COLLISION PREVENTION SYSTEMS REQUIREMENTS VERIFICATION REGIME

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

REV 1

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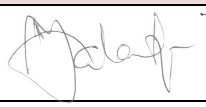
Stanford Malatji	**Minerals Council**		20/10/2025

MINERALS COUNCIL
SOUTH AFRICA

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Definitions and abbreviations

The following definitions and abbreviations will be used to create a common approach for all deliverables.

Table 1: Abbreviations and their definitions appearing in this document

Abbreviation	Definition
Accelerated Development	Developing of CPS products in a coordinated integrated way that will require less time (for the entire SAMI need) than the previous supplier driven CPS product development approach.
Blueprint	Any detailed plan or guide for creating something
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.
Demonstration (SEBoK Original)	Technique used to demonstrate correct operation of the submitted element against operational and observable characteristics **without** using physical measurements (no or minimal instrumentation or test equipment). Demonstration is sometimes called 'field testing'. It generally consists of a set of tests selected by the supplier to show that the element response to stimuli is suitable or to show that operators can perform their assigned tasks when using the element. Observations are made and compared with predetermined/expected responses. Demonstration may be appropriate when requirements or specification are given in statistical terms (e.g. mean time to repair, average power consumption, etc.).
Driver or operator reaction time (also known as perception response time)	The time that elapses from the instant that the driver recognises the existence of a hazard in the road, to the instant that the driver takes appropriate action, for instance, applying the brakes. The response time can be broken down into four separate components: detection, identification, decision and response. When a person responds to something s/he hears, sees, or feels, the total reaction time can be decomposed into a sequence of components namely: • Mental processing time (sensation, perception / recognition, situational awareness, response selection and programming) • Movement time, and • Driver response time. Driver reaction time is also affected by several issues such as visibility, operator state of mind (fatigue), direction or position of perceived danger.
DMPR	Department of Minerals and Petroleum Resources.
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

Abbreviation	Definition
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 of the MHS Act. Loss of control may result in several scenarios: • Machine failure – park brake or service brake, tyre blowout, • Operator disabled – fatigue, medical condition, inattention, distraction, non-compliance with TMP rules (e.g., over speeding on decline, overloading)
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

Abbreviation	Definition
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.
Testing (SEBoK Original)	Technique performed onto the submitted element by which functional, **measurable characteristics**, operability, supportability, or performance capability is **quantitatively** verified when subjected to controlled conditions that are real or simulated. Testing often uses **special test equipment** or instrumentation to obtain accurate quantitative data to be analysed.
This document	CPS Requirements Verification Regime. A document that defines the process and requirements for verifying conformance to CPS requirements.

Abbreviation	Definition
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.
Validation	The action of checking or **proving** the validity or accuracy of something.
Verification	Verification is an extra or final bit of **proof** that establishes something is true. (Inspection, Demonstration, Test, and Analysis)
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

1. Purpose of the document

This document defines the regime for requirements verification of Collision Prevention Systems (CPS) for Trackless Mobile Machines (TMM) in the SA mining industry (SAMI).

2. Background

The four revisions of this document's predecessor, the Integrated CPS Testing Regime were focused on **integrated testing** for CPS in the SAMI. The integrated testing regime was aimed at accelerating the readiness of CPS by establishing a **single** CPS testing facility. With the facility not available, it is necessary to align the approach with the current reality. This revision is defining a requirements verification regime that includes testing but is not limited to testing only.

The document is one of documents of the Mining Occupational Safety and Health (MOSH) CPS guideline developed by the *INDUSTRY ALIGNMENT ON TMM REGULATIONS: SPECIAL PROJECT OF THE MINERALS COUNCIL SOUTH AFRICA.*

3. Executive Summary

The regulatory nature of CPS for the SAMI requires that:

1) Enough CPS products are available for all TMMs working in mining processes where there is a significant risk of collision between TMMs and other TMMs (V-V) on surface and between TMMs and pedestrians (V-P) underground.
2) All CPSs conform with a set of minimum requirements (functional and technical) that will ensure compliance to the TMM regulations.

