2.

Considering the number of potential tests that will have to be performed, given the reality of over 200 open cast/pit mines, 25 CxD providers, 5 interface providers and numerous TMM models on surface operations only, the most viable approach is:

- An integrated, collaborative testing regime that will enable every test conducted on a specific CPS combination to be used by all mines having such a CPS combination on their mine as proof of conformance.
- That mines introduce as many as possible Level 1 to 6 collision controls (as defined by EMESRT) for TMM related processes and ensure physical separation of TMMs if reasonably practicable.
- Advocating for a high-level risk informed approach to the introduction of CPS products into the SAMI. (Attempt to convince the DMRE to take a risk based phased approach to introduce the regulations rather than everything at once.)

8. Principles of the Integrated CPS Test Regime

The following principles are the basis of the integrated CPS Test Regime:

- A single set of User Requirements, Functional and Technical performance requirements, and testing criteria for CPS products.
- Testing at much as possible at the lowest level of component, module, or element.
- All Stage Gate testing to be done by an independent 3rd party testing entity, except for TRL 6 where only a portion of the testing is done by a 3rd party.

- A single set of test protocols for 3rd party testing with clear acceptance criteria.
- Minimizing of the total number of tests to be done on mines by using pilot mines to facilitate specific CPS configurations for testing on behalf of all mines using such configurations.
- Sharing of test facilities and capabilities between TMM OEMs and CxD providers to minimize the cost of testing facilities, testing infrastructure and TMMs to perform tests.
- Sharing of the cost to establish testing capability by all parties (mines, CxD providers and TMM OEMs) as well as executing the 3rd party testing.
- Rigorous CPS development criteria that CxD providers, CxD and TMM CPS Product providers have to demonstrate in a structured ecosystem readiness framework.
- Proof of conformance to all CxD and TMM CPS Product tests criteria to be performed by suppliers themselves.
- 3rd party witnessing of testing and portfolios of evidence of conformance to development and testing requirements and criteria.

9. Alignment of the Integrated CPS Testing Regime with CPS Readiness Criteria

The CPS collaborative initiative is underpinned by a single set of readiness criteria for:

- Functional Readiness,
- Manufacturing Readiness,
- Operational Readiness, and
- Commercial Readiness.

These readiness criteria are a separate deliverable of the CAS Readiness Phase work of the INDUSTRY ALIGNMENT ON TMM REGULATIONS; SPECIAL PROJECT OF THE MINERALS COUNCIL SOUTH AFRICA.

Testing is an integral part of functional readiness, however for the purpose of a singular focus on establishing testing facilities, testing protocols and the identification of pilot mines, the testing criteria are defined in this document and not repeated in the readiness criteria document.

10. Proposed Integrated CPS Testing Regime

The integrated CPS test regime can be divided into two states:

1. The CPS end-state:
   a. where the technology and products are mature, relevant international technical standards are readily available and accredited test facilities

have been developed to verify and validate CPS performance independently.
   b. Where a TMM will be supplied by the TMM OEM with a factory fitted CxD that is fully integrated with the TMM.
   c. Homologation will be available globally.
2. The CPS interim state:
   a. Where the technology and products are immature, a complete set of relevant international or national technical standards are not available, and accredited test facilities are not ready/available/lack capacity.
   b. Is characterized by the presence of 3rd-party CxD developers that interface with TMMs. The TMMs are either intelligent TMMs (with a CxD>>Machine interface by the TMM OEM), or unintelligent and must be retrofitted with a suitable interface (by the TMM OEM or a 3rd-party interface provider).

Conclusion: For the SAMI, the interim state is expected to remain the status quo for a considerable amount of time, at least for the next ten years, possibly longer. An integrated CPS test regime must be established for both states.

7.1 End-state CPS testing regime

It is important for the SAMI to take cognisance of the end-state, because of the unique regulatory environment the SAMI finds itself in. Alignment between the technology development in the SAMI with international CPS initiatives is crucial to the long-term efficacy of CPS. The unique requirements of the CPS need to be communicated to TMM OEMs as well as the ICMM.

Fig.1 illustrates the test regime for the end-state. Technologically mature CPS products will be tested in the end-state by accredited test laboratories, with all other testing at lower readiness levels tested in-house by the TMM OEM or its subcontractors. The homologation process will be like any other homologation process found in other industries.

