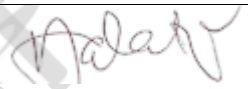
TEST SPECIFICATION FOR COLLISION PREVENTION SYSTEMS

(I.E., WORK PACKAGE 9)

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

REV 4

CPS Test Specification Acceptance			
Name	**Signature**	**Organisation**	**Date**
Kobus Blomerus		**SECDI**	**17 November 2022**
Stanford Malatji		**Minerals Council**	**17 November 2022**

MINERALS COUNCIL SOUTH AFRICA

SECDI SAFETY ENGINEERING COMPETENCY DEVELOPMENT INSTITUTE

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1. Purpose of this document

This document sets out the testing protocols for Stage Gate testing of CPS products so as to ensure minimum safety and commercial risk for mines to investing in such products.

2. Definitions and abbreviations

The following definitions and abbreviations will be used to create a common approach for all deliverables. (Note: The rationale for some of the terms and definitions is set out in the CMS Technical Specification Guideline Review Report).

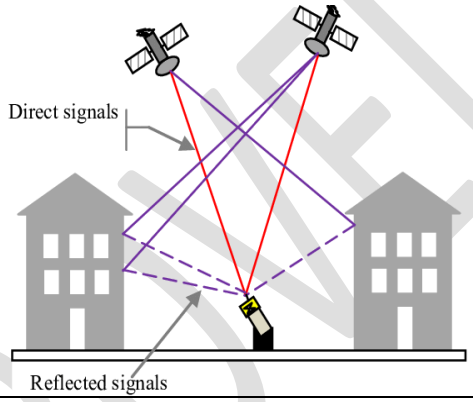
3rd Party	An entity appointed to execute work (testing, witnessing of testing and verifying portfolios of evidence) on behalf of SAMI. Note: The purpose of 3rd party execution is to establish independence and to eliminate duplication.
Accelerated Development	Development of CPS products in a coordinated and integrated way that will require less time (for the entire SAMI need), than the previous individual mine and supplier / OEM driven CPS product development approach.
Accelerated Testing	An initiative to accelerate the testing of CPS solutions with reference to the original test approach and plan.
Accuracy	The degree to which the result of a measurement, calculation, or estimate conforms to the correct value, i.e. the preciseness of the measurement.
C102-F9R	C102-F9R application board Easy evaluation of ZED-F9R with sensor fusion. Application board for ZED-F9R
CMS	Collision Management System: The overall combination of preventative controls, mitigation, recovery and supporting controls, implemented by a mine site to prevent TMM collisions.
Controlled area	Area that is dedicated to testing with no interference from vehicular or pedestrian traffic. Example: Gerotek Test Facilities, section on mine isolated from any mining activity, or demarcated area at a TMM OEM assembly plant.
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.

CWAS/(CxD)	Collision Warning and Avoidance System device (CxD): Device with sensors providing collision warning and avoidance functions, to detect objects in the vicinity of the machine, assess the collision risk level, effectively warn the operator of the presence of object(s) and/or provide signals to the machine control system, to initiate the appropriate interventional collision avoidance action on the machine, to prevent the collision. Note to entry: Proximity Detection System (PDS) is a colloquial industry term for a physical device, providing a warning or collision avoidance functionality.
CxD	Collision warning/detection/management Device.
CxDC	CxD Controller: A sub-system of the CxD, that is typically the computer that contains the decision-making logic.
CxDI	CxD interface: A integration function between the CxD and the Machine Controller.
CxDLK	CxD Log Keeping: The function that receives, and stores CxD data.
D&T	Detect and Track: A functional group of a CxD enabling detection and tracking of TMMs and pedestrians inside the detection area of a surface TMM and an underground TMM respectively.
DAQ	Real time computer with data acquisition and control capabilities. Has ISO21815 interface. Example: DSpace MABX II.
Data scientist	Experienced person in the field of data processing and statistics. This person will analyse data collected during TRL9 pilot site roll-out testing.
Detection	Detection is sensing that an object has entered the detection area.
DMRE	Department of Mineral Resources and Energy.

Driver or operator reaction time (also known as perception response time)	The time that elapses from the instant that the driver recognises the existence of a hazard in the road, to the instant that the driver takes appropriate action, for instance, applying the brakes. The response time can be broken down into four separate components: detection, identification, decision and response. When a person responds to something s/he hears, sees, or feels, the total reaction time can be broken down into a sequence of components namely: • Mental processing time (sensation, perception / recognition, situational awareness, response selection and programming). • Movement time, and • Driver response time. Driver reaction time is also affected by several issues such as visibility, operator state of mind (fatigue), and direction or position of perceived danger.
EAV	Exposure Action Value
ELV	Exposure Limit Value
Element Provider	The organisation that provides one or more of the functional elements of either the CxD or the TMM CPS product.
EM engineer	Qualified person (BEng, BTech) in the EMC environment, with extensive experience in EMI/EMC testing.
EMC	Electromagnetic Compatibility
EMESRT	Earth Moving Equipment Safety Round Table
EMI	Electromagnetic Interference
Employee	Employee means any person who is employed or working at a mine.
EW (Surface)	Effective Warning: For surface TMMs: The expected outcome of the operator action is that the potential collision is prevented, therefore an effective warning must inform the operators of both TMMs what the appropriate action(s) are, to prevent the potential collision.
EW (Underground)	Effective Warning: For Underground TMMs: The expected outcome of the operator and pedestrian action is that the potential collision is prevented. Therefore, an effective warning must inform the operators of TMMs what the appropriate action(s) are to prevent the potential collision and must alert the pedestrian to potential collisions, or interactions with TMMs in the vicinity.
F	Function: Indicates a function of the CPS or functional group.
F&TPR	Functional and Technical Performance Requirements
FMECA	Failure Mode Effect and Criticality Analysis
FTS	Fail to Safe: The functionality that will bring a TMM to a controlled stop

Functional Specification	Specifications that define the function, duty, or role of the product/system. Functional specifications define the task or desired result, by focusing on what is to be achieved, rather than how it is to be done.
G	General: Indicates a general requirement that is applicable to the entire CPS and all of it elements, modules, and components.
High Risk Running Period	A period when a mine change over from one brand or model of cap lamp to another. The changeover cannot be done in one shift. The period of changeover is considered to be a High-Risk Running Period.
Homologation	Homologation means to sanction or "allow." Homologation refers to the process taken to certify that a TMM fitted with a CPS is manufactured, certified, and tested to meet the standards specified for critical safety related devices fitted to TMMs.
HP GNSS	High Precision Global 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.
ICASA	*Independent Communications Authority of South Africa*
ICMM	International Council on Mining and Metals.
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ID	Identifier.
Independent	Separate from the CPS product developer. Note: Independent does not imply an accredited 3rd party, although where required by local or international standards, it includes accredited 3rd parties.
Independent person	A person, typically a test-, software- or EM engineer, who is not affiliated with the CPS provider or TMM OEM, that can provide an unbiased assessment.
Integrated Testing Regime	A holistic method of testing, optimising existing testing facilities that are currently available irrespective of who owns them. This method ensures specific CPS tests are only done once (CxD and TMM CPS Product combinations) and verification is done as early as possible in the development process.

Interface	A boundary across which two independent systems meet and act on or communicate with each other. Four 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. 3. V2X interface – the interface between different CxD devices. V2X is a catch-all term for vehicle-to-everything. It may refer to vehicle-to-vehicle (V-V), vehicle-to-pedestrian (V-P), or vehicle-to-infrastructure (V-E). 4. CxD-peripheral interface – This is an interface between the CxD and other peripheral systems that may be present on the TMM. Examples include a fleet management system, machine condition monitoring system, or fatigue management system. Note: An interface implies that two separate parties (independent systems), are interacting with each other, which may present interoperability and/or EMI and EMC challenges.
LO	Local Object: Denotes the TMM that is detecting other TMMs (S) or pedestrians (P)
Localization	Localization is measuring the position of the object within the detection area; it provides the local object with a map of the remote objects within the environment.
Loss of control	The uncontrolled movement of a TMM due to operator, machine, or environmental reasons. Note: Section 8.10.3 of MHS Act. Loss of control may result in several scenarios: • Machine failure – park brake, or service brake, or tyre blowout. • Operator disabled – fatigue, medical condition, inattention, distraction, or non-compliance with TMP rules (e.g., over speeding on decline, or overloading)
MBS	Machine Braking System: The physical components that makes an unintelligent TMM intelligent and enables the CPS auto slow-down and stop functionality.
MC	Machine Controller.
MCI	Machine Control Interface: The interface between the Machine Controller and the CXD interface.
MHS Act	Mine Health and Safety Act No. 29 of 1996 and Regulations.
MHSC	Mine Health and Safety Council.
Minerals Council	Minerals Council South Africa.

MLK	Machine Log Keeping: The function that receives, and stores TMM CPS data.
MOSH	Mining Industry Occupational Safety and Health.
MRAC	Mining Regulations Advisory Committee.
MRL	Manufacturing Readiness Level. A manufacturing maturity level within a manufacturing readiness framework.
MS	Machine Sensing: Sensing functionality on a TMM that enable a fully functional CPS.
MSDS	Material Safety Data Sheet
Multipath	Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths, typically some direct signals, but also some reflected signals. 
OWS	Operator Warning System: The system that provides the effective warning and other warnings to the operator of a TMM.
PDS	Proximity Detection System – see CxD.
Pedestrian	A person lying, sitting, or walking rather than travelling in a vehicle.
Project	Industry Alignment on TMM Collision Management Systems Project: CAS READINESS PHASE.
PWS	Pedestrian warning System: The system that provides the effective warning to pedestrians.
Quality Assurance	Verifying a process, product, or service; usually conducted by an experienced person in the specific field.
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. © 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.

Reliability (sensor)	Sensor reliability refers to the consistency of a measure. Achieving the same result by using the same methods under the same circumstances, is considered a reliable measurement.
RO	Remote Object: Denotes TMM(s) (S) or pedestrian(s) (U) being detected by the LO.
Robustness (sensor)	Sensor robustness is the ability of the sensing device (sensor), to remain functional in the presence of normal operating conditions of TMMs on a mine, such as electromagnetic interference, mechanical vibration, dust, adverse weather conditions, etc.
S	Surface: Indicating that a specific aspect is applicable to surface TMMs/operations.
Safe Park	A way that a TMM is parked, namely: Machine static, engine switched of and park brake applied.
Safe speed	The speed that will ensure the controlled stopping of a TMM without any immediate negative impact on the operator or machine. Note: This is a conditional variable value, depending on multiple input variables.
SAMI	South African Mining Industry.
Sensor fusion	Sensor fusion is the process of combining sensory data, or data derived from disparate sources, such that the resulting information has less uncertainty than when the sources were to be used individually.
SHERQ	Safety Health Environment Risk and Quality
Significant risk (of collision)	The reasonable possibility of a TMM collision, given all the controls that a mine has put in place to prevent a TMM collision.
Slow down	ISO/TS 21815-2: 2021 defines slow down as: "The SLOW-DOWN action is sent by the CxD to reduce the speed of the machine in a controlled / conventional manner, as defined by the machine control system. The intent of this command is to slow down the machine when the CxD logic determines that a collision / interaction can be avoided by reducing speed".
SME	Surface Mobile Equipment (Surface TMMs)
Software engineer	Qualified person in the communications/computer environment, with extensive experience in ISO 21815 – 2:2021 programming and testing.
SP GNSS with self-recorder	Standard Precision Global Navigation Satellite System: A system that is capable of measuring position with an accuracy of 1.5m, with an update rate of 10Hz. Can also store its own data. Example: UBlox C102-F9R.
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.

Stop	ISO/TS 21815-2: 2021 provides for two definitions, an emergency stop, and a controlled stop, both of which are a 'Stop'. The definitions are: 1. "The EMERGENCY-STOP action is sent by CxD to instruct the machine to implement the emergency stop sequence defined by the machine control system. The intent of this command is to stop the machine motion as rapidly as possible, to reduce the consequence level, if the CxD logic determines that a collision is imminent. The equivalent of an emergency stop is the operator slamming on the brakes in an emergency." 2. "The CONTROLLED-STOP action is sent by CxD to instruct the machine to implement the controlled stop sequence, defined by the machine control system." The intent of this command is to stop the machine motion in a controlled / conventional manner, when the CxD logic determines that a collision / interaction can be avoided by slowing down and stopping. The equivalent of a controlled stop is slowing down and stopping when approaching a red traffic light.
System	A combination of interacting elements organized to achieve one or more stated purposes (ISO/IEC/IEEE 2015).
T	Technical: Indicates a technical requirement of the CPS or functional group.
Technical specification	Specifications that define the technical and physical characteristics and/or measurements of a product, such as physical aspects (e.g. dimensions, colour, and surface finish), design details, material properties, energy requirements, processes, maintenance requirements and operational requirements.
Technician	Competent person with testing experience in the mining / vehicle environment, e.g. testing technician, TMM OEM technician, CxD technician, auto electrician, etc.
Test engineer	Experienced person in the engineering/mining environment with extensive experience in CPS testing.
This document	CPS Accelerated Test Plan
TMLP	Traffic Management Leading Practice: The MOSH Traffic Management Leading Practice for Open Cast/Cut mines in South Africa.
TMM	Trackless Mobile Machine. (Machine, vehicle, etc.)
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 CPS Product Provider	The TMM OEM or organisation approved by the TMM OEM to provide the TMM CPS products

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).
TMP	Traffic Management Plan: A document that defines the traffic management system that a mine employs to ensure the safe movement of TMMs and pedestrians on the mine.
Tracking	Tracking is the monitoring of the progress of the objects in the detection area over time.
TRL	Technology Readiness Level: A technology maturity framework for measuring and monitoring technology maturity in 9 increasing levels from TRL 1 to TRL 9.
U/UG	Underground: Indicating that a specific aspect is applicable to underground TMMs/operations.
UTC	Coordinated Universal Time.
V2X	Vehicle to anything.
V2XIF	Vehicle to anything interface
Vicinity (Surface TMMs) Vicinity (Underground TMM and pedestrians)	The distance/time of two TMMs from the point of a potential collision, such that, if the operators of both machines are instructed to take action to prevent a potential collision, and one or both does not act, then the CPS will be able to prevent the potential collision. Note: Vicinity is a conditional, variable value, depending on multiple input variables. It is smaller than any value that is within the range of normal operation. The distance/time of a TMM from a pedestrian, such that, if the operator of the TMM and the pedestrian do not take action to prevent a potential collision, an emergency slow down and stopping of the TMM can be successfully executed, to prevent a potential collision between the TMM and the pedestrian. Note: Vicinity is a conditional, variable value, depending on multiple input variables. It is smaller than any value that is within the range of normal operation.
V-E	Vehicle to environment.
V-P	Vehicle to pedestrian.
V-V	Vehicle to vehicle.
Walking speed	In the absence of significant external factors, the average human's walking speed is 1.4meters per second. This is included to help define the crawl speed of vehicles.
WP 8	Work Package 8 CAS Readiness Criteria One of the work packages of the Industry Alignment on TMM Collision Management Systems Project: CPS READINESS PHASE
WP 9	Work Package 9: Testing protocols (including legacy equipment). One of the work packages of the Industry Alignment on TMM Collision Management Systems Project: CAS READINESS PHASE.

3. Context of this document

This document is part of the deliverable for Work package 9: Test Protocols, of the Industry Alignment on TMM Regulations Collision Management Systems Special Project of The Minerals Council South Africa: CPS TECHNOLOGY READINESS PHASE work.

4. Background

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

The Industry Alignment on TMM Collision Management Systems Special Project of The Minerals Council South Africa was initiated to facilitate the accelerated development of CPS products.

As a safety system that ultimately takes away the control of a TMM from an operator, specific functional requirements were developed in order to minimise the potential safety and production disruption emanating from the introduction of CPS products to the entire mining industry.

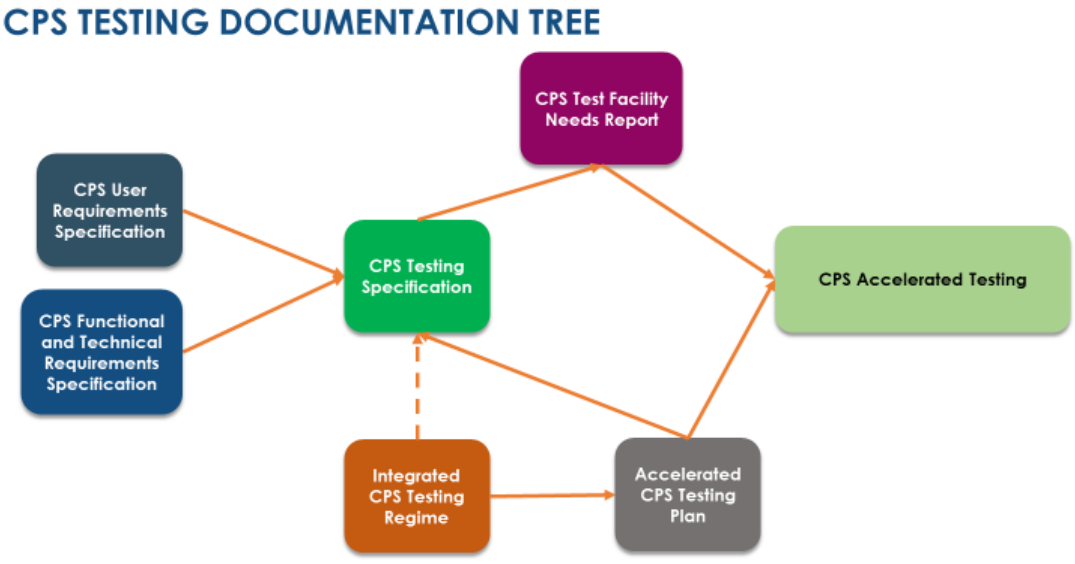


Figure1: CPS Testing Related Documentation

Since it is impractical and too costly for every mine to test its CPS products, an integrated CPS Testing Regime has been developed, see (INTEGRATED COLLISION PREVENTION SYSTEMS TESTING REGIME). Subsequent to the testing regime an Accelerated Testing Plan was developed, see (ACCELERATED TESTING PLAN FOR COLLISION PREVENTION SYSTEMS) with a view to reduce the overall industry wide cost and duration for CPS product testing.

This specification must therefore be read in conjunction with the latest revisions of the ACCELERATED TESTING PLAN FOR COLLISION PREVENTION and the INTEGRATED COLLISION PREVENTION SYSTEMS TESTING REGIME.

5. The Integrated CPS Testing Regime

The integrated testing regime for CPS products is shown in figure 2. The testing regime is built on the technology maturity levels as is defined in the FUNCTIONAL READINESS CRITERIA FOR COLLISION PREVENTION SYSTEMS DEVELOPMENT document. The application of a formal technology readiness framework with applicable readiness criteria is necessitated by both the nature of the challenge to introduce CPS products -by regulation - into the entire SAMI, as well as the implications of functional failure once already introduced into the whole industry.

As mentioned in the background, it is impractical for every mine in the SAMI to test its CPS products. Given the number of CPS products, based on the combination of a specific TMM and CPS, this will take years and cost the SAMI an order of magnitude more than the current approach when the opportunity cost of using production TMMs to do on mine testing is considered. The integrated testing regime is therefore based on Stage Gate testing being done by an independent 3rd Party that will certify that a specific CPS or its elements have demonstrated conformance to the functional requirements for a CPS as it matures through the product development stages.

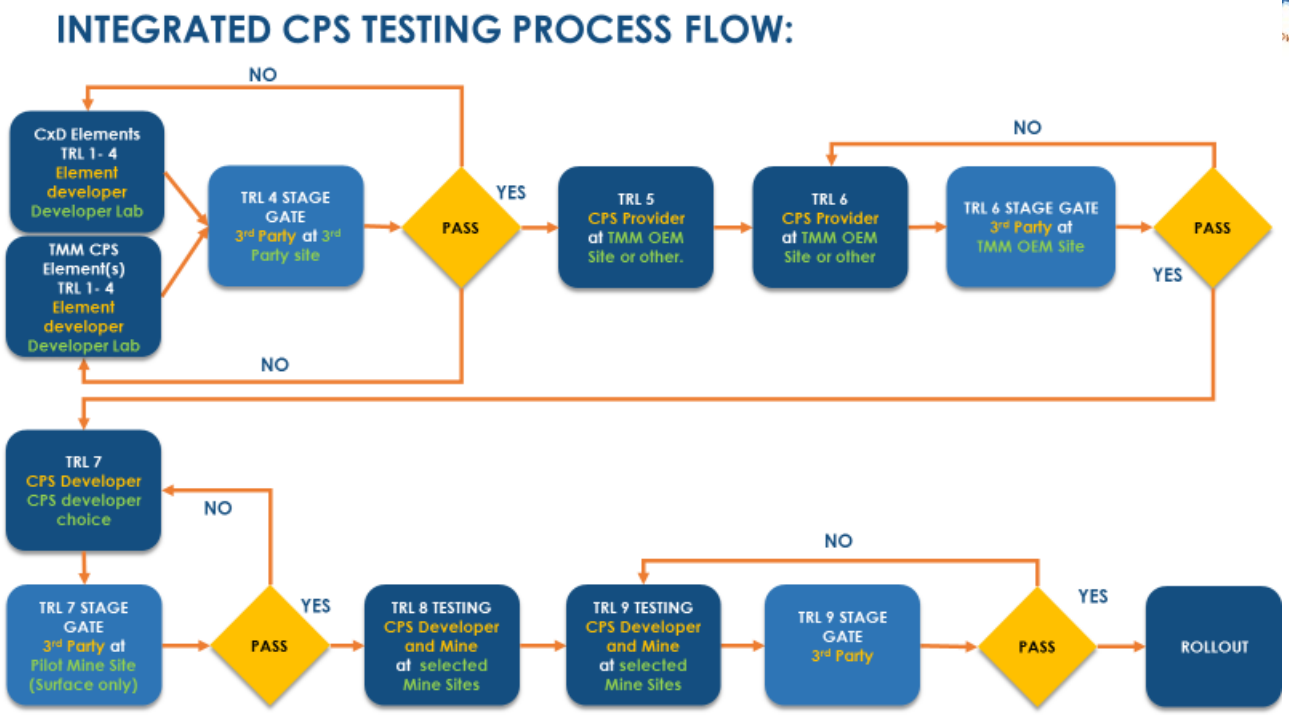


Figure 2: The Integrated CPS Testing Process Flow.

It must be noted that the concept of independent Stage Gate testing assumes that the CxD, TMM CPS provider and/or the CPS developer demonstrates compliance to the functional readiness criteria as documented in FUNCTIONAL READINESS CRITERIA FOR COLLISION PREVENTION SYSTEMS DEVELOPMENT document. As such it can be expected that CPS developers will find the Stage Gate test protocols defined in this specification very useful to know exactly how their system(s) or element(s) will be tested. The protocols will further assist CPS developers to design and execute their own development tests to demonstrate conformance before certifying readiness for a specific Stage Gate test.

6. Stage Gate Test Readiness

It is acknowledged that CPS developers and/or element providers have performed functional tests over the past few years. 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 element provider to demonstrate conformance to the CPS functional requirements. A CPS developer or any of its element providers can certify readiness at any given TRL 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 element provider certify its CPS product(s) or element(s) for a specific Stage Gate, it must demonstrate conformance to the readiness criteria of all prior Stage Gates if applicable.

