INDEPENDENT VERIFICATION TEST SPECIFICATION FOR UNDERGROUND COLLISION WARNING AND AVOIDANCE DEVICES (CxD): TRL4 STAGE GATE

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

REV 1

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Table of contents

Definitions and abbreviations ii
1 Introduction 1
2 Context 2
3 CxD Product Independent Verification Testing 3
4 TRL4 Stage Gate 4
5 Verification test report structure 6
6 Independent Verification test readiness 6
7 Verification test instrumentation 6
8 Test Protocols 7
Appendix 1: UG CxD Interface Test 8
Appendix 2: UG CxD Log Keeping Test 15
Appendix 3: UG CxD Self-Diagnostic Test 18
Appendix 4: UG CxD Detection and Tracking Test 23
Appendix 5: UG CxD Effective Warning Test 28
Appendix 6: UG CxD Controller Test 33
Appendix 7: CxD test information sheet 43
Appendix 8: Test safety protocol 45

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.

Abbreviation	Definition
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.
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
UG	Underground : Indicating that a specific aspect is applicable to underground TMMs/operations.

1 Introduction

This document is intended for Underground (UG) Collision Warning and Avoidance System Devices (CxD) to be used in the South African Mining Industry. 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 TRL4 Stage Gate for UG CxDs, shown in purple in Figure 1.

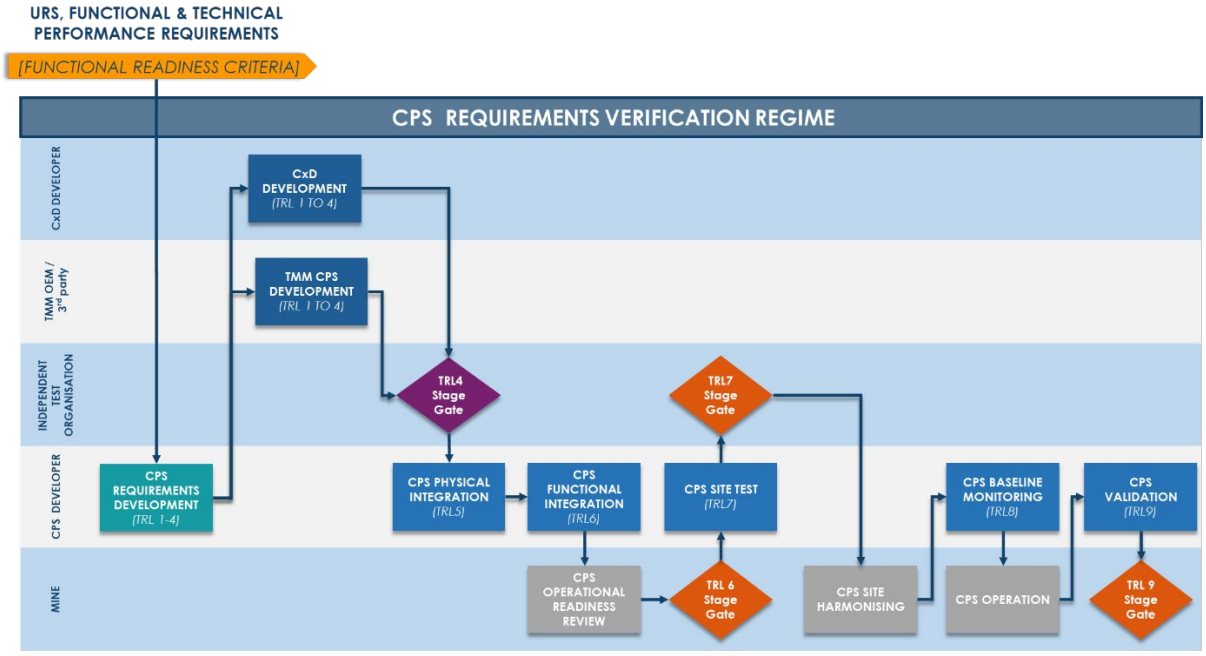

Figure 1: CPS requirements verification regime

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 UG CPS verification test regime. The UG 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.

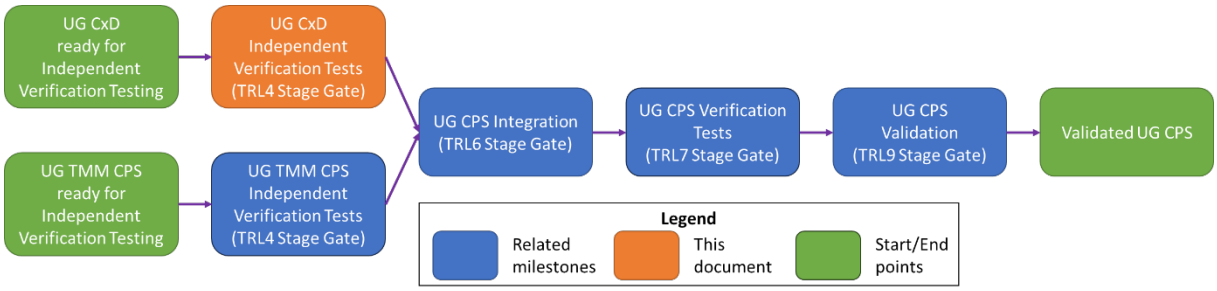

Figure 2: UG CPS independent verification test regime

2 Context

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

User Requirements Specification
- UG CPS

Functional and Technical Performance Requirements
- UG CxD
- UG TMM CPS

Readiness Criteria
- Readiness Criteria For Collision Prevention System Development And Deployement

Requirements Verification Regime
- CPS Requirements Verification Regime

Independent Verification Specifications
- **UG CxD TRL4 Stage Gate**
- UG TMM CPS TRL4 Stage Gate (this document)
- UG CPS Verification TRL7 Stage Gate

Figure 3: CPS functional testing related documentation

This document is the UG CxD Independent Verification Test specification and builds on the User Requirement Specification (URS) for UG CPS and the Functional and Technical Performance Requirements (F&TPRS) for UG CxDs. The purpose of this document is to provide a single test specification to assess the functionality of UG CxDs 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 CxD submitted for verification.

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

- The CPS F&TPR specification for UG CxDs
- The CPS F&TPR specification for UG TMM CPS

- The Independent Verification Test Specification for UG TMM CPS.

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

3 CxD Product Independent Verification Testing

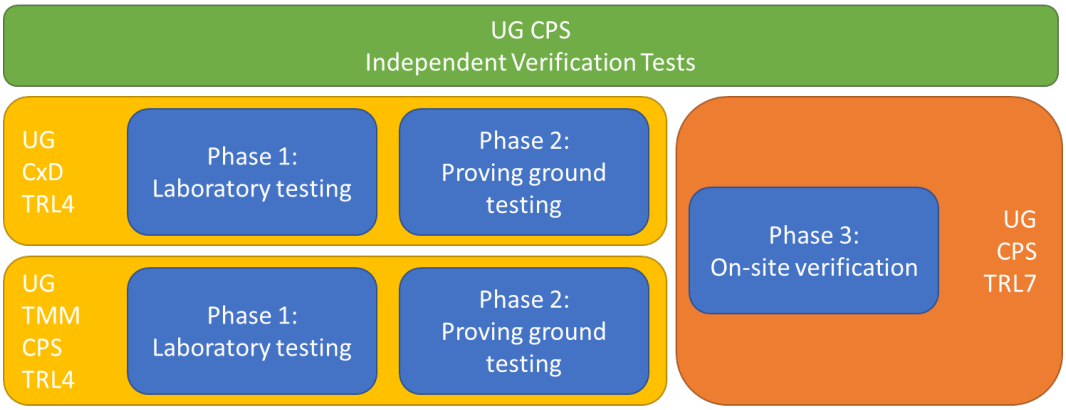

Figure 3: UG CPS independent verification test regime

CxD 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)

The following tests are done for **Phase 1: Laboratory CxD tests**

- UG CxD Interface Test - the ISO/TS 21815-2: 2021 test
- UG CxD Log Keeping Test
- UG CxD Self-Diagnostic Test

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

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

- ICASA Type Approval demonstration The CxD supplier submits its ICASA certificate.
- EMC demonstration, as applicable (consult with an accredited EMC test laboratory). CxD supplier submits its EMC certificates.
- UG CxD Detection and Tracking test
- UG CxD Effective Warning test
- UG CxD Controller test

Phase 2 tests are done at a proving ground, typically at Gerotek Test Facilities. The Phase 2 tests are done with light vehicles, allowing for safe and repeatable testing within a short timeframe.

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

- UG CPS integration
- UG CPS interaction scenarios

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 UG CxD verification testing (TRL4 Stage Gate) consists of six functional tests, each with a specific purpose, test prerequisites, test instrumentation, preparation, test method and acceptance criteria. Ideally, a CxD will be submitted for testing against all six the verification tests in one go with no alterations between tests. At the time of writing, this is unlikely. CxD 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 CxD products between tests.

Figure 4 shows the verification test process. Each test (with the exception of the UG CxD 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 CxD have affected previous test results. Here, the responsibility is placed on the CxD supplier 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 CxD 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 and Provisionally Accept.

- Accept: An Accept recommendation indicates that, on the day of testing, the CxD 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 CxD 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 CxD supplier will be given reasonable opportunity to address any shortcomings. Corrections and updates to such a CxD 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 CxD product will be allowed to proceed to the next verification test. However, if the modifications to the CxD product have not fully addressed the shortcomings, or if they have compromised the performance of functionalities tested earlier, the CxD under test will not be allowed to continue further verification testing. Shortcomings will have to be corrected and the CxD product submitted for retesting. The test engineer will recommend a suitable re-entry point for further testing.