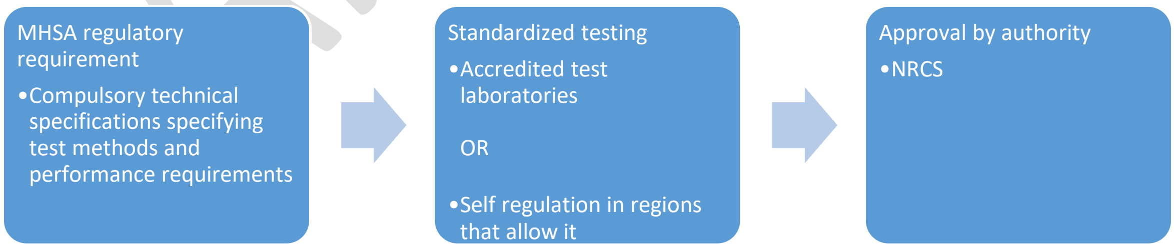


Fig.1 – End-state test regime once all elements of homologation road map are in place

There is a need to consider the establishment of a SAMI homologation for CPS. This is required to:

- Ensure that CPS products can be verified as CPS compliant until such time that the end state materialises for all SAMI TMMs and for when the 1st CxD factory fitted TMMs arrive in RSA.
- Certify CPS TMMs to be delivered to the SAMI.

Homologation Recommendation:

1. **Integrated guideline:** An important contribution that the current Minerals Council SA project can make towards international homologising is the definition of the various pieces of the puzzle leading to homologation for CPS. This contribution must be made in the form of an integrated guideline that can be used locally and made available to the ICMM as a leading practice and that can be adopted as either a national or international standard. The guideline must be built on the following:
    a. Unambiguous interpretation of the regulatory requirements,
    b. Detailed user requirements, or information on how to formulate the user requirements as needed at each site. The user requirements should consider scenario-based risk analysis, the traffic management plan, site-specific requirements, and limitations.
    c. Functional specifications specifying all functions to be demonstrated by a CPS that complies with the regulatory requirements.
    d. Technical specifications that inform the detail design decisions, including (but not limited to) zone functionality, EMC, interoperability, flame proofing, ergonomics, brake performance, etc.
    e. The technical requirements that compliance testing should be conducted against along with clear and unambiguous acceptance criteria.
    f. Considerations for approval by the approval's authority where applicable
2. **CPS homologation project:** It is recommended that the Minerals Council consider a CPS homologation project to develop the integrated guideline within the next 18 months.

    Since items a to f are already contracted to SECDI the development of the guideline would largely be the re-packaging of existing information.

7.2 Interim state CPS testing regime

Currently, CPS technology and products are not mature. For this reason, the CPS development must be managed with a formal maturity development process (see CPS Readiness Criteria Document). This effectively means that the proposed Integrated CPS Test Regime for the interim state must be embedded into the accelerated development process of CPS products. The integrated test regime that is proposed are depicted in increasing levels of detail in figures 2,3 and4 and is described in the associated sections.

The regime is based on the following logic:

1. CPS element and module development is done by technology developers (CxD developer and TMM CPS Products) concurrently. To do this, they need unambiguous user requirements, functional requirements, and technical requirements (including EMC standards, interoperability standards, etc.).
2. Each technology/module/element is also tested in a highly controlled environment such as a laboratory or a proving ground.
3. Only once the modules have demonstrated capability in highly controlled environments, the variables affecting performance are increased by integrating the CxD with the TMM CPS Products.
4. If static integration is successful, further variables are introduced in the form of typical operational environments. (Mock-ups)
5. Once basic functionality is demonstrated in an environment that is representative of the intended operational environment, integrated (CxD only) testing starts to record and trend data with a view to identify hotspots and validate the site Traffic Management Plan.
6. Once the TMP is verified to be workable, limited process demonstration starts, and functionality is gradually activated until the pilot site is fully functional and the CPS is demonstrated.
7. Full functionality is then validated on the pilot site over an extended period (e.g., 3 months or 2000 hours).
8. Once full functionality has been validated, the CPS is ready to go to market once all other commercial readiness criteria is met.

8. Accelerated CPS Development Process

The accelerated CPS development process is defined in detail in the CPS Readiness Criteria Document. Aspects related to integrated testing are extracted and discussed here to provide a holistic view of the integrated testing regime.

