INDEPENDENT VERIFICATION TEST SPECIFICATION FOR SURFACE TRACKLESS MOBILE MACHINERY COLLISION PREVENTION SYSTEMS (TMM CPS): TRL4 STAGE GATE

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

REV 1

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Definitions and abbreviations

Table 1 defines terms and abbreviations used in this document.

Table 1: Abbreviations and their definitions appearing in this document

Abbreviation	Definition
CAN bus	Controller Area Network bus
CAN sniffer	A CAN sniffer is a tool (hardware or software) used to monitor and capture data traffic on a CAN bus.
CAN trace	A recording of all the messages/traffic on a CAN bus
CDI	CxD Interface
CLK	CxD Log keeping
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.)
CPS Developer	The organisation selected for each CPS to act as the single entity to coordinate the development and testing of the specific CPS.
CPS Stop	The state when the CxD intervenes with the intent of stopping or keeping the TMM stationary to avoid a collision or FTSWHI. This is the end state after a CPS intervention, reached by the CxD instructing the TMM to stop via the ISO/TS 21815-2:2021 CAN-bus interface.
CPS Slow	The state when the CxD limits the TMMs speed. The CxD instructs the TMM to slow by sending SLOW_DOWN or APPLY_PROPULSION_SETPOINTS via the ISO/TS 21815-2:2021 CAN-bus interface.
CSD	CxD Self-diagnostics
CxD	Collision Warning and Avoidance System device (CxD): Device with sensors providing collision warning and avoidance functions, to detect objects in the vicinity of the machine, assess the collision risk level, effectively warn the operator of the presence of object(s) and/or provide signals to the machine control system, to initiate the appropriate interventional collision avoidance action on the machine, to prevent the collision. Note to entry: Proximity Detection System (PDS) is a colloquial industry term for a physical device, providing a warning or collision avoidance functionality.
CxDC	CxD Controller
CxDI	CxD interface: A integration function between the CxD and the Machine Controller.
CLK	CxD Log keeping
DAQ	Real time computer with data acquisition and control capabilities. Has ISO21815 interface. Example: dSPACE MABX III.
DTS	Detection and Tracking System
EMC	Electromagnetic compatibility
EW	Effective Warning
F&TPR	Functional and Technical Performance Requirements
FTSWHI	Fail to Safe Without Human Intervention
HME	Heavy Mining Equipment
HP INSS	High Precision Inertial Navigation Satellite System, capable of measuring position, with an absolute accuracy of 0.1m and velocity to within 0.2km/h with an update rate of 100Hz. Example Racelogic VBOX 3i.
ID	Identifier.
Interface	A boundary across which two independent systems meet and act on or communicate with each other. Two examples are: 1. CxD-machine interface – The interface between a Collision Warning and Avoidance System Device (CxD) and the machine. This interface is described in ISO/DTS21815-2. 2. The user interface – Also sometimes referred to as the Graphic User Interface (GUI) when an information display is used. This is the interface between the user (TMM operator or pedestrian) and the CxD or pedestrian warning system. Note: An interface implies that two separate parties (independent systems), are interacting with each other, which may present interoperability and/or EMI and EMC challenges.
LDV	Light duty vehicle
MBS	Machine Braking System: The physical components that makes an unintelligent TMM intelligent and enables the CPS auto slow-down and stop functionality.
MCI	Machine Control Interface: The interface between the Machine Controller and the CXD interface.

Abbreviation	Definition
MHSAct	Mine Health and Safety Act No. 29 of 1996 and Regulations.
MOSH	Mining Industry Occupational Safety and Health Initiative
MSDS	Material Safety Data Sheet
OWS	Operator warning subsystem the device in the vehicle that warns the operator of potential collisions
PWS	Pedestrian Warning System the device that provides a warning to a pedestrian
Reasonably practicable measure	Reasonably practicable means practicable with regards to: (a) The severity and scope of the hazard, or risk concerned. (b) The state of knowledge reasonably available, concerning the hazard or risk, and of any means of removing or mitigating the hazard or risk. (c) The availability and suitability of means to remove or mitigate that hazard or risk, and (d) The costs and the benefits of removing or mitigating that hazard or risk.
Safe park	The TMM is safely parked as per the mine's standard operating procedure, e.g. the operator has engaged the park brake, switched the engine off and exited the cab. The operator has placed chocks or stop blocks under the TMM's wheel(s). This state is typically encountered at the start/end of shifts when the operators are prevented from moving. The TMM is not operational.
SAMI	South African Mining Industry.
Stage gate	A step in the testing regime / process where the CPS product system is tested against acceptance criteria, the failure of which would limit the CPS product system from moving to the next step in the regime / process.
System	A combination of interacting elements organized to achieve one or more stated purposes (ISO/IEC/IEEE 2015).
TMM	Trackless Mobile Machine. (Machine, vehicle, etc.) as defined in MHSAct
TMM CPS	The functional group comprising all TMM CPS related functions.
TMM CPS Product	The product that will make a non-intelligent TMM intelligent and CxD ready.
TMM Emulator	A TMM emulator is system that behaves like a real TMM, enabling the TMM emulator to integrate with a CxD without compromising the performance of the CxD.
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).
TV	Test Vehicle: A vehicle used to conduct the verification scenarios specified in DTS, EW and CxDC test protocols

1 Introduction

This document is intended for Surface Trackless Mobile Machine Collision Prevention Systems (TMM CPS) to be used in the South African Mining Industry (SAMI). The document is one of the documents in the Mining Industry Occupational Safety and Health Initiative (MOSH) Collision Prevention Systems (CPS) guideline. Whilst it is developed as a stand-alone document, it is advisable to view it in the context of the other MOSH CPS guideline documents[1]. This document must be read in conjunction with the CPS Requirements Verification Regime. Figure 1 depicts the CPS Requirements Verification Regime. The CPS Requirements Verification Regime document explains the end-to-end verification steps, including the Stage Gates.

This document covers the Technology Readiness Level 4 (TRL4) Stage Gate for Surface TMM CPS, shown in purple in Figure 1.

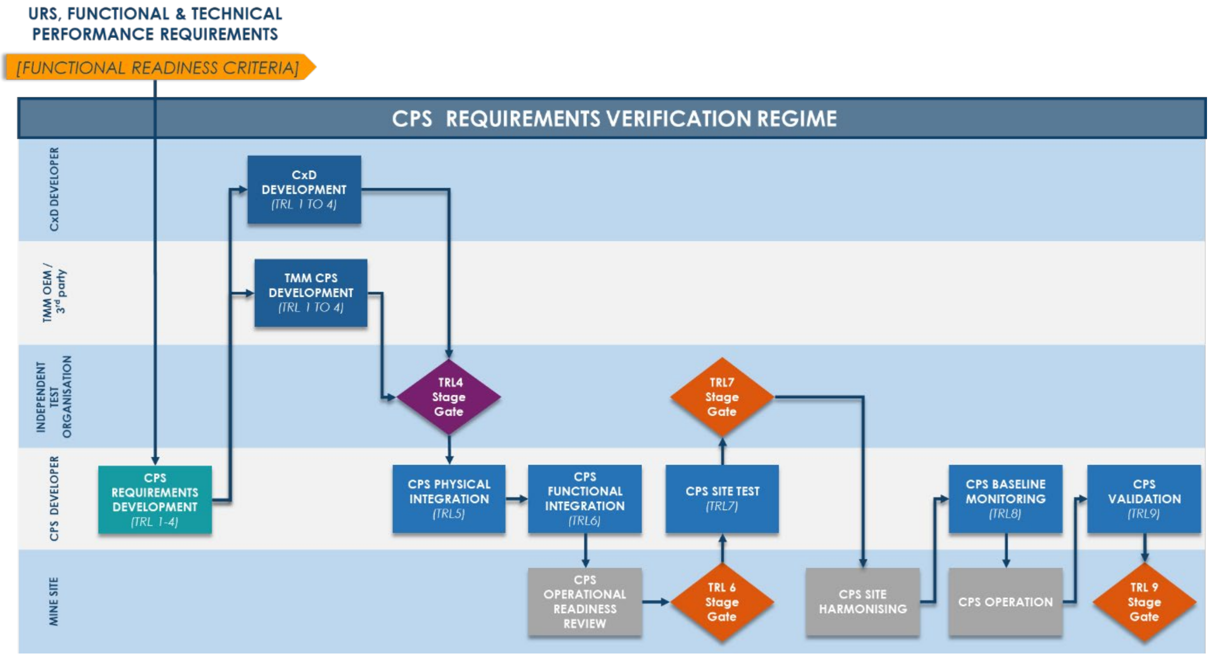

Figure 1: CPS requirements verification regime

This document is an update of the original CPS Test Specification published in November 2022. The original document contained all the Surface and Underground CPS tests. For user convenience, the independent verification test specifications are now structured as independent documents. Refer to the CPS Requirements Verification Regime for the CPS verification documentation tree for a detailed breakdown. The rationale and requirement for independent verification testing is also documented in the CPS Requirements Verification Regime.

Figure 2 shows the Surface CPS verification test regime. The Surface CPS product verification tests (Stage Gates) as shown in Figure 2 are:

1. CPS product independent verification Testing (CxD and TMM CPS) in a controlled environment (e.g., a laboratory or a proving ground), referred to as TRL4 tests.
2. CPS interaction testing in a representative, but controlled environment (e.g., in a test mine or a cordoned off section of an active mine), referred to as TRL7 tests.

1 Available at https://www.mosh.co.za/transport-and-machinery/documents

3. CPS validation testing in the operational environment (e.g. monitoring the performance of a CPS over a period of time at an active mine), referred to as TRL9 tests.