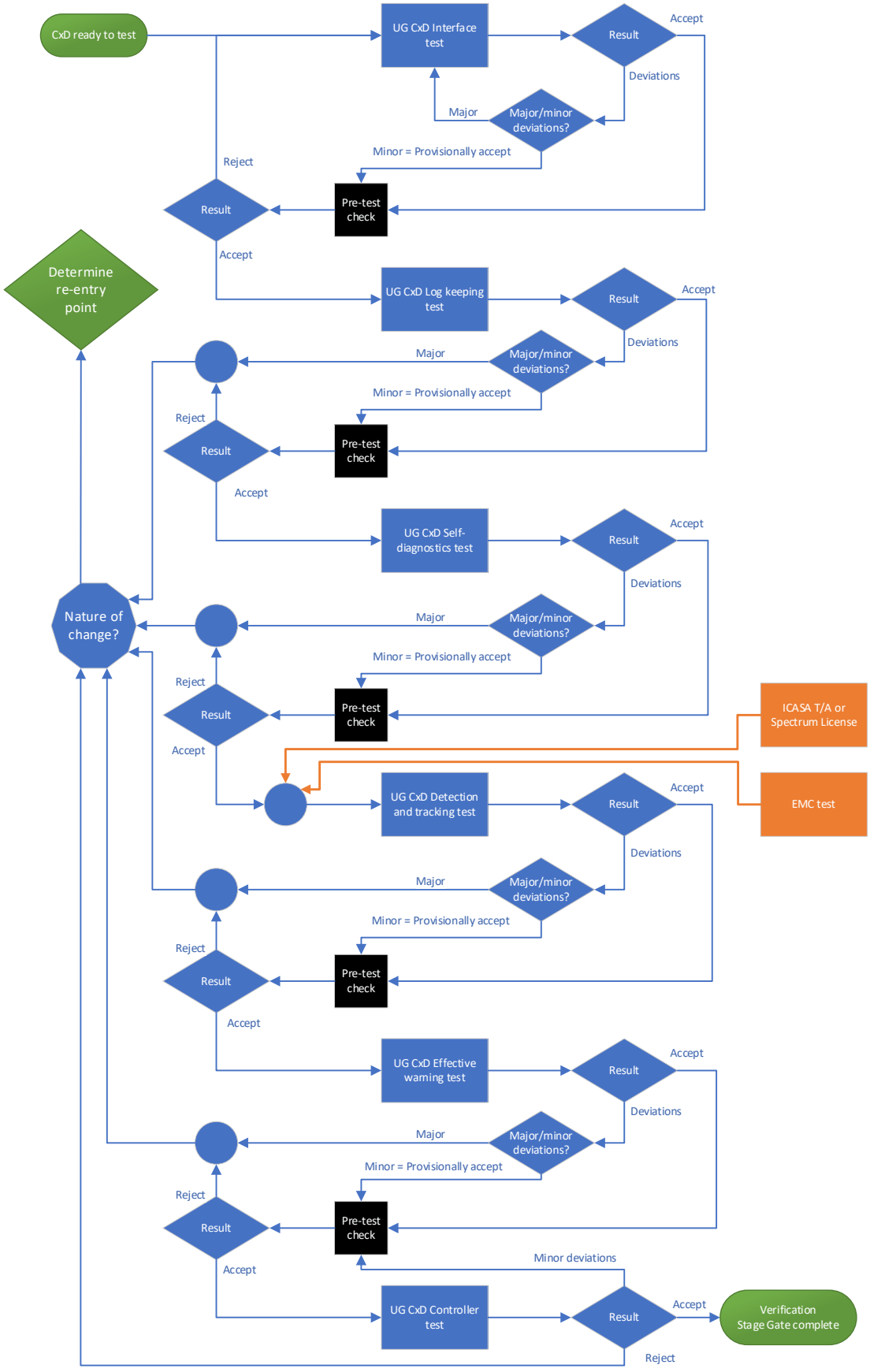

Figure 4: UG CxD verification test process

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 CxD product against the various CxD verification tests. The intent of stage gate reports is to give concise information to a non-technical audience of a CxD product's conformance to the FTPR for UG CxDs. 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 CxD verification tests. The intent of technical test reports is to provide detailed feedback to the CxD product suppliers. Technical test reports are extensive and are intended for a technical audience.

Figure 5 shows the test report structure pertaining to UG CxD verification testing

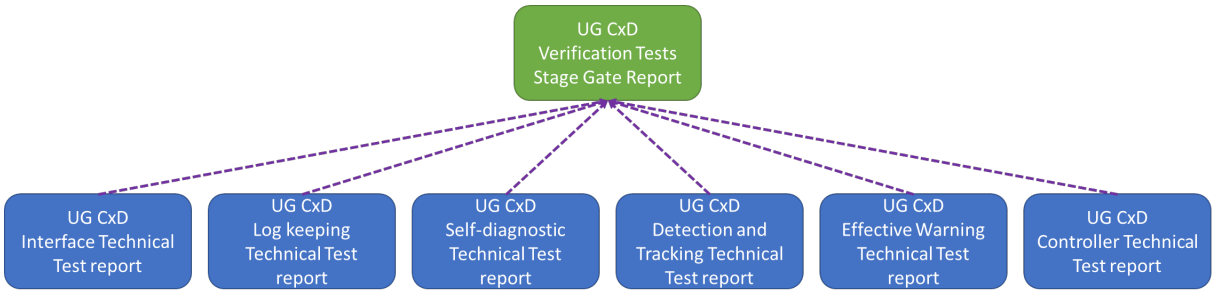

Figure 5: UG CxD verification test report structure

6 Independent Verification test readiness

It is acknowledged that CxD 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°
Camera	Resolution	720p
	Field of view	60°
	Frame rate	30 fps

8 Test Protocols

The UG CxD Verification (TRL4 Stage Gate) test protocols are documented in Appendices 1 to 6.

In preparation for each test, the CxD 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 7.

Appendix 8 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: UG CxD Interface Test

Purpose

The CxD Interface (CxDI) subsystem must be able to communicate with the Machine Control Interface (MCI) using the standard as defined in ISO/TS21815-2:2021. The purpose of this test is to determine if the CxDI is compliant with the standard. It is expected that the CxDI can adapt to the capabilities of the MCI. The test evaluates the CxDI against acceptance criteria based on technical requirements in UG CxD F&TPR Specification.

Preceding tests

1. None

Test facility/site

Tests are static and can be done in a laboratory environment.

Instrumentation

1. 1x TMM Emulator
2. 1x CxDI
3. 1x CAN sniffer

Test preparation

1. The client will supply the CxDs in working order. An authorized person (technology provider representative) will submit the signed CxD test information sheet (Appendix 7). CxD has passed all preceding tests as stipulated in the Preceding Tests section. No modifications to any aspect of the CxDs will be allowed once testing has commenced.
2. Connect TMM Emulator and sniffer to CxDI CAN-bus via the ISO21815 connector.
3. Power is to be supplied to the CxDI via the ISO21815 connector. Connect power supply to pins 2,3 and 4 in the ISO21815 connector.
4. The CxDI must be able to send commands to the TMM Emulator when requested by the test engineer. The CxDI must also be able to report which values and capabilities have been read on the TMM Emulator during testing (e.g. computer may be logged into CxDI to perform these tasks).
5. If any alterations are made to any aspect of the CxDI 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. Document if the Deutsch DT-Series 12-pin socket (male) 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.

1.3. If override is connected on CxD 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.
UG.CxDI.AC.01	Deutsch DT-series 12 pin, part DT04-12PC-BE02 (Key C) is used for connection between CxD and TMM	UG.CxDI.01

2. Negotiation sequence

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

2.2. Have the CxDI attempt to perform negotiation without the use of trust mechanisms. If negotiation cannot be done without the use of trust mechanisms, document it as such and have the CxD developer provide information to enable negotiation between CxDI and TMM Emulator.

2.3. After negotiation has been established between CxDI and TMM Emulator

2.4. Note:

2.4.1. Broadcast rate of CxD>>MachineStatus messages

2.4.2. Broadcast rate of CxD>>MachineCommand messages

Table 4: Negotiation sequence acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.02.1	For negotiation without authentication: Perform negotiation as described in ISO 21815-2	UG.CxDI.02
UG.CxDI.AC.02.2	Negotiation with authentication (optional) Perform negotiation as described in ISO 21815-2 Mechanism to share credentials with interfacing party(ies)	UG.CxDI.02
UG.CxDI.AC.02.3	Send the PROTOCOL_NOP message periodically to maintain the connection	UG.CxDI.03
UG.CxDI.AC.02.4	Send the command message every 100ms to ensure the TMM consistently receives instructions.	UG.CxDI.03

3. Communication loss

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

3.2. Have the CxDI initiate the negotiation sequence and confirm communication is established between the two nodes.

3.3. Sever the connection between TMM Emulator and CxDI while maintaining connection between CAN sniffer and CxDI. Document CxDI behaviour to loss in communication.

3.4. Restore the connection between TMM Emulator and CxDI

3.5. Note:

3.5.1. CxDI behaviour when connection is severed

3.5.2. CxDI behaviour when connection is restored

Table 5: Communication loss acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.03	The CxDI should detect a broken connection Detection within 500ms of disconnection Upon disconnection, CxD may opt to: Stay quiet, FTSWHI needed on TMM Attempt to negotiate again Send STAND_DOWN	UG.CxDI.04

4. Capability enquiry

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

4.2. Pre-set capabilities on the TMM Emulator

4.3. Record a CAN trace of the CxDI attempting to discover machine capabilities using the following methods:

4.3.1. Reading the MCAPS propulsion register with the CxD>>MachineStatus message

4.3.2. Individual capability enquiries on the CxD>>MachineCommand message

Table 6: Capability enquiry acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.04	The CxDI should determine machine capabilities using one or both of the following methods: Sending individual CxD>>MachineCommand messages Reading the PROPULSION_MCAPS register.	UG.CxDI.05

5. Reading protocol registers

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

5.2. Pre-set values for the following protocol registers:

5.2.1. PROTOCOL_REVISION

5.2.2. SUBSYSTEM_MCAPS

5.2.3. INTERFACE_STATE

5.2.4. MACHINE_SOFTWARE_REVISION

5.2.5. MACHINE_ID_0

5.2.6. MACHINE_ID_1

5.2.7. MACHINE_ID_2

5.2.8. MACHINE_ID_3

5.2.9. MACHINE_ID_4

5.2.10. INSTRUCTION_TIMEOUT

5.2.11. NEGOTIATION_TIMEOUT

5.2.12. RENEGOTIATION_TIMEOUT

5.3. Have the CxDI attempt to read protocol registers

Table 7: Reading protocol registers acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.05	The CxDI should attempt to read the following protocol registers: MACHINE_ID_0 to MACHINE_ID_4 MACHINE_SOFTWARE_REVISION	UG.CxDI.06.1

6. Reading propulsion registers

6.1. Pre-set values for the following propulsion registers:

6.1.1. PROPULSION_MCAPS

6.1.2. MIN_BRAKING
6.1.3. MAX_THROTTLE
6.1.4. MAX_SPEED
6.1.5. EMERGENCY_STOP_MAX_SPEED
6.1.6. CONTROLLED_STOP_MAX_SPEED
6.1.7. SLOW_DOWN_MAX_SPEED
6.1.8. MAX_FORWARD_GEAR
6.1.9. MAX_REVERSE_GEAR
6.2. Record a CAN trace of CxDI attempting to read propulsion registers.