CPS Integrated Development Framework

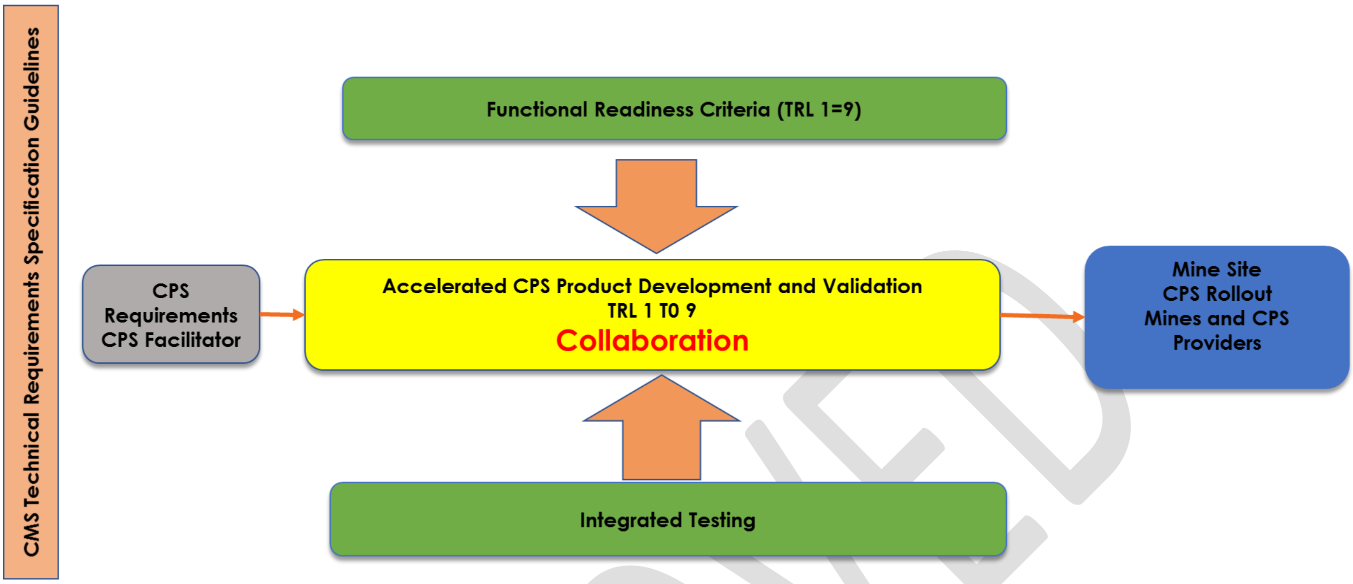


Figure. 2 High Level view of the Accelerated CPS Development Framework

Figure 2 shows a high-level view of the CPS Accelerated Development Process with integrated testing as a foundational element of the CPS product development.