These requirements necessitate:

1) A single set of CPS requirements.
2) Coordination of some of the aspects of development and verification.
3) Traceability of conformance to requirements.

4. Context

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

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

The verification of requirements is therefore considered a **reasonably practicable step** taken to ensure conformance to CPS requirements for both mines and CPS product suppliers.

5. Verification, Validation and Demonstration Testing

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

Testing

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

Verification

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

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

Validation

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

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

Demonstration

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

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

6. The Nature of Regulations in South Africa

Unlike the **prescriptive** and **detailed** laws that might be in place in other mining jurisdictions, the Mine Health and Safety Act (Act 29 of 1996) (MHSAct) sets out the **respective rights** and **duties** of **each stakeholder** (the state, organised labour and employers) in the SAMI.

Important principles arising out of the MHSAct are:

(1) **Employers** have a **duty** and **responsibility** to **protect** the health and safety of employees that are exposed to occupational health and safety hazards and risks.
(2) The **state** has the duty and responsibility to effectively **regulate** health and safety conditions at workplaces on the mines.
(3) The **employee** has the right to refuse to work in an environment that may endanger his/her health or safety.

The MHSAct establishes the Mine Health and Safety Inspectorate (MHSI), headed up by the Chief Inspector of Mines. The Chief Inspector (appointed by the Minister) is required to implement the MHSAct and administer the MHSI. The MHSI plays a **proactive** role in the **promotion** of health and safety, and it has the powers to **enforce** compliance with the MHSAct.

7. The Mine's Legal Duty to Verify

Throughout the MHSAct the term **"must ensure"** is used multiple times. It is important to identify specifically **what** must be ensured and also what the criteria for **"ensure"** are.

Section 2 of the MHSAct states that the **employer** of every mine that is being worked must-

a) **ensure**, as far as reasonably practicable, that the mine is designed, constructed and **equipped**-
(i) to provide conditions for safe operation and a healthy working environment; and
(ii) with a communication system and with electrical, mechanical and other equipment as necessary to achieve those conditions.

(b) ensure, as far as reasonably practicable, that the mine is commissioned, **operated**, maintained and decommissioned in such a way that employees can perform their work without endangering the health and safety of themselves or of any other person.

With **employers** holding at least the two duties listed above, the question that must be answered is: How do employers (mines) fulfil this **duty of ensuring**?

1) **Firstly,** in terms of the **general** provisions the mine "ensures" by doing all the things that the MHSAct requires in terms of the **general** provisions of the MHSAct, i.e.:
    a. Appoints a Health and Safety Committee.
    b. Appoints one or more managers with the qualifications as may be prescribed to be responsible for the day-to-day management and operation of the mine, and if more than one manager is appointed, ensure that the managers' functions do not overlap. (Section 3.1(a) appointee)
    c. Appoints an engineer to be in general charge of machinery. (Minerals Act Regulation 2.13.1 appointee).
2) **Secondly**, the mine purchases/**buys "items**" (equipment and services) that enables it to comply with the requirements of the MHSAct and have the item supplier demonstrate conformance by requiring a Section 21 Technical File that provides traceability of verification results for that specific item.

The legal duty to "ensure" is not **optional** for a mine and failure to "**ensure"** can have severe consequences for a mine/**legal duty holder**, even including criminal liability and jail sentences. With an independent verification testing entity available to the mine, it is a **reasonably practicable step** for both the CPS product suppliers and the mines to require/or submit products for independent verification.

For **CPS** as the **"item"** of purchase, the mine "ensures" by:

- **Specifying** the CPS User Requirements, Functional and Technical Performance Requirements, Readiness criteria and the associated Section 21 Technical File content.
- **Overseeing** that the above aspects are **executed** before allowing the CPS to be operational on the mine and, where appropriate, have the CPS products **independently** verified.

In practical terms the **mine** "ensures" by **establishing** the **requirements** and **confirming conformance** by, amongst others, independent verification that products conform to the requirements.