Table 8: Reading propulsion registers acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.06	The CxDI should read data from the propulsion registers if available	UG.CxDI.06.3

7. Setting protocol registers

7.1. Record a CAN trace of CxDI attempting to set protocol registers.

Table 9: Setting protocol registers acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.07	The CxDI should attempt to write the following protocol registers: CxD_SOFTWARE_REVISION CxD_HARDWARE_REVISION CxD_HARDWARE_ID	UG.CxDI.06.2

8. Reset of registers

8.1. Record a CAN trace of CxDI attempting to reset propulsion and protocol registers.

Table 10: Reset of registers acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.08.1	The CxDI may attempt to reset the data in the protocol registers to default values	UG.CxDI.06.4
UG.CxDI.AC.08.2	The CxDI may attempt to reset the data in the propulsion registers to default values	UG.CxDI.06.4

9. Propulsion commands

9.1. Record a CAN trace of CxDI attempting to execute the following action commands:
9.1.1. EMERGENCY_STOP
9.1.2. CONTROLLED_STOP
9.1.3. SLOW_DOWN
9.1.4. STAND_DOWN
9.1.5. BYPASS_PROPULSION
9.1.6. INHIBIT_COMMAND

Table 11: Propulsion commands acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.09.1	The CxDI must send NORMAL_OPERATION to allow the TMM to operate without restrictions on operator controls	UG.CxDI.07 UG.CxDI.07.1
UG.CxDI.AC.09.2	If the CxD makes use of open-loop interventions, it must send: 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 down 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	UG.CxDI.07.1
UG.CxDI.AC.09.3	The CxDI must send STAND_DOWN to slow down and stop the TMM in a controlled manner when the CxD experiences a fault (fail to safe without human intervention response)	UG.CxDI.07.3
UG.CxDI.AC.09.4	The CxDI must send BYPASS_PROPULSION to reduce the TMM's speed to a predefined crawl speed due to an override on the CxD side of the interface (limp mode)	UG.CxDI.07.4
UG.CxDI.AC.09.5	The CxDI must send INHIBIT_COMMAND must be used to ensure a stationary TMM remains stationary (e.g. during CPS start-up)	UG.CxDI.07.5

10. Apply propulsion set points

10.1. Record a CAN trace of CxDI attempting to set, load and apply the propulsion set points with the following methods:

10.1.1. UPDATE_AND_APPLY.

10.1.2. APPLY_FROM_LIST

10.1.3. MATCH_TAG

Table 12: Apply propulsion set points acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.10	The TMM may be controlled by correctly loading and applying set points using one or more of the following methods: 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	UG.CxDI.06.2 UG.CxDI.07.2

11. Error handling

11.1. Pre-set TMM Emulator to have a certain capability that the CxDI can discover (e.g. EMERGENCY_STOP), but replies with ACTION_ERROR when this command is sent from the CxDI

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

11.2.1. Restart negotiation and capability discovery between CxDI and TMM Emulator

11.2.2. Have CxDI issue the command that was pre-set to reply with ACTION_ERROR

Table 13: Error handling acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.11	If the CxD issues an unsupported command or one that cannot be applied at the current speed, the TMM may return an ACTION_ERROR. The CxDI should handle such errors safely	UG.CxDI.09

12. Machine data

12.1. Modify measurements sent in Machine>>CxDdata message and document interpretation of:

12.1.1. SYSTEM_FAULT

12.1.2. OVERRIDE_FAULT

12.1.3. ROLLBACK_FAULT

12.1.4. TRACTION_FAULT

12.1.5. PAYLOAD_FAULT

12.1.6. SPEED

12.1.7. DIR

12.1.8. MOTION_INHIBIT

12.1.9. GEAR

12.1.10. OVERRIDE_STATUS

12.1.11. ROLLBACK_STATUS

12.1.12. TRACTION_STATUS

12.1.13. PAYLOAD_STATUS

12.1.14. PITCH

12.1.15. ROLL

Table 14: Machine data acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.12	The CxDI should correctly interpret information contained in the Machine>>CxDdata PGN. If only some parameters are used, the CxDI must correctly interpret all utilised parameters.	UG.CxDI.10

13. Delayed status responses

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

13.1.1. While negotiated delay the response from the TMM Emulator on the Machine>>CxDreply message to 50ms.

13.1.2. Sever connection

13.1.3. Perform negotiation between TMM emulator and CxDI

Table 15: Delayed status responses acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.13	The CxDI should be able to handle the case where the TMM delays its response to the CxD>>MachineStatus message by up to 50ms	UG.CxDI.11

14. Override

14.1. CxD maintenance override

14.1.1. Document authentication method used to activate an maintenance override

14.1.2. Record a CAN trace and activate maintenance override

14.2. Machine side override

14.2.1. Record a CAN trace and perform the following action:

14.2.2. Activate override on Machine side of the interface (either a physical switch or on the TMM Emulator)

Table 16: Override acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.11	CxD sends BYPASS_PROPULSION to MCI	UG.CxDI.07.4
UG.CxDI.AC.12	Document indication of machine side override activation on CxD when machine-side override is activated.	UG.CxDI.10

15. Time/Date

Record a CAN trace and perform the following actions:

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

15.1.1. Note receipt of CxD Time/Date message response to message from MCI.

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

15.2.1. Note receipt of Time/Date message request from CxDI.

15.2.2. Note CxDI time request period

Table 17: Time/Date

AC No.	Criteria	Func. Req. No.
UG.CxDI.AC.12.1	The CxDI should use the SAE J1939 Request PGN to request the SAE J1939 Date/Time PGN from the TMM	UG.CxDI.12
UG.CxDI.AC.12.2	The CxDI should respond to any SAE J1939 Request for time addressed to it with the SAE J1939 Date/Time PGN.	UG.CxDI.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 2: UG CxD Log Keeping Test

Purpose

The CxD Log Keeping (CLK) subsystem must be able to store all data from CxD functions as well as data relevant to the machine state. The purpose of this test is to determine if the CLK can perform its log keeping duties successfully to provide a permanent auditable record. The test evaluates the CLK against acceptance criteria based on technical requirements in the UG CxD F&TPR Specification.

Preceding tests

1. UG CxD Interface Test

Test facility/site

Tests are static and can be done in a laboratory environment.

Instrumentation

1. 1x TMM Emulator
2. 1x CxDI
3. 1x CLK
4. 1x Pedestrian PWS (or other mechanism to induce CPS Stop)
5. 1x CAN sniffer

Test preparation

1. The client will supply the CxDs in working order. An authorized person (technology provider representative) will submit the signed CxD test information sheet (Appendix 7). CxD has passed all preceding tests as stipulated in the Preceding Tests section. No modifications to any aspect of the CxDs will be allowed once testing has commenced.
2. Connect CxD Emulator, TMM Emulator and to CxDI CAN-bus via the ISO21815 connector.
3. If any alterations are made to the firmware of the CLK or CxDI during testing, all previous testing becomes invalid and this protocol must be followed from the start.

Test method and acceptance criteria

1. Stored data and accuracy of log file

1.1. Ensure that CxDI and TMM Emulator are ready to negotiate when connected

1.2. Connect the CxDI and TMM Emulator and ensure negotiation is complete and NORMAL_OPERATION has been reached

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

1.3.1. Note start time of test

1.3.2. Connect the CxDI and TMM Emulator and wait for negotiation to complete

1.3.3. NORMAL_OPERATION for 60 s

1.3.4. Effective warning for 10 s

1.3.5. CPS Stop for 10 s

1.3.6. NORMAL_OPERATION for 60 s

1.3.7. Maintenance Override for 10 s

1.3.8. NORMAL_OPERATION for 60 s

1.3.9. CxD fault for 10 s

1.3.10. NORMAL_OPERATION for 60 s

1.3.11. Note end time of test

1.4. Stop recording and transfer data from CLK to computer

Table 18: Stored data and accuracy of log file acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CLK.AC.01.1	Time exchange can be done in post-processing (real-time synch not required) TMM time should be recorded at least once every hour of operation	UG.CLK.01
UG.CLK.AC.01.2	Record all messages shared via the CxDI and MCI: CxD>>MachineStatus CxD>>MachineCommand Machine>>CxDReply Machine>>CxDdata Time/Date requests and responses Data should at least be stored on change, Message ID changes are not considered to be 'on-change' events	UG.CLK.02
UG.CLK.AC.01.3	The following information must be recorded at all times Operator ID CxD firmware Machine ID and relevant information	UG.CLK.03.1
UG.CLK.AC.01.4	All pedestrians inside the detection area are recorded with a unique ID	UG.CLK.03.2
UG.CLK.AC.01.5	Information to be stored must at least include: CxD Time Pedestrian IDs and positions relative to the TMM Effective warning status Minimum resolution of 10Hz required during interventions	UG.CLK.04
UG.CLK.AC.01.6	Maintenance override status Authorized person ID that activates the maintenance Override	UG.CLK.05
UG.CLK.AC.01.7	The presence of any CxD faults must to be recorded	UG.CLK.06

2. Data transfer

2.1. Note sufficient storage space as per CLK supplier product information sheet

2.2. Initiate data transfer and note time required to transfer log file to computer

2.3. Note:

2.3.1. Size of log file

2.3.2. Data transfer interface

2.3.3. Security measures to prevent log file from being deleted on CLK with a computer

2.3.4. Security measures to prevent log file from being altered on CLK with a computer

2.3.5. Measures in place to ensure that the integrity of the log file will not be compromised with physical damage, electrical discharge or magnetic exposure

Table 19: Data transfer acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CLK.AC.02.1	Reasonable provision made to store up to and including 7 days' worth of data If storage capacity is full before 7 days has passed, fail-to-safe response is triggered	UG.CLK.07.1
UG.CLK.AC.02.2	At least once per week using an easily accessible data transfer mechanism, such as: Wi-Fi, Local Area Network (e.g. Ethernet), Personal Area Network (e.g. Bluetooth), USB / serial, Removable storage;	UG.CLK.08
UG.CLK.AC.02.3	Reasonable steps taken to ensure that data containing sensitive information is protected	UG.CLK.09
UG.CLK.AC.02.4	CLK to provide mechanism to prevent unauthorized data deletion CLK to record ID of authorized person deleting data Reasonably practicable measures must be taken	UG.CLK.11
UG.CLK.AC.02.5	CLK to provide mechanism to prevent alteration of stored data. Reasonably practicable measures must be taken	UG.CLK.12

3. Human-readable tracking data

The UG Detection and Tracking test requires analysis of the CLK logs. This analysis aims to ensure that interactor positional tracking requirements are met during all interventions. To enable this analysis, the CxD OEM must provide a mechanism to extract the following data in a human-readable format: range, direction, interactor ID, and EW status and CPS Stop status (including Normal Operation).

3.1. Request the CxD OEM to convert a regular CLK log file containing relevant position data into a human-readable format with only the required data present.

Table 20: Human-readable tracking data acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CLK.AC.02.1	A mechanism to extract range, direction, interactor ID, and intervention state in a human-readable format must be provided	None (testing requirement)

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 or outcome of the test

Appendix 3: UG CxD Self-Diagnostic Test

Purpose

The CxD Controller (CxDC), CxDI, CLK, Detection and Tracking subsystem (DTS), OWS and PWS subsystems must be able to self-diagnose any reasonably foreseeable failure modes that it may experience. The purpose of this test is to determine how the CxD responds to imposed failure modes. The test evaluates the CxD subsystems against acceptance criteria based on technical requirements in the UG CxD F&TPR Specification.

Preceding tests

1. UG CxD interface test
2. UG CxD Log Keeping test

Test facility/site

Tests are static and can be done in a laboratory environment.

Instrumentation

1. 1x Fully commissioned CxD system
2. 1x TMM Emulator
3. 1x Pedestrian PWS
4. 1x CAN sniffer

Test preparation

1. The client will supply the CxDs in working order. An authorized person (technology provider representative) will submit the signed CxD test information sheet (Appendix 7). CxD has passed all preceding tests as stipulated in the Preceding Tests section. No modifications to any aspect of the CxDs will be allowed once testing has commenced.
2. Connect TMM Emulator to the CxD CAN-harness via the ISO21815 connector
3. Complete negotiation sequence between TMM Emulator and CxD and ensure that CxD is in Normal Operation
4. If any alterations are made to the firmware of the CxDC, CxDI, CLK, DTS or EW during testing, all previous testing becomes invalid, and this protocol has to be followed from the start.

Test method and acceptance criteria

1. Power interruption

Test the system response of the CxD to power interruption by performing the following actions. Treat subsystems as one if contained in a single unit that draws power from a single source

1.1. Record a CAN trace

1.2. Disconnect power supply from each of the following subsystems (if possible)

1.2.1. CxDC

1.2.2. CxDI

1.2.3. CLK

1.2.4. DTS

1.2.5. OWS

1.3. Document subsystem behaviour when disconnected from power

1.4. Reconnect power to subsystem

1.5. Document subsystem behaviour when reconnected to power

1.6. Repeat 3 times

1.7. Expected Behaviour:

1.7.1. ***CxDI Active, Other Subsystem Unpowered:*** If the CxDI remains powered while power is removed from *any other* component (CxDC, CLK, DTS, or OWS), the CxDI should send STAND_DOWN message to the TMM.