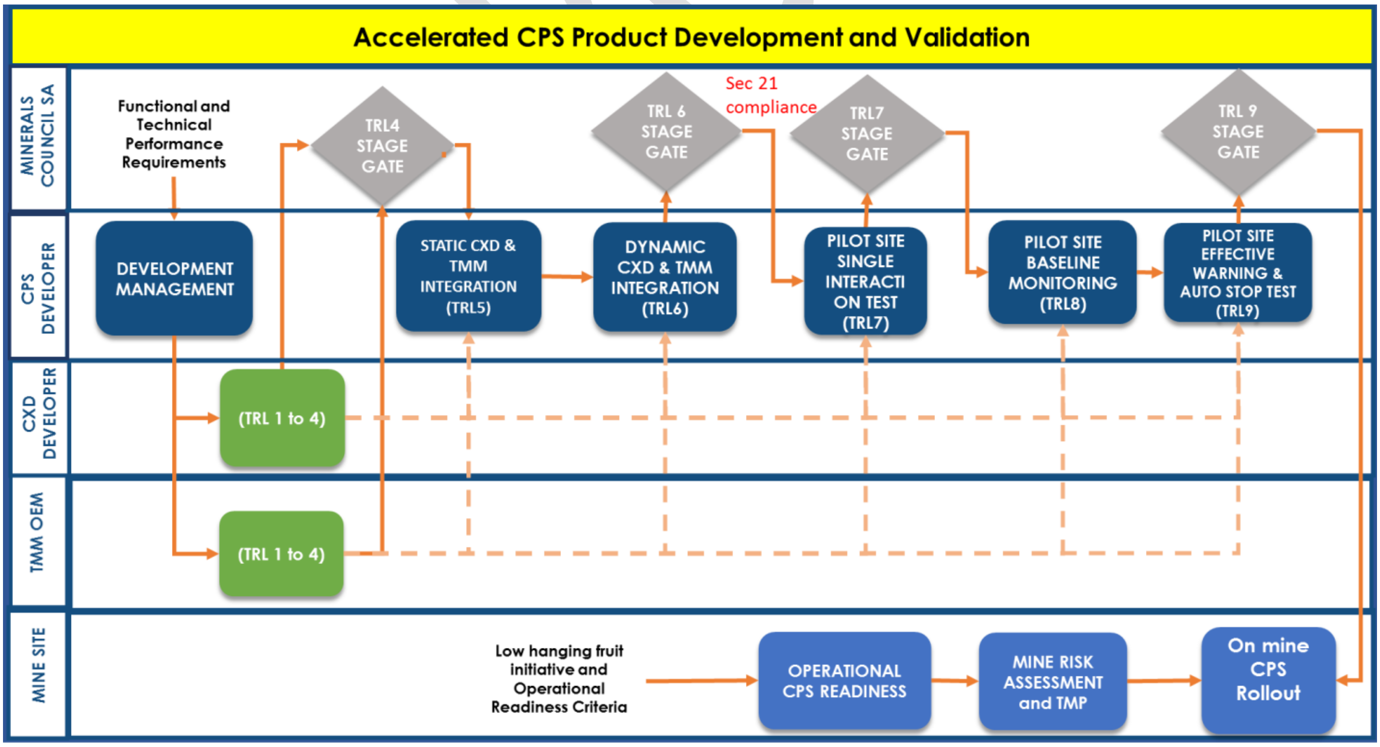


Figure.3 Outline of the Accelerated CPS Products Development Framework

Figure 3 provides an outline of the maturity development process from Technology Readiness Levels1 to 9. **The Integrated CPS Testing Regime is built on this exact outline**. The outline indicates that there are five primary role players in the development, namely:

1. The accelerated CPS Development Facilitator (Minerals Council South Africa),
2. The CPS developer,
3. The CxD provider,
4. The TMM CPS product developers, (TMM OEMs or 3rd Party) and
5. Individual mine sites.

The roles of the accelerated CPS Development Facilitator and that of the CPS Developer is defined in detail in the CMS Technical Specification Guideline Review Report. The role of the CPS developer is specifically important to:

- Ensure integrity and traceability of TRL 5 to 9 development and testing,
- Liaise with the pilot mine for TRL 7 to 9,
- To ensure key aspects such as risk assessments, safety plans, and all logistics arrangements for doing these tests.
- act as the single point of communication with 3rd party testing entities for Stage Gate 6 onwards testing.

Specific Stage Gates are introduced in the maturity process to ensure that only mature technology (both CxD and TMM CPS products) can progress towards higher risk and more costly testing as the maturity progresses to increasing levels of functionality testing with increased complexity.

Note:

- Up to TRL 4, the CxD development is conducted independent of TMM CPS Products or mine sites.
- TMM product developers also develop their TMM products independent of CxDs.
- From TRL 5 onwards, the TMM CPS Product developers and CxD developers are intertwined, and
- From TRL 7 the pilot mine sites become involved.

The implication is that from TRL 5 onward, the CxD matures along with the specific TMM CPS Products, and from TRL 7 onward maturity is developed in conjunction with the pilot mine operational environment.

As indicated in Section 4, all the Stage Gate testing except for a portion of Stage Gate 6 is to be done by a 3rd party testing entity. It will thus have to be facilitated by the Minerals Council South Africa.

9. Stage Gate Testing

CPS products are safety systems. The stage gates are a very important aspect of the integrated CPS Testing Regime as it is assurance and risk management activities of the safety system's development.

The stage gates shown in Figure 3 are described in more detail in this section.

TRL4 Stage Gate: CxD products

The aim of the CxD TRL4 stage gate is to ensure that the CxD complies with the functionalities as specified in the functional requirements in a controlled environment (i.e. in a laboratory or on a proving ground). This test must be done by an independent test facility. There are five stages in the CxD TRL4 stage gate test:

1. **ICASA Type Approval** – ICASA Type Approval must be obtained as the first part of the TRL4 stage gate. This is to ensure that the CxD and its sub-systems and components comply with the relevant legislation (such as not exceeding broadcast power limits, that the emitted frequencies are within the designated bands, that the enclosures are properly designed, etc.).
2. **ISO/TS 21815-2: 2021 bench test -** The ISO/TS 21815-2: 2021 bench test. It verifies that a CxD can communicate as stipulated in ISO/TS 21815-2: 2021. It is essential from a test safety perspective that a CxD passes this test prior to further testing. This test is conducted in a laboratory using an emulated Machine>>CxD interface.
3. **Fail to safe –** The fail to safe test introduces predefined failure modes and verifies that the CxD fails to safe in these failure modes.
4. **Vicinity detection test –** The vicinity detection test ensures that objects in the detection area can be reliably detected. The vicinity detection test is done in a controlled environment on light vehicles at a proving ground.
5. **CxD controller test –** The CxD controller test verifies the decision-making functionality of the CxD. It evaluates the opportunity given for effective warning, and the effectiveness of automatic slowdown and stop interventions. This test is done on light vehicles in the controlled environment of a proving ground.