8. CPS Supplier's Legal Duty to Verify

The CPS requirements verification regime is a **key part** of the CPS compliance journey for the mine, as well as the CPS product suppliers. The following extract from Section 21 of the MHSAct, paraphrased for clarity with underlined text, defines the legal duty of every CPS product supplier.

MHSAct Section 21: **Manufacturers and suppliers *of CPS products'* duty for health and safety**.
(1) Any ***CPS Supplier*** who -

(a) **designs, manufactures**, repairs, **imports, or supplies *a CPS product*** for use at a mine **must ensure**, as far as **reasonably practicable** -

(i) that the article is safe and without risk to health and safety when **used properly**; and

(ii) that it complies with **all the requirements *of Regulation 8.10 as interpreted and specified in the MOSH CPS guideline*** *(where the guideline has been adopted by the specific mine)*

(b) …; or

(c) designs, manufactures, erects, or installs any article for use at a mine must ensure, as far as reasonably practicable, that **ergonomic principles** are considered and implemented during **design**, manufacture, erection, or installation of the ***CPS product***.

The legal duty to "ensure" is not **optional** for a ***CPS product supplier*** and failure to "**ensure"** can have severe consequences for a ***CPS supplier***, even **criminal** liability and jail sentences. Even without the legal consequences, the best option for any CPS product supplier to ensure its product(s) is to have it verified independently against a set of requirements.

Independent verification is in the best interest of **both** the mine and the CPS product suppliers.

9. Requirements to be Verified

As discussed before, verification is not possible if there is no specification(s). The following CPS specifications are part of the MOSH CPS guideline. These requirements, as relevant, are the ones that will be independently verified and for which evidence of conformance must exist and be contained in the Sec 21 Technical Files. They are:

- Underground Diesel TMM CPS User Requirements Specification
- Surface Diesel TMM CPS User Requirements Specification

- Surface collision warning and avoidance device (CxD) Functional and Technical Performance Requirements
- Surface TMM CPS Functional and Technical Performance Requirements
- Underground CxD Functional and Technical Performance Requirements
- Underground TMM CPS Functional and Technical Performance Requirements
- Readiness Criteria for CPS Development and Deployment

10. Independent Verification Testing Specifications

As per the definition of testing and specifically since a CPS is tested independently, it is important that the independent tests are conducted under controlled conditions that will ensure repeatable and accurate results. The MOSH CPS Test specifications are primarily intended for an independent third-party verification entity (e.g. the University of Pretoria). It is however freely available for all mines and all CPS developers and CPS Product suppliers, for transparency to share the "exam" and "how it will be marked" with all stakeholders.

The following **Independent CPS verification testing specifications** are part of the MOSH CPS guideline:

- UGHR CxD Independent Verification Test Specification
- Surface CxD Independent Verification Test Specification
- UGHR TMM CPS Independent Verification Test Specification
- Surface TMM CPS Independent Verification Test Specification
- UGHR CPS Independent Verification Test Specification
- Surface CPS Independent Verification Test Specification

The above documents are stand-alone documents to make it easier to use by the different CPS product suppliers and the CPS developers. However, they should be considered as the parts of one CPS system. The documents are co-dependent and rely on each other to specify a complete CPS with the required functionality to meet the requirements of MHSAct Reg 8.10.

11. CPS Readiness Criteria

To manage Technology development and readiness effectively, international standards such as ISO 15288 and others provide CPS product suppliers and CPS developers with the necessary processes to manage the development. For CPS development the well-known Technology Readiness Levels (TRLs) approach is used for structuring the development process. To ensure that a consistent process is followed that will ensure the necessary governance and evidence for inclusion in the Section 21 Technical File, the MOSH CPS guideline includes a CPS Readiness Criteria document that provides the activities and success criteria for the development of a CPS. It does not only address stage gates, but all TRLs. It is the basis for the content of the CPS Section 21 Technical File. This document must be read in conjunction with the CPS Readiness Criteria for CPS Development and Deployment document.