1.7.2. **CxDI Unpowered:** If the CxDI is *also* unpowered (along with or instead of another component), the CAN connection will be lost. In this case, the TMM would be expected to FTSWHI

2. PWS power failures

2.1. Document steps taken by CxD supplier to ensure:

2.1.1. PWS batteries are adequately charged before issuing to pedestrians

2.1.2. Safety measures and/or procedures in case of low battery charge detected on PWS

2.1.3. Safety measures and/or procedures in case of battery failure on PWS

Table 21: Power interruption/failure acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CSD.AC.01.1	Be able to monitor the health of all DTS elements. As per supplier FMECA Detection of critical failure leads to FTSWHI response	UG.DT.4.1
UG.CSD.AC.02.1	Off-board elements (such as cap lamps, beacons) must fail to safe without human intervention when critical failure mode is detected. As per supplier FMECA	UG.DT.4.2

3. CAN communication interruption

Test the system response when CxDI to CAN communication is interrupted by performing the following actions:

3.1. Record a CAN trace

3.2. Disconnect CAN communication between CxDI and TMM Emulator

3.3. Document behaviour when communication is disconnected

3.4. Reconnect CAN communication between CxDI and TMM Emulator

3.5. Document behaviour when communication is restored

3.6. Repeat 3 times

3.7. Expected Behaviour:

3.7.1. When CAN connection is lost, the TMM is expected to FTSWHI

3.7.2. When CAN connection is restored the CxD may renegotiate and resume operation *or* remain in a non-negotiated state until a technician has located the source of the connection problem.

Table 22: CAN disconnection acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CSD.AC.03.1	Disconnection between the CxDI and MI should be detected and actioned. Detection within 500ms of disconnection Upon disconnection, CxD may opt to: Stay quiet, FTSWHI needed on TMM Attempt to negotiate again Send STAND_DOWN	UG.CxDI.04

4. CLK storage full

Test the system response when CLK storage full condition is detected by performing the following actions:

4.1. Record a CAN trace
4.2. Induce a CLK full state
4.3. Document behaviour when CLK storage full state is detected
4.4. Clear storage to resolve the CLK full state
4.5. Document behaviour when CLK storage full state is resolved
4.6. Expected Behaviour:
4.6.1. When the storage full fault is detected the CxD should send STAND_DOWN to the TMM.
4.6.2. When the storage full fault is resolved the CxD may resume operation.

5. CLK not recording

Test the system response when CLK not recording condition is detected by performing the following actions:

5.1. Record a CAN trace and perform the following:
5.2. Induce a fault which prevents the CLK from recording
5.3. Document behaviour when CLK not recording is detected
5.4. Remove the fault to allow the CLK to record
5.5. Document behaviour when CLK not recording fault is resolved
5.6. Expected Behaviour:
5.6.1. When the CLK not recording fault is detected the CxD should send STAND_DOWN to the TMM.
5.6.2. When the CLK not recording fault is resolved the CxD may resume operation.

Table 23: CLK FTSWHI acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CSD.AC.04.01	Fail to safe response is automatically triggered if CLK functionality is compromised (e.g. power failure, storage media unplugged) CLK error handling mechanisms (e.g. read/write errors) used to activate fail to safe response	UG.CLK.10

6. CxD elements disconnected

Test the system response when elements vital to safe CxD operation are disconnected by performing the following actions:

6.1. Record a CAN trace
6.2. Disconnect each of the following CxD elements:

6.2.1. OWS Screen
6.2.2. Sensors used for detection and tracking
6.2.3. Maintenance Override switch and or elements
6.2.4. Any other elements that can be disconnected
6.3. Document behaviour when each CxD element is disconnected
6.4. Reconnect element
6.5. Document behaviour when each CxD element is reconnected
6.6. Repeat 3 times
6.7. Expected Behaviour:
6.7.1. When the element disconnection is detected the CxD should send STAND_DOWN to the TMM.
6.7.2. When the element connection is restored the CxD may resume operation.

Table 24: CxD elements disconnected acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CSD.AC.06.1	Be able to monitor the health of all DTS elements. As per supplier FMECA Detection of critical failure leads to FTSWHI response	UG.DT.4.1
UG.CSD.AC.06.2	Upon detection or reporting of any critical CxD failure, the CxD must initiate a fail to safe intervention. Within 500ms from critical failure detection.	UG.CxDC.22.2
UG.CSD.AC.06.3	STAND_DOWN to slow down and stop the TMM in a controlled manner when the CxD experiences a fault (fail to safe response)	UG.CxDI.07.3

7. Time/Date exchange fault

Test the system response when Time/Date cannot be exchanged with the Machine by performing the following actions:

7.1. Record a CAN trace
7.2. Initiate Time/Date exchange procedure between CxD and TMM Emulator
7.3. Initiate Time/Date exchange fault by setting the TMM Emulator to not respond to CxD time requests
7.4. Document behaviour when time request is not replied to
7.5. Restore fault by setting the TMM emulator to respond to CxD time requests
7.6. Document behaviour when time request response is restored
7.7. Repeat 3 times
7.8. Expected Behaviour:
7.8.1. When the Time/Date request is ignored the CxD should send STAND_DOWN to the TMM.
7.8.2. When the Time/Date request is responded to the CxD may resume operation.

Table 25: Time/Date exchange fault acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CSD.AC.07.1	500 ms timeout on Time/Date requests. If no response within 500 ms, CxD FTSWHI	UG.CxDI.12 UG.CxDC.22.2

8. Faults display

This test is used to verify whether the CxD communicates faults clearly and allows for a technician to diagnose faults based only on the screen information.

8.1. Document any message, icons, symbols on the screen communicate faults

8.2. Expected Behaviour:

8.2.1. OWS is used to inform operator that a fault is present

8.2.2. OWS can be used by a technician to diagnose faults

8.2.3. Fault warnings use standardized fault codes and icons where appropriate

Table 26: Fault display acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CSD.AC.08.1	Faults are communicated on the display. Standardized fault codes and icons are used where appropriate. Sufficient information is provided to facilitate quick component replacement.	UG.EW.06.2

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: UG CxD Detection and Tracking Test

Purpose

The Detection and Tracking subsystem (DTS) must be able to sense and differentiate between multiple objects at a distance in a harsh mining environment. The purpose of this test is to determine if the sensor suite implemented by the CxD is effective in detecting and tracking multiple objects in a controlled environment. The system will be evaluated using the CLK logs. The test evaluates the DTS against acceptance criteria based on technical requirements in the UG CxD F&TPR Specification.

Supplemental videos

Videos showing the test methods have been posted to the Minerals Council South Africa's YouTube channel and are available at the following link:

https://youtube.com/playlist?list=PLGYvaoV3Ba6IjugeVqv0xrSN-HB74nsQJ&si=2vm0K9HJoLAsfUGQ

Preceding test

1. ICASA Type Approval OR Spectrum License as applicable (consult with an accredited EMC test laboratory)
2. EMC tests as applicable (consult with an accredited EMC test laboratory)
3. UG CxD Interface Test
4. UG CxD Log Keeping Test
5. UG CxD Self-Diagnostic Test

Test facility/site

The site must be appropriately sized for the test being conducted. Tests are highly dynamic and adequate space for run-up, interaction and run-off is required. The site should have a level, even, hard surface.

Instrumentation

1. 1x Test vehicle with CxD installed (TV1)
2. 1x HP INSS
3. 1x DAQ with ISO/TS 21815-2 interface
4. 1x TMM Emulator
5. 11x PWS units

Test preparation

1. The client will supply the CxDs in working order. An authorized person (technology provider representative) will submit the signed CxD test information sheet (Appendix 7). CxD has passed all preceding tests as stipulated in the Preceding Tests section. No modifications to any aspect of the CxDs will be allowed once testing has commenced.
2. Fence off test area. Ensure all aspects in Safety protocol is adhered to.
3. Install HP INSS on TV1 and ensure good satellite reception is obtained.
4. Ensure all personnel, equipment and all obstacles are removed in front and behind the TVs.

Test method and acceptance criteria

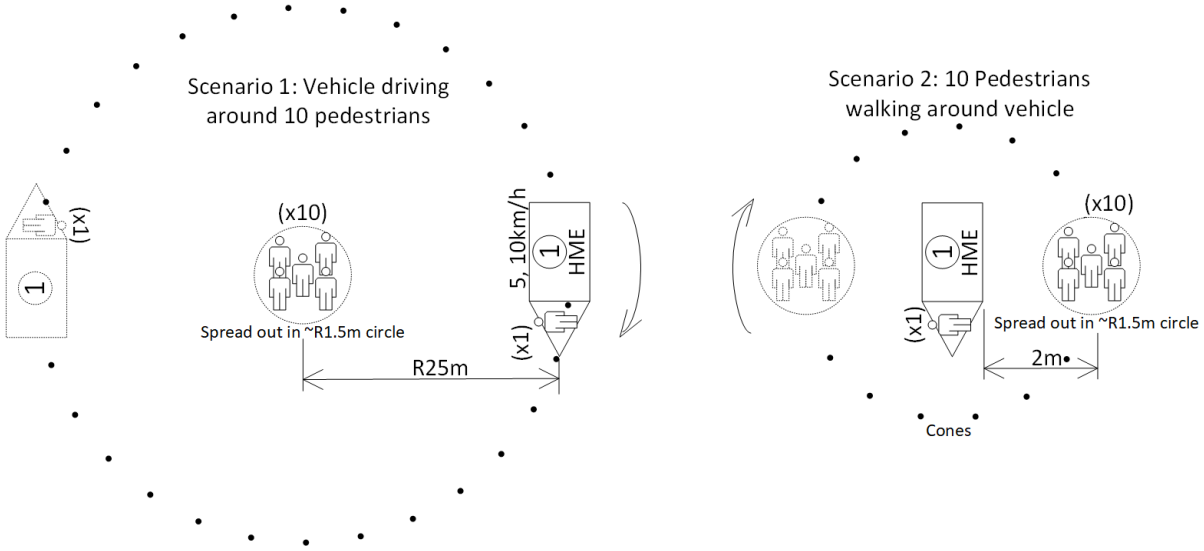

Figure 6: DTS Scenario 1 and 2 test configurations

1. Vehicle driving around ten pedestrians

This test verifies the DTS's ability to track multiple pedestrian PWS units within its detection range while the TV is moving.

1.1. Set up the test area as depicted in the left panel of the figure
1.2. Place 10 pedestrian PWS units in the centre of the test area
1.3. Pedestrian PWS units should be spaced to fit inside an R1.5m circular area to represent a group of pedestrians standing close together
1.4. Pair 1 PWS as an operator inside the machine footprint
1.5. Start recording on TV1
1.6. Drive TV1 drive clockwise around pedestrians in a radius of 25m at speeds of 5 and 10 km/h
1.7. Stop recording when TV1 returns to its start position
1.8. Expected behaviour:
1.8.1. CLK records the position of all 10 PWS units relative to TV1
1.8.2. No dropouts (max 1 s intervals between log entries)
1.8.3. PWS units are tracked constantly while TV1 drives around them
1.8.4. OWS displays the pedestrian location on a map
1.8.5. OWS has no EW and is in Normal Operation
1.9. Repeat 3 times for each speed
1.10. Downloads log from CLK

2. Ten pedestrians walking around the vehicle

This test verifies the DTS's ability to track multiple pedestrian PWS units near the TV.