Passing the CxD TRL4 stage gate does not guarantee that a CxD will be able to meet the functional requirements when integrated with a TMM or when used in a representative environment. However, failing the CxD TRL4 stage gate guarantees that the CxD will not meet the functional requirements when integrated with a TMM and in a representative environment.

TRL4 Stage Gate: TMM CPS Products

The TRL4 stage gate verifies whether a TMM CPS Product has made the TMM to be considered as intelligent or not, and that it complies with the relevant legislation governing brake performance. This test must be done by an independent test facility. This stage gate has two parts:

1. **ISO/TS 21815-2: 2021 test –** The ISO/TS 21815-2: 2021 bench test to verify that a machine controller can communicate as stipulated in ISO/TS 21815-2: 2021.
2. **Brake performance test (Braking System In-Service Performance Test)** (SANS 1589/ISO 3450) – This test must be done after the machine interface has been developed to ensure that the machine still complies with the relevant brake performance requirements after modifications to the brake system.

Passing the TMM CPS Product TRL4 stage gate indicates that the TMM may be considered to be intelligent. It is ready to be integrated with a CxD and provide automatic slowdown and stop functionality.

TRL6 Stage Gate: CxD-TMM integration

The TRL6 stage gate verifies that the CxD has successfully been integrated with the TMM. There are three steps in the TRL6 stage gate:

1. **Vicinity detection testing** - The machine states' effect on vicinity detection (tray up, boom extended, bucket raised) must be determined. This may be done with simplified interactions (such as straight-line approaches) and ensures reliable detection of actors within the detection range.
2. **Machine response to CxD interventions** – The machine's response to specific actions issued by the CxD needs to be determined. This includes the machine's:
   a. Delay to act on an action from the CxD.
   b. The machine deceleration when the CxD actions a specific intervention.
3. **EMI and EMC testing –** The integrated CPS must comply with the requirements as stipulated in SANS 13766.

The outcome of the TRL6 stage gate is the Section 21 Technical File. After passing the TRL6 stage gate, the CPS is ready for pilot site interaction testing.

TRL7 – Stage Gate: Pilot Site Interaction (Representative Environment)

The pilot site interaction stage gate is the first time the CPS will be tested in a representative environment. The aim of this stage gate is to verify the performance of the CPS in this challenging environment. The tests comprise of:

1. **Vicinity detection** – Effect of operating environment on vicinity detection (line-of-sight (pillars, etc.), dust, glare)
2. **CxD controller -** Zone functionality in predefined interaction scenarios in controlled representative environment:
    a. Effective warning distances/times
    b. Auto slow & stop interventions

Passing the TRL7 stage gate verifies that a CPS can perform basic functionalities in a representative environment. It is ready to be tested at a larger scale (multiple machines in operating production environment).

TRL9 Stage Gate: CPS Validation

The final stage gate is the CPS validation testing. This is in-operation testing with effective warning and automatic slow and stop enabled in an actual production area on the pilot site. Data is collected over an extended period (e.g., 3 months or 2000 hours) and analysed. The testing will include aspects of reliability, maintainability, repair, and support. All auto slowdown and stop interventions will be formally analysed and actioned as appropriately.
Passing the TLR9 stage gate indicates that a CPS is ready to be rolled out on the entire mine and can go to market if all other commercial readiness criteria has been met.

10. CxD Testing: TRL 1 to 4

The development process for CxD products is shown in figure 3. The CxD is the most complex of the products consisting of modules and the CxD controller module has multiple elements.