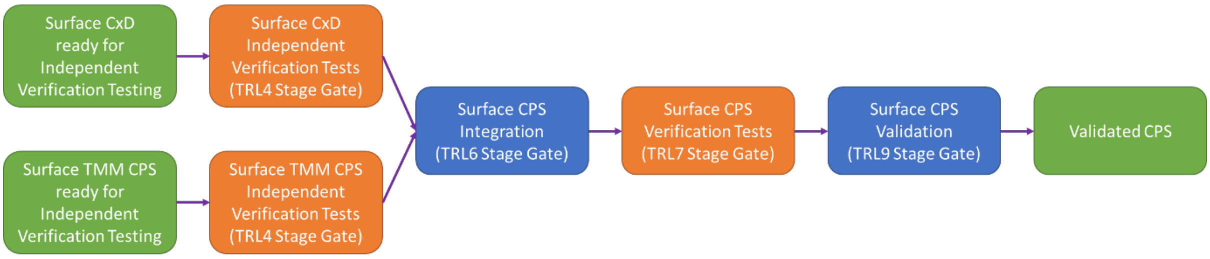

Figure 2: Surface CPS independent verification test regime (independent verification tests indicated in orange)

2 Context

Extensive documentation has been prepared to describe the user requirements, functional and technical performance requirements and test specifications of Surface CPS products. Figure 3 shows the document structure defining the MOSH CPS guideline towards compliant Surface CPS products.

User Requirements Specification

- Surface CPS

Functional and Technical Performance Requirements

- Surface CxD
- Surface TMM CPS

Readiness Criteria

- Readiness Criteria For Collision Prevention System Development And Deployement

Requirements Verification Regime

- CPS Requirements Verification Regime

Independent Verification Specifications

- Surface CxD TRL4 Stage Gate
- **Surface TMM CPS TRL4 Stage Gate (this document)**
- Surface CPS Verification TRL7 Stage Gate

Figure 3: CPS functional testing related documentation

This document is the Surface TMM CPS Independent Verification Test specification and builds on the User Requirement Specification (URS) for Surface CPS and the Functional and Technical Performance Requirements Specification (F&TPRS) for Surface TMM CPS. The purpose of this document is to provide a single test specification to assess the functionality of Surface TMM CPS in accordance with the applicable URS and F&TPRS. Tests documented herein are independent verification tests and are intended for carefully controlled test environments, such as a laboratory or a proving ground (test track) since it must be repeatable and accurate so as not to unfairly reject any TMM CPS submitted for verification.

Since the TMM CPS is just one of the CPS products, this specification must be considered in conjunction with:

- The CPS F&TPR specification for Surface CxDs

- The CPS F&TPR specification for Surface CPS
- The Independent Verification Test Specification for Surface CxD.

Despite the importance of these tests, successful completion of the tests described in this document neither guarantees that a TMM CPS will prevent all collisions under all circumstances, nor does it guarantee that a verified TMM CPS will be deemed compliant with the Mine Health and Safety Act and Regulations. Successfully completing the tests in this document indicates that a TMM CPS is ready for on-site CPS testing, once integrated with a Surface CxD that has completed its TRL4 Stage Gate.

3 TMM CPS Product Independent Verification Testing

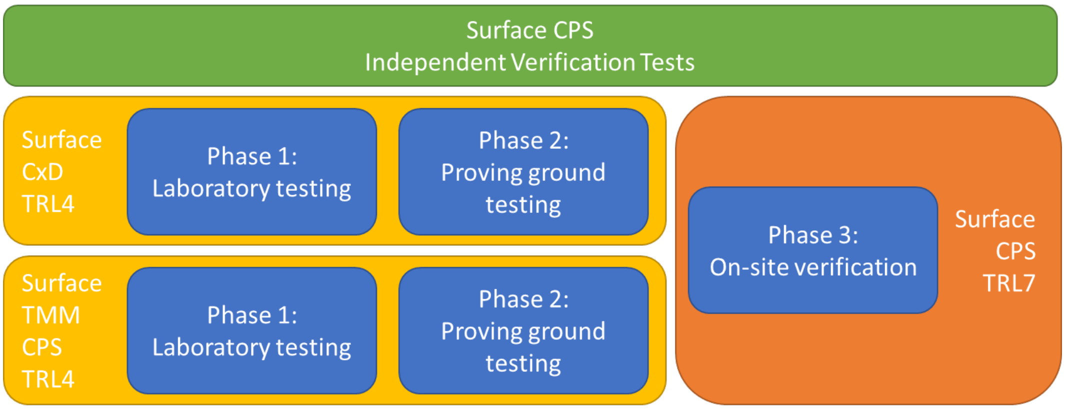

Figure 3: Surface TMM CPS independent verification test regime

TMM CPS product independent verification testing is done in three stages, **laboratory, proving ground** and **on-site**:

- **Phase 1:** Laboratory testing (independent 3rd Party laboratory) and
- **Phase 2:** Proving ground testing (independent 3rd party tests at a proving ground)
- **Phase 3:** On-site verification (independent 3rd party goes to a suitable area, such as a mine site, where the integrated CPS is ready for testing). This is the Surface CPS TRL7 Stage Gate

The following tests are done for **Phase 1: Laboratory TMM CPS tests**

- Surface TMM CPS Interface Test - the ISO/TS 21815-2: 2021 test
- Surface TMM CPS Log Keeping Test

Phase 1 tests are bench-top tests, typically conducted in a laboratory environment with a CxD emulator.

The following tests are done for **Phase 2: Proving Ground TMM CPS tests**

- ISO 3450:2011 brake performance testing. The TMM CPS OEM submits its ISO 3450:2011 brake test report (or equivalent, as applicable).
- EMC demonstration, as applicable (consult with an accredited EMC test laboratory). TMM CPS OEM submits its EMC certificates.
- Surface TMM CPS Self-Diagnostic Test
- Surface TMM CPS Machine Sensing Test
- Surface TMM CPS Controller Test

Phase 2 tests are done at a suitable proving ground or test area. A test area must meet the requirements as set out in the test protocols (see the Appendices in this document). The test engineer responsible for carrying out the tests makes the final decision if testing can be done at a specific location.

The following tests are done for **Phase 3: On-site Surface CPS tests**

- Surface CPS Integration Test
- Surface CPS Representative Environment Test

Phase 3 tests are done with a fully integrated CPS in a representative environment, such as a cordoned-off area of a mine.

4 TRL4 Stage Gate

The Surface TMM CPS verification testing (TRL4 Stage Gate) consists of five functional tests, each with a specific purpose, test prerequisites, test instrumentation, preparation, test method and acceptance criteria. Ideally, a TMM CPS will be submitted for testing against all five the verification tests in one go with no alterations between tests. At the time of writing, this is unlikely. TMM CPS technology is developing rapidly and some changes and alterations are often necessary between testing when not done at the same time. As such, the independent verification test process makes provision for **minor** alterations to TMM CPS products between tests.

Figure 4 shows the verification test process. Each test (with the exception of the Surface TMM CPS Interface test) is preceded by a pre-test check. The intent of the pre-test check is to quickly confirm if any significant changes to the TMM CPS have affected previous test results. Here, the responsibility is placed on the TMM CPS OEM to clearly indicate any changes made since the previous test. It is left to the discretion of the test engineer responsible for the verification test to decide if a TMM CPS passes the pre-test check and that it may proceed with the subsequent verification test.

After completing a functional test, three recommendations may be made by the test engineer: Accept, Reject or Provisionally Accept.

- Accept: An Accept recommendation indicates that, on the day of testing, the TMM CPS under test conformed to all the requirements of that specific test.
- Reject: A Reject recommendation indicates that there are significant shortcomings that need to be rectified before testing can proceed.
- Provisionally Accept: A Provisionally Accept recommendation indicates that the TMM CPS under test does not conform to all of the requirements of that test, but, in the opinion of the test engineer, these deviations are easy to rectify and do not endanger the test team and/or test equipment of subsequent tests.

In the Provisionally Accept case, the TMM CPS OEM will be given reasonable opportunity to address any shortcomings. Corrections and updates to such a TMM CPS product will be allowed, and the pre-test check of the next verification test will be used to determine if corrections and/or updates have rectified the shortcomings. If the shortcomings have been rectified without compromising functionality already tested during prior verification tests, the TMM CPS product will be allowed to proceed to the next verification test. However, if the modifications to the TMM CPS product have not fully addressed the shortcomings, or if they have compromised the performance of functionalities tested earlier, the TMM CPS under test will not be allowed to continue further verification testing.

Shortcomings will have to be corrected and the TMM CPS product submitted for retesting. The test engineer will recommend a suitable re-entry point for further testing.