2.1. Set up the test area as depicted in the right panel of the figure
2.2. Position TV1 in the centre of the test area
2.3. Place 10 pedestrian PWS units 2m from the right of TV1
2.4. PWS units should be spaced to fit inside an R1.5m circular area such that it represents a group of pedestrians standing close together

2.5. Pair 1 PWS as an operator inside machine footprint
2.6. Start recording on TV1
2.7. Have the 10 pedestrian PWS units “walk” clockwise around TV1 while maintaining a distance of 2m from the vehicle
2.8. Stop recording when pedestrian PWS units return to the starting position
2.9. Expected Behaviour:
2.9.1. CLK records the position of all 10 PWS units relative to TV1
2.9.2. No dropouts (max 1 s intervals between log entries)
2.9.3. PWS units are tracked constantly while they move around TV1
2.9.4. OWS displays the pedestrian locations
2.9.5. EW not assessed in this scenario
2.10. Repeat 3 times
2.11. Download logs from CLK

3. Multiple object test

This test verifies the DTS's ability to track multiple pedestrian PWS units at high speed in forward and reverse directions.

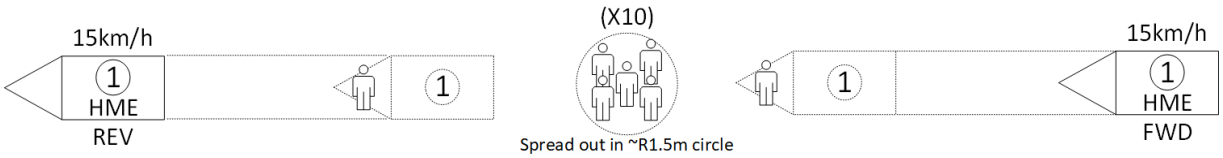

Figure 7: DTS multi object test test configuration

3.1. Place 10 pedestrian PWS in the centre of the test area
3.2. PWS units should be spaced to fit inside an R1.5m circular area such that it represents a group of pedestrians standing close together
3.3. Have TV1 approach the group of pedestrians at 15km/h in both the FWD and REV directions
3.4. Stop TV1 close to the group of pedestrians on each approach
3.5. Expected Behaviour:
3.5.1. CLK records the position of all 10 PWS units relative to itself
3.5.2. No dropouts (max 1 s intervals between log entries)
3.5.3. PWS units are tracked constantly once TV1 is inside the 30m detection range
3.5.4. OWS shows pedestrian locations on display
3.6. Document the maximum distance at which all 10 pedestrians are detected at speed
3.7. Repeat 3 times in each direction
3.8. Download logs from CLK

Table 27 DTS acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.DTS.AC.01.1	Detection of 10 or more pedestrians simultaneously 30 m minimum detection range ±0.5 m or ±10 % range accuracy, whichever is greater	UG.DT.1.1
UG.DTS.AC.01.2	Track 10 pedestrians simultaneously No dropouts (max 1 s intervals between log entries) May not identify one of the pedestrians as a new object (must be the same objects maintained throughout).	UG.DT.2
UG.DTS.AC.01.3	CxD DTS must measure or estimate the distance to any pedestrian within the detection area ±0.5 m or ±10 % range accuracy, whichever is greater	UG.DT.3.1
UG.DTS.AC.01.4	CxD DTS must determine the direction of any pedestrian towards the TMM within the detection area Detection area divided into at least four quadrants Pedestrians detected in correct quadrant at all distances up to 25 m ±15° accuracy when crossing from one quadrant to an adjacent quadrant at 25 m	UG.DT.3.2

4. Pedestrian activated emergency stop

The pedestrian activated emergency stop test evaluates the DTSs' ability to detect the activation of the pedestrian activated emergency stop on the PWS.

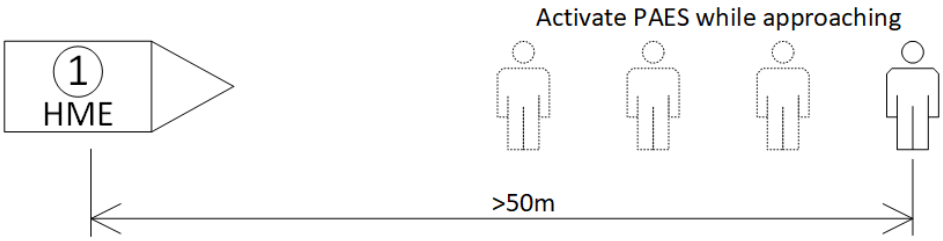

Figure 8: DTS pedestrian activated emergency stop test test configuration

4.1. Position TV1 in the centre of test area

4.2. From a distance of at least 50m, approach TV1 with the pedestrian tag while activating the emergency stop every 2 meters

4.3. Measure distance at which emergency activated stop is actioned on TV1

4.4. Measure the approximate time difference between the activation of the emergency stop and the instant when it is actioned on TV1

4.5. Expected Behaviour:

4.5.1. CLK records the activation of the PAES (position, interactor id)

4.5.2. OWS shows PAES active for duration of event

4.5.3. OWS shows CPS Stop within 1s of PAES activation

4.6. Repeat 3 times

Table 28 PAES DTS acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.DTS.AC.02.1	Pedestrian Activated Emergency Stop detected within 1 s of activation by pedestrian at a distance of 25 m	UG.DT.5

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: UG CxD Effective Warning Test

Purpose

The UG CxD Effective Warning (EW) test focuses on verifying the effectiveness of the Operator Warning Subsystem (OWS) and Pedestrian Warning System (PWS) in UG mining operations. The test evaluates the OWS and PWS against acceptance criteria based on technical requirements in the UG CxD F&TPR Specification.

Supplemental videos

Videos showing the test methods have been posted to the Minerals Council South Africa's YouTube channel and are available at the following link:

https://youtube.com/playlist?list=PLGYvaoV3Ba6LI0OTkEy9UAiYCLpHm3YIz&si=eSzcO-YZzalMW8rI

Preceding tests

1. ICASA Type Approval OR Spectrum License as applicable (consult with an accredited EMC test laboratory)
2. EMC tests as applicable (consult with an accredited EMC test laboratory)
3. UG CxD Interface Test
4. UG CxD Log Keeping Test
5. UG CxD Self-Diagnostic Test
6. UG CxD Detection and Tracking Test

Test facility/site

The site must be appropriately sized for the test being conducted. Tests are highly dynamic and adequate space for run-up, interaction and run-off is required. The site should have a level, even, hard surface.

Instrumentation

1. 1x Test vehicle with CxD installed (TV1)
2. 11x PWS units
3. 1x TMM Emulator
4. 1x HP INSS
5. 2x DAQ with ISO/TS 21815-2 interface
6. 2x Video cameras, each synchronised with a DAQ

Test preparation

1. The client will supply the CxDs in working order. An authorized person (technology provider representative) will submit the signed CxD test information sheet (Appendix 7). CxD has passed all preceding tests as stipulated in the Preceding Tests section. No modifications to any aspect of the CxDs will be allowed once testing has commenced.
2. Fence off test area. Ensure all aspects in Safety protocol are adhered to.
3. Ensure all personnel, equipment and obstacles are removed in front and behind the TV.

4. Install HP INSS on TV1 and ensure good satellite reception is obtained.
5. Synchronise cameras so that footage can be used to evaluate warning timing

Test method and acceptance criteria

1. Warning timing and effectiveness

This test is used to quantify the timing of warnings triggered on the OWS and PWS subsystems by simulating a head on approach. It also assesses the overall warning effectiveness against the defined acceptance criteria.

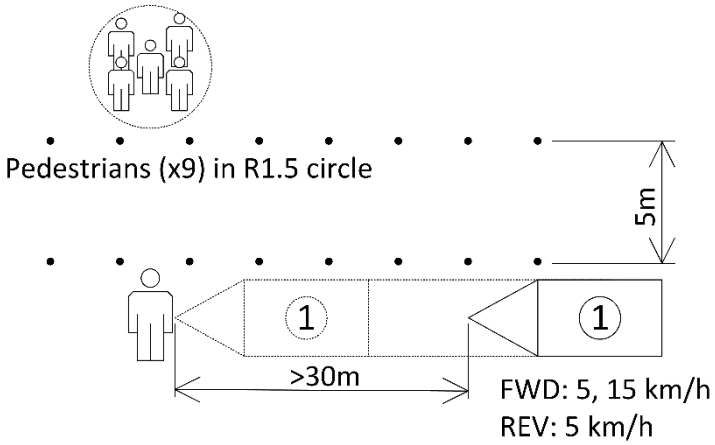

Figure 9: Warning time and effectiveness test configuration

1.1. Set up the test area as depicted in the of the figure
1.2. Place 1 pedestrian PWS in front of TV1 at a distance >30m
1.3. Place 9 pedestrian PWS units (in a R1.5m circle) 5m adjacent to the single pedestrian
1.4. Start recording data on TV1 and pedestrian PWS
1.5. Ensure that the system is in Normal Operation with no EW
1.6. Drive TV1 straight towards the pedestrian at 5km/h to simulate a head-on collision.
1.7. Slow down and stop TV1 allowing a safe stopping distance
1.8. Expected Behaviour:
1.8.1. OWS gives EW 2.5 – 3.0s before entering CPS Stop
1.8.2. OWS uses audible and visual cues to indicate a warning is active
1.8.3. OWS displays the pedestrian locations
1.8.4. OWS indicates pedestrian causing CPS Stop
1.8.5. PWS receives an EW before or at the same time as the OWS
1.8.6. PWS uses audible and visual cues to indicate a warning is active
1.9. Repeat 3 times
1.10. Repeat 1.1 to 1.9 in forward direction at 15 km/h
1.11. Repeat 1.1 to 1.9 in reverse direction at 5 km/h

Table 29: CxD Effective Warning acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.EW.AC.01.1	**EW Timing** PWS warns pedestrian before or simultaneous to the OWS provides 2.5s - 3.0s EW time before automatic slow down and stop intervention	UG.EW.06 UG.CxDC.08.1 UG.CxDC.08.2
UG.EW.AC.01.2	**OWS Audible Warning** A maximum of three audible alarms will be generated per incident. The warning will provide clear verbal instructions, such as "STOP" or "SLOW DOWN". The warning will use programmable language sets, as specified in the mine specifications.	UG.EW.01 UG.EW.04 UG.EW.05 UG.EW.07
UG.EW.AC.01.3	**OWS Visual Warning** A clear warning will be displayed to the operator for the duration of a CPS incident, including any automatic machine slowdown or stop initiated by the system.	UG.EW.01 UG.EW.05
UG.EW.AC.01.4	**OWS Pedestrian Information** The display will indicate the pedestrian with the highest collision priority. The display will show the position of all detected pedestrians relative to the machine. The display will maintain full functionality with up to ten pedestrians within the detection area. The display will only highlight currently relevant information. Information will be communicated using appropriate icons.	UG.EW.02 UG.EW.05 UG.EW.06 UG.EW.06.3 UG.EW.07 UG.CxDC.04
UG.EW.AC.01.5	**OWS Display Characteristics** All CPS display requirements will be integrated into a single display The display will be backlit. The display will have automatic brightness adjustment, bright enough for sunlight viewing and dimmable for low-light conditions.	UG.EW.06 UG.EW.06.1
UG.EW.AC.01.6	**OWS Fault Reporting** Faults will be communicated on the display using standardized fault codes and icons. Sufficient information will be provided to facilitate quick component replacement.	UG.EW.06.2
UG.EW.AC.01.7	**PWS Audible Warning** An audible warning, 3dB above the ambient noise level, will be provided to all pedestrians within the interaction zone.	UG.EW.09.1
UG.EW.AC.01.8	**PWS Visual Warning** A visual warning that may consist of light flashes at varying speeds and colours will be provided to all pedestrians within the interaction zone.	UG.EW.09.2
UG.EW.AC.01.9	**PWS Ergonomics** PWS must not hinder pedestrian movement. PWS must be light enough for a pedestrian to carry for an entire shift.	UG.EW.09.3 UG.EW.09.4

2. Pedestrian activated emergency stop

The pedestrian activated emergency stop test evaluates the CxD's ability to warn the operator of the activation of the pedestrian activated emergency stop on a PWS.