Independent 3rd Party Stage Gate testing is primarily done for the benefit of the mines. The accelerated testing plan provides for a single iteration of testing at every Stage Gate for a specific CPS or CPS element. Failing a Stage Gate test will require a CPS developer or element provider to join the back of the queue (for that Stage Gate) and the cost for re-testing will have to be borne by the CPS developer and/or the element provider respectively, as per their own agreement.

7. Test Specification Structure

In support of the accelerated test plan the Test Specification is structured such that functional groups/modules can be tested as early as possible in the testing process. This ensures that testing bottlenecks can be avoided. Each Test Protocol is documented in a separate Appendix of this Specification. This enables a practical way to use the specification.

8. Test Protocols

The CPS Stage Gate test protocols are documented in Appendix 1 to 24 and a general test site safety procedure is documented in Appendix 25. The general safety procedure is provided to ensure that all Stage Gate tests are conducted without risk to any attendants or participants to the testing. This procedure must be used as a basis for the development of test and test site specific safety procedures by the 3rd Party testing organisation.

9. TRL 4 Tests

TMM CPS Tests

Appendix 1: TRL 4 TMM ISO 21815 Interface Test

TRL4 Stage Gate: TMM ISO21815 Bench Test:
Machine ISO/TS 21815-2:2021 test protocol (MCI)

1. Purpose

The MCI subsystem must be able to communicate with the CxD using the standard as defined in ISO/TS 21815-2:2021. The purpose of this test is to determine if the MCI is compliant with the standard. It is expected that the CxDI can adapt to the capabilities of the MCI.

2. Preceding tests

None

3. Test facility/site

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

4. Instrumentation

- **4.1.** 1x CxD Emulator
- **4.2.** 1x DAQ with ISO/TS 21815-2 interface
- **4.3.** Power supply that can supply voltage as required by DAQ
- **4.4.** Multimeter

5. Test preparation

- **5.1.** MCI to be provided in working condition to the test team. Responsible person to sign-off that MCI is in working condition as designed.
- **5.2.** Get filled out specification sheet from MCI supplier stating which capabilities and data messages are available (see appendix A)
- **5.3.** Connect CxD Emulator and data acquisitioning system to MCI CAN-bus via the ISO21815 connector
- **5.4.** Connect DAQ to CAN-bus on MCI side of connector
- **5.5.** CxD Emulator to be powered by MCI via standardised ISO/TS21815-2 connector
- **5.6.** MCI must be able to supply data to the CxD Emulator (e.g. a computer may be logged into the MCI to send data as required)
- **5.7.** If any alterations are made to any aspect of the MCI during testing (e.g. firmware, rewiring of connector, etc.), all previous testing becomes invalid and this protocol has to be followed from the start

6. Test method

- **6.1.** Note MCI firmware versions
- **6.2.** Connector
  - **6.2.1.** Note if the Deutsch DT-Series 12-pin plug (female) part is used as in 6.2 of the ISO standard
  - **6.2.2.** Verify pin assignment as specified in 6.2 of the ISO/TS 21815-2
  - **6.2.3.** If override is connected on Machine side of the connector, note:
    - **6.2.3.1.** pin assignment as in 6.2 of the ISO standard
    - **6.2.3.2.** logic as in 6.4 of the ISO standard

6.3. Negotiation sequence

6.3.1. If negotiation can be done without the use of trust mechanisms, initiate the negotiation sequence on the CxD Emulator and note:

6.3.1.1. NEGOTIATE_NOP on CxD>>MachineStatus message, Message ID and Time stamp

6.3.1.2. NEGOTIATE_ACK on Machine>>CxDReply message, Message ID and Time stamp

6.3.1.3. PROTOCOL_NOP on CxD>>MachineStatus message, Message ID and Time stamp

6.3.1.4. PROTOCOL_ACK on Machine>>CxDReply message, Message ID and Time stamp

6.3.2. If negotiation cannot be done without the use of trust mechanisms, note it as such and have OEM provide a solution to enable negotiation between MCI and CxD Emulator

6.3.3. After negotiation has been established between CxD Emulator and MCI, note:

6.3.3.1. Average and standard deviation of time delay between repeating PROTOCOL_NOP and PROTOCOL_ACK messages. At least one Message ID counter cycle has to be evaluated.

6.3.3.2. Any messages on CxD>>MachineStatus that does not receive a reply. At least one Message ID counter cycle has to be evaluated.

6.4. Re-negotiation

6.4.1. Initiate the negotiation sequence on the CxD Emulator and confirm repeating PROTOCOL_NOP and PROTOCOL_ACK messages

6.4.2. Sever the connection between CxD Emulator and MCI while maintaining connection between data acquisitioning system and MCI and note:

6.4.2.1. Time delay between last PROTOCOL_NOP and last PROTOCOL_ACK messages

6.4.2.2. Absence of any PROTOCOL_ACK messages on CAN-bus

6.4.3. Restore the connection between CxD Emulator and MCI and note:

6.4.3.1. negotiation sequence as before

6.4.3.2. Time delay between reconnection and completed re-negotiation

6.5. Capability enquiry

6.5.1. Initiate MCAPS propulsion register capability enquiry on CxD>>MachineStatus message and note on Machine>>CxDreply message

6.5.1.1. PROPULSION_ACK

6.5.1.2. Register Value_0

6.5.2. Initiate individual capability enquiries on the CxD>>MachineCommand message and note the response on the Machine>>CxDreply message to the following enquiries

6.5.2.1. EMERGENCY_STOP_CONFIRM

6.5.2.2. CONTROLLED_STOP_CONFIRM

6.5.2.3. SLOW_DOWN_CONFIRM
6.5.2.4. STAND_DOWN_CONFIRM
6.5.2.5. BYPASS_PROPULSION_CONFIRM
6.5.2.6. APPLY_PROPULSION_SETPOINTS_CONFIRM

6.5.3. Confirm reply to each x_CONFIRM enquires are either x_CONFIRM_ACK or ENQUIRY_ERROR

6.5.4. Note average and standard deviation of the time delay between all enquiry and reply messages

6.6. Reading protocol registers

6.6.1. Initiate GET_PROTOCOL_REGISTER enquiry on the CxD>>MachineStatus message and note response on the Machine>>CxDreply message to the following register indexes

6.6.1.1. PROTOCOL_REVISION
6.6.1.2. REGISTER_COUNT
6.6.1.3. SUBSYSTEM_MCAPS
6.6.1.4. INTERFACE_STATE
6.6.1.5. NEGOTIATION_SEED
6.6.1.6. NEGOTIATION_KEY
6.6.1.7. MACHINE_SOFTWARE_REVISION
6.6.1.8. MACHINE_ID_0
6.6.1.9. MACHINE_ID_1
6.6.1.10. MACHINE_ID_2
6.6.1.11. MACHINE_ID_3
6.6.1.12. MACHINE_ID_4
6.6.1.13. INSTRUCTION_TIMEOUT
6.6.1.14. NEGOTIATION_TIMEOUT
6.6.1.15. RENEGOTIATION_TIMEOUT

6.6.2. For each reply on Machine>>CxDreply message, note

6.6.2.1. GET_REGISTER_OK
6.6.2.2. Correct register index
6.6.2.3. Correct REG_FORMAT
6.6.2.4. How register values 0 – 3 compares to specification sheet (Appendix A)

6.6.3. Note average and standard deviation of the time delay between all enquiry and reply messages

6.7. Reading propulsion registers

6.7.1. Initiate GET_PROPULSION_REGISTER enquiry on the CxD>>MachineStatus message and note response on the Machine>>CxDreply message to the following register indexes

6.7.1.1. PROPULSION_MCAPS
6.7.1.2. MIN_BRAKING
6.7.1.3. MAX_THROTTLE
6.7.1.4. MAX_SPEED

6.7.1.5. EMERGENCY_STOP_MAX_SPEED
6.7.1.6. CONTROLLED_STOP_MAX_SPEED
6.7.1.7. SLOW_DOWN_MAX_SPEED
6.7.1.8. MAX_FORWARD_GEAR
6.7.1.9. MAX_REVERSE_GEAR

6.7.2. For each reply on Machine>>CxDreply message, note
6.7.2.1. PROPULSION_ACK
6.7.2.2. Correct register index
6.7.2.3. Correct REG_FORMAT
6.7.2.4. How register values 0 – 3 compares to specification sheet (Appendix A)

6.7.3. Note average and standard deviation of the time delay between all enquiry and reply messages

6.8. Setting and reading protocol registers

6.8.1. Initiate SET_PROTOCOL_REGISTER action on CxD>>MachineStatus message with new values other than those in specification sheet (Appendix A)

6.8.2. Note response on the Machine>>CxDreply message to the following register indexes
6.8.2.1. PROTOCOL_REVISION
6.8.2.2. CxD_SOFTWARE_REVISION
6.8.2.3. CxD_HARDWARE_REVISION
6.8.2.4. CxD_HARDWARE_ID

6.8.3. For each reply on Machine>>CxDreply message, note
6.8.3.1. SET_REGISTER_OK
6.8.3.2. Correct register index
6.8.3.3. Correct REG_FORMAT
6.8.3.4. How register values 0 – 3 compares to specification sheet

6.8.4. Initiate GET_PROTOCOL_REGISTER enquiry on CxD>>MachineStatus message and note response on the Machine>>CxDreply message to the following register indexes
6.8.4.1. PROTOCOL_REVISION
6.8.4.2. CxD_SOFTWARE_REVISION
6.8.4.3. CxD_HARDWARE_REVISION
6.8.4.4. CxD_HARDWARE_ID

6.8.5. For each reply on Machine>>CxDreply message, note
6.8.5.1. GET_REGISTER_OK
6.8.5.2. How register values 0 – 3 compares to new values

6.9. Reset of registers

6.9.1. Initiate RESET_REGISTERS action on CxD>>MachineStatus message and note RESET_REGISTERS_OKAY on the Machine>>CxDreply message

6.9.2. Note time delay between action and reply message

6.9.3. Initiate GET_PROTOCOL_REGISTER enquiry on CxD>>MachineStatus message and note response on the Machine>>CxDreply message to the following register indexes

6.9.3.1. PROTOCOL_REVISION

6.9.3.2. CxD_SOFTWARE_REVISION

6.9.3.3. CxD_HARDWARE_REVISION

6.9.3.4. CxD_HARDWARE_ID

6.9.4. For each reply on Machine>>CxDreply message, note

6.9.4.1. GET_REGISTER_OK

6.9.4.2. How register values 0 – 3 compares to original values in specification sheet (Appendix A)

6.10. Propulsion commands

6.10.1. Initiate the following actions on the CxD>>MachineCommand message

6.10.1.1. EMERGENCY_STOP

6.10.1.2. CONTROLLED_STOP

6.10.1.3. SLOW_DOWN

6.10.1.4. STAND_DOWN

6.10.1.5. BYPASS_PROPULSION

6.10.1.6. APPLY_PROPULSION_SETPOINTS

6.10.1.7. INHIBIT_COMMAND

6.10.2. For each command, note the following on the Machine>>CxDreply message

6.10.2.1. Appropriate x_ACK message

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

6.10.3. Note average and standard deviation of the time delay between all command and reply messages

6.11. Apply propulsion set points

6.11.1. Initiate SET_PROPULSION_SETPOINTS action on CxD>>MachineStatus message with the following register select values

6.11.1.1. SELECT_REGISTER

6.11.1.2. SELECT_AND_TAG

6.11.2. Initiate LOAD_PROPULSION_SETPOINTS action on CxD>>MachineCommand message with the following register select values

6.11.2.1. IMMEDIATE

6.11.2.2. UPDATE_AND_APPLY

6.11.2.3. APPLY_FROM_LIST

6.11.2.4. LOOKUP_INDIRECT

6.11.2.5. MATCH_TAG

6.11.3. Initiate APPLY_PROPULSION_SETPOINTS_CONFIRM enquiry on CxD>>MachineCommand message

6.11.4. Note APPLY_PROPULSION_SETPOINTS_CONFIRM_ACK reply on Machine>>CxDreply message

6.11.5. Initiate APPLY_PROPULSION_SETPOINTS command on CxD>>MachineCOmmand message

6.11.6. Note APPLY_PROPULSION_SETPOINTS_ACK reply on Machine>>CxDreply message

6.12. Machine data

6.12.1. Initiate data stream from machine side on Machine>>CxDdata message

6.12.2. Note on Propulsion Subsystem Header

6.12.2.1. SYSTEM_FAULT

6.12.2.2. OVERRIDE_FAULT

6.12.2.3. ROLLBACK_FAULT

6.12.2.4. TRACTION_FAULT

6.12.2.5. PAYLOAD_FAULT

6.12.3. Note on Propulsion Subsystem Data

6.12.3.1. SPEED

6.12.3.2. DIR

6.12.3.3. MOTION_INHIBIT

6.12.3.4. GEAR

6.12.3.5. OVERRIDE_STATUS

6.12.3.6. ROLLBACK_STATUS

6.12.3.7. TRACTION_STATUS

6.12.3.8. PAYLOAD_STATUS

6.12.3.9. PITCH

6.12.3.10. ROLL

6.13. Varying message frequency

6.13.1. Initiate CxD>>MachineStatus messages while changing the timing between sent messages from 250ms to 10ms with 50ms increments.

6.13.2. For each timing test, note

6.13.2.1. Any messages on CxD>>MachineStatus that does not receive a reply. At least one Message ID counter cycle has to be evaluated.

6.13.2.2. Average and standard deviation for the time delay between sent messages and reply.

6.13.3. Initiate CxD>>MachineCommand messages while changing the timing between sent messages from 250ms to 100ms with 50ms increments.

6.13.4. For each timing test, note

6.13.4.1. Any messages on CxD>>MachineCommand that does not receive a reply. At least one Message ID counter cycle has to be evaluated.

6.13.4.2. Average and standard deviation for the time delay between sent messages and reply.

6.14. Override

6.14.1. Activate override switch

6.14.2. If override switch is connected on the Machine side of the connector, note BYPASS_PROPULSION action on CxD>>MachineCommand message

6.14.3. Note BYPASS_PROPULSION_ACK reply on Machine>>CxDreply message

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is

7.2. The reason for the deviation

7.3. How the deviation may affect the purpose of the test

7.4. Have all parties accept in writing:

7.4.1. the proposed deviation

7.4.2. reason for the proposed deviation and

7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

See separate file: 1.2 TMM_ISO21815_Bench_test_protocol_Appendix_C_28Jan

9. Influence of deviations on outcome

See separate file: 1.2 TMM_ISO21815_Bench_test_protocol_Appendix_C_28Jan

10. Acceptance criteria for this test

See separate file: B 1.2 TMM_ISO21815_Bench_test_protocol_Appendix_B_28Jan

11. Outcome of this test

See separate file: 1.2 TMM_ISO21815_Bench_test_protocol_Appendix_C_28Jan

Appendix 2: TRL 4 TMM Log keeping test.

TRL4 Stage Gate: TMM ISO21815 Bench test:
TMM Log keeping test protocol (MLK, MCI)

1. Purpose

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

2. Preceding tests

2.1. TMM ISO21815 Bench test

3. Test facility/site

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

4. Instrumentation

4.1. CxD Emulator
4.2. Machine Emulator
4.3. DAQ with ISO/TS 21815-2 interface
4.4. Computer

5. Test preparation

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

6. Test method

6.1. Note MCI and MLK firmware versions
6.2. Synchronisation
6.2.1. Initiate UTC synchronisation procedure between CxD or Machine Emulator and MLK
6.3. Stored data and accuracy of log file
6.3.1. Confirm sufficient storage space as per MLK supplier specification sheet
6.3.2. Initiate data stream with CxD and Machine Emulators
6.3.2.1. Negotiation between CxD and Machine Emulators
6.3.2.2. NOP for 60s
6.3.2.3. Intervention for 10s
6.3.2.4. NOP for 60s

6.3.2.5. Override for 10s
6.3.2.6. NOP for 60s
6.3.3. Stop data stream and transfer data to computer
6.3.4. Compare recorded log file with sent data from Emulators and note
6.3.4.1. Discrepancies between data values
6.3.4.2. Discrepancies between time stamps
6.3.4.3. Sample frequency during NOP
6.3.4.4. Intervention sample frequency
6.3.4.5. Preceding recording window before intervention starts

6.4. Data transfer
6.4.1. Note data transfer interface
6.4.2. Generate data until storage reflects a 7-day sized log file
6.4.3. Initiate data transfer and note time duration to transfer log file to computer
6.4.4. Note size of 7-day sized log file and compare against available data storage space

6.5. Data security
6.5.1. Note any security measures to prevent log file from being deleted on MLK with a computer
6.5.2. Note any security measures to prevent log file from being altered on MLK with a computer
6.5.3. Note redundant measures to ensure that the integrity of the log file will not be compromised with physical damage, electrical discharge, or magnetic exposure

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
7.4.1. the proposed deviation
7.4.2. reason for the proposed deviation and
7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 1: **Example** of noted log keeping functionality*

MLK firmware version	1.6.1.8
MCI firmware version	3.1.4
Synchronisation from CxD or Machine	CxD
Synchronisation successful	Yes
Storage space available	2GB
Discrepancies between log values	None
Discrepancies between time stamps	None

Sample frequency during NOP	1Hz
Sample frequency during intervention	10Hz
Preceding recording window of intervention	10s
Data transfer interface	Wifi
Duration to download 7-day sized file	2.3s
Size of 7-day log file	120MB
Security measures to prevent deletion	Password request upon Wifi login
Security measures to prevent alteration	Password request upon Wifi login
Redundant measures to ensure integrity	2 redundant MLKs, each with RAID-1 storage

9. Influence of deviations on outcome

None

10. Acceptance criteria for this test

10.1. Synchronisation

10.1.1. MLK can synchronise with either CxD or with Machine Emulator

10.2. Stored data and accuracy of log file

10.2.1. No discrepancies between sent and stored data to within machine precision, AND

10.2.2. Less than 100ms discrepancy between time stamps of sent and stored data, AND

10.2.3. Sample frequency during NOP is 1Hz or faster, AND

10.2.4. Sample frequency during intervention is 10Hz or faster, AND

10.2.5. Recording window starts 5s or earlier before intervention occurs

10.3. Data transfer

10.3.1. Sufficient storage space for 7day-sized log file

10.4. Data security

10.4.1. Some measure in place to prevent deletion, AND

10.4.2. Some measure in place to prevent alteration, AND

10.4.3. Redundant measures in place to ensure log integrity against physical damage, electrical discharge or magnetic exposure

11. Outcome of this test

Table 2: example of outcome of Log keeping test

Synchronisation	Pass
Stored data and accuracy	Pass
Data transfer	Pass
Data security	Pass

12. Applicable document

See separate file: 1.3 TMM_Log_keeping_test_protocol_Appendix_A_28Jan

Appendix 3: TRL 4 TMM Machine sensing test

TRL4 Stage Gate: TMM FTS and Machine response: **Machine sensing test protocol (MS, MC, MCI, MLK)**

1. Purpose

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

2. Preceding tests

2.1. TMM ISO21815 Bench test

2.2. TMM Log keeping test

3. Test facility/site

Site where machine is available. Tests are dynamic and need adequate space for run-up, conducting the test and run-off. A large open space is required to conduct a constant radius test to induce a roll angle on the machine. A level surface is required for most of the tests, however a ramp of 10% or more is also required to induce a pitch angle on the machine. Infrastructure is needed to change the payload on the machine.

4. Instrumentation

4.1. CxD Emulator

4.2. DAQ with ISO/TS 21815-2 interface

4.3. 1x HP GNSS with IMU

5. Test preparation

5.1. TMM to be provided in working condition to the test team. Responsible person to sign-off that TMM is in working condition as designed. Firmware versions of MCI, MBS and MLK to be the same as tested during Appendix 1 and Appendix 2.

5.2. Fence off test area. Ensure all aspects Safety protocol is adhered to.

5.3. Install HP GNSS on machine and ensure good satellite reception is obtained.

5.4. Connect CxD Emulator and data acquisitioning system to the machine CAN-harness via the ISO/TS 21815-2 connector

5.5. Ensure all personnel, equipment and all obstacles are removed in front and behind of the machine. All personnel to be within safe area declared in Safety protocol.

5.6. Start machine and let idle.

5.7. Complete negotiation sequence between CxD Emulator and MC and ensure that MC is in NOP.

6. Test method

6.1. Note firmware versions of MLK, MC and MCI

6.2. Note machine OEM, model and serial number

6.3. Initiate UTC synchronisation procedure between CxD or Machine Emulator and MLK

6.4. Dynamic test

6.4.1. Start recording ISO/TS 21815-2 messages on data acquisitioning system
6.4.2. Allow 10s of data recording while machine is stationary with no action from the operator
6.4.3. Instruct operator to drive in FWD direction while cycling through all available gears of the machine up to 30km/h or machine's top speed
6.4.4. Instruct operator to gradually stop machine and put in safe park
6.4.5. Allow 10s of data recording while machine is stationary with no action from the operator
6.4.6. Instruct operator to drive in REV direction while cycling through all available gears of the machine up to 15km/h or top speed, whichever is higher.
6.4.7. Instruct operator to gradually stop machine and put in safe park
6.4.8. Stop recording
6.4.9. Download log from MLK and compare with recorded data from HP GNSS and test notes
6.4.10. Repeat 3 times

6.5. Attitude test
6.5.1. Start recording ISO/TS 21815-2 messages data acquisitioning system
6.5.2. If pitch sensor is available:
6.5.2.1. Using a ramp, instruct operator to drive machine such that a significant amount of pitch angle is observed
6.5.3. If roll sensor is available:
6.5.3.1. Instruct operator to drive machine at a constant radius around a centre point
6.5.3.2. While it is safe to do so, and while below roll-over speed, increase speed while maintaining the radius such that a significant amount of roll angle is observed
6.5.4. Stop recording
6.5.5. Download log from MLK and compare with recorded data from HP GNSS

6.6. Status change
6.6.1. Start recording ISO/TS 21815-2 messages on data acquisitioning system
6.6.2. Instruct operator to cycle through all statuses available on machine
6.6.3. Use a forklift, crane or any other means to change the payload status on the machine
6.6.4. Stop recording
6.6.5. Download log from MLK and compare with test notes

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
7.4.1. the proposed deviation

7.4.2. reason for the proposed deviation and

7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 3: **Example** of noted comparisons between log and measurements*

Firmware versions	
MC	Version 2.7.1.8
MCI	Version 3.1.4
Dynamic test	
GEAR	Compare log to test notes
DIR	Compare log to test notes
SPEED	Compare log to HP GNSS measurements
LO latitude	Compare log to HP GNSS measurements
LO longitude	Compare log to HP GNSS measurements
Attitude test	
PITCH	Compare log to HP GNSS IMU measurements
ROLL	Compare log to HP GNSS IMU measurements
Status test	
Loading	Compare log to test notes
Tramming	Compare log to test notes
Dumping	Compare log to test notes

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

10.1. Dynamic run

10.1.1. Machine>>CxDdata message log

10.1.1.1. DIR AND GEAR is consistent between log and test notes, AND

10.1.1.2. SPEED, PITCH AND ROLL is consistent between log and HP GNSS, AND

10.1.1.3. No faults in message

10.1.2. Additional Continuous log

10.1.2.1. Latitude, longitude AND status is consistent between log and HP GNSS, AND

10.1.2.2. Statuses are consistent between log and test notes, AND

10.1.2.3. No faults in log

11. Outcome of this test

Table 4: Example outcome for machine sensing test

All measurements in Machine>>CxDdata log	Pass
All measurements in Additional Continuous log	Pass

Appendix 4: TRL 4 TMM self – diagnostic test

TRL4 Stage Gate: TMM FTS and Machine response: **TMM Self-diagnostics (MC, MCI, and MLK)**

1. **Purpose**

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

2. **Preceding tests**
   - **2.1.** SANS1589-1 (UG only) / 1.1 ISO3450 (S only) test
   - **2.2.** ISO21815 Bench test
3. **Test facility/site**

Site where machine is available. Tests are mostly static.