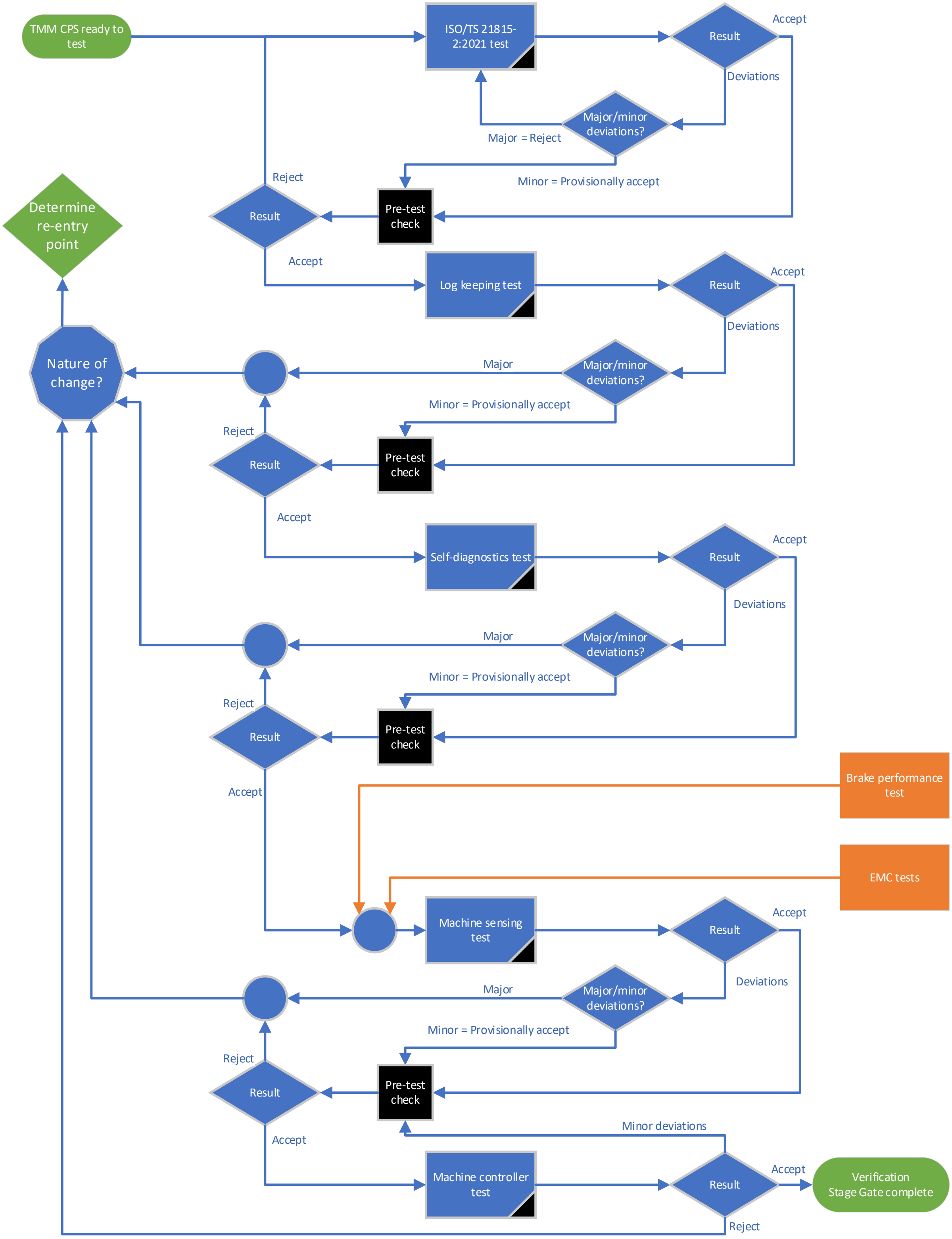

Figure 4: TMM CPS TRL4 verification test process

5 Verification test report structure

Two categories of reports are prepared subsequent to verification tests:

1. Stage gate reports
2. Technical test reports

Stage gate reports indicate the high-level progress of a TMM CPS product against the various TMM CPS verification tests. The intent of stage gate reports is to give concise information to a non-technical audience of a TMM CPS product's conformance to the F&TPRS for Surface TMM CPS. Stage gate reports summarize the findings and recommendations of the technical test reports for that specific stage. The stage gate report also highlights critical information that may affect later stage gate tests.

Technical test reports are detailed technical reports providing the specifics of TMM CPS verification tests. The intent of technical test reports is to provide detailed feedback to the TMM CPS product suppliers. Technical test reports are extensive and are intended for a technical audience.

Figure 5 shows the test report structure pertaining to Surface TMM CPS verification testing

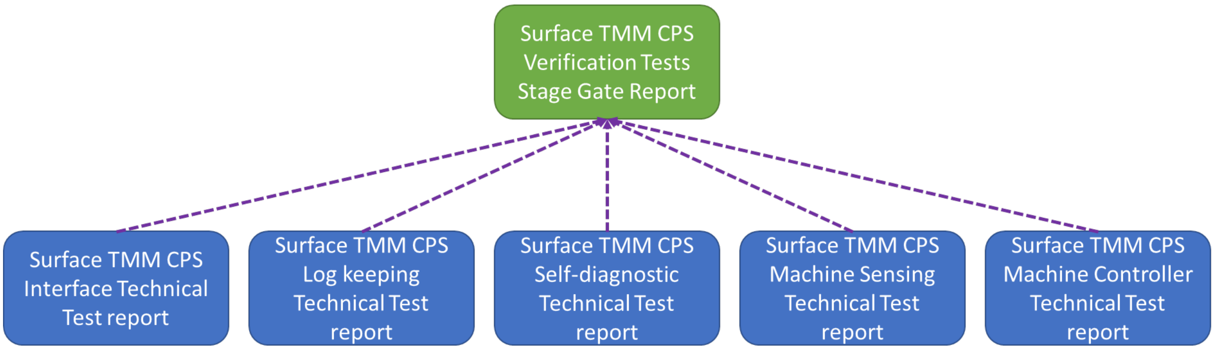

Figure 5: Surface TMM CPS verification test report structure

6 Independent Verification test readiness

It is acknowledged that TMM CPS developers / suppliers have performed functional tests over the past few years. CPS product suppliers are expected to do extensive in-house tests to verify conformance of its products. Independent verification testing is a reasonably practicable measure to ensure that mining employees are not injured as a result of TMM collisions. It is not the intention or a requirement of the project to have any CPS and/or element re-tested. The onus of such decision is entirely up to the CPS developer or product supplier to demonstrate conformance to the functional requirements. A CPS developer or any of its element providers can certify readiness at any given Stage Gate, together with all the information to demonstrate conformance. Such demonstration must include all the relevant functional readiness criteria as defined for all relevant Stage Gates.

Where a CPS developer or product supplier certifies its CPS product(s)for a specific Stage Gate, it must demonstrate conformance to the readiness criteria of all **prior** Stage Gates, as applicable.

7 Verification test instrumentation

Since the tests documented here are independent verification tests and are performed in carefully controlled test environments, such as a laboratory or a proving ground (test track), accurate and reliable instrumentation is a minimum requirement. Various measurements are collected during testing. Table 2 documents the accuracy required of the instrumentation to be used when conducting the verification tests in this document. Independent 3rd party verifiers need to ensure that instruments are properly maintained and have valid calibration certificates, as directed by the instrument suppliers.

Table 2: Verification test instrumentation specification

Instrument	State	Accuracy (RMS)
High-precision INSS (HP INSS)	Velocity	0.1 km/h
	Update rate	100 Hz
	Position	0.3 m 95 % CEP
	Heading	0.1°
	Angle	0.1°
Standard-precision GNSS (SP GNSS)	Speed	0.1 km/h
	Update rate	10
	Position	1.5 m CEP
	Heading	0.3°

8 Test Protocols

The Surface TMM CPS Verification (TRL4 Stage Gate) test protocols are documented in Appendices 1 to 5.

In preparation for each test, the TMM CPS supplier will be required to complete a product information sheet. The goal of the product information sheet is to:

1. Describe the product to ensure that the specifics are accurately reflected in the test reports.
2. Provide a formal sign-off to confirm that the product under test is fully functional and properly commissioned. The product is considered ready for testing.

The product information sheet is available in Appendix 6.

Appendix 7 documents a safety protocol to be followed prior to each test. The aim of the safety protocol is to ensure the safety of the test team and observers.

Appendix 1: Surface TMM CPS Machine Controller Interface Test

Purpose

The MCI subsystem must be able to communicate with the CxD as described in ISO/TS 21815-2:2021. The purpose of this test is to determine if the MCI conforms to the standard as specified in the Surface TMM F&TPR. It is expected that the CxD interface (CxDI) can adapt to the capabilities of the MCI.

Preceding tests

1. None

Test facility/site

Site where MCI is available. Tests are static and can be done in a lab or office environment.

Instrumentation

1. 1x CxD Emulator
2. 1x MCI
3. Power supply that can supply voltage as required (typically 12V or 24V)
4. CAN sniffer

Test preparation

1. The client will supply the TMM CPS MCI in working order. An authorized person (technology provider representative) will submit the signed TMM CPS test information sheet (Appendix 6). TMM CPS has passed all preceding tests as stipulated in the Preceding Tests section. No modifications to any aspect of the TMM CPS will be allowed once testing has commenced.
2. Connect CxD Emulator and CAN sniffer to MCI CAN-bus via the ISO21815-2:2021 connector
3. CxD Emulator to be powered by MCI via standardised ISO/TS21815-2 connector
4. MCI must be able to supply data to the CxD Emulator (e.g. a computer may be logged into the MCI to send data as required)
5. If any alterations are made to any aspect of the MCI during testing (e.g. firmware, rewiring of connector, etc.), all previous testing becomes invalid, and this protocol has to be followed from the start.

Test method and acceptance criteria

1. Connector

1.1. Note if the Deutsch DT-Series 12-pin plug (female) part is used as in 6.2 of the ISO standard.

1.2. Verify pin assignment as specified in 6.2 of the ISO/TS 21815-2:2021.

1.3. If override is connected on Machine side of the connector, note logic as in 6.4 of the ISO standard.

Table 3: Connector acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.01	Deutsch DT-series 12 pin, part DT06-12SC-EP06 (Key C) is used for connection between CxD and TMM Deutsch DT-series 12 pin, part DT06-12SC-EP06 (Key C)	SM.MCI.01

2. Negotiation sequence

2.1. If negotiation can be done without the use of trust mechanisms, record a CAN trace of the MCI attempting to perform the negotiation sequence.

2.2. If negotiation cannot be done without the use of trust mechanisms, note it as such and have TMM OEM provide specifics to enable negotiation between MCI and CxD Emulator. Record a CAN trace of the MCI attempting to perform the negotiation sequence using trust mechanisms.