12. Principles of CPS Requirements Verification and Verification Regime

The following principles are the basis of the CPS Requirements Verification Regime:

- The CPS requirements verification regime is based on the well-known technology readiness maturity model, extensively used internationally for complex systems development, specifically for high impact systems such as airplanes, deep sea drilling rigs, aerospace, and the like. Its objective is to save system developers' time and money and protect users against health and safety harm. The model is specifically effective for novel, complex technology systems such as CPS.
- Specific **Stage Gates** are introduced in the technology maturity process to facilitate **independent verification** by 3rd party entities. This ensures independent confirmation of product conformance and thus, only mature technology (both CxD and TMM CPS products) can progress towards higher risk and more costly testing. As maturity progresses to increasing levels of functionality testing, complexity of testing also increases towards the real operational environment.
- A **single set** of User Requirements, Functional and Technical performance requirements, Testing and Readiness criteria for CPS products, as part of the MOSH CPS guideline, defines the requirements of a CPS. This "one-rule" principle ensures that all stakeholders know **exactly** what is to be achieved and how independent verification will be done.
- Rigorous CPS **development criteria** (functional readiness) that CxD suppliers, TMM CPS suppliers, the CPS developers as well as the mines themselves must conform with, to ensure full functionality of CPS.
- CPS product verification is **the legal duty of the CPS product supplier** and is a **prerequisite** for any independent verification. The independent verification entity must ensure that the product supplier is ready for independent verification. Independent verification testing is not to be considered as development testing. **CxD and TMM CPS suppliers** must do their **own** verification in accordance with its inhouse process, plans and quality control. For CPS such plans must include the work and outputs required by the CPS Readiness Criteria.
- As per Sec 21 of the MHSAct, the **legal duty** for CPS products, i.e. the CxD and the TMM CPS, is 100% with the CPS **product supplier**. Every and all steps to be taken to **ensure** conformance, including the cost of any independent verification testing, inspection, demonstration or analysis, preparation of technical files etc., is the responsibility of the specific product supplier and the CPS developer as appropriate.
- **Proof** of conformance to all CxD and TMM CPS Product tests criteria to be performed by **suppliers** themselves.
- **Portfolios** of evidence of conformance to requirements and criteria (Section 21 tech file) to be compiled as the product matures.
- Up to and including Product Independent Verification, testing is done **entirely** independently by the CxD and TMM CPS suppliers respectively.
- **Formal** legal agreements between the CPS legal duty holders (CxD and TMM CPS suppliers) to bound liability and requirements.

- CPS Product Independent Verification Testing as well as CPS independent verification testing (Stage Gates at TRL4 and TRL 7 testing) to be done by a credible i**ndependent 3rd party** testing entity**).**
- A **single** ruler for independent verification (set of test protocols for 3rd party testing with clear acceptance criteria for all CPS products and clear readiness criteria for physical and information verification).
- Every TMM **CPS product (CxD/TMM combination)** must be independently verified, i.e. every TMM Type, Model and serial number where similar models have different braking characteristics.
- TRL 1-3,5 and 8 do **not** require independent verification, they do not have stage gates however traceable conformance evidence for a TRL must be provided at the next stage gate as a prerequisite for starting that stage gate's work.
- Independent Verification Testing is done at the **lowest** level of the product first, before doing CPS verification.
- CPS integration Verification and CPS validation (Stage Gates, TRL 6 and TRL 9) are the responsibility of the mine by contracting a capable 3rd party entity for providing such service.

13. CPS Stakeholders

Various parties are considered to be the key CPS stakeholders, with definitions provided in the next section), they are:

1. Independent Testing entity
2. The CPS developer as decided by the mine,
3. The CxD supplier,
4. The TMM CPS product suppliers (TMM OEMs and 3rd Party interface/TMM CPS suppliers) and
5. Individual mine sites.