4. **Instrumentation**
   - **4.1.** 1x CxD Emulator
5. **Test preparation**
   - **5.1.** TMM to be provided in working condition to the test team. Responsible person to sign-off that TMM is in working condition as designed. Firmware versions of MCI, MBS and MLK to be the same as tested during 1.1 and 1.2.
   - **5.2.** Fence off test area. Ensure all aspects in Safety protocol is adhered to.
   - **5.3.** Connect CxD Emulator to the machine CAN-harness via the ISO21815 connector.
   - **5.4.** Ensure all personnel, equipment and all obstacles are removed in front and behind of the machine. Personnel should be in the safe area defined in Safety protocol.
   - **5.5.** Start machine and let idle
   - **5.6.** Complete negotiation sequence between CxD Emulator and MC and ensure that MC is in NOP
   - **5.7.** Instruct operator that during each test run AND unless unsafe:
     - **5.7.1.** Take-off is only required to be gradual, slow and short since MI is being evaluated
     - **5.7.2.** Manually operated brakes may not be used at any time during the test run (e.g. brake pedal, park brake lever, etc.)
   - **5.8.** A computer may be logged into the MCI to send subsystem fault (SF) message
   - **5.9.** If any alterations are made to the firmware of the MC, MCI or MLK during testing, all previous testing becomes invalid and this protocol must be followed from the start
6. **Test method**
   - **6.1.** Note firmware versions of MC, MCI and MLK
   - **6.2.** MC power interruption
     - **6.2.1.** Disconnect power supply to MC
     - **6.2.2.** Instruct operator to attempt to take-off in FWD and REV and note MI response
     - **6.2.3.** Reconnect power to MC
     - **6.2.4.** Instruct operator to take-off in FWD and REV and note NOP response

6.2.5. Repeat 3 times

6.3. MCI comms interruption

6.3.1. Disconnect CAN communication between MCI and CxD Emulator

6.3.2. Instruct operator to attempt to take-off in FWD and REV and note MI response

6.3.3. Reconnect CAN communication between MCI and CxD Emulator

6.3.4. Instruct driver to take-off in FWD and REV and note NOP response

6.3.5. Repeat 3 times

6.4. MLK power interruption

6.4.1. Disconnect power supply to MLK

6.4.2. Instruct operator to attempt to take-off in FWD and REV and note MI response

6.4.3. Reconnect power to MC

6.4.4. Instruct operator to take-off in FWD and REV and note NOP response

6.4.5. Repeat 3 times

6.5. MLK storage full

6.5.1. Fill MLK with data

6.5.2. Instruct operator to attempt to take-off in FWD and REV and note MI response

6.5.3. Delete data from MLK to free up space

6.5.4. Instruct operator to take-off in FWD and REV and note NOP response

6.6. MLK fault

6.6.1. Initiate SF fault in Machine>>CxDdata message

6.6.2. Instruct operator to attempt to take-off in FWD and REV and note MI response

6.6.3. Restore SF fault in Machine>>CxDdata message

6.6.4. Instruct operator to take-off in FWD and REV and note NOP response

6.7. Synchronisation fault

6.7.1. Initiate synchronisation procedure between CxD Emulator and machine

6.7.2. Initiate synchronisation mismatch on CxD Emulator by changing the real-time clock

6.7.3. Instruct operator to attempt to take-off in FWD and REV and note MI response

6.7.4. Restore fault by initiating synchronisation procedure between CxD Emulator and machine

6.7.5. Instruct operator to take-off in FWD and REV and note NOP response

6.8. Override switch disconnected

6.8.1. If equipped, disconnect both wires of the override switch

6.8.2. Instruct operator to attempt to take-off in FWD and REV and note MI response

6.8.3. Reconnect both wires of the override switch

6.8.4. Instruct operator to take-off in FWD and REV and note NOP response

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is

7.2. The reason for the deviation

7.3. How the deviation may affect the purpose of the test

7.4. Have all parties accept in writing:

7.4.1. the proposed deviation
7.4.2. reason for the proposed deviation and
7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 5: **Example** of noted machine response to introduced failure modes*

	Run1	Run2	Run3	Notes
MC firmware version				2.7.1.8
MCI firmware version				3.1.4
MLK firmware version				1.6.1.8
MC power interrupted	MI	MI	MI	
MC power restored	NOP	NOP	NOP	
MCI power interrupted	N/A	N/A	N/A	Integrated unit
MCI power restored	N/A	N/A	N/A	Integrated unit
MCI comms interrupted	MI	MI	MI	
MCI comms restored	NOP	NOP	NOP	
MLK power interrupted	N/A	N/A	N/A	Integrated unit
MLK power restored	N/A	N/A	N/A	Integrated unit
MLK storage full	MI	MI	MI	
MLK storage available	NOP	NOP	NOP	
MLK fault	MI	MI	MI	
MLK restored	NOP	NOP	NOP	
Synchronisation mismatch	MI	MI	MI	
Synchronisation restored	NOP	NOP	NOP	
Override disconnected	MI	MI	MI	

9. Influence of deviation on outcome

Example: MC, MCI and MLK power interruption test could not be completed separately because the three subsystems are contained in one unit.

9.1. Proposed deviation: Disrupt power supply to all three subsystems at the same time
9.2. Reason: Subsystems all integrated in one unit with one power supply
9.3. Motivation why it won't affect the purpose of the test: Interrupting the supply of power to all subsystems concurrently or separately will result in the same measurable outcome of the test, namely is MI achieved or not.

10. Acceptance criteria for this test

10.1. MC:

10.1.1. MI achieved in both FWD AND REV directions with power interruption, AND

10.1.2. System returns to NOP after power is restored

10.1.3. For all test runs

10.2. MCI:

10.2.1. MI achieved in both FWD AND REV directions, AND

10.2.2. System returns to NOP after restoring failure mode

10.2.3. For power interruption AND comms interruption failure modes

10.2.4. For all test runs

10.3. MLK:

10.3.1. MI achieved in both FWD AND REV directions, AND

10.3.2. System returns to NOP after restoring failure mode, AND

10.3.3. For power interruption, storage full, fault, AND synchronisation mismatch failure modes

10.3.4. For all test runs

10.4. Override:

10.4.1. MI achieved in both FWD AND REV directions, AND

10.4.2. System returns to NOP after restoring failure mode

10.4.3. For all test runs

11. Outcome of this test

*Table 6:**Example** of outcome for self-diagnostics test*

		Pass
MC	MI response to power interruption	Yes
MCI	MI response to power interruption	Yes
MLK	MI response to power interruption	Yes
MCI	MI response to CAN comms interruption	Yes
MLK	MI response to full storage	Yes
Override	MI response to being disconnected	Yes

Appendix 5: TRL 4 Surface TMM Machine Controller Test

TRL4 Stage Gate: TMM FTS and Machine response:
TMM Machine Controller Surface response (MC)

1. Purpose

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

2. Preceding test

- **2.1.** ISO3450 test
- **2.2.** TMM ISO21815 Bench test
- **2.3.** TMM Machine sense test
- **2.4.** TMM Self-diagnostics test

3. Test facility/site

Site where machine is available. Tests are dynamic and need adequate space for run-up, conducting the test and run-off. Surface needs to be level.

4. Instrumentation

- **4.1.** CxD Emulator
- **4.2.** HP GNSS
- **4.3.** DAQ with ISO/TS 21815-2 interface

5. Test preparation

- **5.1.** TMM to be provided in working condition to the test team. Responsible person (OEM representative) to sign-off that TMM is in working condition as designed.
- **5.2.** Fence off test area. Ensure all aspects in Safety protocol is adhered to.
- **5.3.** Install HP GNSS on machine and ensure good satellite reception is obtained.
- **5.4.** Connect CxD Emulator and data acquisitioning system to the machine CAN-harness via the ISO21815 connector.
- **5.5.** Ensure all personnel, equipment and all obstacles are removed in front and behind of the machine. Personnel must be within safe area as declared with Safety protocol.
- **5.6.** Start machine and let idle.
- **5.7.** Complete negotiation sequence between CxD Emulator and MC and ensure that MC is in NOP.
- **5.8.** Instruct operator that during each test run AND unless unsafe:
  - **5.8.1.** The accelerator pedal must stay depressed during the entire duration of the test run
  - **5.8.2.** Manually operated brakes may not be used at any time during the test run

6. Test method

6.1. Note firmware versions of MC and MCI

6.2. Note OEM, model and serial number of the machine

6.3. Note and describe the overall implementation and interaction between the MC, MBS, hydraulic hardware and propulsion system

6.4. Note any speed-dependent logic for slowdown, stop or override

6.5. Machine response to MI commands:

6.5.1. Note and describe how MI is achieved in terms of MC, hydraulic hardware and MBS

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

6.5.2.1. INHIBIT_COMMAND

6.5.2.2. EMERGENCY_STOP

6.5.2.3. CONTROLLED_STOP

6.5.2.4. STAND_DOWN

6.5.2.5. APPLY_PROPULSION_SETPOINTS with SET_PROPULSION_REGISTER to stop machine

6.5.3. For each command:

6.5.3.1. Note Machine>>CxDreply message

6.5.3.2. Instruct operator to take-off in FWD and note MI response

6.5.3.3. Instruct operator to take-off in REV and note MI response

6.5.4. Repeat 3 times for each command

6.6. Attachment response to MI commands:

6.6.1. Note and describe how Attachment-MI is achieved in terms of MC and hydraulic hardware

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

6.6.2.1. INHIBIT_COMMAND

6.6.2.2. EMERGENCY_STOP

6.6.2.3. CONTROLLED_STOP

6.6.2.4. STAND_DOWN

6.6.2.5. APPLY_PROPULSION_SETPOINTS with SET_PROPULSION_REGISTER to stop machine

6.6.3. With each command, instruct operator to use attachment and note Attachment-MI response

6.6.4. Repeat 3 times for each command

6.7. Articulation response to MI commands:

6.7.1. Note and describe how Attachment-MI is achieved in terms of MC and hydraulic hardware

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

6.7.2.1. INHIBIT_COMMAND

6.7.2.2. EMERGENCY_STOP

6.7.2.3. CONTROLLED_STOP

6.7.2.4. STAND_DOWN

6.7.2.5. APPLY_PROPULSION_SETPOINTS with SET_PROPULSION_REGISTER to stop machine

6.7.3. With each command, instruct operator articulate machine and note Articulation-MI response

6.7.4. Repeat 3 times for each command

6.8. Machine response to slowdown commands:

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

6.8.2. Instruct operator to drive machine at the following speeds:

6.8.2.1. 5km/h

6.8.2.2. 10km/h

6.8.2.3. 30km/h

6.8.2.4. Or maximum speed in each gear AND direction up to 30km/h

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

6.8.3.1. SLOW_DOWN

6.8.3.2. STAND_DOWN

6.8.3.3. APPLY_PROPULSION_SETPOINTS with SET_PROPULSION_REGISTER to slow machine down

6.8.4. With each speed and command combination, note:

6.8.4.1. Machine>>CxDreply message

6.8.4.2. Time delay between command and 5% speed reduction

6.8.4.3. Deceleration between 5% reduction and 5% above safe braking speed

6.8.4.4. Crawl speed at which the machine settles

6.8.4.5. If the service brake is available during slowdown

6.9. Machine response to stop commands:

6.9.1. Note and describe how stop is achieved in terms of MC, MBS, hydraulic hardware and propulsion system

6.9.2. Instruct operator to drive machine to the following speeds:

6.9.2.1. 5km/h

6.9.2.2. 10km/h

6.9.2.3. 15km/h

6.9.2.4. Or maximum speed in each gear and direction up to 15km/h

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

6.9.3.1. EMERGENCY_STOP

6.9.3.2. CONTROLLED_STOP

6.9.3.3. APPLY_PROPULSION_SETPOINTS with SET_PROPULSION_REGISTER to stop machine

6.9.4. With each speed and command combination, note

6.9.4.1. Machine>>CxDreply message

6.9.4.2. Time delay between command and 5% speed reduction

6.9.4.3. Deceleration between 5% and 1km/h
6.9.4.4. MI after machine has come to a stop

6.10. Machine response to unexpected CxD behaviour
6.10.1. Instruct operator to drive machine FWD at the following speeds:
6.10.1.1. 5km/h
6.10.1.2. 10km/h
6.10.1.3. 30km/h
6.10.1.4. Or maximum speed in each gear up to 30km/h
6.10.2. For each speed, issue a INHIBIT_COMMAND to the MC with the CxD emulator and note:
6.10.2.1. Machine>>CxDreply message
6.10.2.2. Machine response
6.10.3. For each speed, disconnect the CxD emulator from the CAN-bus and note machine response

6.11. Machine response to override:
6.11.1. Note and describe how the override function works in terms of MC, MBS, hydraulic hardware and propulsion system
6.11.2. Note if override is implemented on CxD or on Machine side of the ISO21815-2 connector
6.11.3. Instruct operator to drive 15km/h, activate override switch and note:
6.11.3.1. Machine>>CxDreply message
6.11.3.2. Crawl speed at which the machine settles

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
7.4.1. the proposed deviation
7.4.2. reason for the proposed deviation and
7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 7: **Example** of noted machine response to introduced failure modes*

	CxD>>MachineCommand	Vel	Run1	Run2	Run3
Firmware versions					
MC			Version 2.7.1.8		
MCI			Version 3.1.4		
Machine details					
OEM			Komatsu		
Model			WX18H		
Serial number			14414		
MI commands					
Machine>>CxDreply	INHIBIT_COMMAND	0	INHIBIT_RESPONSE ON	INHIBIT_RESPONSE ON	INHIBIT_RESPONSE ON
	EMERGENCY_STOP	0	EMERGENCY_STOP_ACK	EMERGENCY_STOP_ACK	EMERGENCY_STOP_ACK
	CONTROLLED_STOP	0	ACTION_ERROR	ACTION_ERROR	ACTION_ERROR
	STAND_DOWN	0	ACTION_ERROR	ACTION_ERROR	ACTION_ERROR
	APPLY_PROPULSION_SETPOINTS	0	ACTION_ERROR	ACTION_ERROR	ACTION_ERROR
Machine response	INHIBIT_COMMAND	0	MI	MI	MI
	EMERGENCY_STOP	0	MI	MI	MI
	CONTROLLED_STOP	0	MI	MI	MI
	STAND_DOWN	0	MI	MI	MI
	APPLY_PROPULSION_SETPOINTS	0	MI	MI	MI
Attachment response	INHIBIT_COMMAND	0	MI	MI	MI
	EMERGENCY_STOP	0	MI	MI	MI
	CONTROLLED_STOP	0	MI	MI	MI
	STAND_DOWN	0	MI	MI	MI
	APPLY_PROPULSION_SETPOINTS	0	MI	MI	MI

Articulation response to	INHIBIT_COMMAND	0	MI	MI	MI
	EMERGENCY_STOP	0	MI	MI	MI
	CONTROLLED_STOP	0	MI	MI	MI
	STAND_DOWN	0	MI	MI	MI
	APPLY_PROPULSION_SETPOINTS	0	MI	MI	MI
Slowdown commands					
Machine>>CxDreply	SLOW_DOWN	30	SLOW_DOWN_ACK	SLOW_DOWN_ACK	SLOW_DOWN_ACK
	Service brake available	30	Yes	Yes	Yes
	STAND_DOWN	30	N/A	N/A	N/A
	Service brake available	30	Yes	Yes	Yes
	APPLY_PROPULSION_SETPOINTS	30	N/A	N/A	N/A
	Service brake available	30	Yes	Yes	Yes
decel. 5% speed red. To 5% above safe braking speed	SLOW_DOWN	5	N/A	N/A	N/A
	STAND_DOWN	5	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	5	N/A	N/A	N/A
	SLOW_DOWN	10	0.1g	0.12g	0.11g
	STAND_DOWN	10	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	10	N/A	N/A	N/A
	SLOW_DOWN	30	0.1g	0.12g	0.11g
	STAND_DOWN	30	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	30	N/A	N/A	N/A
delay 5% velocity red.	SLOW_DOWN	5	N/A	N/A	N/A
	STAND_DOWN	5	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	5	N/A	N/A	N/A
	SLOW_DOWN	10	0.5s	0.6s	0.55s

	STAND_DOWN	10	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	10	N/A	N/A	N/A
	SLOW_DOWN	30	0.5s	0.6s	0.55s
	STAND_DOWN	30	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	30	N/A	N/A	N/A
Stop commands					
Machine>>CxDreply	EMERGENCY_STOP	10	EMERGENCY_STOP_ACK	EMERGENCY_STOP_ACK	EMERGENCY_STOP_ACK
	CONTROLLED_STOP	10	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	10	N/A	N/A	N/A
decel. 5% speed red to 5% above safe braking speed	EMERGENCY_STOP	5	0.34g	0.36g	0.34g
	CONTROLLED_STOP	5	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	5	N/A	N/A	N/A
	EMERGENCY_STOP	10	0.34g	0.36g	0.34g
	CONTROLLED_STOP	10	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	10	N/A	N/A	N/A
delay 5% velocity red.	EMERGENCY_STOP	5	0.5s	0.7s	0.6s
	CONTROLLED_STOP	5	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	5	N/A	N/A	N/A
	EMERGENCY_STOP	10	0.5s	0.7s	0.6s
	CONTROLLED_STOP	10	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	10	N/A	N/A	N/A
Unexpected CxD behaviour					
	INHIBIT_COMMAND	5	NOP response	NOP response	NOP response
	CxD Emulator disconnected	5	Slowdown and stop	Slowdown and stop	Slowdown and stop

	INHIBIT_COMMAND	10	NOP response	NOP response	NOP response
	CxD Emulator disconnected	10	Slowdown and stop	Slowdown and stop	Slowdown and stop
	INHIBIT_COMMAND	30	NOP response	NOP response	NOP response
	CxD Emulator disconnected	30	Slowdown and stop	Slowdown and stop	Slowdown and stop
Override					
Override on CxD or Machine side?			Machine	Machine	Machine
Machine>>CxDreply	BYPASS_PROPULSION	0	BYPASS_PROPULSION_ACK	BYPASS_PROPULSION_ACK	BYPASS_PROPULSION_ACK
Machine response to override	BYPASS_PROPULSION	0	NOP	NOP	NOP
		15	Crawl at 5km/h	Crawl at 5km/h	Crawl at 5km/h

9. Influence of deviations on outcome of test

Example: None

10. Acceptance criteria for this test

10.1. Machine MI:

10.1.1. MI achieved in all test runs in both directions with the INR command OR at least one of the stop commands, AND

10.1.2. MI is achieved after vehicle has stopped for the same stop command

10.1.3. For all test runs

10.2. Attachment MI:

10.2.1. Attachment is inoperable

10.2.2. For all test runs

10.3. Articulation MI:

10.3.1. Articulation is not possible

10.3.2. For all test runs

10.4. Slowdown:

10.4.1. Machine slows down with at least one of the slowdown commands, AND

10.4.2. Settles on the crawl speed, AND

10.4.3. Correct reply message received with the same slowdown command

10.4.4. For all test runs

10.4.5. For all speeds

10.5. Set point tracking

10.5.1. For constant speed limit (e.g. speed limited zone) speed is maintained below set point

10.5.2. For decreasing set point, prescribed set point if tracked to within 1km/h

10.6. Stop:

10.6.1. Machine stops with at least one of the slowdown commands, AND

10.6.2. Correct reply message received with the same slowdown command, AND

10.6.3. For all test runs, AND

10.6.4. For all speeds

10.7. Unexpected CxD behaviour

10.7.1. Machine NOP with MI command when in motion, AND

10.7.2. Machine auto-slow and stops with communication interrupted, AND

10.7.3. For all test runs, AND

10.7.4. For all speeds

10.8. Override:

10.8.1. Override switch correctly installed as per ISO/TS21815:2021, AND

10.8.2. Correct reply message received, AND

10.8.3. Machine slows down, AND

10.8.4. Settles on the predetermined emergency speed, AND

10.8.5. For all test runs

10.9. Acceleration and delays

10.9.1. Slowdown deceleration rate within OEM's spec, AND

10.9.2. Machine delay between slowdown command and response within OEM's spec, AND

10.9.3. Stop deceleration rate within OEM's spec, AND

10.9.4. Machine delay between stop command and response within OEM's spec, AND

10.9.5. For all test runs

11. Outcome of this test

*Table 8: **Example** outcome for machine controller response test*

		Pass
Machine MI	Machine response to MI commands	Yes
Attachment MI	Attachment response to MI commands	Yes
Articulation MI	Articulation response to MI commands	Yes
Slowdown	Machine response to Slowdown commands	Yes
Stop	Machine response to Stop commands	Yes
Override	Machine response to Override	Yes

*Table 9: **Example** response of machine*

	Value
Average machine delay to Slowdown	0.5 s
Average machine delay to Stop	0.5 s
Average machine deceleration to Slowdown	0.13 g
Average machine deceleration to Stop	0.35 g
Average crawl speed with Slowdown	5 km/h
Average emergency speed with Override	5 km/h

Appendix 6: TRL 4 Underground TMM Machine Controller Test

TRL4 Stage Gate: TMM FTS and Machine response: **TMM Machine controller UG response (MC)**

1. Purpose

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

2. Preceding test

- **2.1.** SANS1589
- **2.2.** TMM ISO21815 Bench test
- **2.3.** TMM Machine sensing test
- **2.4.** TMM Self-diagnostics test

3. Test facility/site

Site where machine is available. Tests are dynamic and need adequate space for run-up, conducting the test and run-off. Surface needs to be level.

4. Instrumentation

- **4.1.** CxD Emulator
- **4.2.** HP GNSS
- **4.3.** DAQ with ISO21815 interface.