2.3. After negotiation has been established between CxD Emulator and MCI, confirm:

2.3.1. Response time of the Machine>>CxDreply to CxD messages.

2.3.2. Broadcast rate of Machine>>CxDdata message.

Table 4: Negotiation sequence acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.02.1	For negotiation without authentication: • Perform negotiation as described in ISO 21815-2	SM.MCI.02
SM.MCI.AC.02.2	Negotiation with authentication (optional) • Perform negotiation as described in ISO 21815-2 • Mechanism to share credentials with interfacing party(ies)	SM.MCI.02
SM.MCI.AC.02.3	Reply to the PROTOCOL_NOP message to indicate system health maintain the connection	SM.MCI.03
SM.MCI.AC.02.4	Reply to the CxD>>MachineCommand message to indicate execution of instructions	SM.MCI.03

3. Communication loss

3.1. Record a CAN trace while performing the following actions:

3.2. Initiate the negotiation sequence on the CxD Emulator and confirm communication is established between the two nodes.

3.3. Sever the connection between CxD Emulator and MCI while maintaining connection between CAN sniffer and MCI.

3.4. Note MCI behaviour to loss in communication

3.5. Restore the connection between CxD Emulator and MCI and note MCI behaviour

Table 5: Communication loss acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.03	The MCI should detect a broken connection • Detection should occur within 500 ms of disconnection • MCI Disconnection should trigger the TMM to FTSWHI	SM.MCI.04

4. Capability enquiry

4.1. Record a CAN trace and initiate individual capability enquiries on the CxD>>MachineCommand message and note the response on the Machine>>CxDreply message

4.2. Record a CAN trace and initiate MCAPS propulsion register capability enquiry on CxD>>MachineStatus message and note Machine>>CxDreply message.

Table 6: Capability enquiry acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.04	The MCI should allow machine capabilities to be discovered by using one or both of the following methods: • Replying to individual CxD>>MachineCommand messages • Replying to reads of the PROPULSION_MCAPS register	SM.MCI.05

5. Reading protocol registers

5.1. Record a CAN trace and initiate GET_PROTOCOL_REGISTER enquiries on the CxD>>MachineStatus message and note response on the Machine>>CxDreply message

Table 7: Reading protocol registers acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.05.1	The MCI should populate and allow reading of the following protocol registers: • MACHINE_ID_0 to MACHINE_ID_4 • MACHINE_SOFTWARE_REVISION	SM.MCI.06.1
SM.MCI.AC.05.2	The MCI should accept write instructions to the following protocol registers: • CxD_SOFTWARE_REVISION • CxD_HARDWARE_REVISION • CxD_HARDWARE_ID	SM.MCI.06.2

6. Reading propulsion registers

6.1. Record a CAN trace and initiate GET_PROPULSION_REGISTER enquiries on the CxD>>MachineStatus message and note response on the Machine>>CxDreply message. Note:

6.1.1. If TMM CPS makes use of EMERGENCY_STOP_MAX_SPEED, CONTROLLED_STOP_MAX_SPEED or SLOW_DOWN_MAX_SPEED propulsion registers.

Table 8: Reading propulsion registers acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.06	The MCI should allow the CxD to read propulsion information from the propulsion registers.	SM.MCI.06.3

7. Setting and reading protocol registers

7.1. Record a CAN trace while performing the following actions:

7.2. Modify READ_WRITE protocol registers. Initiate SET_PROTOCOL_REGISTER action on CxD>>MachineStatus message with the modified values.

7.3. Note response on the Machine>>CxDreply message.

7.4. Initiate GET_PROTOCOL_REGISTER enquiry on CxD>>MachineStatus message and note response on the Machine>>CxDreply messages

Table 9: Setting and reading protocol registers

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.07	The MI should accept write instructions to the following protocol registers: • CxD_SOFTWARE_REVISION • CxD_HARDWARE_REVISION • CxD_HARDWARE_ID	SM.MCI.06.2

8. Reset of registers

8.1. If reset register functionality is implemented, then perform the following test:

8.2. Record a CAN trace while performing the following actions:

8.3. Initiate RESET_REGISTERS action on CxD>>MachineStatus message on protocol and propulsion subsystem and note Machine>>CxDreply message

8.4. Initiate GET_PROTOCOL_REGISTER enquiry on CxD>>MachineStatus message and note response on the Machine>>CxDreply message

8.5. Initiate GET_PROPULSION_REGISTER enquiry on CxD>>MachineStatus message and note correct response on the Machine>>CxDreply message

Table 10: Reset of registers acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.08.1	The MCI should allow resetting of the protocol registers to default values if the functionality is implemented	SM.MCI.06.4
SM.MCI.AC.08.2	The MCI should allow resetting of the propulsion registers to default values if the functionality is implemented	SM.MCI.06.4

9. Propulsion commands

9.1. Record a CAN trace while performing the following actions:

9.2. Initiate the following actions on the CxD>>MachineCommand message. For each command, note the reply on the Machine>>CxDreply message

9.2.1. EMERGENCY_STOP

9.2.2. CONTROLLED_STOP

9.2.3. SLOW_DOWN

9.2.4. STAND_DOWN

9.2.5. INHIBIT_COMMAND

9.3. In the case of the INHIBIT_COMMAND, note INHIBIT_RESPONSE reply

9.4. Initiate the APPLY_PORPULSION_SETPOINTS intervention.

9.5. Note the reply on the Machine>>CxDreply message for:

9.5.1. UPDATE_AND_APPLY.

9.5.2. APPLY_FROM_LIST

9.5.3. MATCH_TAG

9.6. Activate override on CxD emulator (BYPASS_PROPULSION).

9.7. Note BYPASS_PROPULSION_ACK on Machine>>CxDreply message.

Table 11: Propulsion commands acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.09.1	The MCI must reply to correctly to CxD>>MachineCommand messages	SM.MCI.03
SM.MCI.AC.09.2	The MCI must action CxD>>MachineCommand messages using either or both of SM.MCI.AC.09.2.1 and SM.MCI.AC.09.2.2	SM.MCI.07

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.09.2.1	The MCI replies to commands used to control TMM operation in an open loop manner. The MCI must implement the following commands to control the TMM and achieve appropriate responses: • NORMAL_OPERATION to allow the TMM to operate without restrictions on operator controls • EMERGENCY_STOP to apply all available measures to stop the TMM as quickly as possible. Reserved for use when the collision cannot be avoided and the consequences of the collision must be mitigated by reducing TMM speed • CONTROLLED_STOP to slow and stop the TMM in a controlled manner • SLOW_DOWN to reduce the TMM's speed to a predefined crawl speed and not exceeding the crawl speed while active	SM.MCI.07.1
SM.MCI.AC.09.2.2	The CxDI uses set point functionality to control the TMM in a closed loop manner. The MCI must correctly implement one or more of the following methods to correctly load and apply set points: • UPDATE_AND_APPLY to apply only a single set point at a time • MATCH_TAG to apply multiple retagged set points • APPLY_FROM_LIST to apply all set points in a list	SM.MCI.07.2
SM.MCI.AC.09.3	The MCI must accept the STAND_DOWN command if a critical CxD failure is detected • STAND_DOWN to slow and stop the TMM in a controlled manner when the CxD experiences a fault (fail to safe response)	SM.MCI.07.3
SM.MCI.AC.09.4	The MCI must accept BYPASS_PROPULSION when an override is triggered on the CxD • BYPASS_PROPULSION to reduce the TMM's speed to a predefined crawl due to an override on the CxD (limp mode)	SM.MCI.07.4
SM.MCI.AC.09.5	The MCI must implement INHIBIT_COMMAND • INHIBIT_COMMAND must be used to ensure a stationary TMM remains stationary (e.g. during CPS start-up)	SM.MCI.07.5
SM.MCI.AC.09.6	The time between a CxD>>MachineStatus/Command message and a Machine>>CxDreply message should not be longer than 50 ms to ensure all instructions are executed promptly	SM.MCI.08

10. Machine data

10.1. Record a CAN trace and Initiate data stream from machine side on Machine>>CxDdata message.

10.1.1. Note the field values of:

10.1.1.1. SYSTEM_FAULT
10.1.1.2. OVERRIDE_FAULT
10.1.1.3. ROLLBACK_FAULT
10.1.1.4. TRACTION_FAULT
10.1.1.5. PAYLOAD_FAULT
10.1.1.6. SPEED
10.1.1.7. DIR
10.1.1.8. MOTION_INHIBIT
10.1.1.9. GEAR
10.1.1.10. OVERRIDE_STATUS
10.1.1.11. ROLLBACK_STATUS
10.1.1.12. TRACTION_STATUS
10.1.1.13. PAYLOAD_STATUS

10.1.1.14. PITCH

10.1.1.15. ROLL

10.2. Modify the fields described in 11.1 and repeat 11.

Table 12: Machine data acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.10	The MCI should correctly populate all fields contained in the Machine>>CxDdata PGN. • If some parameters are not available they should be correctly indicated as not available as per ISO21815-2. • The PGN should be sent at the ISO21815-2 specified 100 ms rate.	SM.MCI.09 SM.MS.1.7

11. TMM Override

11.1. Record a CAN trace and perform the following actions:

11.1.1. Activate emergency override on MCI.

11.1.1.1. Note OS bitfield on Machine>>CxDdata message and emergency override trigger mechanism.

11.1.2. Activate maintenance override on MCI.

11.1.2.1. Note OS bitfield on Machine>>CxDdata message and maintenance override trigger mechanism.

Table 13: Override acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.11	MCI communicates the status and fault state of the TMM side override to the CxD • Note: Override status in Machine>>CxDdata message is used to indicate the TMM's override functionality status • MCI must not use override status in Machine>>CxDdata message to indicate BYPASS_PROPULSION command sent from CxD • Credentials required to activate Authorized Override	SM.MCI.11

12. Unsupported Commands

12.1. Record a CAN trace and perform the following actions:

12.1.1. Send all command that are not supported by the MCI (e.g. APPLY_PROP_SETPOINTS).

12.1.2. Note receipt of ACTION_ERROR for each unsupported command and FTSWHI behaviour.

Table 14: Unsupported commands criteria

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.12	MCI replies with ACTION_ERROR for all unsupported commands	SM.MCI.07 SM.MCI.12 SM.MC.15

13. Time/Date

13.1. Record a CAN trace and perform the following actions:

13.1.1. Send SAE J1939 request for Time/Date from CxDI to MCI.

13.1.1.1. Note receipt of MCI Time/Date message response to message from CxDI

13.1.2. Send SAE J1939 request for Time/Date from MCI to CxDI.

13.1.2.1. Note receipt of Time/Date message request from MCI.

13.1.2.2. Note MCI time request period

Table 15: Time/Date

AC No.	Criteria	Func. Req. No.
SM.MCI.AC.13.1	The MCI should use the J1939 Request PGN to request the J1939 Date/Time PGN from the CxD	SM.MCI.10
SM.MCI.AC.13.2	The MCI should respond to any J1939 Request for time addressed to it with the J1939 Date/Time PGN.	SM.MCI.10

Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, have all parties accept in writing:

1. The proposed deviation
2. Reason for the proposed deviation and
3. Motivation why the proposed deviation will not affect the purpose of the test

Appendix 2: Surface TMM CPS Machine Log keeping test.