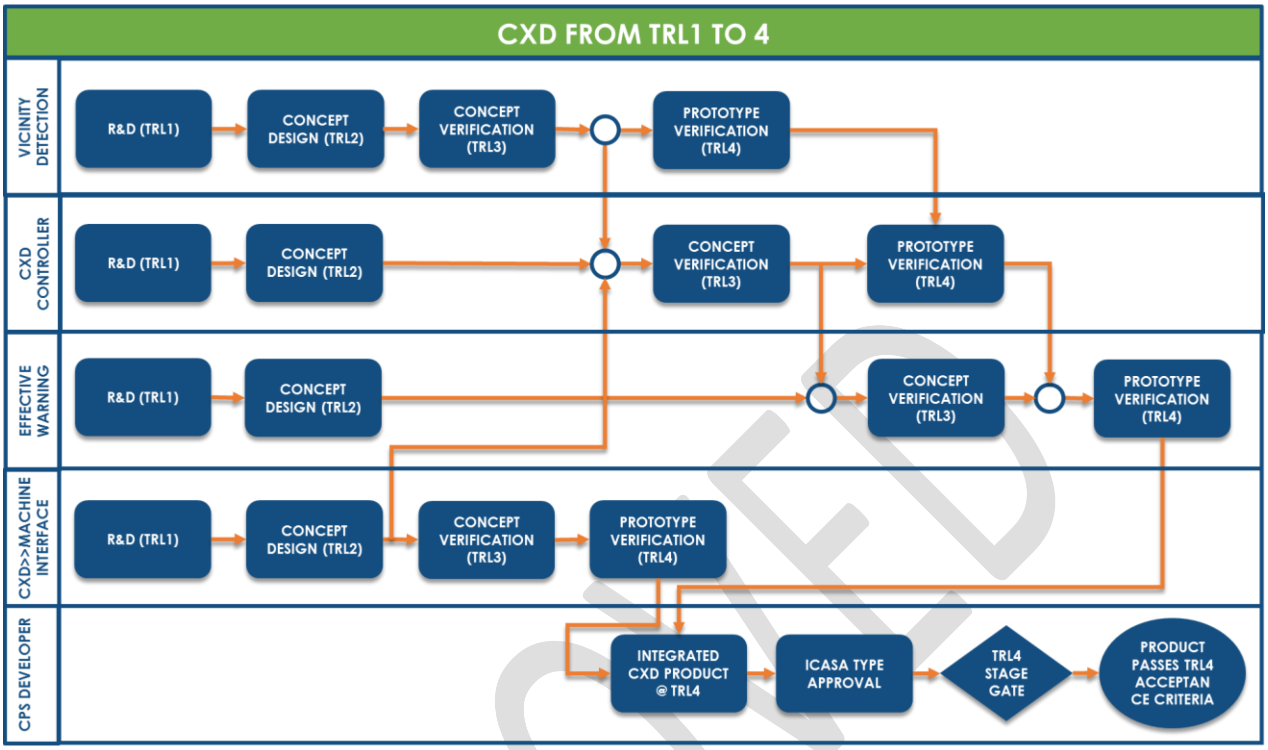


Figure 4: CxD Development process TRL 1 to TRL 4

Figure 3 shows how the CxD modules mature and are systematically integrated until it is an integrated CxD product.

Table 1 defines the TRLs for a CxD product from TRL1 to TRL4. The table briefly describes the development activity within the TRL and exit criteria against which a CPS must be tested to advance from one TRL to the next. After demonstrating acceptable performance at the TRL4 stage gate, a CxD developer is deemed to have scaling potential and the CxD can progress to integration with an actual TMM CPS product.

TRL	Description of activity within TRL				Success criteria for TRL
	Vicinity detection	**CxD controller**	**Effective warning**	**CxD>>Machine interface**	
1	User requirements, functional specifications and performance requirements are being analysed. Scientific knowledge is being consulted and designs are being conceptualized.				CxD solution 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	Sensor placement, sensor fusion, V2X communication and pedestrian detection detail design done.	Decision making algorithms designed.	Human interface (for operator and pedestrian) designed.	CxD>>Machine interface is designed.	Detail design is completed. Drawings available.
3	Sensors are simulated to determine accuracy, sensor performance.	Decision making is simulated, functional performance compared to functional and performance requirements.	Effectiveness of warning verified through simulator work (such as the Vienna/Dover test)	CxD>>Machine interface is simulated with a machine interface emulator.	Proof of concept shown with simulation models.
4	**CPS Provider with support from Module providers (if any)**				**Stage Gate** Proving ground test done in controlled environment with light vehicles according to standardized test procedures. Results demonstrate capability and scaling potential. **Currently done as 'lab-scale' test (in old guidelines)**
	Prototype is built. Basic testing conducted on light vehicles in controlled environment to verify functional performance against requirements. **ICASA approval obtained**				

Table 1- CXD TRL 1 to TRL 4 Testing

11. TMM CPS Product Testing: TRL 1 to 4

The development process for TMM CPS Products is shown in figure 4.