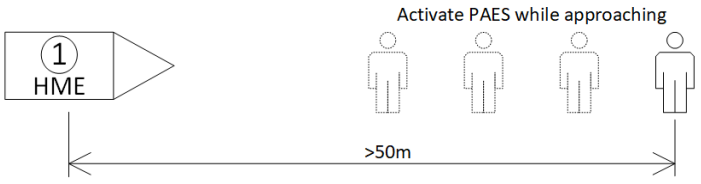

Figure 10: EW pedestrian activated emergency stop test configuration

2.1. Position TV1 in the centre of test area
2.2. From a distance of at least 50m, approach TV1 with the pedestrian PWS while activating the emergency stop every 2 meters
2.3. Expected behaviour:
2.3.1. Pedestrian PWS should indicate that PAES has been activated
2.3.2. OWS in TV1 should warn that PAES has been activated
2.3.3. OWS in TV1 should indicate pedestrian that is causing the intervention
2.3.4. TV1 should be held stationary with INHIBIT_COMMAND
2.3.5. CPS Stop should be actioned on TV1 within 1s of the PAES being activated on the PWS
2.3.6. PAES activation should be detected at a distance >25m
2.4. Repeat 3 times

Table 30: PEAS EW acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.EW.AC.02.1	Activation of a PAES must trigger a distinct visual and audible alarm on the PWS that activated the PAES. PAES should protect against accidental activation	UG.EW.10 UG.EW.11
UG.EW.AC.02.2	PEAS detected within 1s of activation at a distance of 25m	UG.DT.5

3. Speed limit zone warning

The speed limit zone warning test evaluates the effective warning on the OWS when a TMM approaches and enters a speed limited zone.

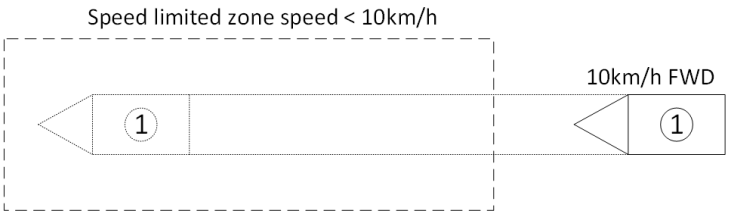

Figure 11: Speed limit zone warning test configuration

3.1. Set up test area as depicted in the figure
3.2. Set up a speed-limited zone with a speed limit <10 km/h
3.3. Record the GPS position of the zone border
3.4. TV1 with paired operator PWS is outside the speed zone

3.5. **Stage 1: Vehicle entering speed limit zone**
3.5.1. Drive TV1 towards the edge of the speed-limited zone at 10km/h
3.5.2. Expected behaviour:
3.5.2.1. TV1 has EW before CPS Slow is actioned
3.5.2.2. Operator PWS has no EW

3.6. **Stage 2: Vehicle below speed limit**
3.6.1. Drive TV1 into the speed-limited zone at or below the speed limit
3.6.2. Expected behaviour:
3.6.2.1. TV1 has speed limit indicated on OWS while in the speed-limited zone
3.6.2.2. Operator PWS has no EW

3.7. **Stage 3: Vehicle above speed limit**

3.7.1. While inside the speed-limited zone increase speed and attempt to exceed the speed limit with TV1

3.7.2. Expected behaviour:

3.7.2.1. TV1 has speed limit indicated on OWS while in the speed-limited zone

3.7.2.2. Operator PWS has no EW

3.8. Repeat all stages in sequence, 3 times

Table 31: Speed limit EW acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.EW.AC.03.1	Operator warned when speed is within 2 km/h of the speed limit Operator to be instructed to slow down if she/he exceeds the speed limit	UG.EW.08

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: UG CxD Controller Test

Purpose

The CxD Controller (CxDC) subsystem is at the heart of the CxD and must be able to decide on the correct action in complex scenarios to prevent collisions in an underground mine. The purpose of this test is to determine if the logic of the CxDC is able to provide effective collision prevention in the 12 defined underground scenarios. The test evaluates the CxDC against acceptance criteria based on technical requirements in the UG CxD F&TPR Specification.

Supplemental videos

Videos showing the test methods have been posted to the Minerals Council South Africa's YouTube channel and are available at the following link:

https://youtube.com/playlist?list=PLGYvaoV3Ba6JvL07NXzdHYWEItSG7yZl-&si=Zp0rNErPXVUHvEe-

Preceding test

1. ICASA Type Approval OR Spectrum License as applicable (consult with an accredited EMC test laboratory)
2. EMC tests as applicable (consult with an accredited EMC test laboratory)
3. UG CxD Interface Test
4. UG CxD Log Keeping Test
5. UG CxD Self-Diagnostic Test
6. UG CxD Effective Warning Test
7. UG CxD Detection and Tracking Test

Test facility/site

The site must be appropriately sized for the test being conducted. Tests are highly dynamic and adequate space for run-up, interaction and run-off is required. The site should have a level, even, hard surface.

Instrumentation

1. 2x test vehicles with CxD installed (TV1 and TV2)
2. 2x brake robots
3. 2x HP INSSs
4. 1x SP GNSS with self-recorder
5. 2x DAQs with ISO/TS 21815-2 interface
6. 12 Pedestrian warning system (PWS) units
7. 1 mannequin onto which PWS is fitted during test

Test preparation

1. The client will supply the CxDs in working order. An authorized person (technology provider representative) will submit the signed CxD test information sheet (Appendix 7). CxD has passed all preceding tests as stipulated in the Preceding Tests section. No modifications to any aspect of the CxDs will be allowed once testing has commenced.
2. Fence off test area. Ensure all aspects in Safety protocol is adhered to.

3. Install HP INSS on bot TVs and ensure good satellite reception is obtained.
4. Connect DAQ to the CxD CAN-harness via the ISO21815 connector.
5. Complete negotiation sequence between CxD and TMM Emulator.
6. Set slowdown and stop decelerations on brake robot to 0.2g and 0.4g respectively.
7. Set machine delay on brake robot to 0.5s.
8. Ensure all personnel, equipment and all obstacles are removed in front and behind the TVs.
9. PWS units not being used must be kept in area where it will not interfere with the test being conducted

Test method and acceptance criteria

For all of the following scenarios the following General CxDC acceptance criteria will apply. These criteria should be read in conjunction with any specific criteria in any of the test procedures in this test protocol

Table 32: General CxDC acceptance criteria,

AC No.	Criteria	Func. Req. No.
UG.CxDC.AC.00.1	2.5s - 3.0s EW time before automatic slow down and stop intervention	UG.CxDC.08.1 UG.CxDC.08.2
UG.CxDC.AC.00.2	2.5m - 3.0m stop gap (shortest distance from TMM to nearest pedestrian) for all UG interaction scenarios Stop gap will depend on correct configuration of CxD to accommodate test vehicle MBS • TMM condition (e.g. brake wear, tyre wear) must be considered when determining the vicinity boundary • TMM specific brake performance to be considered and configured • TMM size and shape (footprint) considered and configured • TMM movements & attachments considered and configured	UG.CxDC.02 UG.CxDC.03 UG.CxDC.05 UG.CxDC.06 UG.CxDC.07
UG.CxDC.AC.00.3	No false interventions and false warnings	UG.CxDC.09
UG.CxDC.AC.00.4	EW and CPS Stop successfully initiated in all cases Intervention strategy must use TMM capability as reported by TMM during ISO21815-2:2021 capability discovery. Intervention strategy to be consistent and repeatable	UG.CxDC.10
UG.CxDC.AC.00.5	No movement of TMM when pedestrian within the vicinity and TMM is stationary Vicinity is determined by readily available TMM information indicating operator's intended action	UG.CxDC.12
UG.CxDC.AC.00.6	CxDC must allow TMM to return to Normal Operation if there is no significant risk of collision as per the mine's standard operating procedure	UG.CxDC.20

1. Operators and Passengers

This test is used to verify the correct functioning of the CxDC during CPS Start-up, operator/passenger pairing, passenger transport, and both expected and unexpected passenger exit scenarios.

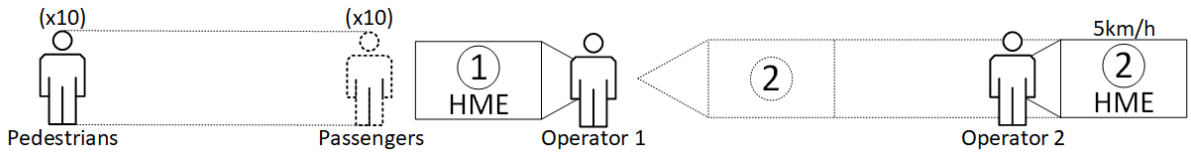

Figure 12: Operators and passengers test configuration

1.1. TV1 is in Safe Park

1.2. TV2 is > 30 m away from TV1 with:

1.2.1. Operator PWS paired in TV2.
1.2.2. Normal Operation (no EW, no CPS Stop)
1.3. **Stage 1: Operator approach**
1.3.1. Place 1 PWS inside TV1 to simulate an unpaired operator
1.3.2. Expected behaviour:
1.3.2.1. OWS inside TV1 has no EW
1.3.2.2. Unpaired PWS has no EW
1.4. **Stage 2: Operator pairing**
1.5. **Cps-start-up**
1.5.1. Pair the Operator PWS as “operator”
1.5.2. Expected behaviour:
1.5.2.1. OWS inside TV1 has no EW and INHIBIT_COMMAND active
1.5.2.2. Operator PWS has no EW
1.6. **Stage 3: Passengers approach**
1.6.1. Ensure TV1 is in Operator Stop
1.6.2. Bring 10 PWS units into the vicinity
1.6.3. Expected behaviour:
1.6.3.1. OWS inside TV1 has no EW, Normal Operation and INHIBIT_COMMAND active
1.6.3.2. Operator PWS has no EW
1.6.3.3. All 10 PWS units have no EW
1.7. **Stage 4: Passengers pairing**
1.7.1. Pair 10 PWS units as “passengers”
1.7.2. Expected behaviour:
1.7.2.1. OWS in TV1 has no EW and Normal Operation active
1.7.2.2. Operator PWS has no EW
1.7.2.3. All 10 passenger PWS units have no EW
1.8. **Stage 5: Vehicle Approaching**
1.8.1. Drive TV2 with into the vicinity at 5km/h
1.8.2. Expected behaviour:
1.8.2.1. OWS in TV1 has no EW and Normal Operation active
1.8.2.2. OWS in TV2 has no EW and Normal Operation active
1.8.2.3. Both operator PWS units have no EW
1.8.2.4. All 10 passenger PWS units have no EW
1.8.3. Drive TV2 out of the vicinity
1.9. **Stage 6: Safe passenger exit**
1.9.1. Ensure TV1 is in Operator Stop
1.9.2. Have a passenger exit TV1 (passenger becomes pedestrian)
1.9.3. Expected behaviour:
1.9.3.1. OWS inside TV1 has no EW, Normal Operation and INHIBIT_COMMAND active
1.9.3.2. Operator PWS has no EW
1.9.3.3. Passenger PWS units have no EW
1.9.3.4. Pedestrian is unpaired
1.9.3.5. Pedestrian PWS has no EW
1.9.4. Engage Normal Operation on TV1
1.9.5. Expected behaviour:

1.9.5.1. OWS inside TV1 has EW and INHIBIT_COMMAND active
1.9.5.2. Pedestrian PWS has EW
1.9.5.3. Operator PWS has no EW
1.9.5.4. Passenger PWS units have no EW
1.9.6. Remove pedestrian PWS from vicinity
1.10. **Stage 7: Unsafe passenger exit**
1.10.1. Engage Normal Operation on TV1
1.10.2. Have a passenger exit TV1 (passenger becomes pedestrian)
1.10.3. Expected behaviour:
1.10.3.1. OWS inside TV1 has EW and CPS Stop active
1.10.3.2. Operator PWS has no EW
1.10.3.3. Passenger PWS units have no EW
1.10.3.4. Pedestrian is unpaired
1.10.3.5. Pedestrian PWS has EW
1.10.4. Remove pedestrian PWS from vicinity
1.11. **Repeat all stages in sequence, 3 times**

Table 33: Operators and Passengers acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDC.AC.00	Conforms to requirements of Table 32	See Table 32 UG.CxDC.11 UG.CxDC.12
UG.CxDC.AC.01.1	No false warnings from operators and pedestrians approaching and entering Safe Parked or Operator Stopped TMM	UG.CxDC.11.1
UG.CxDC.AC.01.2	No false warnings from operators and pedestrians safely inside the TMM	UG.CxDC.11.2
UG.CxDC.AC.01.3	No false warnings Alighting passengers/operator to be visible to TMMs in the vicinity when exiting TMM	UG.CxDC.11.3
UG.CxDC.AC.01.4	Operator assigned unique ID Operator ID logged on CLK Operator training/authorization considered during start-up Interlock preventing unauthorized operation of TMM	UG.CxDC.18.2
UG.CxDC.AC.01.5	Pedestrians assigned unique ID Pedestrian ID logged in CLK when detected	UG.CxDC.18.3
UG.CxDC.AC.01.6	During start-up, the CxD shall prevent movement of the TMM	UG.CxDC.24

2. CxD Maintenance Override

This test is used to verify the correct functioning of the CxDC before and after CxD maintenance override is activated.

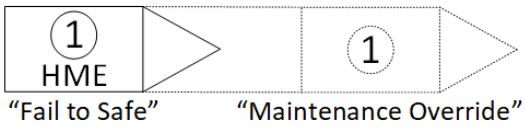

Figure 13: Maintenance override test configuration

2.1. TV1 with paired operator is stationary with Normal Operation active
2.2. **Stage 1: Override inactive**
2.2.1. Induce a failure that will result in FTSWHI on the CxD and STAND_DOWN active
2.2.2. Expected behaviour:

2.2.2.1. OWS inside TV1 has EW and STAND_DOWN active
2.2.2.2. Pedestrian PWS has EW
2.3. **Stage 2: Maintenance override active**
2.3.1. Activate CxD maintenance override on TV1
2.3.2. Expected behaviour:
2.3.2.1. OWS requires authentication to activate override
2.3.2.2. OWS inside TV1 clearly indicates override active
2.3.2.3. CxDC uses BYPASS_PROPULSION to indicate override
2.4. Repeat 3 times

Table 34: Override acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDC.AC.00	Conforms to requirements of Table 32	See Table 32
UG.CxDC.AC.02.1	Credentials required to activate maintenance override Maintenance override implemented as specified in ISO 21815-1:2022	UG.CxDC.21
UG.CxDC.AC.02.2	BYPASS_PROPULSION is used to indicate override	UG.CxDI.07.4

3. Broken-down TMM

This test is used to verify the correct functioning of the CxDC when an employee is working on a disabled vehicle. The pedestrian PWS, simulating the employee, is placed under TV2 and is therefore obscured.

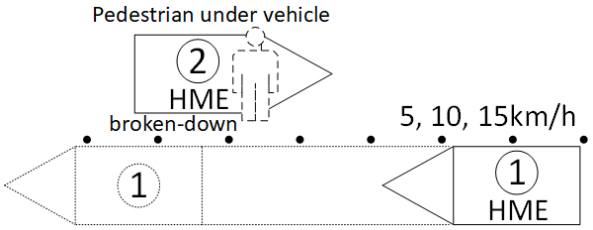

Figure 14: Broken down TMM test configuration

3.1. TV1 with paired operator PWS is outside vicinity in Normal Operation
3.2. TV2 CxD is off or marked as disabled, outside the detection area of the test
3.3. Place pedestrian PWS underneath TV2
3.4. Record GPS coordinates of pedestrian PWS
3.5. Attempt to drive TV1 past the pedestrian PWS at 5, 10 and 15km/h
3.6. Expected behaviour:
3.6.1. TV1 has EW and CPS Stop response for all speeds
3.6.2. TV1 is held stationary after stopping
3.6.3. Stop gap is between 2.5m and 3.0m
3.7. **Repeat 3 times at each speed**

Table 35: Broken down TMM acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDC.AC.00	Conforms to requirements of Table 32	See Table 32 UG.CxDC.14

4. Pedestrian activated emergency stop

This test is used to verify the correct functioning of the CxDC when a pedestrian activates the emergency stop functionality on their PWS.

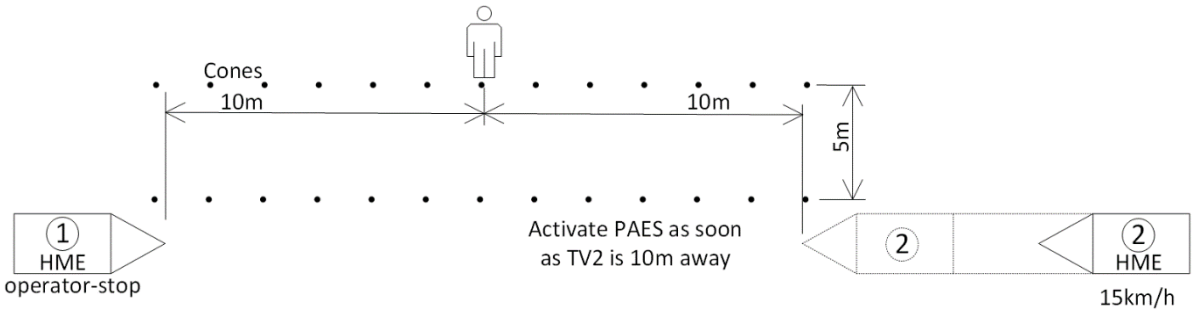

Figure 15: Pedestrian activated emergency stop test configuration

4.1. TV1 with paired operator PWS and Operator Stop active is 10m away from pedestrian PWS
4.2. TV2 with paired operator PWS has enough run-up to reach to 15km/h
4.3. Pedestrian PWS is outside the vicinity of both TVs
4.4. Drive TV2 towards TV1 head-on at 15km/h
4.5. Activate pedestrian activated emergency stop as soon as TV2 is 10m away from pedestrian
4.6. Expected behaviour:
4.6.1. TV1 indicates PAES on OWS
4.6.2. TV1 has INHIBIT_COMMAND active
4.6.3. TV2 has CPS Stop response
4.6.4. TV2 indicates PAES on OWS
4.6.5. TV2 is held stationary after stopping
4.7. Repeat 3 times

Table 36: Pedestrian activated emergency stop acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDC.AC.00	Conforms to requirements of Table 32	See Table 32
UG.CxDC.AC.04.1	All machines in detection area slow down and stop when pedestrian activated emergency stop is activated Response time of less than 1.0s	UG.CxDC.15

5. Congested passing

This test is used to verify the correct functioning of the CxDC when operating close to pedestrians in congested areas.

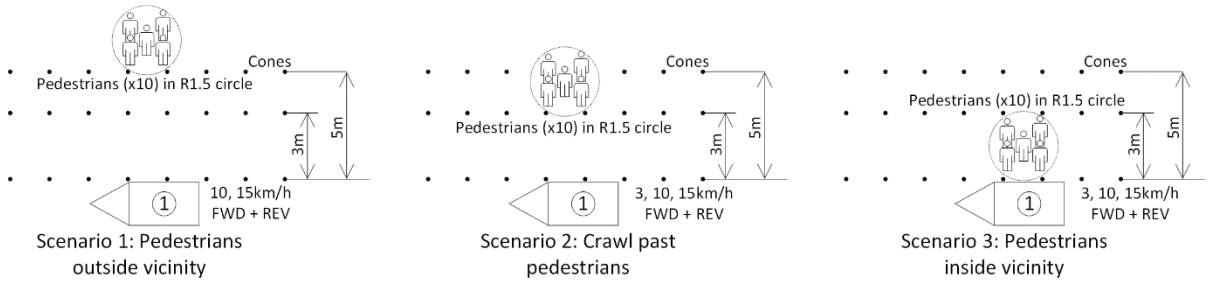

Figure 16: Congested passing test configuration

5.1. Set up test area as depicted in the figure

5.2. TV1 with paired operator is outside vicinity

5.3. **Scenario 1: Pedestrians outside vicinity**

5.3.1. Place 10 pedestrian PWS units outside vicinity (5m from TV1's path) in a R1.5m circle

5.3.2. Record GPS coordinates of closest pedestrian PWS

5.3.3. Have TV1 drive past pedestrians at speeds of 10 and 15km/h

5.3.4. Expected behaviour:

5.3.4.1. TV1 has no warnings and Normal Operation response

5.3.4.2. Pedestrian PWS has no warnings

5.3.5. Repeat scenario 3 times each speed for FWD and REV directions

5.4. **Scenario 2: Crawl past pedestrians**

5.4.1. Place 10 pedestrian PWS units 3m away from TV1's path in a R1.5m circle

5.4.2. Record GPS coordinates of closest pedestrian PWS

5.4.3. Drive TV1 past pedestrians at 3, 10 and 15km/h

5.4.4. Expected behaviour:

5.4.4.1. TV1 can pass pedestrians at 3km/h

5.4.4.2. TV1 has EW and CPS Stop response at 10 and 15km/h

5.4.4.3. TV1 is held stationary after stopping

5.4.4.4. Stop gap is between 2.5m and 3.0m

5.4.4.5. Pedestrian tag has EW at all speeds

5.4.5. Repeat 3 times at each speed for FWD and REV directions

5.5. **Scenario 3: Pedestrians inside vicinity**

5.5.1. Place 10 pedestrian PWS units such that TV1 will pass within the vicinity

5.5.2. Record GPS coordinates of closest pedestrian PWS

5.5.3. Drive TV1 towards pedestrians and attempt to pass at speeds of 3, 10 and 15km/h

5.5.4. Expected behaviour:

5.5.4.1. TV1 has EW and CPS Stop response for all speeds and directions

5.5.4.2. TV1 is held stationary after stopping

5.5.4.3. Stop gap is between 2.5m and 3.0m

5.5.5. Repeat each scenario 3 times at each speed for FWD and REV directions

Table 37: Pedestrian approach and passing acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDC.AC.00	Conforms to requirements of Table 32	See Table 32
UG.CxDC.AC.05.1	Prioritise most likely potential collision of up to 10 pedestrians Prevent collisions in the presence of up to at least 10 pedestrians	UG.EW.02 UG.CxDC.04 UG.CxDC.13.1 UG.CxDC.13.2 UG.CxDC.13.3 UG.CxDC.16.1 UG.CxDC.16.3

6. Speed limits

This test is used to verify the correct functioning of the CxDC when the TMM is driven into a speed-limited zone and when the design speed limit is exceeded.