5. Test preparation

- **5.1.** TMM to be provided in working condition to the test team. Responsible person (OEM representative) to sign-off that TMM is in working condition as designed.
- **5.2.** Fence off test area. Ensure all aspects in Safety protocol is adhered to.
- **5.3.** Install HP GNSS on machine and ensure good satellite reception is obtained.
- **5.4.** Connect CxD Emulator and data acquisitioning system to the machine CAN-harness via the ISO/TS 21815-2 connector.
- **5.5.** Ensure all personnel, equipment and all obstacles are removed in front and behind of the machine. Personnel should be in the safe area as required by Safety protocol.
- **5.6.** Start machine and let idle.
- **5.7.** Complete negotiation sequence between CxD Emulator and MC and ensure that MC is in NOP.
- **5.8.** Instruct operator that during each test run AND while it remains safe to do so:
  - **5.8.1.** The accelerator pedal must stay depressed during the entire duration of the test run
  - **5.8.2.** Manually operated brakes may not be used at any time during the test run

6. Test method

- **6.1.** Note firmware versions of MC and MCI

6.2. Note OEM, model and serial number of the machine

6.3. Note and describe the overall implementation and interaction between the MC, MBS, hydraulic hardware and propulsion system

6.4. Note any speed-dependent logic for slowdown, stop or override

6.5. Machine response to MI commands:

6.5.1. Note and describe how MI is achieved in terms of MC, hydraulic hardware and MBS

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

6.5.2.1. INHIBIT_COMMAND

6.5.2.2. EMERGENCY_STOP

6.5.2.3. CONTROLLED_STOP

6.5.2.4. STAND_DOWN

6.5.2.5. APPLY_PROPULSION_SETPOINTS with SET_PROPULSION_REGISTER to stop machine

6.5.3. For each command:

6.5.3.1. Note Machine>>CxDreply message

6.5.3.2. Instruct operator to take-off in FWD and note MI response

6.5.3.3. Instruct operator to take-off in REV and note MI response

6.5.4. Repeat 3 times for each command

6.6. Attachment response to MI commands:

6.6.1. Note and describe how Attachment-MI is achieved in terms of MC and hydraulic hardware

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

6.6.2.1. INHIBIT_COMMAND

6.6.2.2. EMERGENCY_STOP

6.6.2.3. CONTROLLED_STOP

6.6.2.4. STAND_DOWN

6.6.2.5. APPLY_PROPULSION_SETPOINTS with SET_PROPULSION_REGISTER to stop machine

6.6.3. With each command, instruct operator to use attachment and note Attachment-MI response

6.6.4. Repeat 3 times for each command

6.7. Articulation response to MI commands:

6.7.1. Note and describe how Attachment-MI is achieved in terms of MC and hydraulic hardware

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

6.7.2.1. INHIBIT_COMMAND

6.7.2.2. EMERGENCY_STOP

6.7.2.3. CONTROLLED_STOP

6.7.2.4. STAND_DOWN

6.7.2.5. APPLY_PROPULSION_SETPOINTS with SET_PROPULSION_REGISTER to stop machine

6.7.3. With each command, instruct operator articulate machine and note Articulation-MI response

6.7.4. Repeat 3 times for each command

6.8. Machine response to slowdown commands:

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

6.8.2. Instruct operator to drive machine to the following speeds:

6.8.2.1. 5km/h

6.8.2.2. 10km/h

6.8.2.3. 15km/h

6.8.2.4. Or maximum speed in each gear AND direction

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

6.8.3.1. SLOW_DOWN

6.8.3.2. STAND_DOWN

6.8.3.3. APPLY_PROPULSION_SETPOINTS with SET_PROPULSION_REGISTER to slow machine down

6.8.4. With each speed and command combination, note:

6.8.4.1. Machine>>CxDreply message

6.8.4.2. Time delay between command and 5% speed reduction

6.8.4.3. Deceleration between 5% speed reduction and 5% above crawl speed

6.8.4.4. Crawl speed at which the machine settles

6.8.4.5. If service brakes are available during slowdown

6.9. Machine response to stop commands:

6.9.1. Note and describe how stop is achieved in terms of MC, MBS, hydraulic hardware and propulsion system

6.9.2. Instruct operator to drive machine to the following speeds:

6.9.2.1. 5km/h

6.9.2.2. 10km/h

6.9.2.3. 15km/h

6.9.2.4. Or maximum speed in each gear and direction up to 10km/h

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

6.9.3.1. EMERGENCY_STOP

6.9.3.2. CONTROLLED_STOP

6.9.3.3. APPLY_PROPULSION_SETPOINTS with SET_PROPULSION_REGISTER to stop machine

6.9.4. With each speed and command combination, note

6.9.4.1. Machine>>CxDreply message

6.9.4.2. Time delay between command and 5% speed reduction

6.9.4.3. Deceleration between 5% reduction and standstill

6.9.4.4. MI after machine has come to a stop

6.10. Machine response to unexpected CxD behaviour

6.10.1. Instruct operator to drive machine FWD at the following speeds:

6.10.1.1. 5km/h

6.10.1.2. 10km/h

6.10.1.3. 30km/h

6.10.1.4. Or maximum speed in each gear up to 30km/h

6.10.2. For each speed, issue a INHIBIT_COMMAND to the MC with the CxD emulator and note:

6.10.2.1. Machine>>CxDreply message

6.10.2.2. Machine response

6.10.3. For each speed, disconnect the CxD emulator from the CAN-bus and note machine response

6.11. Machine response to override:

6.11.1. Note and describe how the override function works in terms of MC, MBS, hydraulic hardware and propulsion system

6.11.2. Note if override is implemented on CxD or on Machine side of the ISO21815-2 connector

6.11.3. With machine stationary, activate override switch and noteMachine>>CxDreply message

6.11.4. Instruct operator to take-off and note Crawl speed at which the machine settles

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is

7.2. The reason for the deviation

7.3. How the deviation may affect the purpose of the test

7.4. Have all parties accept in writing:

7.4.1. the proposed deviation

7.4.2. reason for the proposed deviation and

7.4.3. motivation why the proposed deviation will not affect the purpose of the test

12. Test result

*Table 10: **Example** of noted machine response to introduced failure modes*

	CxD>>MachineCommand	Vel	Run1	Run2	Run3
Firmware versions					
MC			Version 2.7.1.8		
MCI			Version 3.1.4		
Machine details					
OEM			Komatsu		
Model			WX18H		
Serial number			14414		
MI commands					
Machine>>CxDreply	INHIBIT_COMMAND	0	INHIBIT_RESPONSE ON	INHIBIT_RESPONSE ON	INHIBIT_RESPONSE ON
	EMERGENCY_STOP	0	EMERGENCY_STOP_ACK	EMERGENCY_STOP_ACK	EMERGENCY_STOP_ACK
	CONTROLLED_STOP	0	ACTION_ERROR	ACTION_ERROR	ACTION_ERROR
	STAND_DOWN	0	ACTION_ERROR	ACTION_ERROR	ACTION_ERROR
	APPLY_PROPULSION_SETPOINTS	0	ACTION_ERROR	ACTION_ERROR	ACTION_ERROR
Machine response	INHIBIT_COMMAND	0	MI	MI	MI
	EMERGENCY_STOP	0	MI	MI	MI
	CONTROLLED_STOP	0	MI	MI	MI
	STAND_DOWN	0	MI	MI	MI
	APPLY_PROPULSION_SETPOINTS	0	MI	MI	MI
Attachment response	INHIBIT_COMMAND	0	MI	MI	MI
	EMERGENCY_STOP	0	MI	MI	MI
	CONTROLLED_STOP	0	MI	MI	MI
	STAND_DOWN	0	MI	MI	MI
	APPLY_PROPULSION_SETPOINTS	0	MI	MI	MI

Articulation response to	INHIBIT_COMMAND	0	MI	MI	MI
	EMERGENCY_STOP	0	MI	MI	MI
	CONTROLLED_STOP	0	MI	MI	MI
	STAND_DOWN	0	MI	MI	MI
	APPLY_PROPULSION_SETPOINTS	0	MI	MI	MI
Slowdown commands					
Machine>>CxDreply	SLOW_DOWN	15	SLOW_DOWN_ACK	SLOW_DOWN_ACK	SLOW_DOWN_ACK
	Service brake available	15	Yes	Yes	Yes
	STAND_DOWN	15	N/A	N/A	N/A
	Service brake available	15	Yes	Yes	Yes
	APPLY_PROPULSION_SETPOINTS	15	N/A	N/A	N/A
	Service brake available	15	Yes	Yes	Yes
decel. 5% speed red to 5% above crawl speed	SLOW_DOWN	5	0.1g	0.12g	0.11g
	STAND_DOWN	5	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	5	N/A	N/A	N/A
	SLOW_DOWN	10	0.1g	0.12g	0.11g
	STAND_DOWN	10	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	10	N/A	N/A	N/A
	SLOW_DOWN	15	0.1g	0.12g	0.11g
	STAND_DOWN	15	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	15	N/A	N/A	N/A
delay 5% velocity red.	SLOW_DOWN	5	N/A	N/A	N/A
	STAND_DOWN	5	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	5	N/A	N/A	N/A

	SLOW_DOWN	10	0.5s	0.6s	0.55s
	STAND_DOWN	10	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	10	N/A	N/A	N/A
	SLOW_DOWN	15	0.5s	0.6s	0.55s
	STAND_DOWN	15	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	15	N/A	N/A	N/A
Stop commands					
Machine>>CxDreply	EMERGENCY_STOP	10	EMERGENCY_STOP_ACK	EMERGENCY_STOP_ACK	EMERGENCY_STOP_ACK
	CONTROLLED_STOP	10	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	10	N/A	N/A	N/A
decel. 5% speed red to standstill	EMERGENCY_STOP	5	0.34g	0.36g	0.34g
	CONTROLLED_STOP	5	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	5	N/A	N/A	N/A
	EMERGENCY_STOP	10	0.34g	0.36g	0.34g
	CONTROLLED_STOP	10	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	10	N/A	N/A	N/A
delay 5% velocity red.	EMERGENCY_STOP	5	0.5s	0.7s	0.6s
	CONTROLLED_STOP	5	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	5	N/A	N/A	N/A
	EMERGENCY_STOP	10	0.5s	0.7s	0.6s
	CONTROLLED_STOP	10	N/A	N/A	N/A
	APPLY_PROPULSION_SETPOINTS	10	N/A	N/A	N/A
Unexpected CxD behaviour					

	INHIBIT_COMMAND	5	NOP response	NOP response	NOP response
	CxD Emulator disconnected	5	Slowdown and stop	Slowdown and stop	Slowdown and stop
	INHIBIT_COMMAND	10	NOP response	NOP response	NOP response
	CxD Emulator disconnected	10	Slowdown and stop	Slowdown and stop	Slowdown and stop
	INHIBIT_COMMAND	15	NOP response	NOP response	NOP response
	CxD Emulator disconnected	15	Slowdown and stop	Slowdown and stop	Slowdown and stop
Override					
Override on CxD or Machine side?			Machine	Machine	Machine
Machine>>CxDreply	BYPASS_PROPULSION	0	BYPASS_PROPULSION_ACK	BYPASS_PROPULSION_ACK	BYPASS_PROPULSION_ACK
Machine response to override	BYPASS_PROPULSION	0	NOP	NOP	NOP
		0	Crawl at 5km/h	Crawl at 5km/h	Crawl at 5km/h

13. Influence of deviations on outcome

Example: None

14. Acceptance criteria for this test

14.1. Machine MI:

14.1.1. MI achieved in all test runs in both directions with the INR command OR at least one of the stop commands, AND

14.1.2. MI is achieved after vehicle has stopped for the same stop command

14.1.3. For all test runs

14.2. Attachment MI:

14.2.1. Attachment is inoperable

14.2.2. For all test runs

14.3. Articulation MI:

14.3.1. Articulation is not possible

14.3.2. For all test runs

14.4. Slowdown:

14.4.1. Machine slows down with at least one of the slowdown commands, AND

14.4.2. Settles on the crawl speed, AND

14.4.3. Correct reply message received with the same slowdown command, AND

14.4.4. Service brake is available with all slowdown commands, AND

14.4.5. For all test runs

14.4.6. For all speeds

14.5. Set point tracking

14.5.1. For constant speed limit (e.g. speed limited zone) speed is maintained below set point

14.5.2. For decreasing set point, prescribed set point if tracked to within 1km/h

14.6. Stop:

14.6.1. Machine stops with at least one of the slowdown commands, AND

14.6.2. Correct reply message received with the same slowdown command, AND

14.6.3. For all test runs, AND

14.6.4. For all speeds

14.7. Unexpected CxD behaviour

14.7.1. Machine NOP with MI command when in motion, AND

14.7.2. Machine auto-slow and stops with communication interrupted, AND

14.7.3. For all test runs, AND

14.7.4. For all speeds

14.8. Override:

14.8.1. Override switch correctly installed as per ISO/TS21815:2021, AND

14.8.2. Correct reply message received, AND

14.8.3. Settles on the predetermined emergency speed, AND

14.8.4. For all test runs

14.9. Acceleration and delays

14.9.1. Slowdown deceleration rate within OEM's spec, AND

14.9.2. Machine delay between slowdown command and response within OEM's spec, AND

14.9.3. Stop deceleration rate within OEM's spec, AND

14.9.4. Machine delay between stop command and response within OEM's spec, AND

14.9.5. For all test runs

15. Outcome of this test

*Table 11: **Example** outcome for machine controller response test*

		Pass
Machine MI	Machine response to MI commands	Yes
Attachment MI	Attachment response to MI commands	Yes
Articulation MI	Articulation response to MI commands	Yes
Slowdown	Machine response to Slowdown commands	Yes
Stop	Machine response to Stop commands	Yes
Override	Machine response to Override	Yes

*Table 12: **Example** response of machine*

	Value
Average machine delay to Slowdown	0.5 s
Average machine delay to Stop	0.5 s
Average machine deceleration to Slowdown	0.13 g
Average machine deceleration to Stop	0.35 g
Average crawl speed with Slowdown	5 km/h
Average emergency speed with Override	5 km/h

CxD Tests

TRL4 Stage Gate CxD ISO21815 Bench test
CxD ISO/TS21815-2:2021 test protocol (CXDI)

1. Purpose

The CxDI subsystem must be able to communicate with the 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.

2. Preceding tests

None

3. Test facility/site

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

4. Instrumentation

- **4.1.** 1x TMM Emulator
- **4.2.** 1x DAQ with ISO 21815-2 interface
- **4.3.** Power supply that can supply voltage as required (typically 12V or 24V)
- **4.4.** DC current meter
- **4.5.** Multimeter

5. Test preparation

- **5.1.** Get filled out specification sheet from CxDI supplier stating which capabilities and data messages are available (see Appendix A)
- **5.2.** Connect TMM Emulator and DAQ to CxDI CAN-bus via the ISO21815 connector
- **5.3.** If power is to be supplied to the CxDI via the ISO21815 connector, then connect power supply to pins 2,3 and 4 in the ISO21815 connector
- **5.4.** If power is to be supplied to CxDI externally, then connect power supply to this as well
- **5.5.** 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)
- **5.6.** If any alterations are made to any aspect of the MCI during testing (e.g. firmware, rewiring of connector, etc.), all previous testing becomes invalid and this protocol has to be followed from the start

6. Test method

- **6.1.** Note CxDI firmware versions
- **6.2.** Connector
  - **6.2.1.** Note if the Deutsch DT-Series 12-pin socket (male) part is used as in 6.2 of the ISO standard
  - **6.2.2.** Verify pin assignment as specified in 6.2 of the ISO/TS 21815-2
  - **6.2.3.** Confirm availability to accommodate override functionality provided by the TMM and note on CxD side of the connector:

6.2.3.1. Pin assignment as in 6.2 of the ISO standard

6.2.3.2. Logic as in 6.4 of the ISO standard

6.3. Negotiation sequence

6.3.1. If negotiation can be done without the use if trust mechanisms, have the CxDI initiate the negotiation sequence and note:

6.3.1.1. NEGOTIATE_NOP on CxD>>MachineStatus message, Message ID and Time stamp

6.3.1.2. NEGOTIATE_ACK on Machine>>CxDReply message, Message ID and Time stamp

6.3.1.3. PROTOCOL_NOP on CxD>>MachineStatus message, Message ID and Time stamp

6.3.1.4. PROTOCOL_ACK on Machine>>CxDReply message, Message ID and Time stamp

6.3.2. If negotiation cannot be done without the use if trust mechanisms, note it as such and have CxD developer provide a solution to enable negotiation between CxDI and TMM Emulator

6.3.3. After negotiation has been established between CxDI and TMM Emulator, note

6.3.3.1. Average and standard deviation of time delay between repeating PROTOCOL_NOP and PROTOCOL_ACK messages. At least one Message ID counter cycle has to be evaluated

6.3.3.2. Broadcast rate of PROTOCOL_NOP messages

6.4. Re-negotiation

6.4.1. Have the CxDI initiate the negotiation sequence and confirm repeating PROTOCOL_NOP and PROTOCOL_ACK messages

6.4.2. Sever the connection between TMM Emulator and CxDI while maintaining connection between data acquisitioning system and CxDI and note:

6.4.2.1. Time delay between last PROTOCOL_ACK message from TMM Emulator and first NEGOTIATE_NOP message from the CxDI

6.4.3. Restore the connection between TMM Emulator and CxDI and note:

6.4.3.1. Negotiation sequence as before

6.4.3.2. Time delay between reconnection and completed re-negotiation

6.5. Capability enquiry

6.5.1. Pre-set certain capabilities on the TMM Emulator

6.5.2. Confirm that the CxDI can correctly identify the available capabilities of the TMM Emulator with:

6.5.2.1. The MCAPS propulsion register capability enquiry on the CxD>>MachineStatus message

6.5.2.2. Individual capability enquiries on the CxD>>MachineCommand message for

6.5.2.2.1. EMERGENCY_STOP_CONFIRM

6.5.2.2.2. CONTROLLED_STOP_CONFIRM

6.5.2.2.3. SLOW_DOWN_CONFIRM

6.5.2.2.4. STAND_DOWN_CONFIRM

6.5.2.2.5. BYPASS_PROPULSION_CONFIRM

6.5.2.2.6. APPLY_PROPULSION_SETPOINTS_CONFIRM

6.5.3. Confirm that the CxDI can correctly identify the unavailable capabilities of the TMM Emulator as well

6.5.4. Note average and standard deviation of the time delay between all enquiry and reply messages

6.6. Reading protocol registers

6.6.1. Pre-set certain values for the following protocol registers:

6.6.1.1. PROTOCOL_REVISION
6.6.1.2. REGISTER_COUNT
6.6.1.3. SUBSYSTEM_MCAPS
6.6.1.4. INTERFACE_STATE
6.6.1.5. NEGOTIATION_SEED
6.6.1.6. NEGOTIATION_KEY
6.6.1.7. MACHINE_SOFTWARE_REVISION
6.6.1.8. MACHINE_ID_0
6.6.1.9. MACHINE_ID_1
6.6.1.10. MACHINE_ID_2
6.6.1.11. MACHINE_ID_3
6.6.1.12. MACHINE_ID_4
6.6.1.13. INSTRUCTION_TIMEOUT
6.6.1.14. NEGOTIATION_TIMEOUT
6.6.1.15. RENEGOTIATION_TIMEOUT

6.6.2. Confirm that the CxDI can correctly read each protocol register

6.6.3. Confirm that the CxDI can correctly read ERROR or INVALID_DATA responses as well

6.6.4. Note average and standard deviation of the time delay between all enquiry and reply messages

6.7. Reading propulsion registers

6.7.1. Pre-set certain values for the following propulsion registers:

6.7.1.1. PROPULSION_MCAPS
6.7.1.2. MIN_BRAKING
6.7.1.3. MAX_THROTTLE
6.7.1.4. MAX_SPEED
6.7.1.5. EMERGENCY_STOP_MAX_SPEED
6.7.1.6. CONTROLLED_STOP_MAX_SPEED
6.7.1.7. SLOW_DOWN_MAX_SPEED
6.7.1.8. MAX_FORWARD_GEAR
6.7.1.9. MAX_REVERSE_GEAR

6.7.2. Confirm that the CxDI can correctly read each propulsion register

6.7.3. Confirm that the CxDI can correctly read ERROR or INVALID_DATA responses as well

6.7.4. Note average and standard deviation of the time delay between all enquiry and reply to messages

6.8. Setting of protocol registers

6.8.1. Confirm that the CxDI can set new values on the TMM Emulator for the following protocol registers

6.8.1.1. PROTOCOL_REVISION
6.8.1.2. CxD_SOFTWARE_REVISION
6.8.1.3. CxD_HARDWARE_REVISION
6.8.1.4. CxD_HARDWARE_ID

6.9. Reset of registers

6.9.1. Confirm that the CxDI can issue a RESET_REGISTERS action on the CxD>>MachineStatus message by having the following registers return to their default values:

6.9.1.1. PROTOCOL_REVISION
6.9.1.2. CxD_SOFTWARE_REVISION
6.9.1.3. CxD_HARDWARE_REVISION
6.9.1.4. CxD_HARDWARE_ID

6.10. Propulsion commands

6.10.1. Confirm that the CxDI can issue each of the following action commands:

6.10.1.1. EMERGENCY_STOP
6.10.1.2. CONTROLLED_STOP
6.10.1.3. SLOW_DOWN
6.10.1.4. STAND_DOWN
6.10.1.5. BYPASS_PROPULSION
6.10.1.6. APPLY_PROPULSION_SETPOINTS
6.10.1.7. INHIBIT_COMMAND

6.11. Apply propulsion set points

6.11.1. Confirm that the CxDI can set propulsion set points by using the SET_PROPULSION_SETPOINTS action with the following register select values

6.11.1.1. SELECT_REGISTER
6.11.1.2. SELECT_AND_TAG

6.11.2. Confirm that the CxDI can load propulsion set points by using the LOAD_PROPULSION_SETPOINTS action with the following register select values

6.11.2.1. IMMEDIATE
6.11.2.2. UPDATE_AND_APPLY
6.11.2.3. APPLY_FROM_LIST
6.11.2.4. LOOKUP_INDIRECT
6.11.2.5. MATCH_TAG

6.11.3. Confirm that the CxDI checks for set point validity with the APPLY_PROPULSION_SETPOINTS_CONFIRM command

6.11.4. Confirm that the CxDI can apply propulsion set points by using the APPLY_PROPULSION_SETPOINTS command

6.12. Error handling

6.12.1. 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

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

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

6.12.4. Confirm that the CxDI resends command until any timeout is reached

6.12.5. Confirm that the CxDI performs a new renegotiation sequence

6.13. Machine data

6.13.1. Initiate data stream from TMM Emulator on Machine>>CxDdata message

6.13.2. Confirm correct interpretation on the Propulsion subsystem Header of

6.13.2.1. SYSTEM_FAULT

6.13.2.2. OVERRIDE_FAULT

6.13.2.3. ROLLBACK_FAULT

6.13.2.4. TRACTION_FAULT

6.13.2.5. PAYLOAD_FAULT

6.13.3. Confirm correct interpretation on Propulsion subsystem Data of

6.13.3.1. SPEED

6.13.3.2. DIR

6.13.3.3. MOTION_INHIBIT

6.13.3.4. GEAR

6.13.3.5. OVERRIDE_STATUS

6.13.3.6. ROLLBACK_STATUS

6.13.3.7. TRACTION_STATUS

6.13.3.8. PAYLOAD_STATUS

6.13.3.9. PITCH

6.13.3.10. ROLL

6.14. Varying message frequency

6.14.1. Delay the response from the TMM Emulator on the Machine>>CxDreply message from 10ms to 100ms in 10ms increments

6.14.2. With each increment, have the CxDI issue commands and enquiries to the TMM Emulator and note

6.14.2.1. Any messages on CxD>>MachineStatus that are repeated. At least one Message ID counter cycle has to be evaluated

6.14.2.2. Any messages on CxD>>MachineCommand that are repeated. At least one Message ID counter cycle has to be evaluated

6.14.2.3. Average and standard deviation for the time delay between sent messages and reply

6.15. Override

6.15.1. If available, activate override switch on CxD side of the connector

6.15.2. Note BYPASS_PROPULSION action on CxD>>MachineCommand message

6.15.3. Activate override switch on Machine side of the connector and note BYPASS_PROPULSION action on CxD>>MachineCommand message

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
  7.4.1. the proposed deviation
  7.4.2. reason for the proposed deviation and
  7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

See separate file: 2.1 CxD_ISO21815_Bench_test_protocol_Appendix_C_28Jan

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

See separate file: 2.1 CxD_ISO21815_Bench_test_protcol_Appendix_B_28Jan

11. Outcome of this test

See separate file: 2.1 CxD_ISO21815_Bench_test_protocol_Appendix_C_28Jan

Appendix 8: TRL 4 CxD Log keeping Test

TRL4 Stage Gate: CxD ISO21815 Bench test

CxD Log keeping test protocol (CxDLK, CxDI)

1. **Purpose**

The CxDLK 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 CxDLK can perform its log keeping duties successfully to provide a permanent auditable record.