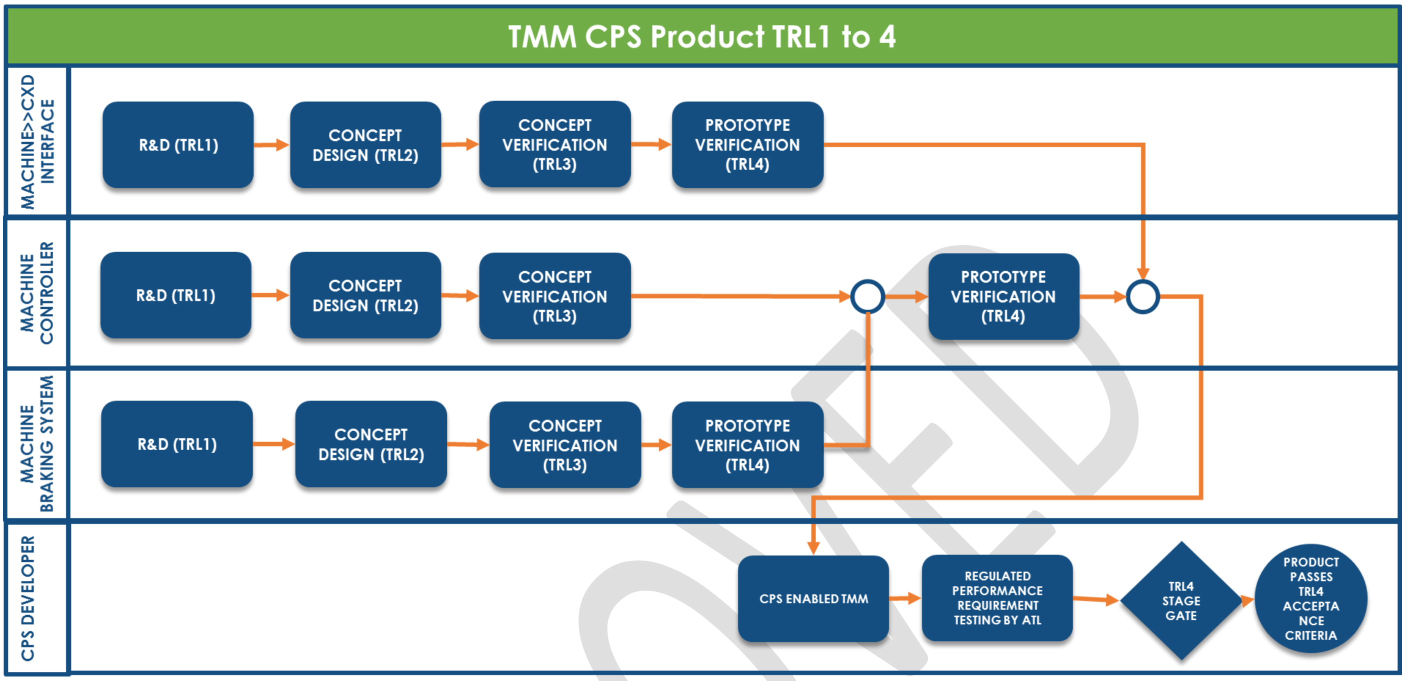


Figure 5 - TMM CPS Product Development Process TRL 1 to TRL 4

Table 2 defines the TRLs for the TMM CPS Product to develop a CxD-ready TMM. Exit criteria to advance from one TRL to the next are also given. After demonstrating acceptable performance at the TRL4 stage gate, a TMM CPS product is considered to make the TMM to be intelligent and ready to integrate with a CxD.

TRL	Description of activity within TRL	Success criteria for TRL
1	User requirements, functional requirements and Technical performance requirements are analysed. Focus is on: 1. Interfacing with a 3rd party CxD 2. Automatic slowdown and stop 3. Brake system design to accommodate proportional braking.	Functional analysis completed. Concepts ready to be evaluated and selected for detail design.
2	Conceptual designs are compared, final concepts selected. Detail design is done, with details on: 1. Negotiation sequence 2. Capability checking 3. Responding to enquiries and actions from the CxD	Detail design is completed. TMM models and serial numbers of applicable TMMs available. Legacy equipment solution documented.

TRL	Description of activity within TRL	Success criteria for TRL
	4. Measuring and transmitting machine data (such as speed, gear selection, payload information, etc.)	
3	Developer simulates interface and brake control system, confirming performance against functional specifications and performance requirements.	Proof of concept shown with simulation models.
4	Prototype is built. **Brake performance testing is done (SANS 1589-2 or ISO 3450).** Machine delays to CxD>>Machine actions established. Deceleration rates for various control strategies confirmed.	**Stage Gate** Proving ground test done in controlled environment. CxD emulator used to negotiate, enquire and action different features.

Table 2 – TRLs 1 to 4 for testing for TMM CPS Products

12. CxD-TMM CPS Product integration Testing: TRL 5 to 9

Once both the CxD and TMM CPS product have progressed through the TRL4 stage gates, integration of the CxD with the TMM CPS Product may commence. From this point on, technology readiness is developed cooperatively by the CxD developer and the TMM CPS Product developer. At this stage the role of the CPS developer becomes significant.