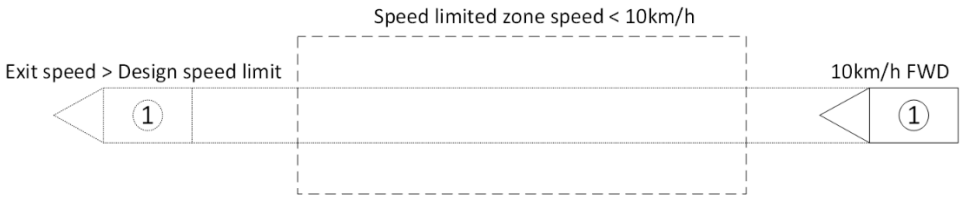

Figure 17: Speed limits test configuration

6.1. Set up the test area as depicted in the figure
6.2. Set up a speed-limited zone with a speed limit <10 km/h
6.3. Record the GPS position of the zone border
6.4. TV1 with paired operator PWS is outside the speed zone
6.5. **Stage 1: Vehicle entering speed limit zone**
6.5.1. Drive TV1 towards the edge of the speed-limited zone at 10km/h
6.5.2. Expected behaviour:
6.5.2.1. TV1 has EW before CPS Slow is actioned
6.5.2.2. TV1 has CPS Slow active before entering the speed-limited zone
6.5.2.3. TV1 reaches speed limit before entering the speed-limited zone
6.5.2.4. Operator PWS has no EW

6.6. **Stage 2: Vehicle driving in zone**
6.6.1. Drive TV1 through the speed-limited zone at or below the speed limit
6.6.2. Expected behaviour:
6.6.2.1. TV1 has speed limit indicated on OWS while in the speed-limited zone
6.6.2.2. Operator PWS has no EW
6.6.2.3. Operator cannot exceed speed limit while in the speed-limited zone

6.7. **Stage 3: Exceed design speed limit**
6.7.1. Drive TV1 away from the speed-limited zone and try to exceed the design speed limit
6.7.2. Expected behaviour:
6.7.2.1. TV1 has EW
6.7.2.2. TV1 has CPS Slow active when operator attempts to exceed design speed limit
6.7.2.3. Operator PWS has no EW

6.8. Repeat all stages in sequence, 3 times

Table 38: Pedestrian approach and passing acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDC.AC.00	Conforms to requirements of Table 32	See Table 32
UG.CxDC.AC.06.1	CxDC must ensure the TMM stays at or below the speed limit while inside speed-limited zone	UG.CxDC.13.1 UG.CxDC.13.2 UG.CxDC.13.3
UG.CxDC.AC.06.2	CxDC must ensure the TMM stays at or below the CPS Design Speed Limit	UG.CxDC.19

7. TMM turning corner towards pedestrian

This test is used to verify the correct functioning of the CxDC when the TMM is driven around a corner towards a pedestrian.

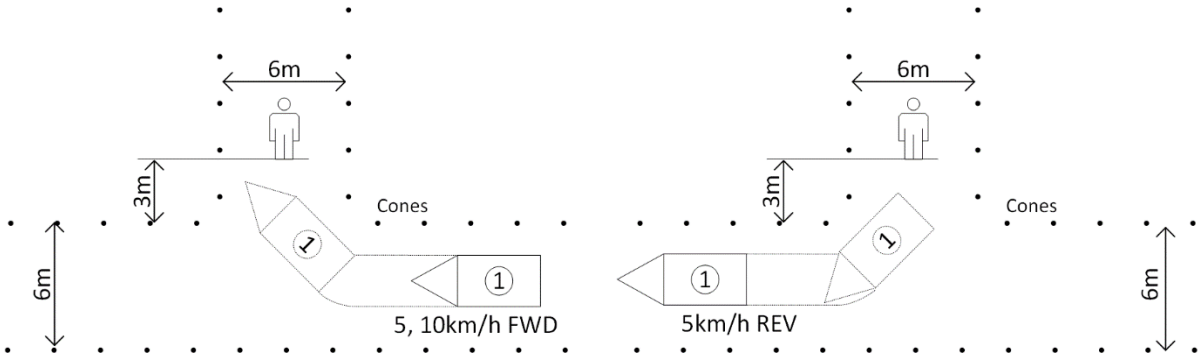

Figure 18: TMM turning towards pedestrian test configuration

7.1. Set up test area to simulate an obscured pedestrian as depicted in the figure

7.2. TV1 with paired operator is positioned outside of vicinity

7.3. Record GPS coordinates of pedestrian

7.4. Drive TV1 straight past the corner and steer towards obscured pedestrian at 5 and 10km/h in FWD and 5km/h in REV

7.5. Expected behaviour:

7.5.1. TV1 has EW and CPS Stop response for all speeds and directions

7.5.2. TV1 is held stationary after stopping

7.5.3. Pedestrian PWS has EW at all speeds and directions when TV1 is in the vicinity

7.6. Repeat scenario 3 times at each speed for FWD and REV directions

Table 39: TMM turning corner towards pedestrian acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDC.AC.00	Conforms to requirements of Table 32	See Table 32 UG.CxDC.16.2 UG.CxDC.16.3

8. Multiple TMMs with Pedestrian

This test is used to verify the correct functioning of the CxDC when a pedestrian is moving in the vicinity of multiple TMMs.

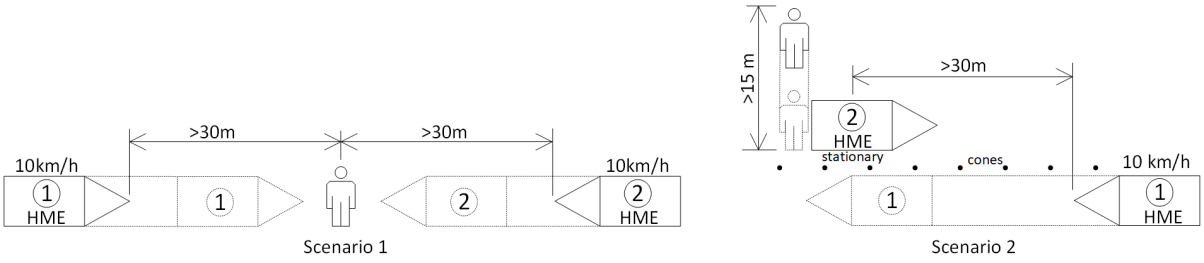

Figure 19: Multiple TMMs with pedestrian test configuration

8.1. **Scenario 1: Approach pedestrian with multiple vehicles**

8.1.1. TV1 with paired operator PWS with Normal Operation active is >30m away from stationary pedestrian

8.1.2. TV2 with paired operator PWS with Normal Operation active is >30m away from stationary pedestrian
8.1.3. Pedestrian PWS is placed in the centre of the test area
8.1.4. Record GPS coordinates of pedestrian PWS
8.1.5. Simultaneously, drive the two TVs towards the pedestrian at 10km/h
8.1.6. Expected behaviour:
8.1.6.1. TV1 has EW and CPS Stop response
8.1.6.2. TV1 is held stationary after stopping
8.1.6.3. TV2 has EW and CPS Stop response
8.1.6.4. TV2 is held stationary after stopping
8.1.6.5. Stop gap is between 2.5m and 3.0m from both TVs to the pedestrian
8.2. **Scenario 2: Obscured pedestrian passing**
8.2.1. TV1 with paired operator PWS is >30m away from TV2 with Normal Operation active
8.2.2. TV2 with paired operator PWS is stationary with Normal Operation active
8.2.3. Pedestrian PWS is worn by a test engineer >15m away from TV2
8.2.4. Record GPS coordinates of pedestrian PWS final position
8.2.5. Instruct pedestrian to approach rear of TV2 at a walking pace
8.2.6. Pedestrian stops when they have reached an obscured position (directly behind TV2)
8.2.7. Attempt to drive TV1 past TV2 and the obscured pedestrian at 10 km/h
8.2.8. Expected behaviour:
8.2.8.1. TV1 has EW and INHIBIT_COMMAND active when pedestrian is in vicinity
8.2.8.2. TV2 has EW and CPS Stop response when attempting to pass obscured pedestrian
8.2.8.3. TV2 is held stationary after stopping
8.2.8.4. Stop gap is between 2.5m and 3.0m from TV1 to the pedestrian

Table 40: Multiple TMMs with pedestrian approaching acceptance criteria

AC No.	Criteria	Func. Req. No.
UG.CxDC.AC.00	Conforms to requirements of Table 32	See Table 32 UG.CxDC.17

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 7: CxD test information sheet

Table 41: CxD product information sheet

Test details	
UG CxD test(s) performed	
Test location	
Test date	
TMM Emulator	
TMM Emulator Hardware	
TMM Emulator Firmware	
Name of test engineer	
Signature	
Signing this test information sheet confirms that the TMM Emulator and all test instrumentation used during the test were properly calibrated and commissioned and integration with the CxD product was checked prior to commencing with the test.	
CxD Details	
CxD Developer / Vendor	
CxD model	
Serial number	
ICASA T/A or Spectrum License? Provide details	
EMC tests passed? Provide details	
CxDC Details	
CxDC Hardware	
CxDC Firmware	
CxDC Other information	
CxDI Details	
Interface Hardware	
Interface Firmware	
ISO21815-2 Version	
ISO21815-2 Negotiation sequence specifics	
CLK Details	
CLK firmware	
Specifics recorded in log file	
CLK storage capacity	
Estimated storage period	
Mechanism to obtain log files	
Security measures to prevent log file deletion and alteration	
EW Details	
OWS Specifics	
PWS Specifics	
DTS Details	
RF operating frequencies	
DTS sensing technologies	

CxD Developer / Vendor Sign-off	
Name of duly authorized CxD developer / vendor representative	
Date	
Signature	
Signing this test information sheet confirms that the CxD product under test was commissioned and tested as per the CxD specification prior to the commencement of the test. Reasonable steps were taken to ensure integration with the TMM 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 8: Test safety protocol have been followed and will be adhered to	

Appendix 8: Test safety protocol

1. 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.

2. Scope

The scope of this document applies to the safety management for all CPS testing performed at 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.

3. 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 issue-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 issue-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.

4. 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 appointees and all those involved in the test on that day.

5. 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.

6. Safety management

In accordance with the MHSA and the 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:

7. Before work begins

The site safety officer shall assess whether the site, task and issue-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 operator 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 condition reporting document and log).

8. 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,
- Hydrocarbon spills that need 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.

9. 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, exit the TMMs, 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.

10. 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, and 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.

11. Communication

Communication during testing will be via the following means:

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

12. 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.

13. 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 must be 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.

14. 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.