2. **Preceding tests**
   - **2.1.** CxD ISO21815 Bench test
3. **Test facility/site**

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

4. **Instrumentation**
   - **4.1.** CxD Emulator
   - **4.2.** Machine Emulator
   - **4.3.** DAQ with ISO 21815-2 interface
   - **4.4.** Computer
5. **Test preparation**
   - **5.1.** CxD LK complete with CxDI in working order will be supplied to the technical service. An authorized person (technology provider representative) will sign-off that the supplied CxDI is in working order as designed. No modifications to any aspect of the CxDI will be allowed once testing has commenced.
   - **5.2.** Get filled out specification sheet from CxDLK supplier stating which data messages are recorded on the CxDLK (see appendix A)
   - **5.3.** Connect CxD Emulator, Machine Emulator and data acquisitioning system to CxDI CAN-bus via the ISO21815 connector
   - **5.4.** If any alterations are made to the firmware of the CxDLK or CxDI during testing, all previous testing becomes invalid and this protocol must be followed from the start
6. **Test method**
   - **6.1.** Note CxDI and CxDLK firmware versions
   - **6.2.** Synchronisation
     - **6.2.1.** Initiate UTC synchronisation procedure between CxD or Machine Emulator and CxDLK
   - **6.3.** Stored data and accuracy of log file
     - **6.3.1.** Note sufficient storage space as per CxDLK supplier specification sheet
     - **6.3.2.** Initiate data stream with CxD and Machine Emulators
       - **6.3.2.1.** Negotiation between CxD and Machine Emulators
       - **6.3.2.2.** NOP for 60s
       - **6.3.2.3.** Effective warning for 10s
       - **6.3.2.4.** Intervention for 10s
       - **6.3.2.5.** NOP for 60s

6.3.2.6. Override for 10s
6.3.2.7. NOP for 60s
6.3.3. Stop data stream and transfer data to computer
6.3.4. Compare recorded log file with sent data from Emulators and note
6.3.4.1. Discrepancies between data values
6.3.4.2. Discrepancies between time stamps
6.3.4.3. Sample frequency during NOP
6.3.4.4. Intervention sample frequency
6.3.4.5. Preceding recording window before intervention starts
6.4. Data transfer
6.4.1. Note data transfer interface
6.4.2. Generate data until storage reflects a 7-day sized log file
6.4.3. Initiate data transfer and note time duration to transfer log file to computer
6.4.4. Note size of 7-day sized log file
6.5. Data security
6.5.1. Note any security measures to prevent log file from being deleted on CxDLK with a computer
6.5.2. Note any security measures to prevent log file from being altered on CxDLK with a computer
6.5.3. Note redundant measures to ensure that the integrity of the log file will not be compromised with physical damage, electrical discharge or magnetic exposure

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
7.4.1. the proposed deviation
7.4.2. reason for the proposed deviation and
7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 13: **Example** of noted log keeping functionality*

Firmware versions	
CxDLK firmware version	1.6.1.8
CxDI firmware version	3.1.4
Synchronisation	
Synchronisation from CxD or Machine	CxD
Synchronisation successful	Yes
Stored data and accuracy of log	
Storage space available	2GB
Discrepancies between log values	None
Discrepancies between time stamps	None
Sample frequency during NOP	1Hz

Sample frequency during intervention	10Hz
Preceding recording window of intervention	5s
Data transfer	
Data transfer interface	Wifi
Duration to download 7-day sized file	2.3s
Size of 7-day log file	120MB
Security	
Security measures to prevent deletion	Password request upon Wifi login
Security measures to prevent alteration	Password request upon Wifi login
Redundant measures to ensure integrity	2 redundant CxDLKs, each with RAID-1 storage

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

10.1. Synchronisation

10.1.1. CxDLK can synchronise with either CxD or with Machine Emulator

10.2. Stored data and accuracy of log file

10.2.1. All required data as per functional requirement is being recorded, AND

10.2.2. No discrepancies between sent and stored data to within machine precision, AND

10.2.3. Less than 100ms discrepancy between time stamps of sent and stored data, AND

10.2.4. Sample frequency during NOP is 1Hz or faster, AND

10.2.5. Sample frequency during intervention is 10Hz or faster, AND

10.2.6. Recording window starts 5s or earlier before intervention occurs

10.3. Data transfer

10.3.1. Sufficient storage space for 7day-sized log file

10.4. Data security

10.4.1. Some measure in place to prevent deletion, AND

10.4.2. Some measure in place to prevent alteration, AND

10.4.3. Redundant measures in place to ensure log integrity against physical damage, electrical discharge or magnetic exposure

11. Outcome of this test

*Table 14: **Example** of outcome of Log keeping test*

Synchronisation	Pass
Stored data and accuracy	Pass
Data transfer	Pass
Data security	Pass

12. Applicable document

See separate file: 2.2_CxD_Log_keeping_test_protocol_Appendix_A_28Jan

Appendix 9: TRL 4 CxD Self-diagnostic Test

TRL4 Stage Gate: CxD Interaction scenario: **Self-diagnostics (CxDC, CxDI, CxDLK, D&T, OWS)**

1. Purpose

The CxDC, CxDI, CxDLK, D&T and OWS 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.

2. Preceding tests

2.1. CxD ISO21815 bench test protocol

2.2. CxD log-keeping test protocol

3. Test facility/site

Site where fully commissioned CxD system is available on a test vehicle. Tests are mostly static and can be done in a laboratory environment.

4. Instrumentation

4.1. Test vehicle commissioned with full CxD system

4.2. Machine Emulator

5. Test preparation

5.1. The client will supply a CxD in working order. An authorized person (technology provider representative) will sign-off that the supplied CxD is in working order as designed that has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the CxD will be allowed once testing has commenced.

5.2. Fence off test area. Ensure all aspects in Safety protocol is adhered to

5.3. Connect Machine Emulator to the CxD CAN-harness via the ISO21815 connector

5.4. Ensure all personnel, equipment and all obstacles are removed in front and behind of the test vehicle

5.5. Complete negotiation sequence between Machine Emulator and CxD and ensure that CxD is in NOP

5.6. If any alterations are made to the firmware of the CxDC, CxDI, CxDLK, D&T or EW during testing, all previous testing becomes invalid and this protocol has to be followed from the start

6. Test method

6.1. Note firmware versions of CxDC, CxDI, CxDLK, D&T and EW subsystems

6.2. Power interruption

6.2.1. Disconnect power supply to each of the following subsystems

6.2.1.1. CxDC

6.2.1.2. CxDI

6.2.1.3. CxDLK

6.2.1.4. D&T

6.2.1.5. OWS

6.2.2. For each of the subsystems
6.2.2.1. note MI response in FWD and REV directions
6.2.2.2. Reconnect power to subsystem
6.2.2.3. Note NOP response in FWD and REV
6.2.2.4. Repeat 3 times
6.2.3. Treat subsystems as one if contained in a single unit that draws power from a single source

6.3. Comms interruption
6.3.1. Disconnect CAN communication between CxDI and Machine Emulator
6.3.2. Note MI response in FWD and REV directions
6.3.3. Reconnect CAN communication between CxDI and Machine Emulator
6.3.4. Note NOP response in FWD and REV directions
6.3.5. Repeat 3 times

6.4. CxDLK storage full
6.4.1. Fill CxDLK with data
6.4.2. Note MI response in FWD and REV
6.4.3. Delete data from CxDLK to free up space
6.4.4. Note NOP response

6.5. CxDLK not recording
6.5.1. Initiate recording fault in CxDLK
6.5.2. Note MI response in FWD and REV
6.5.3. Restore fault in CxDLK
6.5.4. Note NOP response in FWD and REV

6.6. CxD elements unplugged
6.6.1. Disconnect each of the following elements
6.6.1.1. OWS Screen
6.6.1.2. D&T sensors
6.6.1.3. Any other elements that can be unplugged
6.6.2. Note MI response in FWD and REV
6.6.3. Reconnect unplugged element
6.6.4. Note NOP response in FWD and REV

6.7. Synchronisation fault
6.7.1. Initiate synchronisation procedure between CxD and Machine Emulator and note NOP
6.7.2. Initiate synchronisation mismatch on CxD by changing the real-time clock on Machine Emulator
6.7.3. Note MI response in FWD and REV
6.7.4. Restore fault by initiating synchronisation procedure between CxD and Machine Emulator
6.7.5. Note NOP response in FWD and REV

6.8. Override switch disconnected
6.8.1. Disconnect both wires of the override switch
6.8.2. Note MI response in FWD and REV
6.8.3. Reconnect both wires of the override switch
6.8.4. Note NOP response in FWD and REV

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
  7.4.1. the proposed deviation
  7.4.2. reason for the proposed deviation and
  7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 15: **Example** of machine response to introduced failure modes*

Firmware versions				
CxDC firmware version				2.7.1.8
CxDI firmware version				3.1.4
CxDLK firmware version				1.6.1.8
D&T firmware version				2.7.1.8
OWS firmware version				3.1.4
Power interruption				
	Run1	**Run2**	**Run3**	**Notes**
CxDC interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
CxDI interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
CxDLK interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
D&T interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
OWS interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
Comms interrupted				
CxDI interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
CxDLK				
CxDLK storage full	MI	MI	MI	
CxDLK storage available	NOP	NOP	NOP	
CxDLK fault	MI	MI	MI	
CxDLK restored	NOP	NOP	NOP	
CxD Elements unplugged				
OWS screen unplugged	MI	MI	MI	
OWS screen reconnected	NOP	NOP	NOP	
D&T sensor unplugged	MI	MI	MI	
D&T sensor reconnected	NOP	NOP	NOP	
Synchronisation				

Synchronisation mismatch	MI	MI	MI	
Synchronisation restored	NOP	NOP	NOP	
Override disconnected				
Override disconnected	MI	MI	MI	
Override reconnected	NOP	NOP	NOP	

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

10.1. CxDC:

10.1.1. MI achieved in both directions with power interruption, AND

10.1.2. System returns to NOP after power is restored, AND

10.1.3. For all test runs

10.2. CxDI:

10.2.1. MI achieved in both directions with power interruption and comms interruption, AND

10.2.2. System returns to NOP after failure mode is restored, AND

10.2.3. For all test runs

10.3. CxDLK:

10.3.1. MI achieved in both directions with power interruption, full storage, recording fault, synchronisation mismatch, AND

10.3.2. System returns to NOP after failure mode is restored, AND

10.3.3. For all test runs

10.4. D&T:

10.4.1. MI achieved in both directions with power interruption, sensors unplugged, AND

10.4.2. System returns to NOP after failure mode is restored, AND

10.4.3. For all test runs

10.5. OWS:

10.5.1. MI achieved in both directions with power interruption, sensors unplugged, AND

10.5.2. System returns to NOP after failure mode is restored, AND

10.5.3. For all test runs

10.6. Override:

10.6.1. MI achieved in both directions when unplugged, AND

10.6.2. System returns to NOP after restoring failure mode

10.6.3. For all test runs

11. Outcome of this test

*Table 16: **Example** outcome for self-diagnostics test*

		Pass
CxDC	Fail to safe with all failure modes and restore to NOP	Yes
CxDI	Fail to safe with all failure modes and restore to NOP	Yes
CxDLK	Fail to safe with all failure modes and restore to NOP	Yes

D&T	Fail to safe with all failure modes and restore to NOP	Yes
OWS	Fail to safe with all failure modes and restore to NOP	Yes
Override	Fail to safe with all failure modes and restore to NOP	Yes

Appendix 10: TRL 4 CxD Self-diagnostic Test

TRL4 Stage Gate: CxD Interaction scenario: **Self-diagnostics Underground test protocol (CxDC, CxDI, CxDLK, D&T, OWS and PWS)**

1. **Purpose**

The CxDC, CxDI, CxDLK, D&T 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.

2. **Preceding tests**
   - **2.1.** CxD ISO21815 bench test protocol
   - **2.2.** CxD log-keeping test protocol
3. **Test facility/site**

Site where fully commissioned CxD system is available on a test vehicle. Tests are mostly static and can be done in a laboratory environment.

4. **Instrumentation**
   - **4.1.** Test vehicle commissioned with full CxD system
   - **4.2.** Machine Emulator
   - **4.3.** 1 Pedestrian tag
5. **Test preparation**
   - **5.1.** The client will supply a CxD in working order. An authorized person (technology provider representative) will sign-off that the supplied CxD is in working order as designed that has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the CxD will be allowed once testing has commenced.
   - **5.2.** Fence off test area. Ensure all aspects in Safety protocol is adhered to
   - **5.3.** Connect Machine Emulator to the CxD CAN-harness via the ISO21815 connector
   - **5.4.** Ensure all personnel, equipment and all obstacles are removed in front and behind of the test vehicle
   - **5.5.** Complete negotiation sequence between Machine Emulator and CxD and ensure that CxD is in NOP
   - **5.6.** If any alterations are made to the firmware of the CxDC, CxDI, CxDLK, D&T or EW during testing, all previous testing becomes invalid and this protocol has to be followed from the start
6. **Test method**
   - **6.1.** Note firmware versions of CxDC, CxDI, CxDLK, D&T and EW subsystems
   - **6.2.** Power interruption
     - **6.2.1.** Disconnect power supply to each of the following subsystems
       - **6.2.1.1.** CxDC
       - **6.2.1.2.** CxDI
       - **6.2.1.3.** CxDLK

6.2.1.4. D&T
6.2.1.5. OWS
6.2.1.6. PWS

6.2.2. For each of the subsystems
6.2.2.1. note MI response in FWD and REV directions
6.2.2.2. Reconnect power to subsystem
6.2.2.3. Note NOP response in FWD and REV
6.2.2.4. Repeat 3 times

6.2.3. Treat subsystems as one if contained in a single unit that draws power from a single source

6.3. Comms interruption
6.3.1. Disconnect CAN communication between CxDI and Machine Emulator
6.3.2. Note MI response in FWD and REV directions
6.3.3. Reconnect CAN communication between CxDI and Machine Emulator
6.3.4. Note NOP response in FWD and REV directions
6.3.5. Repeat 3 times

6.4. CxDLK storage full
6.4.1. Fill CxDLK with data
6.4.2. Note MI response in FWD and REV
6.4.3. Delete data from CxDLK to free up space
6.4.4. Note NOP response

6.5. CxDLK not recording
6.5.1. Initiate recording fault in CxDLK
6.5.2. Note MI response in FWD and REV
6.5.3. Restore fault in CxDLK
6.5.4. Note NOP response in FWD and REV

6.6. CxD elements unplugged
6.6.1. Disconnect each of the following elements
6.6.1.1. OWS Screen
6.6.1.2. D&T sensors
6.6.1.3. Any other elements that can be unplugged
6.6.2. Note MI response in FWD and REV
6.6.3. Reconnect unplugged element
6.6.4. Note NOP response in FWD and REV

6.7. Synchronisation fault
6.7.1. Initiate synchronisation procedure between CxD and Machine Emulator and note NOP
6.7.2. Initiate synchronisation mismatch on CxD by changing the real-time clock on Machine Emulator
6.7.3. Note MI response in FWD and REV
6.7.4. Restore fault by initiating synchronisation procedure between CxD and Machine Emulator
6.7.5. Note NOP response in FWD and REV

6.8. Override switch disconnected
6.8.1. Disconnect both wires of the override switch

6.8.2. Note MI response in FWD and REV
6.8.3. Reconnect both wires of the override switch
6.8.4. Note NOP response in FWD and REV

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
7.4.1. the proposed deviation
7.4.2. reason for the proposed deviation and
7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 17: **Example** noted machine response to introduced failure modes*

Firmware versions				
CxDC firmware version				2.7.1.8
CxDI firmware version				3.1.4
CxDLK firmware version				1.6.1.8
D&T firmware version				2.7.1.8
OWS firmware version				3.1.4
PWS firmware version				1.6.1.8
Power interruption				
	Run1	**Run2**	**Run3**	**Notes**
CxDC interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
CxDI interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
CxDLK interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
D&T interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
OWS interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
PWS interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
Comms interrupted				
CxDI interrupted	MI	MI	MI	
Restored	NOP	NOP	NOP	
CxDLK				
CxDLK storage full	MI	MI	MI	
CxDLK storage available	NOP	NOP	NOP	
CxDLK fault	MI	MI	MI	

CxDLK restored	NOP	NOP	NOP	
CxD Elements unplugged				
OWS screen unplugged	MI	MI	MI	
OWS screen reconnected	NOP	NOP	NOP	
D&T sensor unplugged	MI	MI	MI	
D&T sensor reconnected	NOP	NOP	NOP	
Synchronisation				
Synchronisation mismatch	MI	MI	MI	
Synchronisation restored	NOP	NOP	NOP	
Override disconnected				
Override disconnected	MI	MI	MI	
Override reconnected	NOP	NOP	NOP	

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

10.1. CxDC:

10.1.1. MI achieved in both directions with power interruption, AND

10.1.2. System returns to NOP after power is restored, AND

10.1.3. For all test runs

10.2. CxDI:

10.2.1. MI achieved in both directions with power interruption and comms interruption, AND

10.2.2. System returns to NOP after failure mode is restored, AND

10.2.3. For all test runs

10.3. CxDLK:

10.3.1. MI achieved in both directions with power interruption, full storage, recording fault, synchronisation mismatch, AND

10.3.2. System returns to NOP after failure mode is restored, AND

10.3.3. For all test runs

10.4. D&T:

10.4.1. MI achieved in both directions with power interruption, sensors unplugged, AND

10.4.2. System returns to NOP after failure mode is restored, AND

10.4.3. For all test runs

10.5. OWS:

10.5.1. MI achieved in both directions with power interruption, sensors unplugged, AND

10.5.2. System returns to NOP after failure mode is restored, AND

10.5.3. For all test runs

10.6. PWS:

10.6.1. Clear indication on PWS that failure mode is present

10.7. Override:

10.7.1. MI achieved in both directions when unplugged, AND

10.7.2. System returns to NOP after restoring failure mode

10.7.3. For all test runs

11. Outcome of this test

*Table 18: **Example** outcome for self-diagnostics test*

		Pass
CxDC	Fail to safe with all failure modes and restore to NOP	Yes
CxDI	Fail to safe with all failure modes and restore to NOP	Yes
CxDLK	Fail to safe with all failure modes and restore to NOP	Yes
D&T	Fail to safe with all failure modes and restore to NOP	Yes
OWS	Fail to safe with all failure modes and restore to NOP	Yes
PWS	Clear indication that failure mode exists	Yes
Override	Fail to safe with all failure modes and restore to NOP	Yes

Appendix 11: TRL 4 Surface CxD Effective Warning Test

TRL4 Stage Gate: CxD Interactive scenario:
Effective warning Surface test protocol (OWS)

1. Purpose

The EW system consists of the OWS subsystem and must be able to issue an effective warning to both operators in the case of surface mining operations. The purpose of this test is to determine if the warning issued to both parties is effective.

2. Preceding test

- **2.1.** CxD ISO21815 Bench test
- **2.2.** CxD log-keeping test
- **2.3.** CxD Self-diagnostics test

3. Test facility/site

Site where 2 test vehicles are available. Tests are dynamic and need adequate space for run-up, conducting the test and run-off. Surface needs to be level.

4. Instrumentation

- **4.1.** 2x Test vehicles with CxDC, CxDI and D&T subsystems installed
- **4.2.** 2x HP GNSS
- **4.3.** 2x DAQs with ISO 21815-2 interfaces
- **4.4.** 2x Video cameras, each synchronised with DAQ

5. Test preparation

- **5.1.** The client will supply a CxD in working order. An authorized person (technology provider representative) will sign-off that the supplied CxD is in working order as designed that has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the CxD will be allowed once testing has commenced.
- **5.2.** Fence off test area. Ensure all aspects in Safety protocol is adhered to
- **5.3.** Install HP GNSS on test vehicles and ensure good satellite reception is obtained
- **5.4.** Install video camera to record alerts on OWS on each test vehicle
- **5.5.** Ensure all personnel, equipment and all obstacles are removed in front and behind of the test vehicles

6. Test method

- **6.1.** Note firmware versions of OWS
- **6.2.** Timing between two OWSs
  - **6.2.1.** In flat open space
  - **6.2.2.** Have two test vehicles approach one another head-on at 5km/h
  - **6.2.3.** Note the time difference between start of the warnings for the two OWSs
  - **6.2.4.** Repeat 3 times
- **6.3.** Effectiveness of OWS
  - **6.3.1.** Describe device/devices briefly
  - **6.3.2.** Approach other test vehicle head-on at 5km/h and note all of the following

6.3.2.1. Visual: note screen size, clarity of displayed information, changing backlight to accommodate both bright sunlight and dark operating conditions, flashing lights or other methods used to draw the operator's attention

6.3.2.2. Audible: note information conveyed, use of voice or alarm

6.3.2.3. During NOP: note machine information displayed, clear indication that no interactors are detected, clarity that system is healthy and in NOP, any disturbance that may distract operator

6.3.2.4. During detection: alerts to draw operator's attention, note how interactors are displayed relative to operator's and machine's orientation, update rate of interactors' information, what information about interactor state is conveyed

6.3.2.5. During warning: note clear communication of interactor with highest priority, use of visuals and audible alerts, persistency of alarms, advisory information supplied to operator, clarity of how the situation can be resolved

6.3.2.6. During intervention: note clear communication to operator of active intervention, instructions on what is expected from operator after intervention, clear indication if intervention is because of vehicle proximity or restricted area beacon

6.3.3. Note overall success of human centred design

6.4. Ergonomics of OWS

6.4.1. Backlight adjustable, inputs available to operator to interact with OWS, intensity of audible alarms effective in representative environment and still within safe limits

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is

7.2. The reason for the deviation

7.3. How the deviation may affect the purpose of the test

7.4. Have all parties accept in writing:

7.4.1. the proposed deviation

7.4.2. reason for the proposed deviation and

7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 19: **Example** of noted machine response to introduced failure modes*

Firmware versions				
OWS		2.7.1.8		
Timing between warning systems				
Time difference		**Run1**	**Run2**	**Run3**
FWD	**5km/h**	0.1s	0.2s	0.2s
REV	**5km/h**	0.1s	0.2s	0.2s
OWS				
Brief description		Mounted screen with buttons on side		

Visual	10inch screen, manually adjustable backlight, multi-colour flashing LED used to alert operator
Audible	Simple voiced commands “warning”, “stop”
NOP	Empty map displayed with Machine in centre
Detection	Interactors displayed on map with Machine in centre, updates every 0.5s, range in m of each interactor shown, green LED flashes once every 3 seconds
Warning	Highest priority interactor highlighted on screen, red LED flashes rapidly, loud “warning” alert three times
Intervention	Highest priority interactor highlighted on screen, solid red LED, loud “stop” alert three times

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

10.1. Time difference between vehicle EWs less than 1s

10.2. Vehicle EW visual

10.2.1. Clear distinction between NOP, warning and stop alert levels, AND

10.2.2. Visual alerts clear easy to understand during intervention, AND

10.2.3. Visual alerts non-distracting during NOP, AND

10.2.4. Screen clearly shows the interactor with highest priority during warning AND intervention

10.3. Vehicle EW audible

10.3.1. Audible alerts non-distracting during NOP, AND

10.3.2. Audible alerts volume adjustable, AND

10.3.3. Audible alerts clear easy to understand during warning AND intervention

11. Outcome of this test

*Table 20: **Example** outcome for machine controller response test*

	Pass
OWS EW Visual alerts	Yes
OWS EW Audible alerts	Yes

Appendix 12: TRL 4 Underground CxD Effective Warning Test

TRL4 Stage Gate: CxD Interactive scenario (UG)

Effective Warning Underground test protocol (OWS & PWS)

1. Purpose

The EWS system consists of the OWS and PWS subsystems and must be able to issue an effective warning to both operator and pedestrian in the case of underground mining operations. The purpose of this test is to determine if the warning issued to both parties is effective.