Purpose

The MLK subsystem must be able to store all data from the MCI as well as data relevant to the Machine state. The purpose of this test is to determine if the MLK can perform its log keeping duties successfully and provide a permanent, auditable record.

Preceding tests

1. TRL4 Surface TMM CPS Controller Interface Test

Test facility/site

Site where MLK and MCI is available. Tests are static and can be done in a lab or office environment.

Instrumentation

1. CxD Emulator

Test preparation

1. MLK and MCI to be provided in working condition to the test team. Responsible person to sign-off that MLK and MCI is in working condition as designed.
2. Get filled out test information sheet from MLK supplier (Appendix 6) stating which data messages are recorded on the MLK
3. Connect CxD Emulator and Machine Emulator to MCI CAN-bus via the ISO21815 connector. If not integrated into a single component, the MCI must be connected to the MLK
4. If any alterations are made to the firmware of the MLK or MCI during testing, all previous testing becomes invalid and this protocol has to be followed from the start

Test method and acceptance criteria

1. Stored data and accuracy of log file

1.1. Confirm sufficient storage space as per test information sheet

1.2. Record a CAN trace and perform the following actions:

1.2.1. Initiate data stream with CxD and Machine

1.2.2. Negotiation between CxD emulator and Machine

1.2.3. NOP for 60s

1.2.4. Intervention for 10s

1.2.5. NOP for 60s

1.2.6. MC fault for 10s

1.2.7. NOP for 60s

1.2.8. Override for 10s

1.2.9. NOP for 60s

1.3. Stop data stream and transfer MLK log file to computer

Table 16: Stored data and accuracy of log file acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MLK.AC.1.1	It must be possible to synchronize TMM and CxD logs based on time • Synchronization can be done in post-processing (real-time synch not required) • TMM time should be recorded at least once every hour of operation	SM.MLK.01
SM.MLK.AC.1.2	Record all messages shared via the CxDI and MCI: • CxD>>MachineStatus • CxD>>MachineCommand • Machine>>CxDdata • Time/Date requests and responses • Data should at least be stored on change ○ MessageID changes are not considered to be 'on-change' events	SM.MLK.02
SM.MLK.AC.1.3	Record information describing the operator, TMM and CPS at all times. The following information must be recorded at all times: • CxD information (obtained in MCI Protocol Registers) • TMM ID • TMM firmware information	SM.MLK.03
SM.MLK.AC.1.4	During interventions, all information needed to recreate interaction scenarios to be stored at a minimum resolution of 10 Hz. Information to be stored must at least include: • CxD Time • TMM speed • TMM pitch angle • TMM override status • Any TMM CPS faults if present • If TMM design payload is > 40% of TMM GVM ○ Payload status	SM.MLK.04
SM.MLK.AC.1.5	Authorized override data must be stored • Authorized override status • Authorized person ID that activates the Authorized Override	SM.MLK.05.1
SM.MLK.AC.1.6	Emergency override status must be recorded	SM.MLK.05.2
SM.MLK.AC.1.7	Record TMM CPS system health information • The presence of any TMM CPS faults	SM.MLK.06

2. Data transfer

2.1. Verify that data transfer interface functions as documented in product information sheet

2.2. If possible, generate data until storage reflects a 7-day sized log file. If not, generate a log file and note the duration. Extrapolate to determine the size of a 7-day log file.

2.3. Initiate data transfer and note time duration to transfer log file to computer

2.4. Note size of 7-day sized log file and compare against available data storage space

Table 17: Data transfer acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MLK.AC.2.1	Reasonable provision made to store up to and including 7 days' worth of data on the TMM	SM.MLK.07
SM.MLK.AC.2.2	If storage capacity is full before 7 days has passed, fail-to-safe response is triggered	SM.MLK.07 SM.MLK.10
SM.MLK.AC.2.3	Make provision for a data transfer mechanism to access machine logs periodically, as needed according to the mine’s specification. The data transfer mechanism may be wireless or require a physical connection or make use of removable storage. • Reasonable considerations must be taken to grant authorized persons access to the logs after an incident has occurred.	SM.MLK.08

3. Data security

3.1. Note any security measures to prevent log file from being deleted on MLK with a computer

3.2. Note any security measures to prevent log file from being altered on MLK with a computer

3.3. Note redundant measures to ensure that the integrity of the log file will not be compromised with physical damage, electrical discharge, or magnetic exposure

Table 18: Data security acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MLK.AC.09	Reasonable steps taken to ensure that data containing sensitive information is protected	SM.MLK.09
SM.MLK.AC.10	MLK to provide mechanism to prevent unauthorized data deletion • MLK to record ID of authorized person deleting data • Reasonably practicable measures must be taken	SM.MLK.11
SM.MLK.AC.11	MLK to provide mechanism to prevent alteration of stored data. • Reasonably practicable measures must be taken	SM.MLK.12

Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, have all parties accept in writing:

1. The proposed deviation
2. Reason for the proposed deviation and
3. Motivation why the proposed deviation will not affect the purpose of the test

Appendix 3: Surface TMM CPS Machine Self-Diagnostic Test

Purpose

The MC, MCI and MLK subsystems must be able to self-diagnose failure modes that compromise the performance of the TMM CPS. The purpose of this test is to determine how the TMM responds to imposed failure modes.

Preceding tests

1. TRL4 Surface TMM CPS Controller Interface test
2. TRL4 Surface TMM CPS Log keeping test

Test facility/site

Site where machine is available. Site must have sufficient space for TMM to manoeuvre.

Instrumentation

1. CxD Emulator
2. CAN sniffer

Test preparation

1. TMM to be provided in working condition to the test team. Responsible person to sign-off that TMM is in working condition as designed.
2. Get filled out test information sheet from MCI supplier
3. Fence off test area. Ensure all aspects in Safety protocol is adhered to.
4. Connect CxD Emulator to the machine CAN-harness via the ISO21815 connector.
5. Ensure all personnel, equipment and all obstacles are removed in front and behind of the machine. Personnel should be in the safe area defined in Safety protocol.
6. Start machine and let idle
7. Complete negotiation sequence between CxD Emulator and MC and ensure that MC is in NOP
8. Instruct operator that during each test run and while it is safe, take-off should be gradual, slow and short since MSD is being evaluated
9. Manually operated brakes may not be used at any time during the test run (e.g. brake pedal, park brake lever, etc.)
10. A computer may be logged into the MCI to send subsystem fault (SF) message
11. If any alterations are made to the firmware of the MC, MCI or MLK during testing, all previous testing becomes invalid and this protocol must be followed from the start

Test method and acceptance criteria

1. MC faults

1.1. Record a CAN trace and perform the following actions:

1.2. Disconnect power supply to MC

1.3. Instruct operator to attempt to take-off in FWD and REV and note FTSWHI response

1.4. Repeat 3 times

Table 19: MC faults acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MSD.AC.01	Upon MC power interruption: • FTSWHI achieved in both FWD AND REV directions • Transmits subsystem fault on machine>>CxDdata message	SM.MC.14 SM.T06

2. MCI faults

2.1. MCI Power interruption
2.1.1. Record a CAN trace and perform the following actions:
2.1.2. Disconnect power supply to MCI
2.1.3. Instruct operator to attempt to take-off in FWD and REV and note FTSWHI response
2.1.4. Repeat 3 times
2.2. MCI Communication interruption
2.2.1. Record a CAN trace and perform the following actions:
2.2.2. Disconnect CAN communication between MCI and CxD Emulator
2.2.3. Instruct operator to attempt to take-off in FWD and REV and note FTSWHI response
2.2.4. Repeat 3 times

Table 20: MCI faults acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MSD.AC.02	Upon power interruption AND comms interruption • FTSWHI achieved in both FWD AND REV directions	SM.MCI.11 SM.T06

3. MLK faults:

3.1. MLK Power interruption
3.1.1. Record a CAN trace and perform the following actions:
3.1.2. Disconnect power supply to MLK
3.1.3. Instruct operator to attempt to take-off in FWD and REV and note FTSWHI response
3.1.4. Repeat 3 times
3.2. MLK storage full
3.2.1. Record a CAN trace and perform the following actions:
3.2.2. Fill MLK with data
3.2.3. Instruct operator to attempt to take-off in FWD and REV and note FTSWHI response
3.2.4. Repeat 3 times
3.3. MLK not recording fault
3.3.1. Record a CAN trace and perform the following actions:
3.3.2. Initiate MLK not recording fault
3.3.3. Instruct operator to attempt to take-off in FWD and REV and note FTSWHI response
3.3.4. Repeat 3 times