14. CPS Requirements Verification Regime

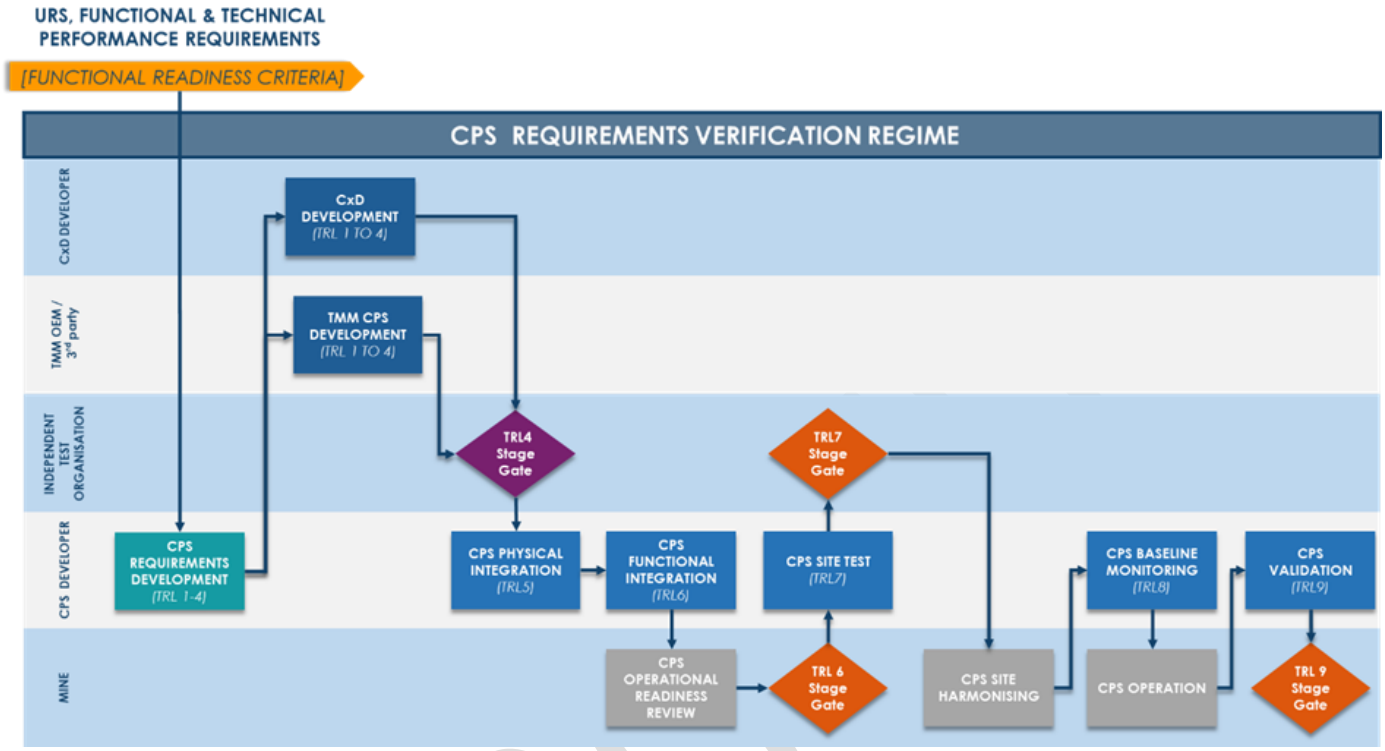

Figure 1: CPS Requirements Verification Regime

Figure 1 is structured in 5 swim lanes each indicating the activities to be performed by a specific stakeholder.

CPS Developer

The role of the CPS developer is that of the single responsible party for the development of every CPS i.e. the integrated CxD and the TMM CPS Product. 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.

It is important to note that the CPS Development work at system level (CPS) for TRL 1 to TRL 3 was done for and on behalf of all the CPS developers by the Minerals Council South Africa. The MOSH CPS guideline is the output of this work.

The role of the CPS developer is specifically important to:

- Ensure integration and traceability of TRL 5 to 9 development and testing activities between CxD and TMM CPS or 3rd Party TMM CPS suppliers.
- Liaise with the mine's appointed TRL 6 and TRL 9 independent verification entities.
- 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 verification entities for Stage Gate 6 onwards testing.