2. Preceding test

- **2.1.** CxD ISO21815 Bench test
- **2.2.** CxD log-keeping test
- **2.3.** CxD Self-diagnostics test

3. Test facility/site

Site where test vehicle is available. Tests are dynamic and need adequate space for run-up, conducting the test and run-off. Surface needs to be level.

4. Instrumentation

- **4.1.** Test vehicle with CxDC, CxDI and D&T subsystems installed
- **4.2.** HP GNSS
- **4.3.** 2x DAQs with ISO 21815-2 interfaces (one for OWS, one for PWS)
- **4.4.** 2x Video cameras, each synchronised with a DAQ
- **4.5.** 2x microphones, each synchronised with a DAQ
- **4.6.** 1x pedestrian tag

5. Test preparation

- **5.1.** The client will supply a CxD in working order. An authorized person (technology provider representative) will sign-off that the supplied CxD is in working order as designed that has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the CxD will be allowed once testing has commenced.
- **5.2.** Fence off test area. Ensure all aspects in Safety protocol is adhered to.
- **5.3.** Install HP GNSS on test vehicles and ensure good satellite reception is obtained.
- **5.4.** Install video camera, microphone to record alerts on OWS.
- **5.5.** Install video camera, microphone, SP GNSS and DAQ to record alerts on PWS.
- **5.6.** Ensure all personnel, equipment and all obstacles are removed in front and behind of the test vehicles.

6. Test method

- **6.1.** Note firmware versions of OWS and PWS
- **6.2.** Timing between OWS and PDS
  - **6.2.1.** In flat open space
  - **6.2.2.** Place pedestrian tag approximately 40m away from test vehicle
  - **6.2.3.** Approach pedestrian tag head-on at 5km/h

6.2.4. Note the time difference between start of the warnings for the OWS and PWS

6.2.5. Repeat 3 times

6.3. Effectiveness of OWS

6.3.1. Describe device/devices briefly

6.3.2. Approach pedestrian tag head-on at 5km/h and note all of the following

6.3.2.1. Visual: note screen size, clarity of displayed information, changing backlight to accommodate both bright sunlight and dark operating conditions, flashing lights or other methods used to draw the operator's attention

6.3.2.2. Audible: note information conveyed, use of voice or alarm

6.3.2.3. During NOP: note machine information displayed, clear indication that no interactors are detected, clarity that system is healthy and in NOP, any disturbance that may distract operator

6.3.2.4. During detection: alerts to draw operator's attention, note how interactors are displayed relative to operator's and machine's orientation, update rate of interactors' information, what information about interactor state is conveyed

6.3.2.5. During warning: note clear communication of interactor with highest priority, use of visuals and audible alerts, persistency of alarms, advisory information supplied to operator, clarity of how the situation can be resolved

6.3.2.6. During intervention: note clear communication to operator of active intervention, instructions on what is expected from operator after intervention, clear indication if intervention is because of pedestrian proximity or pedestrian activated emergency stop or restricted area beacon

6.3.3. Note overall success of human centred design

6.4. Effectiveness of PWS

6.4.1. Describe device/devices briefly

6.4.2. Approach pedestrian tag head-on at 5km/h and note all of the following

6.4.2.1. Visual: note visual alerts used to communicate to pedestrian wearing the PWS, alerts to other nearby pedestrians, clear distinction between NOP and warning and intervention, use of coloured lights, use of flashes

6.4.2.2. Audio: note audible alerts used to communicate to pedestrian, use of voice or alarm, clear distinction between NOP and warning and intervention

6.4.2.3. Haptic: note any vibration alerts to communicate to pedestrian

6.4.2.4. During NOP: clear indication that no interactors are detected, clear indication that system is healthy and in NOP, clear indication of battery life, clear indication of NOP to nearby pedestrians

6.4.2.5. During detection: alerts used to draw pedestrian's attention, clear indication that pedestrian is detected

6.4.2.6. During warning: alerts used to draw pedestrian's attention, clear indication that concerning pedestrian is being warned

6.4.2.7. During intervention: alerts used to draw pedestrian's attention; clear indication that concerning pedestrian caused intervention

6.4.2.8. Emergency activated stop: note ease of use, protection against accidental activation

6.4.3. Approach pedestrian tag head-on at 5km/h

6.4.4. Activate emergency stop when test vehicle is 25m away from pedestrian tag

6.4.4.1. Note time delay between trigger and vehicle response

6.4.4.2. Note clear indication to pedestrian that emergency stop has been activated

6.4.5. Note overall success of human centred design

6.5. Ergonomics of OWS

6.5.1. Backlight adjustable, inputs available to operator to interact with OWS, intensity of audible alarms effective in representative environment and still within safe limits

6.6. Ergonomics of PWS

6.6.1. Ease of integration of PWS into standard mining kit, weight of PWS, intensity of audible alarms effective in representative environment and still within safe limits

6.7. Tamper proof PWS

6.7.1. Note any tamperproof mechanisms the PWS has in place

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is

7.2. The reason for the deviation

7.3. How the deviation may affect the purpose of the test

7.4. Have all parties accept in writing:

7.4.1. the proposed deviation

7.4.2. reason for the proposed deviation and

7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 21: **Example** of noted machine response to introduced failure modes*

Firmware versions				
PWS		3.1.4		
OWS		2.7.1.8		
Timing between warning systems				
Time difference		**Run1**	**Run2**	**Run3**
FWD	**5km/h**	0.1s	0.2s	0.2s
REV	**5km/h**	0.1s	0.2s	0.2s
OWS				
Brief description		Mounted screen with buttons on side		
Visual		10inch screen, manually adjustable backlight, multi-colour flashing LED used to alert operator		
Audible		Simple voiced commands “warning”, “stop”		
NOP		Empty map displayed with Machine in centre		
Detection		Interactors displayed on map with Machine in centre, updates every 0.5s, range in m of each interactor shown, green LED flashes once every 3 seconds		
Warning		Highest priority interactor highlighted on screen, red LED flashes rapidly, loud “warning” alert three times		
Intervention		Highest priority interactor highlighted on screen, solid red LED, loud “stop” alert three times		

PWS				
Brief description		Hip worn unit with cap lamp on 1.2m lead		
Visual		Multi-coloured flashing LED used to alert pedestrian, LED bright and clearly visible to nearby pedestrians		
Audible		High pitched alarm that changes tone		
Haptic		Vibration to alert pedestrian		
NOP		Green flashing LED once every 5s		
Detection		Yellow flashing LED once every 1s		
Warning		Red rapidly flashing LED, vibration		
Intervention		Solid red LED, vibration		
Emergency stop		Large button on top, flip-up cover for accidental activation, can be activated with one hand		
Pedestrian activated emergency stop				
Time difference		**Run1**	**Run2**	**Run3**
FWD	**5km/h**	0.2s	0.3s	0.4s
REV	**5km/h**	0.2s	0.3s	0.4s

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

10.1. Time difference between vehicle EW and pedestrian EW less than 1s

10.2. Vehicle EW visual

10.2.1. Clear distinction between NOP, warning and stop alert levels, AND

10.2.2. Visual alerts clear easy to understand during intervention, AND

10.2.3. Visual alerts non-distracting during NOP, AND

10.2.4. Screen clearly shows the interactor with highest priority during warning AND intervention

10.3. Vehicle EW audible

10.3.1. Audible alerts non-distracting during NOP, AND

10.3.2. Audible alerts volume adjustable

10.3.3. Audible alerts clear easy to understand during warning AND intervention

10.4. Pedestrian EW visual

10.4.1. Clear distinction between NOP, warning and stop alert levels, AND

10.4.2. Visual alerts non-distracting during NOP, AND

10.4.3. Visual alerts clearly attract pedestrian's attention during warning AND intervention

10.5. Pedestrian EW audible

10.5.1. Audible alerts non-distracting during NOP, AND

10.5.2. Audible alerts clearly attract pedestrian's attention during warning AND intervention

10.6. Pedestrian activated emergency stop

10.6.1. Easily accessible, AND

10.6.2. Protected against accidental activation

10.7. PWS protected against tampering

10.7.1. PWS protected against tampering

11. Outcome of this test

*Table 22: **Example** outcome for machine controller response test*

	Pass
OWS EW Visual alerts	Yes
OWS EW Audible alerts	Yes
PWS EW Visual alerts	Yes
PWS EW Audible alerts	Yes
PWS activated emergency stop	Yes
PWS tag protected against tampering	Yes

Appendix 13: TRL 4 Surface CxD Basic Detection and Tracking Test

TRL4 CxD Interactive scenario stage gate

CxD Basic detection and tracking Surface test protocol (D&T)

1. Purpose

The D&T subsystem must be able to detect, track 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 representative environment.

2. Preceding test

- **2.1.** CxD ISO21815 Bench test
- **2.2.** CxD log-keeping test
- **2.3.** CxD Self-diagnostics test
- **2.4.** CxD Effective warning test

3. Test facility/site

Site where a fully commissioned CxD system is available on a test vehicle. Tests are dynamic and need adequate space for run-up, conducting the test and run-off.

4. Instrumentation

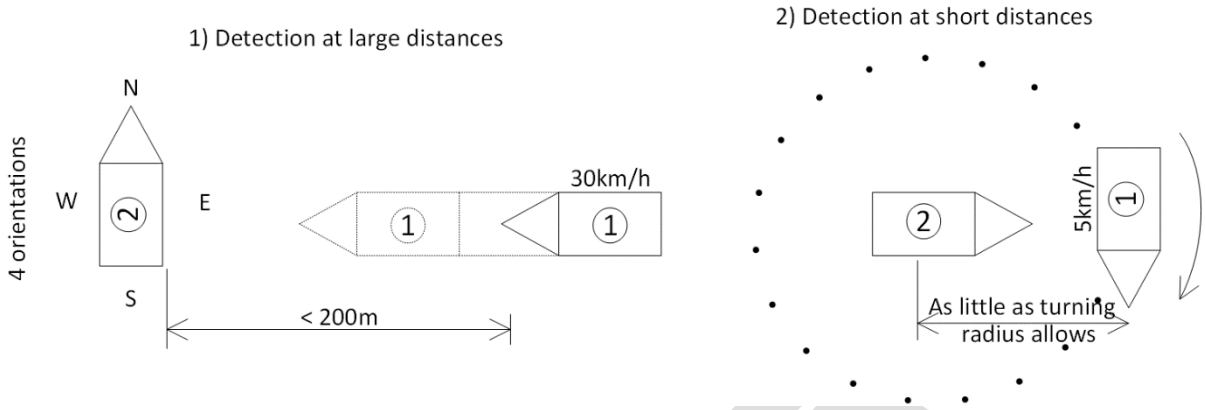
- **4.1.** 7x Test vehicles with CxDs installed
- **4.2.** 3x HP GNSS
- **4.3.** 4x SP GNSS
- **4.4.** 7x DAQs with ISO/TS 21815-2 interface
- **4.5.** 7x Machine Emulator

5. Test preparation

- **5.1.** The client will supply seven CxDs in working order, one for each test vehicle. Each CxD to be configured as per test vehicle machine type. An authorized person (technology provider representative) will sign-off that the supplied CxD is in working order as designed that has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the CxD will be allowed once testing has commenced.
- **5.2.** Fence off test area. Ensure all aspects in Safety protocol is adhered to.
- **5.3.** Install HP GNSS on test vehicle and ensure good satellite reception is obtained.
- **5.4.** Ensure all personnel, equipment and all obstacles are removed in front and behind of the test vehicles.
- **5.5.** Survey test area with HP GNSS to place cones at the correct positions

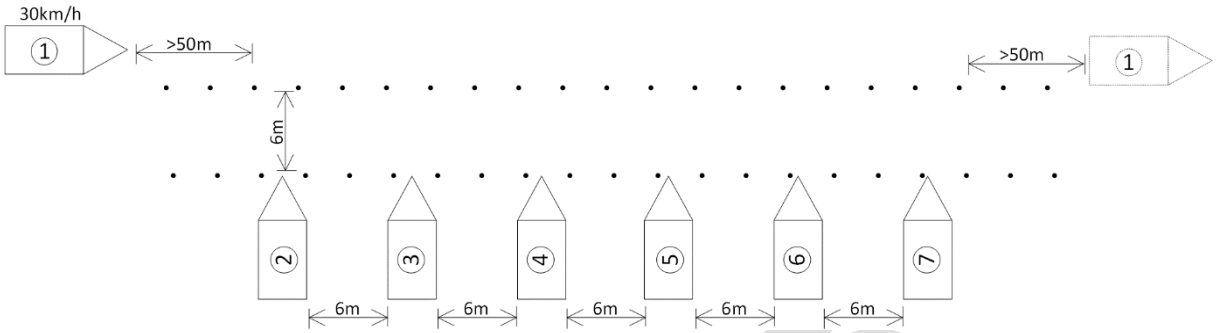
6. Test method

- **6.1.** Note firmware versions of CxDC, CxDI, CxDLK
- **6.2.** Initiate UTC synchronisation procedure between CxD and Machine Emulator
- **6.3.** Test configuration 1: Drop-out and range test



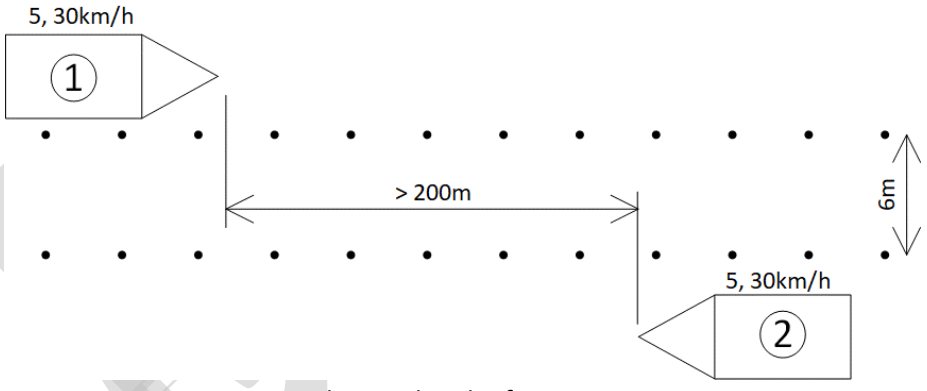
6.3.1. Set up test area as depicted in the left panel of the figure
6.3.2. Scenario 1: Detection at large distances
6.3.3. Position test vehicle 2 in the centre of test area such that it is orientated to allow test vehicle 1 to approach it from an Easterly direction
6.3.4. Start recording on test vehicle 1
6.3.5. Have test vehicle 1 approach test vehicle 2 at a speed of 30km/h from a distance of at least 200m
6.3.6. Stop recording on test vehicle 1 when close to test vehicle 2
6.3.7. Download log from CxDLK and note continuous detection of test vehicle 2 in Additional Continuous message in log file
6.3.8. Note the maximum distance at which test vehicle 2 is detected
6.3.8.1. Repeat 3 times
6.3.8.2. Re-position test vehicle 2 and repeat test for each North-South-East-West orientation
6.3.9. Set up test area as depicted in the right panel of the figure
6.3.10. Scenario 2: Detection at short distances
6.3.11. Position test vehicle 2 in the centre of test area
6.3.12. Have test vehicle 1 drive clockwise around test vehicle 2 in the smallest radius that the turning radius allows at a speed of 5km/h
6.3.13. Stop recording when test vehicle 1 returns to its starting position
6.3.14. Download log from CxDLK and note continuous detection of test vehicle 1 in Additional Continuous message in log file
6.3.15. Repeat 3 times

6.4. Test configuration 2: Multiple object test



6.4.1. Set up test area as depicted in the figure
6.4.2. Position test vehicles 2 to 7 in a line such that there is a 6m gap between each vehicle
6.4.3. Start recording on test vehicle 1 at least 50m away from test vehicle 2
6.4.4. Have test vehicle 1 pass all stationary test vehicles with a pass gap of 6m at a speed of 30km/h
6.4.5. Stop recording on test vehicle 2 at least 50m away from test vehicle 7
6.4.6. Download logs and note detection of 6 vehicles in Additional_Continuous message on log file
6.4.7. Repeat 3 times

6.5. Test configuration 3: Passing



6.5.1. Set up test area as depicted in the figure
6.5.2. Start recording on both test vehicles 1 and 2
6.5.3. Have the two test vehicles approach and pass one another head-on from a distance of at least 200m at speed combinations of 5-5 and 30-30km/h
6.5.4. Continue driving until the two test vehicles are again at least 200m apart
6.5.5. Stop recording
6.5.6. Download logs and note detection of 6 vehicles in Additional_Continuous message on log file
6.5.7. Repeat 3 times for each speed combination

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
  7.4.1. the proposed deviation
  7.4.2. reason for the proposed deviation and
  7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 23: **Example** of noted machine response to introduced failure modes*

Firmware versions				
CxDC		3.1.4		
CxDI		2.7.1.8		
CxDLK		1.6.1.8		
Drop-out and range test				
		Run1	**Run2**	**Run3**
Detected vehicles large dist	N	1	1	1
Drop-outs during test	N	0	0	0
Detected vehicles large dist	E	1	1	1
Drop-outs during test	E	0	0	0
Detected vehicles large dist	S	1	1	1
Drop-outs during test	S	0	0	0
Detected vehicles large dist	W	1	1	1
Drop-outs during test	W	0	0	0
Detected vehicles short dist	-	1	1	1
Drop-outs during test	-	0	0	0
Multiple objects test				
		Run1	**Run2**	**Run3**
Detected vehicles large dist		6	6	6
Drop-outs during test		0	0	0
Passing test				
Detected vehicles		1	1	1
Drop-outs during test		0	0	0
Max detected distance		211m	208m	207m

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

10.1. Drop-out and range test:
  10.1.1. Detect vehicle for the entire time that data was recorded at large distance, AND
  10.1.2. Detect vehicle for the entire time that data was recorded at small distance, AND

10.1.3. For all three runs

10.2. Multiple objects test

10.2.1. Detect all 6 vehicles, AND

10.2.2. For entire duration of recording, AND

10.2.3. For all runs

10.3. Passing test

10.3.1. Detected vehicle for entire time that data was recorded, AND

10.3.2. Maximum detection distance is greater than 200m, AND

10.3.3. For all runs

11. Outcome of this test

*Table 24: **Example** outcome for machine controller response test*

	Pass
Drop-out and range test	Yes
Multiple object test	Yes
Passing test	Yes

Appendix 14: TRL 4 Underground CxD Basic Detection and Tracking Test

TRL4 Stage Gate: CxD Interactive scenario:
CxD Basic detection and tracking Underground test protocol (D&T)

1. Purpose

The D&T subsystem 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 representative environment.

2. Preceding test

- **2.1.** CxD ISO21815 Bench test
- **2.2.** CxD log-keeping test
- **2.3.** CxD Self-diagnostics test
- **2.4.** CxD Effective warning test

3. Test facility/site

Site where a fully commissioned CxD system is available on a test vehicle. Tests are dynamic and need adequate space for run-up, conducting the test and run-off.

4. Instrumentation

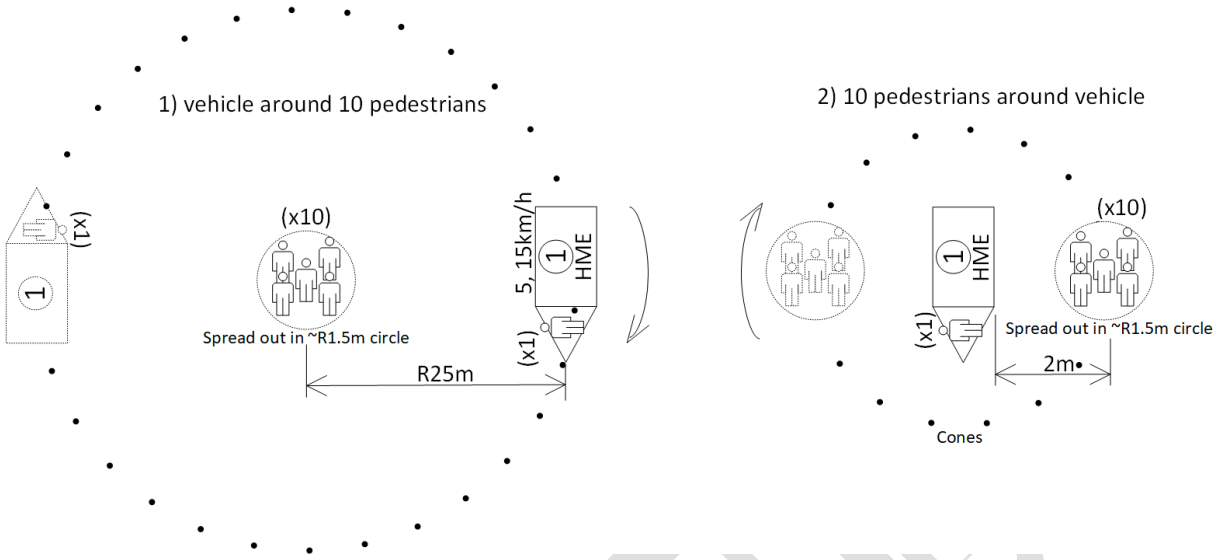
- **4.1.** 1x Test vehicle with CxD installed
- **4.2.** 1x HP GNSS
- **4.3.** 1x DAQ with ISO/TS 21815-2 interface
- **4.4.** 1x Machine Emulator
- **4.5.** 11x pedestrian tags

5. Test preparation

- **5.1.** The client will supply a CxD in working order. An authorized person (technology provider representative) will sign-off that the supplied CxD is in working order as designed that has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the CxD will be allowed once testing has commenced.
- **5.2.** Fence off test area. Ensure all aspects in Safety protocol is adhered to.
- **5.3.** Install HP GNSS on test vehicle and ensure good satellite reception is obtained.
- **5.4.** Ensure all personnel, equipment and all obstacles are removed in front and behind of the test vehicles.
- **5.5.** Survey test area with HP GNSS to place cones at the correct distances

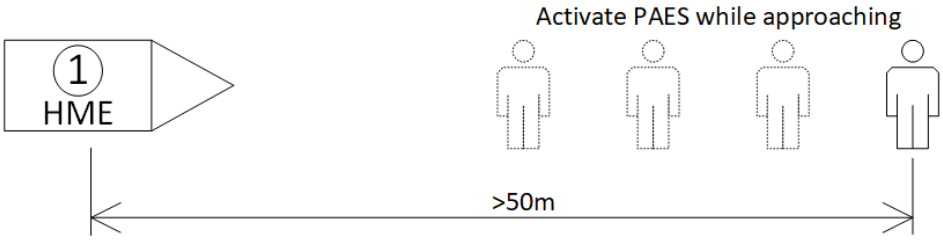
6. Test method

- **6.1.** Note firmware versions of CxDC, CxDI, CxDLK
- **6.2.** Test configuration 1: Drop-out and range test