Table 21: MLK faults acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MSD.AC.03	Upon MLK power interruption, MLK storage full and MLK not recording faults: • FTSWHI achieved in both FWD AND REV directions • Transmits subsystem fault on machine>>CxDdata message For all test runs	SM.MLK.10 SM.T06

4. Time exchange fault

4.1. Record a CAN trace and perform the following actions:

4.2. Initiate time exchange fault by setting CxD emulator to stop responding to TMM time requests

4.3. Instruct operator to attempt to take-off in FWD and REV and note FTSWHI response

4.4. Repeat 3 times

Table 22: Time exchange faults acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MSD.AC.04	Upon time/date exchange faults: • FTSWHI achieved in both FWD AND REV directions • Transmits subsystem fault on machine>>CxDdata message	SM.MLK.10 SM.T06

5. Override fault

5.1. Record a CAN trace and perform the following actions:

5.2. If equipped, disconnect the override switch

5.3. Instruct operator to attempt to take-off in FWD and REV and note FTSWHI response

5.4. Repeat 3 times

Table 23: Override faults acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MSD.AC.05	For all test runs upon any Override faults (if equipped): • FTSWHI achieved in both FWD AND REV directions • Transmits override fault on machine>>CxDdata message	SM.MC.14 SM.T06 SM.MS.1.7

6. Payload fault

6.1. If TMM design payload is > 40% of TMM GVM:

6.1.1. Record a CAN trace and perform the following actions:

6.1.2. Activate PAYLOAD_STATUS fault

6.1.3. Instruct operator to attempt to take-off in FWD and REV and note FTSWHI response

6.1.4. Repeat 3 times

Table 24: Payload faults acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MSD.AC.06	For all test runs upon PAYLOAD_STATUS fault (if equipped): • FTSWHI achieved in both FWD AND REV directions • Transmits payload fault on machine>>CxDdata message	SM.MC.14 SM.T06 SM.MS.1.7

7. Sensing fault

7.1. Record a CAN trace and perform the following actions:

7.2. If possible, disconnect the following sensors:

7.2.1. Speed

7.2.2. Pitch

7.2.3. Gear

7.2.4. Direction

7.2.5. Door Switch

7.3. With each sensor disconnected individually, instruct operator to attempt to take-off in FWD and REV and note FTSWHI response

7.3.1. Repeat 3 times for each sensor

Table 25: Status faults acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MSD.AC.08	For all test runs upon sensor fault: • FTSWHI achieved in both FWD AND REV directions • Transmits subsystem fault on machine>>CxDdata message	SM.MC.14 SM.T06 SM.MS.1.7

Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, have all parties accept in writing:

1. The proposed deviation
2. Reason for the proposed deviation and
3. Motivation why the proposed deviation will not affect the purpose of the test

Appendix 4: Surface TMM CPS Machine Sensing test

Purpose

The MS subsystem must be able to measure the state of the machine so that it may be used by the CPS. The purpose of this test is to determine if the measurements sent from the MS via the Machine>>CxDdata message are accurate and reliable.

Preceding tests

1. ISO3450:2011 or equivalent
2. EMC tests as applicable (consult with an accredited EMC test laboratory)
3. TRL4 Surface TMM CPS Controller Interface Test
4. TRL4 Surface TMM CPS Log keeping Test
5. TRL4 Surface TMM CPS Self-diagnostics Test

Test facility/site

1. Site where machine is available. Tests are dynamic and need adequate space for run-up, conducting the test and run-off. Site must have access to:
   - A level, even, hard surface
   - A ramp with incline of 10% or more
2. If TMM equipped with roll sensor, a large open space is required to conduct a constant radius test to induce a roll angle on the machine.
3. If design payload is larger than 40% of TMM GVM, infrastructure is needed to change the payload on the machine.

Instrumentation

1. CxD Emulator
2. DAQ with ISO/TS 21815-2 interface
3. HP GNSS with IMU

Test preparation

1. TMM to be provided in working condition to the test team. Responsible person to sign-off that TMM is in working condition as designed.
2. Get filled out test information sheet from MCI supplier
3. If any alterations are made to the firmware of the MC, MCI or MLK during testing, all previous testing becomes invalid and this protocol must be followed from the start
4. Ensure all aspects of safety protocol is adhered to.
5. Install HP GNSS on machine and ensure good satellite reception is obtained.
6. Connect CxD Emulator and data acquisitioning system to the machine CAN-harness via the ISO/TS 21815-2 connector
7. Ensure all personnel, equipment and all obstacles are removed in front and behind of the machine. All personnel to be within safe area declared in Safety protocol.
8. Start machine and let idle.
9. Complete negotiation sequence between CxD Emulator and MC and ensure that MC is in NOP.

Test method and acceptance criteria

1. Dynamic test: SPEED, DIR, GEAR

1.1. Start recording ISO/TS 21815-2 messages and HP GNSS measurements
1.2. Allow 10s of data recording while machine is stationary with no action from the operator
1.3. Instruct operator to drive in FWD direction while cycling through all available gears of the machine up to 30km/h or machine's top speed
1.4. Instruct operator to gradually stop machine and engage safe park
1.5. Allow 10s of data recording while machine is stationary with no action from the operator
1.6. Instruct operator to drive in REV direction while cycling through all available gears of the machine up to 15km/h or top speed, whichever is higher.
1.7. Instruct operator to gradually stop machine and put in safe park
1.8. Stop recording
1.9. Repeat 3 times

Table 26: SPEED, DIR and GEAR acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MS.AC.1	DIR in recorded CAN messages is consistent with test performed	SM.MS.1 SM.MS.1.4
SM.MS.AC.1.1	GEAR in recorded CAN messages is consistent with test performed	SM.MS.1 SM.MS.1.3
SM.MS.AC.1.2	SPEED transmitted is within ±1.5 km/h or 5% accuracy of the HP GNSS measurement, whichever is greater	SM.MS.1 SM.MS.1.1
SM.MS.AC.1.3	Time delay between SPEED transmitted and HP GNSS measurement of < 1 s	SM.MS.1 SM.MS.1.1

2. Incline/decline test

2.1. Start recording ISO/TS 21815-2 messages and HP GNSS measurements
2.2. Using a ramp, instruct operator to drive machine such that a significant amount of pitch angle is observed in positive and negative directions
2.3. Stop recording

Table 27: PITCH acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MS.AC.2.1	PITCH transmitted within ±5° of HP GNSS IMU measurement	SM.MS.1 SM.MS.1.2
SM.MS.AC.2.2	Time delay between PITCH transmitted and HP GNSS IMU measurement of < 1 s	SM.MS.1 SM.MS.1.2

3. Status change

3.1. Start recording ISO/TS 21815-2 messages and HP GNSS measurements
3.2. Instruct operator to cycle through all statuses available on machine
3.3. If design payload is larger than 40% of machine GVM, use a forklift, crane or any other means to change the payload status on the machine
3.4. Stop recording

Table 28: Status change acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MS.AC.3.1	OS in recorded CAN messages is consistent with test performed	SM.MS.1.5
SM.MS.AC.3.2	If design payload is larger than 40% of GVM, PS consistent between log and test notes	SM.MS.1

4. Motion Inhibit

4.1. Start recording ISO/TS 21815-2 messages and HP GNSS measurements
4.2. Send INHIBIT_COMMAND = ON from the CxD emulator
4.3. Note that MI status is set to ON
4.4. Send INHIBIT_COMMAND = OFF from the CxD emulator
4.5. Note that MI status is set to OFF
4.6. Instruct operator to trigger an action which will result in FTSWHI
4.7. Note that MI status is set to ON
4.8. Stop recording

Table 29: Motion Inhibit acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MS.AC.4.1	MI in recorded CAN messages is consistent with test performed	SM.MS.1.6
SM.MS.AC.4.2	When FTSWHI is triggered MI status is set to ON in recorded CAN messages	SM.MS.1.6
SM.MS.AC.4.3	When FTSWHI is triggered Subsystem fault (SF) is set to ON in recorded CAN messages	SM.MS.1.6

Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, have all parties accept in writing:

1. The proposed deviation
2. Reason for the proposed deviation and
3. Motivation why the proposed deviation will not affect the purpose of the test

Appendix 5: Surface TMM CPS Machine Controller test

The MC subsystem must be able to translate commands from the CxD into actionable control of the MBS. Commands from the CxD may vary between suppliers. Implementations of the MC and MBS will vary between suppliers, TMM OEMs and types of machines. Thus, the purpose of this test is twofold, being (1) to determine if the implementation of the MC is acceptable, and (2) to determine the delay, deceleration and crawl speed of the machine in response to CxD commands.