Figure 3: Outline of the Accelerated CPS Products Development Framework, will be used to discuss TRL 5 to 9 testing.

12.1 CxD-TMM CPS Product integration Testing: TRL 5 and 6 testing

TRLs 5 and 6 are defined in Table . After successful integration testing is complete the CPS can enter the stage gate 6 testing.

TRL	Description of activity within TRL	Success criteria for TRL
5	Integration with actual TMMs to start: 1. Sensor locations identified. 2. Interfacing with TMM established. 3. Control techniques for specific applications identified. 4. EMI/EMC 5. Fail to safe 6. Ergonomics	CxD completely integrated with TMM with OEM approval.

6	Testing TMMs in conjunction with TMM OEM confirming basic functionality such as: 1. Actioning instructions from the CxD (slow down, speed set point enforced, automatic stop). 2. Machine delay times 3. Machine deceleration on actions from CxD. 4. Repeatability 5. EMI/EMC 6. Fail to safe Tests at a test area owned by TMM OEM (for example). **SANS 13766 testing to be conducted by accredited test laboratory.** **SANS 1589/ISO 3450 compliance to be demonstrated after CxD integration.** **Flameproof integrity to be maintained.**	**Stage gate** Test results indicating successful integration and performance in highly controlled environment available. Tests conducted by TMM OEM sufficient (no need for independent verification), if TMM report is made available to pilot mine test site responsible person. **Section 21 Technical File compiled.**

Table 3 –TRL5 and TRL6 testing for CxD and TMM CPS Products

The TRL6 stage gate confirms the performance of the integrated CPS Product.

12.2 CPS Pilot Site Testing: TRL 7 to 9

Once the CxD has been successfully integrated with the TMM CPS Product on a specific TMM, pilot site testing can commence. Pilot site testing represents a significant increase in complexity and requires engagement with responsible persons at the pilot site. Again, the CPS developer's role is important. Matters to be resolved include:

1. Access to at least two machines for a significant period of time (production impact).
2. Risk management associated with
    a. Instrumenting test machines with prototype CxD equipment.
    b. Safety risks of conducting interaction testing (specifically for head-on and dovetail testing).
3. Suitable test area to be identified and cordoned off.

TRL 7, 8 and 9 conducted at the pilot mine site are described in Table 4.

TRL	Description of activity within TRL	Success Criteria for TRL
7	On-site test with TMMs in operational environment at pilot site, but in a controlled fashion. Controlled environment means: 1. Demarcated area 2. No other machines/pedestrians within vicinity 3. Standardized scenarios 4. Environment representative of operational environment in terms of friction coefficient, line-of-sight, presence of ore body, dust, heat, etc.	**Stage Gate** Independent test facility conducts pilot site test. Independent test facility test report available, indicating capability and potential for scaling. **Currently done as 'single-machine' test (in old guidelines)**
8	In-operation testing with effective warning & automatic slow and stop disabled (operator unaware). Logs kept of all warnings and potential interventions. Establishes baseline site conditions (adherence to TMP, number of near misses, etc.) before activation of CPS. This analysis includes comparison with a traffic flow analysis and risk assessment done prior to the CPS testing. Interaction hot spots must be identified (false and true positives) and reported incidents must be compared with CxD logs to determine if any false negatives are present. Potential impacts on production should also be quantified and confirmation of an optimised Traffic Management Plan is crucial for successful introduction of CPS to the mine.	Pilot site demonstration done. Heat map analysis conducted to identify hotspots. Hotspots addressed to the satisfaction of the responsible person. TMP enhancements completed and verified.
9	In-operation testing with effective warning and automatic slow and stop enabled in demarcated area on site (such as one section of the mine). Effective warning enabled and monitored before enabling automatic slow and stop.	**Stage Gate** Data over extended period (e.g. 3 months) analysed to determine number of false positives, near misses, etc. Analysis done by independent body.

Table 4 – TRL 7 – 9 Testing

13. Operational Readiness

An effective Traffic Management Plan is a prerequisite for CPS. Although operational readiness will be addressed at length in the CPS Readiness Criteria Document it is such a crucial aspect of the technology development process that it is mentioned here. It is important to note that CPS will not solve traffic management problems. On the contrary, an effective traffic management plan is a prerequisite to ensure the proper operation of CPS. It is thus not a choice between either following the TMLP or buying a CPS; both TMLP principles and CPS are required.