6.2.1. Set up test area as depicted in the left panel of the figure
6.2.2. Scenario 1: Vehicle around 10 pedestrians
6.2.3. Place 10 pedestrian tags in the centre of test area
6.2.4. Pedestrians tags should be spaced to fit inside a R1.5m circular area such that it represents a group of pedestrians standing close together
6.2.5. Pair 1 pedestrian tag as operator inside machine footprint
6.2.6. Start recording on test vehicle 1
6.2.7. Have test vehicle 1 drive clockwise around pedestrians in a radius of 25m at speeds of 5 and 10km/h and note for each speed
6.2.7.1. Stop recording when test vehicle 1 returns to its start position
6.2.7.2. Download log from CxDLK and note continuous detection of 10 pedestrian tags and 1 operator tag in Additional_Continuous message in log file
6.2.7.3. Repeat 3 times for each speed
6.2.8. Set up test area as depicted in the right panel of the figure
6.2.9. Scenario 2: 10 pedestrians around vehicle
6.2.10. Position test vehicle 1 in the centre of test area
6.2.11. Place 10 pedestrian tags at 2m from the right of the test vehicle
6.2.12. Pedestrians tags should be spaced to fit inside a R1.5m circular area such that it represents a group of pedestrians standing close together
6.2.13. Pair 1 pedestrian tag as operator inside machine footprint
6.2.14. Start recording on test vehicle 1
6.2.15. Have the 10 pedestrian tags move clockwise together around test vehicle 1 while maintaining a 2m distance from the vehicle
6.2.16. Stop recording when pedestrian tags return to the starting position
6.2.17. Download log from CxDLK and note continuous detection of 10 pedestrian tags in Additional_Continuous message in log file
6.2.18. Repeat 3 times

6.3. Test configuration 2: Pedestrian activated emergency stop



6.3.1. Position test vehicle 1 in the centre of test area

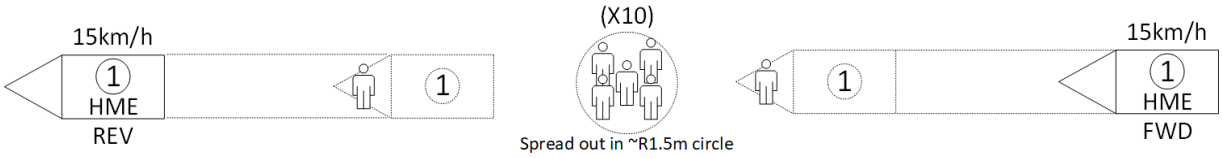
6.3.2. From a distance of at least 50m, approach test vehicle 1 with the pedestrian tag while activating the emergency stop every 2 meters

6.3.3. Note distance at which emergency activated stop is actioned on test vehicle

6.3.4. Note the approximate time difference between the activation of the emergency stop and the instant when it is actioned on the test vehicle

6.3.5. Repeat 3 times

6.4. Test configuration 3: Multiple object test



6.4.1. Place 10 pedestrian tags in the centre of test area

6.4.2. Pedestrian tags should be spaced to fit inside a R1.5m circular area such that it represents a group of pedestrians standing close together

6.4.3. Have test vehicle 1 approach group of pedestrians at 15km/h in both the FWD and REV directions

6.4.4. Stop test vehicle close to group of pedestrians on each approach

6.4.5. Repeat each direction 3 times

6.4.6. Download logs and note detection of 10 pedestrian tags in Additional_Continuous message on log file

6.4.7. Note the maximum distance at which all 10 pedestrians are detected at speed

6.4.8. Repeat 3 times

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is

7.2. The reason for the deviation

7.3. How the deviation may affect the purpose of the test

7.4. Have all parties accept in writing:

7.4.1. the proposed deviation

7.4.2. reason for the proposed deviation and

7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 25: **Example** of noted machine response to introduced failure modes*

Firmware versions				
CxDC		3.1.4		
CxDI		2.7.1.8		
CxDLK		1.6.1.8		
Drop-out and range test				
		Run1	**Run2**	**Run3**
Detected tags with TV1 at 25m		10	10	10
Drop-outs during test		0	0	0
Detected tags with peds at 2m		10	10	10
Drop-outs during test		0	0	0
Pedestrian activated emergency stop				
		Run1	**Run2**	**Run3**
Detection distance		23m	25m	24m
Approximate time delay < 1s		Yes	Yes	Yes
Multiple objects test				
Detection distance		**Run1**	**Run2**	**Run3**
FWD	**15km/h**	28m	29m	30m
REV	**15km/h**	28m	29m	30m

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

10.1. Drop-out and range test:

10.1.1. Detect all 10 pedestrian tags with vehicle at 25m, AND

10.1.2. For the entire time that data was recorded, AND

10.1.3. Detect all 10 pedestrian tags with group of pedestrians at 2m, AND

10.1.4. For the entire time that data was recorded, AND

10.1.5. For all three runs

10.2. Pedestrian activated emergency stop

10.2.1. Emergency stop is communicated to vehicle at a distance of at least 25m, AND

10.2.2. Emergency stop is actioned on vehicle within approximately 1s when activated on pedestrian tag, AND

10.2.3. For all three runs

10.3. Multiple objects test

10.3.1. Detect all 10 pedestrian tags, AND

10.3.2. Detect all pedestrian tags at a distance of at least 25m, AND

10.3.3. In both directions, AND

10.3.4. For all runs

11. Outcome of this test

*Table 26: **Example** outcome for machine controller response test*

	Pass
Drop-out and range test	Yes
Pedestrian activated emergency stop	Yes
Multiple object test	Yes

Appendix 15: TRL 4 Surface CxD Scenario Test

TRL4 Stage Gate: CxD Interactive scenario:
CxDC Surface logic test protocol (CxDC)

1. Purpose

The 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 a surface mining operation. The purpose of this test is to determine if the logic of the CxDC is able to provide effective collision prevention in the 15 defined surface scenarios.

2. Preceding test

- **2.1.** CxD ISO21815 Bench test
- **2.2.** CxD log-keeping test
- **2.3.** CxD Self-diagnostics test
- **2.4.** Effective warning test
- **2.5.** Basic detection and tracking test

3. Test facility/site

Site where 7 fully commissioned CxD systems on 7 test vehicles are available. An additional test vehicle with no CxD system installed is also required. Site must have level, hard and dry surface. Tests are highly dynamic and adequate space for run-up, interaction and run-off is required.

4. Instrumentation

- **4.1.** 8x test vehicles of which 7 are installed with CxDs
- **4.2.** Provision must be made for CxD installation for 3 HME type machines, 3 LDV type machines, 1 FEL or grader or dozer type machine, and 1 water bowser type machine
- **4.3.** Provision must be made to assign priorities to different test vehicles
- **4.4.** 7x brake robots
- **4.5.** 3x HP GNSSs
- **4.6.** 3x DAQs with ISO/TS 21815-2 interfaces
- **4.7.** 4x SP GNSS with self-recorders

5. Test preparation

- **5.1.** The client will supply sufficient CxDs in working order, correctly configured for each TMM type to be tested. An authorized person (technology provider representative) will sign-off that the supplied CxD is in working order as designed that has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the CxD will be allowed once testing has commenced.
- **5.2.** Fence off test area. Ensure all aspects in Safety protocol is adhered to.
- **5.3.** Install HP GNSS test vehicles 1, 2, and 4. Ensure good satellite reception is obtained.
- **5.4.** Install SP GNSS with self-recorders on test vehicles 3, 5, 7 and 8. Ensure good satellite reception is obtained.
- **5.5.** Connect DAQ to the CxD CAN-harness via the ISO/TS 21815-2 connector.

5.6. Set test vehicles 1,2,3 type as HME with slowdown and stop decelerations on brake robot to 0.15g and 0.28g respectively. Test vehicle 3 is a priority TMM.

5.7. Set test vehicles 4,5,6 type as LDV with slowdown and stop decelerations on brake robot to 0.2g and 0.4g respectively

5.8. Set test vehicle 7 as FEL or grader with slowdown and stop decelerations on brake robot to 0.15g and 0.28g respectively

5.9. Set test vehicle 8 as water bowser with slowdown and stop decelerations on brake robot to 0.15g and 0.28g respectively

5.10. Complete negotiation sequence between CxD and Machine Emulator on test vehicles 1, 2 and 4. Ensure system is in NOP after negotiation.

5.11. Set machine delay on brake robot to 0.5s.

5.12. Ensure all personnel, equipment and all obstacles are removed in front and behind of the test vehicles.

6. Test method

6.1. Note firmware versions of CxDC, CxDI, CxDLK

6.2. Test configuration 1: Restricted areas

6.2.1. Test vehicle 1 is HME and outside vicinity of both test vehicle 2 and restricted zone

6.2.2. Test vehicle 4 is LDV and outside vicinity of both test vehicle 1 and restricted zone

6.2.3. Test vehicles 2,3,5,6,7,8 is outside vicinity and does not partake in the test

6.2.4. Scenario 1: Set up a restricted zone for LDVs

6.2.5. Note GPS coordinates of edge of restricted zone

6.2.6. Have test vehicle 1 and 4 approach restricted zone head-on in tandem at a speed of 5, 10 and 30 km/h and note:

6.2.6.1. Confirm test vehicle 1 has NOP response as it passes through the restricted LDV zone

6.2.6.2. Confirm test vehicle 4 has stop-EW and auto-slow and stop response

6.2.6.3. Confirm test vehicle 4 has MI after stopping

6.2.6.4. Confirm stop gap between edge of restricted zone and test vehicle 4 is between 10-12m

6.2.6.5. Repeat 3 times for each speed

6.2.7. Scenario 2: Set up a restricted zone for HMEs

6.2.8. Note GPS coordinates of edge of restricted zone

6.2.9. Have test vehicle 4 and 1 approach restricted zone head-on in tandem at a speed of 5, 10 and 30 km/h and note:

6.2.9.1. Confirm test vehicle 4 has NOP response as it passes through the restricted HME zone

6.2.9.2. Confirm test vehicle 1 has stop-EW and auto-slow and stop response

6.2.9.3. Confirm test vehicle 1 has MI after stopping

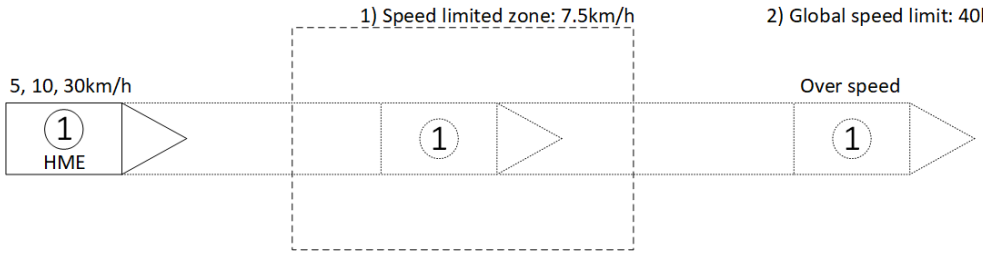
6.2.9.4. Confirm stop gap between edge of restricted zone and test vehicle 1 is between 10-11m

6.2.9.5. Repeat 3 times for each speed

6.3. Test configuration 2: Escorted vehicle

6.3.1. Test vehicle 1 is HME and outside vicinity of all other test vehicles
6.3.2. Test vehicle 4 is LDV and outside vicinity of all other test vehicles
6.3.3. Test vehicle 5 is LDV and outside vicinity of all other test vehicles
6.3.4. Test vehicle 6 is LDV and does not have CxD installed
6.3.5. Test vehicles 2,3,7 and 8 are outside vicinity and does not partake in test
6.3.6. All other test vehicles are outside vicinity and does not partake in the test
6.3.7. Pass gap between convoy and test vehicle 1 is 6m
6.3.8. Have test vehicles 4, 5 and 6 in tandem approach test vehicle 1 at a speed of 5, 10 and 30km/h
6.3.9. When test vehicle 4 is in vicinity of test vehicle 1, have test vehicle 1 attempt to FWD take-off
6.3.10. Confirm immediate stop-EW and MI response of test vehicle 1
6.3.11. Confirm immediate stop-EW and auto-slow and stop response of test vehicles 4 and 5
6.3.12. Repeat 3 times for each speed

6.4. Test configuration 3: Speed limited zone



6.4.1. Set up a speed limited zone of 7.5km/h as depicted in the figure
6.4.2. Note GPS coordinates of edge of speed limited zone
6.4.3. Set up global speed limit of 40km/h
6.4.4. Test vehicle 1 is HME and outside vicinity of speed limited zone
6.4.5. Test vehicles 2,3,4,5,6,7 and 8 are outside vicinity and does not partake in the test
6.4.6. Scenario 1: Speed limited zone
6.4.7. Have vehicle approach speed limited zone at speeds of 5, 10 and 30 km/h and note for each speed:

6.4.7.1. Distance between edge of zone and position at which speed limit is achieved

6.4.7.2. Confirm test vehicle 1 has NOP response before entering the speed limited zone below the limit speed

6.4.7.3. Confirm test vehicle 1 has speed-limit-EW and auto-slow response before entering the speed limited zone when attempting to enter the speed limited zone above the limit speed

6.4.7.4. Confirm test vehicle 1 has speed-limit-EW and auto-slow response when trying to exceed the limit speed inside zone

6.4.7.5. Confirm test vehicle 1 has NOP after exiting the speed limited zone

6.4.7.6. Repeat 3 times for each speed, and during the 30km/h runs:

6.4.7.7. Scenario 2: Global speed limit

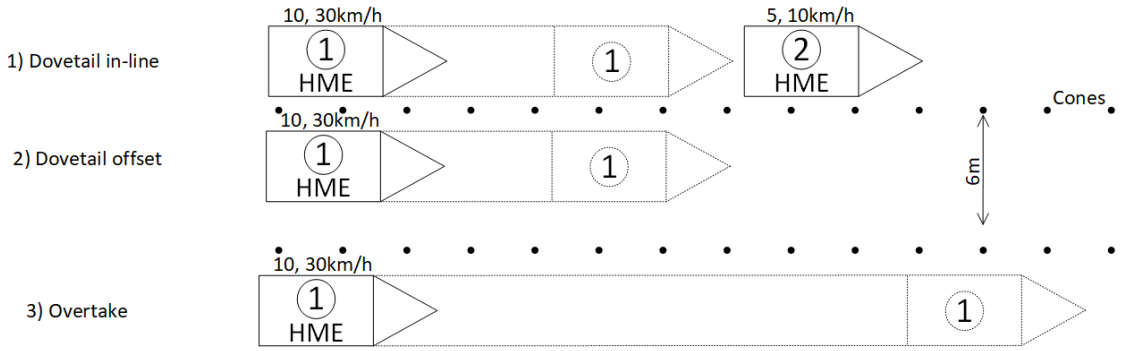
6.4.7.7.1. Have test vehicle 1 attempt to over-speed and exceed the global speed limit after exiting the speed limited zone and note:

6.4.7.7.2. Maximum recorded speed

6.4.7.7.3. Confirm test vehicle has speed-limit-EW and auto-slow response

6.4.7.7.4. NOP after reducing speed to below global limit

6.5. Test configuration 4: Dove-tail & overtaking



6.5.1. Set up test area with pass gap of 6m as depicted in the figure

6.5.2. Test vehicle 1 is HME, outside vicinity of test vehicle 2 and can travel at 10 and 30km/h

6.5.3. Test vehicle 2 is HME, outside vicinity of test vehicle 1 and can travel at 5 and 10km/h

6.5.4. Test vehicles 3,4,5,6,7and 8 are outside vicinity and does not partake in test

6.5.5. Scenario 1: Dovetail in-line

6.5.6. Have test vehicle 1 approach test vehicle 2 at combinations of 10-5, 30-5, 30-10 km/h respectively in dove-tail fashion directly in-line

6.5.7. Note for each speed combination:

6.5.7.1. Distance when effective warning on test vehicle 1 is issued

6.5.7.2. Distance when auto-slow is activated on test vehicle 1

6.5.7.3. Time difference between effective warning and activation of auto-slow on test vehicle 1

6.5.7.4. Confirm that test vehicle 1 has slow-EW and auto-slow response

6.5.7.5. Confirm that test vehicle 2 has proximity-EW and NOP response

6.5.7.6. Confirm that test vehicle 1 and 2 can platoon at the same speed

6.5.7.7. Distance between two vehicles when platooning

6.5.8. Scenario 2: Dovetail offset

6.5.9. Have test vehicle 1 approach test vehicle 2 at combinations of 10-5, 30-5, 30-10 km/h respectively in dove-tail fashion with a narrow pass gap offset

6.5.10. Note for each speed combination:

6.5.10.1. Distance when effective warning on test vehicle 1 is issued

6.5.10.2. Distance when auto-slow is activated on test vehicle 1

6.5.10.3. Time difference between effective warning and activation of auto-slow on test vehicle 1

6.5.10.4. Confirm that test vehicle 1 has slow-EW and auto-slow response

6.5.10.5. Confirm that test vehicle 2 proximity-EW and NOP response

6.5.10.6. Confirm that test vehicle 1 and 2 can platoon at the same speed

6.5.10.7. Distance between two vehicles when platooning

6.5.11. Scenario 3: Overtaking

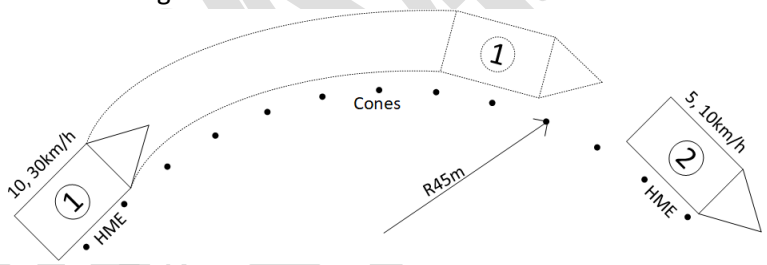
6.5.12. Have test vehicle 1 approach test vehicle 2 at combinations of 10-5, 30-5, 30-10km/h respectively in overtaking fashion (i.e. in outside lane)

6.5.13. Note for each speed combination:

6.5.13.1. Confirm no warnings and NOP of both test vehicles during overtaking

6.5.13.2. Repeat 3 times for each speed combination

6.6. Test configuration 5: Curving dove-tail



6.6.1. Set up test area as depicted in the figure

6.6.2. Test vehicle 1 is HME, outside vicinity of test vehicle 2 and can travel at 10 and 30km/h

6.6.3. Test vehicle 2 is HME and cab travel at 5 and 10 km/h

6.6.4. Test vehicles 3,4,5,6,7,8 is outside vicinity and does not partake in test

6.6.5. Have test vehicle 1 approach test vehicle 2 at combinations of 10-5, 30-5, 30-10 km/h respectively in dove-tail fashion and note for each speed combination:

6.6.5.1. Straight line distance when effective warnings on both OWSs are issued

6.6.5.2. Straight line distance when auto-slow is activated on test vehicle 1

6.6.5.3. Time difference between effective warning and activation of auto-slow on test vehicle 1

6.6.5.4. Confirm that test vehicle 1 has slow-EW and auto-slow response

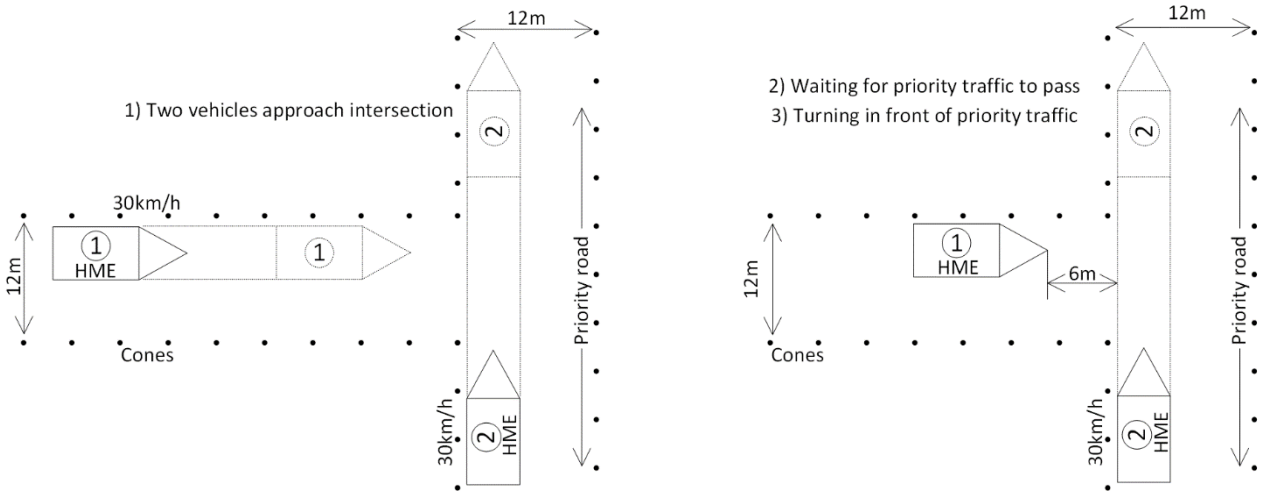
6.6.5.5. Confirm that test vehicle 2 has proximity-EW and NOP response

6.6.5.6. Confirm that test vehicle 1 and 2 can platoon at the same speed

6.6.5.7. Distance between two vehicles when platooning

6.6.5.8. Repeat 3 times for each speed combination

6.7. Test configuration 6: T-junction



6.7.1. Set up a T-intersection in test area with a priority road as depicted in the figure

6.7.2. Test vehicle 1 is HME, on the secondary road and outside the vicinity of both the intersection and test vehicle 2

6.7.3. Test vehicle 2 is HME, on the priority road and outside the vicinity of the intersection and test vehicle 1

6.7.4. Scenario 1: Two vehicles approaching intersection

6.7.5. Have test vehicle 1 and 2 approach one another at a speed of 30km/h such that the collision point will be inside the intersection

6.7.6. Confirm that test vehicle 1 has stop-EW and auto-slow and stop response

6.7.7. Confirm that test vehicle 2 has proximity-EW and NOP response

6.7.8. Confirm pass gap is at least 6m

6.7.9. Confirm NOP on test vehicle 1 after test vehicle 2 is out of vicinity

6.7.10. Repeat 3 times

6.7.11. Scenario 2: Allowing priority traffic to pass

6.7.12. Position test vehicle 1 6m away from intersection to simulate a vehicle waiting in the secondary road for traffic on the priority road

6.7.13. Have test vehicle 2 approach the intersection at a speed of 30km/h

6.7.14. Confirm proximity-EW and NOP on test vehicle 1

6.7.15. Confirm proximity-EW and NOP on test vehicle 2

6.7.16. Repeat 3 times

6.7.17. Scenario 3: Attempting to disrupt priority traffic

6.7.18. Position test vehicle 1 6m away from intersection to simulate a vehicle attempting to disrupt traffic on the priority road

6.7.19. Have test vehicle 2 approach the intersection at a speed of 30km/h

6.7.20. When test vehicle 2 enters the vicinity of the intersection, have test vehicle 1 attempt to disrupt priority traffic by entering the intersection