Preceding tests

1. ISO3450:2011
2. EMC tests as applicable (consult with an accredited EMC test laboratory)
3. TRL4 Surface TMM CPS Machine Interface test
4. TRL4 Surface TMM CPS Log keeping test
5. TRL4 Surface TMM CPS Self-diagnostics test
6. TRL 4 Surface TMM CPS Machine sensing test

Test facility/site

1. Site where machine is available. Tests are dynamic and need adequate space for run-up, conducting the test and run-off. Site must have access to: A level, even, hard surface

Instrumentation

1. CxD Emulator
2. DAQ with ISO/TS 21815-2 interface
3. HP GNSS with IMU

Test preparation

1. TMM to be provided in working condition to the test team. Responsible person (TMM OEM representative) to sign-off that TMM is in working condition as designed.
2. Get filled out test information sheet from MCI supplier
3. If any alterations are made to the firmware of the MC, MCI, MLK or MS during testing, all previous testing becomes invalid and this protocol must be followed from the start
4. Fence off test area. Ensure all aspects in Safety protocol is adhered to.
5. Install HP GNSS on machine and ensure good satellite reception is obtained.
6. Connect CxD Emulator and data acquisitioning system to the machine CAN-harness via the ISO/TS 21815-2 connector.
7. Ensure all personnel, equipment and all obstacles are removed in front and behind of the machine. Personnel should be in the safe area as required by Safety protocol.
8. Start machine and let idle.
9. Complete negotiation sequence between CxD Emulator and MC and ensure that MC is in NOP.
10. Instruct operator that during each test run AND while it remains safe to do so:
    - The accelerator pedal must stay depressed during the entire duration of the test run
    - Manually operated brakes may not be used at any time during the test run

Test method and acceptance criteria

1. Machine response to commands which prevent movement:

1.1. Describe how TMM locomotion is prevented in terms of MC, hydraulic hardware and MBS.

1.2. If the TMM is equipped with a controllable attachment, describe how attachment movement prevented is achieved in terms of MC and hydraulic hardware.

1.3. Start recording ISO/TS 21815-2 messages and HP GNSS measurements

1.4. With the TMM stationary:

1.4.1. Release the Park Brake

1.4.2. Issue the following commands to the MC with the CxD emulator:

1.4.2.1. INHIBIT_COMMAND

1.4.2.2. EMERGENCY_STOP

1.4.2.3. CONTROLLED_STOP

1.4.2.4. STAND_DOWN

1.4.2.5. APPLY_PROPULSION_SETPOINTS with set point appropriate to stop the TMM

1.4.3. For each command:

1.4.3.1. Instruct operator to take-off in FWD and ensure locomotion is prevented

1.4.3.2. Instruct operator to take-off in REV and ensure locomotion is prevented

1.4.3.3. Instruct operator to use attachment and ensure attachment movement is prevented

1.4.3.4. Instruct operator to articulate machine and ensure articulation is prevented

1.4.4. Repeat 3 times for each command

Table 30: Machine response to MOTION_INHIBIT acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MC.AC.1.1	Locomotion is prevented in all test runs in both directions with all supported stop commands	SM.MC.1 SM.MC.3 SM.MC.7 SM.MBS.1
SM.MC.AC.1.2	Attachment movement is prevented for all test runs	SM.MC.3

2. Machine response to slowdown commands:

2.1. Describe how slowdown is achieved in terms of MC, MBS, hydraulic hardware, electromechanical retarders or regenerative braking and propulsion system

2.2. Start recording ISO/TS 21815-2 messages and HP GNSS measurements

2.3. Instruct operator to drive machine at the maximum speed in each gear in both FWD and REV

2.4. If supported, issue the following commands to the MC with the CxD emulator:

2.4.1. SLOW_DOWN

2.4.2. APPLY_PROPULSION_SETPOINTS with set point appropriate to slow the TMM

2.5. Repeat 3 times for each command, speed and direction

Table 31: Slow down acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MC.AC.2.1	Machine slows down with all supported slowdown commands for all test runs Settles on the crawl speed for all test runs Service brake is available with all slowdown commands for all test runs	SM.MC.4 SM.MC.4.1 SM.MC.4.1.3 SM.MC.4.2 SM.MC.4.2.2 SM.MC.5 SM.MC.8 SM.MC.11 SM.MBS.1 SM.MBS.2
SM.MC.AC.2.2	APPLY_PROPULSION_SETPOINT tracking • For constant speed limit (e.g. speed limited zone), speed limit never exceeded by 2 km/h	SM.MC.4 SM.MC.4.2 SM.MC.4.2.1 SM.MBS.1 SM.MBS.2
SM.MC.AC.2.3	Operator maintains directional control during slow down • No locking/dragging of wheels • No significant veering of direction • No spinning • No excessive jerk exerted on operator	SM.MC.2 SM.MC.12

3. Machine response to stop commands:

3.1. Describe how stop is achieved in terms of MC, MBS, hydraulic hardware and propulsion system

3.2. Start recording ISO/TS 21815-2 messages and HP GNSS measurements

3.3. Instruct operator to drive machine at the maximum speed in each gear in both FWD and REV. Note:

3.3.1. No more than 3 speeds will be tested in each direction

3.3.2. Suitable test speeds to be determined by test engineer, taking due consideration of the number of gears, intended operating speeds, maximum safe stopping speeds (i.e. from propulsion registers), etc. (Consult the OEM technical specification).

3.3.3. Document motivations for test speed selection.

3.4. If supported, issue the following commands to the MC with the CxD emulator:

3.4.1. EMERGENCY_STOP

3.4.2. CONTROLLED_STOP

3.4.3. STAND_DOWN

3.4.4. APPLY_PROPULSION_SETPOINTS with set point appropriate to stop the TMM

3.5. Repeat 3 times for each command, speed and direction

Table 32: Stop acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MC.AC.3.1	Machine stops with all supported stop commands, for all test runs	SM.MC.4 SM.MC.4.1 SM.MC.8

AC No.	Criteria	Func. Req. No.
SM.MC.AC.3.2	For EMERGENCY_STOP, the maximum stopping distance is determined by the following equation: $$S = \frac{vt}{3.6} + \frac{v^2}{13 \times 2a}$$ Where $S\ is\ stopping\ distance, in\ metres\ (m)$ $v\ is\ the\ test\ speed, in\ kilometres\ per\ hour\ (km/h)$ $t = 0.35\ s$ And $a = 1.9\ m/s^2$ for TMMs with top speed > 20 km/h $a = 1.0\ m/s^2$ for all other TMMs	SM.MC.4.1.1 SM.MC.4.1.2 SM.MC.4.2 SM.MC.4.2.1 SM.MC.8 SM.MBS.1 SM.MBS.2
SM.MC.AC.3.3	For CONTROLLED_STOP and APPLY_PROPULSION_SETPOINTS with set point appropriate to stop the TMM, the maximum stopping distance is determined by the following equation: $$S = \frac{vt}{3.6} + \frac{v^2}{13 \times 2a}$$ Where $S\ is\ stopping\ distance, in\ metres\ (m)$ $v\ is\ the\ test\ speed, in\ kilometres\ per\ hour\ (km/h)$ $t = 0.35\ s$ And $a = 1.0\ m/s^2$ for TMMs with top speed > 20 km/h $a = 0.5\ m/s^2$ for all other TMMs	SM.MC.4.1.1 SM.MC.4.1.2 SM.MC.4.2 SM.MC.4.2.1 SM.MC.8 SM.MBS.1 SM.MBS.2
SM.MC.AC.3.4	For STAND_DOWN, TMM comes to a complete stop.	SM.MC.4.1.1 SM.MC.4.1.2 SM.MC.4.2 SM.MC.4.2.1 SM.MC.8 SM.MBS.1 SM.MBS.2
SM.MC.AC.3.5	Operator maintains directional control during stop • No locking/dragging of wheels • No significant veering of direction • No spinning	SM.MC.12

4. Machine response to unexpected CxD behaviour

4.1. Start recording ISO/TS 21815-2 messages and HP GNSS measurements

4.2. Instruct operator to drive machine at the maximum speed in each gear in FWD

4.3. For each speed, initiate the following unexpected behaviour

4.3.1. Issue an INHIBIT_COMMAND to the MC with the CxD emulator and note machine response

4.3.2. Disconnect the CxD emulator from the CAN-bus and note machine response

4.3.3. If the MCI does not support all ISO/TS 21815-2:2021 commands (as communicated during MCI initialisation), send the unsupported commands to test unexpected CxD behaviour

4.4. Repeat 3 times for each speed and unexpected behaviour

Table 33: Unexpected behaviour acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MC.AC.4.1	Machine FTSWHI with communication interrupted for all test runs	SM.MC.14 SM.MC.15
SM.MC.AC.4.2	Machine FTSWHI when unsupported command is sent to machine	

5. Machine response to override:

5.1. Describe how the override function works in terms of MC, MBS, hydraulic hardware and propulsion system

5.2. Note if override is implemented using pins on the ISO21815-2 connector

5.3. Start recording ISO/TS 21815-2 messages and HP GNSS measurements

5.4. With machine stationary initiate the following actions

5.4.1. Send a stop intervention from the CxD then activate maintenance override on machine side of the interface

5.4.2. Send a stop intervention from the CxD then activate emergency override on machine side of the interface

5.4.3. Send BYPASS_PROPULSION from the CxD to initiate CxD side override.

5.5. Instruct operator to take-off and note speed at which the machine settles (maximum speed that can be achieved with override activated)

Table 34: Override acceptance criteria

AC No.	Criteria	Func. Req. No.
SM.MC.AC.5	All override methods limit machine speed to < 10 km/h for all test runs Emergency Override time limited to less than 5 min Emergency Override time limit is configurable as per mine specification	SM.MC.6 SM.MC.9 SM.MC.10

Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, have all parties accept in writing:

1. The proposed deviation
2. Reason for the proposed deviation and
3. Motivation why the proposed deviation will not affect the purpose of the test

Appendix 6: TMM CPS test information sheet

Table 35: TMM CPS product information sheet

Test details	
Surface TMM CPS test(s) performed	
Test location	
Test date	
CxD Emulator	
CxD Emulator Hardware	
CxD Emulator Firmware	
Name of test engineer	
Signature	
Signing this test information sheet confirms that the CxD Emulator and all test instrumentation used during the test were properly calibrated and commissioned and integration with the TMM CPS product was checked prior to commencing with the test.	
TMM details	
TMM CPS OEM	
TMM CPS model	
TMM type	
TMM GVM	
TMM design payload	
Serial number	
TMM MC specifics	
TMM CPS MBS specifics	
Interface details	
Interface OEM (if third-party)	
Interface Hardware	
Interface Firmware	
ISO21815-2 Version	
ISO21815-2 Negotiation sequence specifics	
TMM MLK details	
MLK firmware	
Specifics recorded in log file	
MLK storage capacity	
Estimated storage period	
Mechanism to obtain log files	
Security measures to prevent log file deletion and alteration	

TMM CPS OEM Sign-off	
Name of duly authorized TMM CPS OEM representative	
Date	
Signature	
Signing this test information sheet confirms that the TMM CPS product under test was commissioned and tested as per the TMM CPS OEM specification prior to the commencement of the test. Reasonable steps were taken to ensure integration with the CxD Emulator was successful.	
Safety sign-off	
Name of test safety officer	
Date	
Signature	
Signing this test information sheet confirms that the test safety officer has taken reasonably practicable measures to ensure the safety of those present at the CPS test, including but not limited to: • A site risk assessment • Ensuring adequate emergency medical supplies are available • Test safety briefing prior to the commencement of testing • Ensuring steps set out in Appendix 7: Test safety protocol have been followed and will be adhered to	

Appendix 7: Test safety protocol

Purpose

The purpose of this document is to prescribe the safety management and controls required to ensure that safety and health risks are minimised due to interactions between TMMs and pedestrians during testing at the identified test sites.