CxD Product Supplier (TRL 1 to TRL 4)

The detailed activities and criteria are documented in the CPS Readiness Criteria document.
It is important to note that TRL 4 (not the stage gate) includes functional testing to be done by the CxD supplier. Since the TRL 4 Stage Gate testing was developed as part of the MOSH CPS guideline documents, it is reasonable to expect that the CxD supplier's own testing will include at least the stage gate tests.

TMM CPS Product Supplier (TRL 1 to TRL 4)

The detailed activities and criteria are documented in the CPS Readiness Criteria document.
It is important to note that TRL 4 (not the stage gate) includes functional testing to be done by the TMM CPS supplier. Since the TRL 4 Stage Gate testing was developed as part of the MOSH CPS guideline documents, it is reasonable to expect that the TMM CPS supplier's own testing will include at least the stage gate tests.

CxD Independent Verification Testing (TRL4 Stage Gate)

CxD product independent verification testing is done in two stages, basic and advanced, where basic is also done in two stages:

- Laboratory testing (3rd Party Laboratory: UP) **Phase 1** and
- Simulated testing (independent tests site Gerotek) **Phase 2** (the product come to the verifier)

The following tests are done for **Phase 1**

- CxD Interface test - The ISO/TS 21815-2:2021 bench test.
- CxD Log Keeping Test
- CxD Self-Diagnostic Test (FTSWHI)
- ICASA Type Approval or Spectrum License demonstration (The CxD supplier submit its ICASA certificate).
- EMC testing as defined in the relevant Functional & Technical Performance Requirement specification as appropriate and as advised by an accredited EMC test laboratory.

The following tests are done for **Phase 2**

- CxD Detection and Tracking Subsystem test
- CxD Effective Warning Test
- 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.

Phase 2 tests are typically done at Gerotek.

TMM CPS Independent Verification Testing (TRL4 Stage Gate)

The TRL4 stage gate verifies whether a TMM CPS Product has made the TMM to be considered as intelligent, and that it complies with the relevant legislation governing brake performance. This test must be done by an independent test facility.

The following tests are done:

- TMM interface test (ISO/TS 21815-2: 2021).
- TMM Log Keeping Test
- TMM Self-Diagnostic Test (FTSWHI)
- TMM Machine sensing test
- TMM Machine Controller test
- SANS 1589 or ISO 3450 brake testing demonstration, as appropriate
- Demonstration of EMC testing by an accredited EMC test laboratory, as appropriate
- Demonstration of ICASA type approval or spectrum license, if appropriate

TMM CPS product verification testing is done at any physical site where the TMM CPS is installed on the TMM. (The independent verifier goes to the product). In some cases, Gerotek may be used (depending on the size and mass of the TMM CPS to be tested).

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

CxD-TMM CPS Physical Integration (TRL 5)

The detailed activities and criteria are documented in the CPS Readiness Criteria document. The **CPS developer** is responsible to ensure conformance to the requirements and availability of the portfolio of evidence.

CPS physical integration verification is done wherever the CPS developer can arrange for the integration to be done. Ideally, it should be done at the TMM OEM factory or maintenance facility.

Operational Readiness (OR) (TRL 6)

The detailed activities and criteria are documented in the CPS Readiness Criteria document. Operational readiness is a very significant endeavour that the mine must start many months before planning to install and test the CPS. Reg 8.10 requires consideration of reasonably practicable measures of which technology is the last resort. Besides that, for CPS to correctly function, proper traffic management is key enabler. Operational readiness is primarily a mine responsibility, however due to the specialised technology involved, mines may require external support. Operational readiness is addressed in detail in the CPS Readiness Criteria document.

CxD-TMM Integration and Operation Readiness Independent Verification (Stage Gate TRL 6)

The TRL6 stage gate independently verifies that the CxD has successfully been integrated with the TMM to become a CPS.