Note: this document does not take the place of the pre-test risk assessment which may identify risks that are local or local environment induced. A pre-test risk assessment is always required, which includes a test site safe declaration, prior to the commencement of the tests each day or after a significant event.

Scope

The scope of this document applies to the safety management for all CPS testing performed any test site where the MHSA is not in force. The scope of this document defines the following safety controls at the CPS test sites:

1. Access control and safety management during testing,
2. Emergency management of the test site during CPS testing,
3. Risk assessment completed for the testing,
4. Test area layout including signage for the test area,
5. Evacuation plan,
6. Test plan for each test.

Risk assessment

A CPS testing site risk assessment must be compiled for the test site and tests to be carried out. This risk assessment must be filed in a separate document and kept in the site office on the test site for easy access and reference by all on site.

A separate risk assessment will be conducted with all contractors on site and be available on the test site for ease of access and reference by all.

Each CxD and TMM CPS provider or contractor shall have completed an issues-based risk assessment for the fitting to and removal of their CPS systems from the TMMs.

Each TMM OEM provider or contractor shall have completed an issues-based risk assessment for the fitting to and removal of their CPS systems from the TMMs.

All controls defined in the risk assessments must be implemented.

Pre-test risk assessment

Prior to testing each day, a pre-test risk assessment must be conducted to ensure that any specific environmental or other risks specific to that day or tests are identified and controls put into place. Note: no tests may be conducted without the pre-test risk assessment being completed and signed off by both the legal appointments and all those involved in the test on that day.

Site entry register

Site entry to any person either included in the testing or invited is limited.

All persons entering the site are required to sign a test site entry register and sign out before leaving the site.

Safety management

In accordance with the Mine Health and Safety Act (Act 29 of 1996) (MHSA) and the Occupational Health and Safety Act (Act 85 of 1993) (OHSA) as well as the site safety policy, safety is the top priority on the test site. All persons or TMMs entering the test site must have authorisation to do so and shall comply with all site safety procedures and the test site specific safety requirements contained in this document.

The overarching safety management approach is the safety approach that would normally be followed in accordance with the MHSA and the OHSA. The safety approach is expanded below:

Before work begins

The site safety officer shall assess whether the site, task and issues-based risk assessment controls are still valid and address all the risks in the risk assessment,

The site safety officer shall conduct the pre-test risk assessment and sign it off with the test engineer,

- Safety talk led by the site safety officer – all people performing test site work must attend and sign the safety talk attendance register.
- Each TMM operator shall have a pre-start check performed by the operator. The completed pre-start check sheet shall be filed in the filing system and kept in the test site office.
- Each TMM shall perform a functional brake test on each TMM prior to the start of testing each day (see Annexure 3 for pre-start checklist),
- The test site responsible engineer shall verify that the test site is safe and that the roads are in an acceptable and safe condition (see Annexure 4 for road audit methodology) and declare the site safe for testing to resume every day.
- The test site safety officer shall check that all people on site are wearing the appropriate PPE and that any tools being used are in a safe working condition and being used safely.
- Both the test site safety officer and site test engineer shall declare the site safe for testing and sign the safe declaration form.

Note 1: No tests shall commence unless all the above has been completed and signed off.

Note 2: While not derogating from employees' rights in terms of Section 22 and 23 of the MHSA, the test site safety officer and/or the test site engineer may stop the test at any time when they deem any situation to be unsafe.

Note 3: Any unsafe condition must be reported and can be reported by anyone on the test site (see Annexure 6 for unsafe reporting document and log).

Changes in risk during the day

Any changes that may increase the risk to safety and render current controls insufficient, will result in the test being placed on hold or suspended pending further risk assessment. The site safety officer and or the site test engineer will perform a pre-test risk assessment and make the final decision on whether the controls specified in the revised risk assessment are adequate to control the changes in risk. This revised pre-work risk assessment shall be filed in the risk assessment file in the site office.

Note: Changes in risk can emanate from (this list is not exhaustive):

- Heavy rainstorms, high wind where visibility is reduced due to dust,
- Dark cloud that impinges visibility,
- Tyre change,
- Diesel spill that needs to be cleaned,
- Pedestrians or vehicles inadvertently wandering on to the test site,
- Severe road damage that requires repair,
- Lightning,
- Illness of someone who requires immediate treatment on site,
- Injury on site,
- High environmental temperature that has a high risk of inducing heat stroke,
- TMM accident where persons are injured,
- Near misses where a high potential of interaction between TMM and TMM or TMM and pedestrian occurs.

Emergencies

For all emergencies, the number below shall be contacted, and the test site emergency plans enacted.

Emergency number

In the case of an emergency being declared, the following persons will take charge:

- Test site safety officer, and if not available then
- Test site responsible engineer, and if not available then
- The next highest-ranking test site employee on the test site.

All emergencies, as listed below, shall be reported to the site safety officer as incidents as per the test site incident management procedure. The safety officer shall ensure that the incident is reported and follows the above procedure. A copy of the procedure must be available at the test area.

Should an emergency be declared, the process below shall be followed:

- The person in charge shall immediately identify themselves and contact the number above and follow the test site emergency procedures and plans,
- All persons on site, shall listen to the instructions given by the person in charge,
- If possible, the operators of the TMMs shall drive the TMMs to the test site parking area, safe park the TMMs, egress the TMM, hand keys to the person in charge (if TMM has keys) and follow instruction given by that person,
- Before doing all of this, all movement/operations on site must be stopped.

Personal protective equipment (PPE)

There are four different PPE requirements for the test site:

- Visitors who remain behind the safety barrier in front of the site office: no PPE is required,

- Test site personnel who are not working on the vehicles: safety shoes, reflective vests, or other acceptable high-visibility apparel, (hat, cap or similar sunshade system is recommended),
- Persons working on the TMMs: overall (with reflective bands), safety shoes, hard hat, gloves (if applicable for the task being performed), dust goggles may be required if wind is blowing,
- TMM operators: overalls, safety shoes, safety hats.
- Access to the test site shall be limited to those involved in performing the test, invited visitors, CxD technology providers, CPS interface provider, OEMs and various test functions required to support the test. No person other than those designated to perform the test are allowed on the test site without the permission of either the site safety officer or the site test engineer.

Communication

Communication during testing will be via the following means:

1. Two-way handheld radios on a channel specifically for the test,
2. Mobile communication via mobile phones,

TMM fitment and work area

All CxD technology, CPS interface technology and any OEM fitments will be done in the TMM parking area referred to as the test vehicle parking bay. A 220V power point must be provided for tool energy.

Note: All employees (test site, CxD, OEMs and contractors) shall adhere to the test site tool safety standard. The site safety officer will audit the tools being used and the way in which they are being used on an ad hoc basis. Note: the test site has zero tolerance for any unsafe power tool or other tool used and any deviation from this will not be tolerated on the test site. It is the contractor supervisor that must ensure all fitment and tools used for the fitment are carried out in a safe manner and in accordance with the test site safety standards. The power tool safety and use thereof procedure shall be available in the site office.

CxD technology providers shall ensure that they have consulted with the OEM and have approved drawings for installation on the OEM TMMs. These drawings are to include the location of each component on the TMM (with any accompanying instructions) and electrical connections etc and included in the Section 21 files.

Environmental management

All chemicals brought onto site and used must have an accompanying Material Safety Data Sheet (MSDS). The MSDS must be lodged with the site safety officer and filed in the MSDS file in the site office. No chemicals are permitted on the test site without an MSDS. (this is for both health, fire risks and controls and environmental risks and management),

Hydrocarbon spills: All hydrocarbon (fuel and oil) spills will be treated in accordance with the test site environmental management procedure, a copy of which is available in the site office. All spills must be reported to the site safety officer,

Waste and rubbish: Rubbish bins must be provided for the different types of waste. These bins must be located close to the test site office.

Smoking area

Smoking is only allowed in the area demarcated. No smoking is allowed in any other area on the test site.

At the conclusion of testing

1. The site test engineer shall declare work ended for the day,
2. All TMMs will go to the test vehicle parking bay, where they will safely park, lock the vehicles and insert wheel chocks,
3. The TMM keys (if TMM has keys) will be handed to the site safety officer who will lock them in the site office key cabinet,
4. If contractors wish to leave their vehicles on site, then the vehicles must be safely parked in the LDV parking area and keys handed to the site safety officer who will lock them in the site office key cabinet,
5. The site safety officer shall check the attendance register and ensure that all employees have signed out for the day,
6. The site safety officer shall check the site and declare it safe to be locked for the night and ensure that all employees are off site and shall lock the pedestrian gate.