The readiness requirements are defined in the CPS Readiness Criteria document. This stage gate is the first formal review of the CxD, TMM CPS and the CPS Section 21 Technical File Information. Additional aspects such as EMC/ EMI testing and brake testing (where necessary) are verified for successful results and evidence of conformance. It includes the mine's operational readiness independent review. The stage gate includes an independent Operational Readiness Review done by credible 3rd party institution.

A TRL 6 Stage Gate review report is part of the portfolio of evidence for the stage gate.

After passing the TRL6 stage gate, the CPS is ready for independent verification testing.

Stage Gate 6 verification is the responsibility of the mine by contracting a capable 3rd party entity to provide the service.

CPS Independent Verification Testing (TRL7)

Once the TRL 6 independent verification is successfully completed, "on-site testing" can commence. Once the test area is prepared, the CPS is installed and the TMMs passed their pre-use inspections, the CPS developer can do its own CPS interaction tests to make sure that the independent verification tests will be passed. The CPS developer is responsible to coordinate and manage the CPS interaction tests that will require engagement with responsible persons where the tests are to be conducted.

Again, the CPS developer's role is important. Matters to be resolved include:

1. Access to at least three 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
3. Suitable test area to be identified and cordoned off.

CPS Independent Verification Testing (TRL7 – Stage Gate - Representative Environment)

The CPS interaction verification stage gate is a set of tests. It 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 a representative environment.

On-site tests with TMMs in operational environment but in a controlled manner, where controlled 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.

The tests comprise of:

1. Robust detection and tracking (effect of the TMM and the environment on the CPS), including:
    a. TMM size and shape
    b. CxD mounting locations, orientations, vibration, etc. effect on sensors.
    c. Environmental impact on sensors (e.g. line-of-sight, dust, glare, etc.)
2. CxD controller - Zone functionality in predefined interaction scenarios in controlled representative environment:
    a. Effective warning distances/times
3. Automatic slow down & stop interventions, resulting in acceptable stop gaps
4. Fail to safe without human intervention

The tests are conducted as per the UGHR and Surface CPS Independent Interaction Verification and Validation Test Specifications.

Passing the TRL7 stage gate verifies that a CPS can perform its functions in a representative environment. If correlation between TRL 4 independent verification tests is confirmed, multiple machines in operating production environment can be introduced.

CPS interaction verification testing is done wherever the CPS developer and the mine arranged for the verification to be done. (Mine site or Test site)

Site Integration / Harmonisation

The detailed activities and criteria are documented in the CPS Readiness Criteria document. While the mine's operational readiness work will most likely have resulted in a number of road and operational area improvements, operational procedures, training material and competency evaluation, the site harmonisation stage allows the mine to verify that all the work done is practically executable and in particular that the collision hotspots that were identified are indeed resolved. The purpose of the harmonisation is also to minimise the production impact of collision hotspots.

Tests in this stage include:

- In-operation testing with effective warning & automatic slow down and stop disabled (operator unaware).
- Logs kept of all warnings and potential interventions. Establishes baseline site conditions (adherence to Traffic Management Plan, number of near misses, etc.) before activation of CPS.
- This analysis includes comparison with a traffic flow analysis.

Interaction hot spots must be identified (false and true positives) and reported incidents (false and true negatives) must be compared with CxD logs to determine if any discrepancies 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.

CPS Baseline Monitoring (TRL8)

While the mine is busy with harmonisation, the CPS developer is doing all the data analysis and reporting analysis to assist the mine.

CPS Operation

This is the start of CPS operation on the mine and includes execution of all the operational processes and procedures.

CPS Validation (TRL 9)

This is in-operation testing done by the **CPS developer** with effective warning and automatic slow down and stop enabled during actual production. 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 automatic slow down and stop interventions must be formally analysed and actioned as appropriately.

CPS Independent Validation (TRL9 Stage Gate)

The final stage gate is the CPS validation. The detailed activities and criteria are documented in the CPS Readiness Criteria document.

Data over extended period (e.g. 3 months) analysed to determine number of false positives, near misses, etc. Analysis done by an independent 3rd party entity.

15. References

The following documents are referenced in this document:

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

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

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

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

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