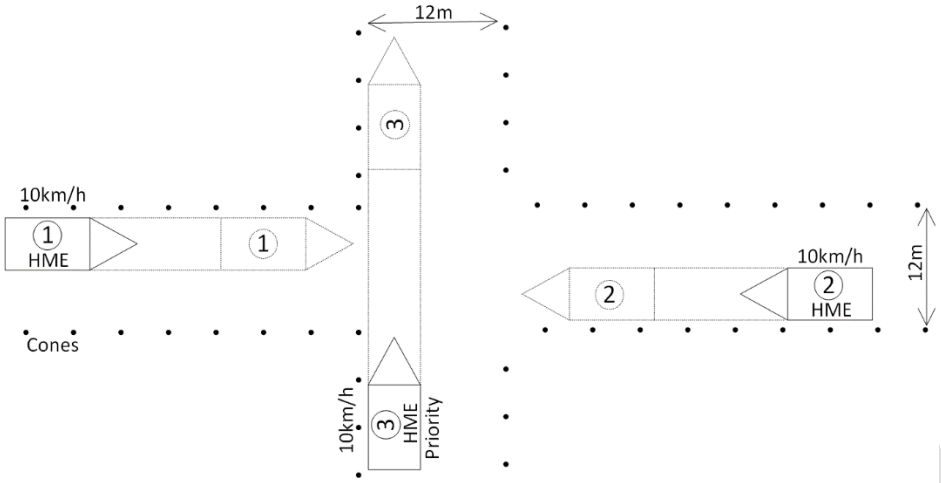
6.7.21. Confirm that test vehicle 1 has immediate stop-EW and MI response

6.7.22. Confirm that test vehicle 2 has proximity-EW and NOP

6.7.23. Confirm NOP on test vehicle 1 after test vehicle 2 is out of vicinity

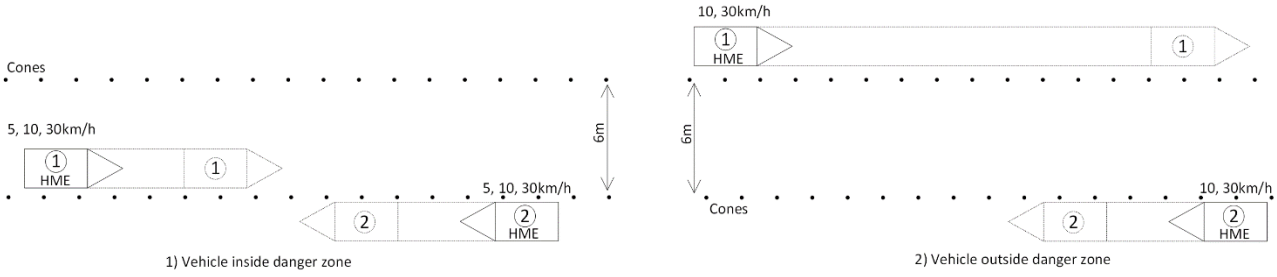
6.7.24. Repeat 3 times

6.8. Test configuration 7: Crossing with multiple TMMs



6.8.1. Set up a crossing in test area as depicted in the figure
6.8.2. Test vehicle 1 is HME, outside the vicinity of all other vehicles, and the intersection
6.8.3. Test vehicle 2 is HME, outside the vicinity of all other vehicles, and the intersection
6.8.4. Test vehicle 3 is a priority HME, outside the vicinity of all other vehicles, and the intersection
6.8.5. Have countdown or trigger event to have test vehicles 1, 2 and 3 approach one another at 10km/h such that the collision point will be inside the intersection
6.8.6. Confirm that test vehicles 1 and 2 has stop-EW and auto-slow and stop response
6.8.7. Confirm that test vehicle 3 has proximity-EW and NOP response
6.8.8. Confirm that pass gap of both test vehicles 1 and 2 are between 10-12m
6.8.9. Repeat 3 times

6.9. Test configuration 8: Head-on & passing



6.9.1. Set up test area as depicted in figure
6.9.2. Test vehicle 1 is HME and outside vicinity of all other test vehicles
6.9.3. Test vehicle 2 is HME and outside vicinity of all other test vehicles
6.9.4. Test vehicles 3,4,5,6,7,8 is outside vicinity and does not partake in test
6.9.5. Scenario 1: Passing inside danger zone
6.9.6. Place test vehicles 1 and 2 such that vehicles will attempt to pass each other within the danger zone
6.9.7. Have test vehicle 1 approach test vehicle 2 head-on at speed combinations of 5-5, 10-5, 10-10, 30-10, 30-30km/h and note for each combination:

6.9.7.1. Distance when effective warnings on both OWSs are issued

6.9.7.2. Distance when auto-slow is activated on test vehicle 1

6.9.7.3. Time difference between effective warning and activation of auto-slow and/or stop on test vehicle 1

6.9.7.4. Confirm that stop gap is between 10-12m

6.9.7.5. Repeat 3 times for each speed combination

6.9.8. Scenario 2: Passing outside danger zone

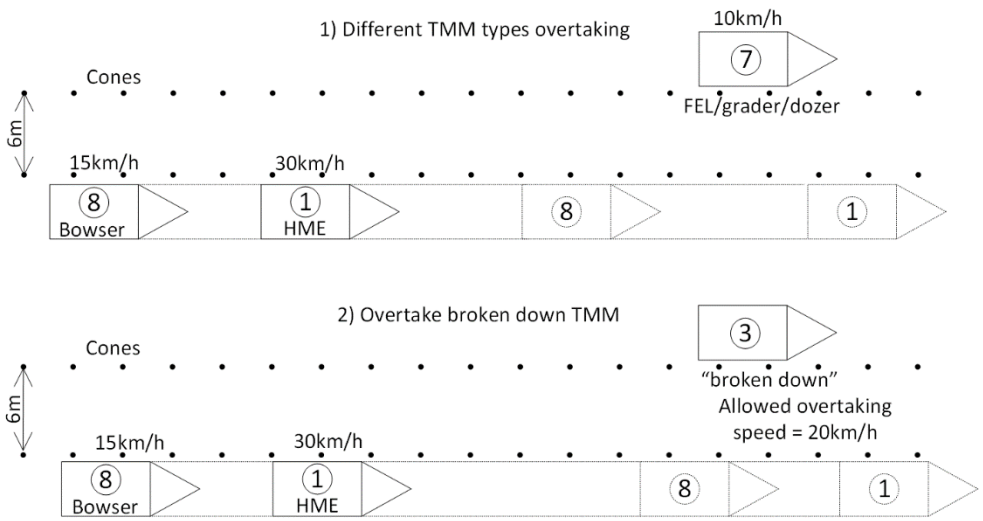
6.9.9. Position test vehicles 1 and 2 such that vehicles will pass each other with a gap of 6m

6.9.10. Have test vehicle 1 approach and pass test vehicle 2 head-on at speed combinations of 10-10, 15-10, 30-10, 30-30km/h and note for each combination:

6.9.10.1. Confirm that test vehicles 1 and 2 has no alerts and NOP response

6.9.10.2. Repeat 3 times for each speed combination

6.10. Test configuration 9: Multi object overtake



6.10.1. Set up test area as depicted in the figure

6.10.2. Maximum allowed overtaking speed of a broken-down vehicle must be set at 20km/h

6.10.3. Test vehicle 1 is HME and outside vicinity of all other vehicles

6.10.4. Test vehicle 3 is HME and outside vicinity of all other vehicles

6.10.5. Test vehicle 7 is FEL/grader/dozer and outside vicinity of all other vehicles

6.10.6. Test vehicle 8 is water bowser and outside vicinity of all other vehicles

6.10.7. Test vehicles 2,4,5,6,8 is outside vicinity and does not partake in the test

6.10.8. Scenario 1: Different TMM types passing

6.10.9. Have test vehicle 7 drive at a speed of 10km/h

6.10.10. Have test vehicle 1 overtake and test vehicle 8 attempt to overtake test vehicle 7 at speeds of 30 and 15km/h respectively

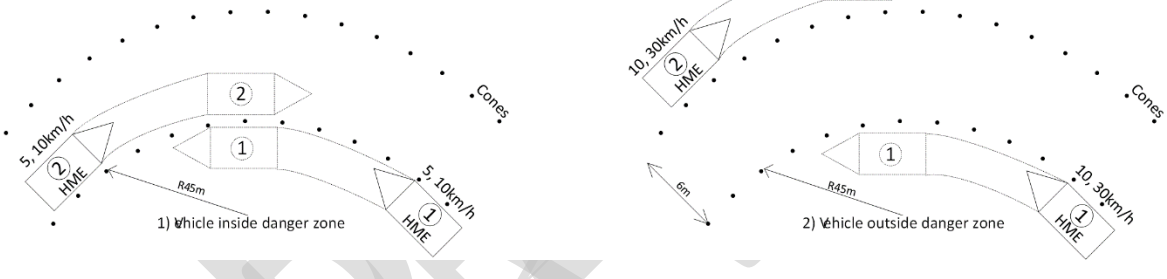
6.10.11. Confirm that test vehicle 1 has NOP response

6.10.12. Confirm that test vehicle 8 has slow-EW and slowdown response

6.10.13. Distance between vehicles 7 and 8 when effective warning is issued

6.10.14. Distance between vehicles 7 and 8 when auto-slow intervention is triggered
6.10.15. Repeat 3 times
6.10.16. Remove test vehicle 7 from test area and introduce test vehicle 3 in a broken-down status
6.10.17. Scenario 2: Overtake broken down TMM
6.10.18. Have test vehicles 1 and 8 overtake test vehicle 3 at speeds of 30 and 15km/h respectively
6.10.19. Confirm that test vehicle 1 has speed-limit-EW and slowdown response to ensure overtaking at 20km/h
6.10.20. Note distance between vehicles 1 and 3 when effective warning is issued
6.10.21. Note distance between vehicles 1 and 3 when auto-slow and stop intervention is triggered
6.10.22. Confirm that test vehicle 8 has no alerts and NOP response
6.10.23. Repeat 3 times

6.11. Test configuration 10: Curved head-on & passing



6.11.1. Set up test area as depicted in figure
6.11.2. Test vehicle 1 is HME and outside vicinity of test vehicle 2
6.11.3. Test vehicle 2 is HME and outside vicinity of test vehicle 1
6.11.4. Test vehicles 3,4,5,6,7,8 are outside vicinity and does not partake in test
6.11.5. Scenario 1: Passing within danger zone
6.11.6. Position test vehicles 1 and 2 such that vehicles will attempt to pass each other within the danger zone
6.11.7. Have test vehicle 1 approach test vehicle 2 head-on at speed combinations of 5-5, 10-5, 10-10km/h and note for each combination:
6.11.7.1. Confirm that both test vehicles 1 and 2 has stop-EW and auto-slow and stop response
6.11.7.2. Straight line distance when effective warnings on both OWSs are issued
6.11.7.3. Time difference between effective warning and activation of auto-slow and/or stop on test vehicle 1
6.11.7.4. Confirm that stop gap is greater than 10m
6.11.7.5. Repeat 3 times for each speed combination
6.11.8. Scenario 2: Passing outside danger zone
6.11.9. Position test vehicles 1 and 2 such that vehicles will pass each other outside the danger zone

6.11.10. Have test vehicle 1 approach and pass test vehicle 2 head-on at speed combinations of 10-10, 30-10, 30-30km/h and note for each combination:

6.11.10.1. Confirm that test vehicles 1 and 2 has no alerts and NOP response

6.11.10.2. Repeat 3 times for each speed combination

6.12. Test configuration 11: Motion Inhibit and override

6.12.1. Test vehicle 1 is HME and outside vicinity for all other vehicles

6.12.2. Test vehicle 4 is LDV and outside vicinity for all other vehicles

6.12.3. Test vehicles 2,3,5,6,7,8 are outside vicinity and does not partake in test

6.12.4. Scenario 1: Have test vehicle 4 approach test vehicle 1 at a speed of 10km/h to simulate a service vehicle approaching a stationary TMM and:

6.12.5. Confirm that test vehicle 4 has stop-EW and auto-slow and stop response

6.12.6. Note distance at which auto-slow and/or stop command is issued

6.12.7. Note stop gap

6.12.8. Have test vehicle 1 attempt to take-off in FWD and REV directions

6.12.9. Confirm that test vehicle 1 has immediate stop-EW and MI response

6.12.10. Scenario 2: Engage safe park status on test vehicle 1 and allow test vehicle 4 to approach and stop in danger zone

6.12.11. Confirm that test vehicle 4 has proximity-EW and NOP response

6.12.12. Scenario 3: Disengage safe park status on test vehicle 1

6.12.13. Confirm that test vehicle 1 has immediate stop-EW and MI response

6.12.14. Confirm that test vehicle 4 has immediate stop-EW and MI response

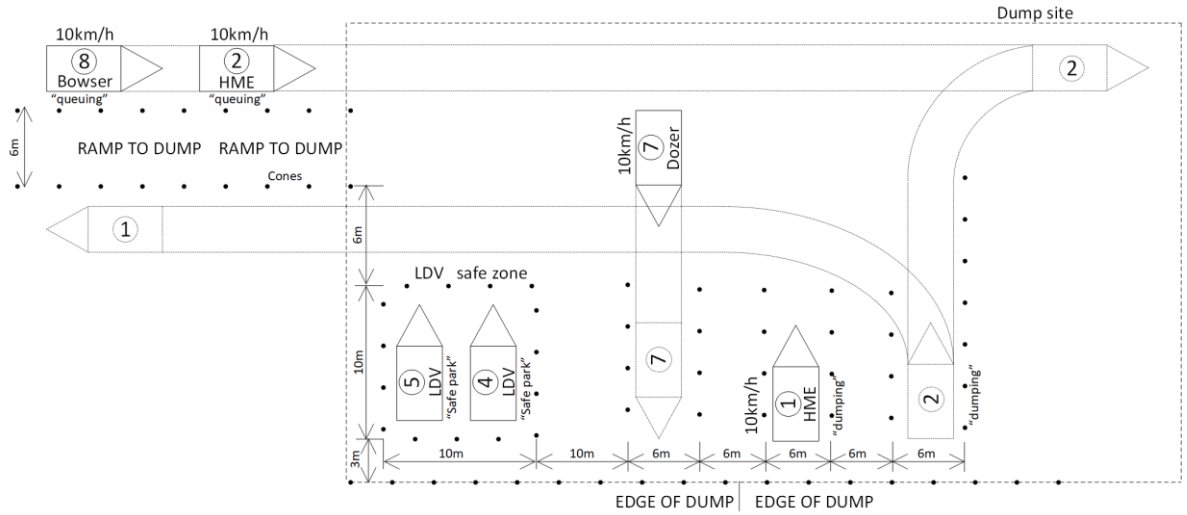
6.12.15. Scenario 4: Activate override on test vehicle 1 and start timer for cool down

6.12.16. Confirm that test vehicles 1 and 4 have proximity-EW and NOP response

6.12.17. Wait until override cool down runs out and note duration

6.12.18. Repeat 3 times

6.13. Test configuration 12: Dump



6.13.1. Set up test area to simulate a dump scenario as depicted in the figure

6.13.2. Test vehicle 1 is HME, outside vicinity of all other vehicles and is in "dumping" status

6.13.3. Test vehicle 2 is HME, outside vicinity of all other vehicles and is in "queuing" status

6.13.4. Test vehicles 4 and 5 are LDVs, inside an LDV safe-zone, outside vicinity of all other vehicles and in "safe park" status

6.13.5. Test vehicle 7 is Dozer and outside vicinity of all other vehicles

6.13.6. Test vehicle 8 is water bowser, outside vicinity of all other vehicles and in "queuing" status

6.13.7. Movement 1: Have a countdown or triggering event to perform the following 3 instructions concurrently to simulate a dumping-dozing-entering scenario:

6.13.7.1. Have test vehicle 7 drive FWD at a speed of 10km/h to simulate a levelling and shaping task towards the edge of a dump

6.13.7.2. Have test vehicle 2 enter the dump by driving FWD to at a speed of 10km/h to such a point that it is in position to REV to the edge

6.13.8. Confirm that all test vehicles inside the dump area have no alerts and NOP response

6.13.9. Movement 2: Have a countdown or triggering event to perform the following 3 instructions concurrently to simulate an exiting-reversing-queuing scenario:

6.13.9.1. Have test vehicle 1 exit the dump by disengaging dumping status, driving FWD at 10km/h towards the ramp and passing the Dozer, LDV safe-zone, and queuing vehicles (6m passing gap)

6.13.9.2. Have test vehicle 2 simulate a dumping task by driving REV at 5km/h, stopping at the edge and engaging dump status

6.13.9.3. Have test vehicle 8 take the next position in the queue by driving forward at 5km/h and stopping before the dump area

6.13.10. Confirm that all test vehicles inside the dump area have no alerts and NOP response

6.13.11. Have test vehicle 8 enter the dump by driving FWD at a speed of 10km/h to simulate a dust suppression task

6.13.12. Confirm that all test vehicles inside the dump area have proximity-EW while stationary

6.13.13. Have test vehicle 2 attempt to exit the dump by disengaging dumping status, driving FWD at 10km/h towards the ramp and passing the queuing vehicles

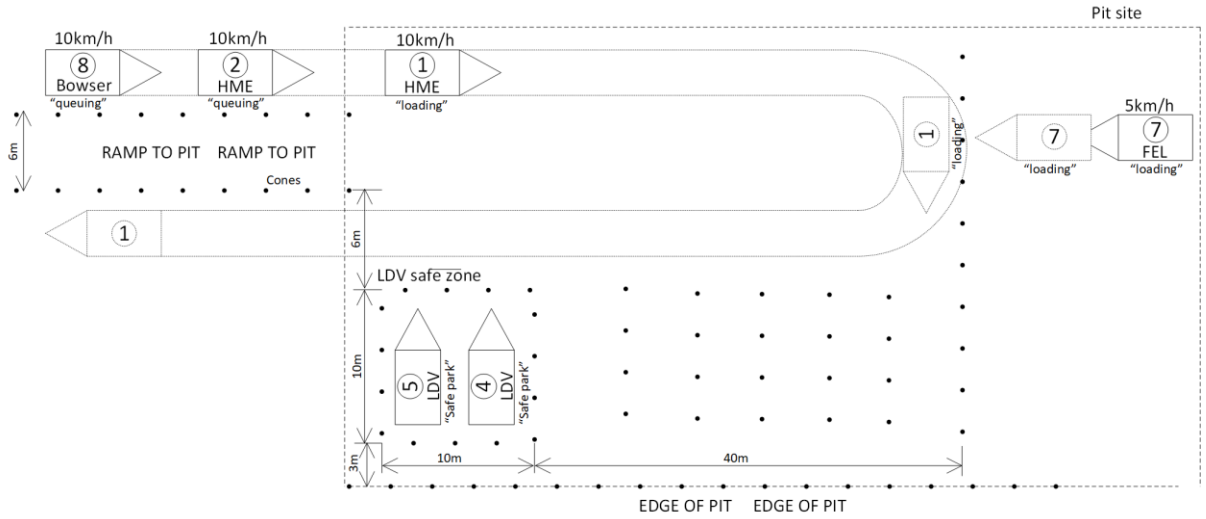
6.13.13.1. Confirm that test vehicle 2 has immediate stop-EW and MI response

6.13.13.2. Have test vehicle 7 attempt to return to its original position by driving REV at 10km/h

6.13.13.3. Confirm that test vehicle 7 has immediate stop-EW and MI response

6.13.13.4. Repeat 3 times

6.14. Test configuration 13: Pit



6.14.1. Set up test area to simulate a pit scenario as depicted in the figure

6.14.2. Test vehicle 1 is HME, outside vicinity of all other vehicles and in "loading" status

6.14.3. Test vehicle 2 is HME, outside vicinity of all other vehicles and is in "queuing" status

6.14.4. Test vehicles 4 and 5 are LDVs, inside an LDV safe-zone, outside vicinity of all other vehicles and in "safe park" status

6.14.5. Test vehicle 7 is FEL and outside vicinity of all other vehicles and in "loading" status

6.14.6. Test vehicle 8 is water bowser, outside vicinity of all other vehicles and in "queuing" status

6.14.7. Have FEL drive at 5km/h to the loading cones and engage loading status

6.14.8. Movement 1: Have a countdown or trigger event to perform the following 2 instructions concurrently to simulate a loading-queuing scenario:

6.14.8.1. Have test vehicle 1 get in position for loading by approaching test vehicle 7, stopping such that test vehicle 7 is in close proximity to the side

6.14.8.2. Have test vehicles 2 and 8 move along in the queue

6.14.9. Have test vehicle 7 simulate a loading task by driving slowly towards test vehicle 1 until stop is issued

6.14.10. Confirm that this load gap is smaller than the stop gap requirement

6.14.11. Movement 2: Have a countdown or triggering event to perform the following 3 instructions concurrently to simulate an exiting-entering-LDV in pit scenario:

6.14.11.1. Have test vehicle 1 disengage "loading" status and attempt to exit the pit

6.14.11.2. Have test vehicle 2 attempt to enter the pit

6.14.11.3. Have test vehicle 4 exit the LDV safe-zone

6.14.12. Confirm that all test vehicles inside pit area have stop-EW and auto-slow and stop response

6.14.13. Have test vehicle 4 return to LDV safe-zone and engage "safe park" status

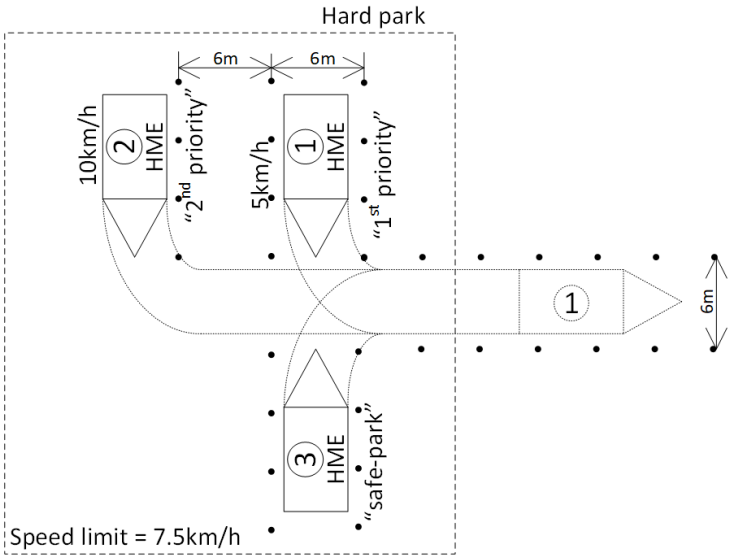
6.14.14. Confirm that all test vehicles have no alerts and NOP response

6.14.15. Have test vehicle 1 attempt to exit the pit by over speeding while passing the LDV safe-zone and queuing vehicles

6.14.16. Confirm that test vehicle 1 has speed-limit-EW and auto-slow response

6.14.17. Repeat 3 times

6.15. Test configuration 14: Parking area



6.15.1. Set up test area to simulate a hard park as depicted in the figure

6.15.2. Test vehicle 1 is HME, outside vicinity of all other test vehicles and has 1st priority to depart

6.15.3. Test vehicle 2 is HME, outside vicinity of all other test vehicles and has 2nd priority to depart

6.15.4. Test vehicle 3 is HME, outside vicinity of all other test vehicles, and in "safe-park"

6.15.5. Have test vehicle 2 attempt to exit the hard-park out of turn

6.15.6. Confirm that test vehicle 2 has immediate stop-EW and MI response

6.15.7. Have test vehicle 1 exit the hard-park at a speed of 5km/h

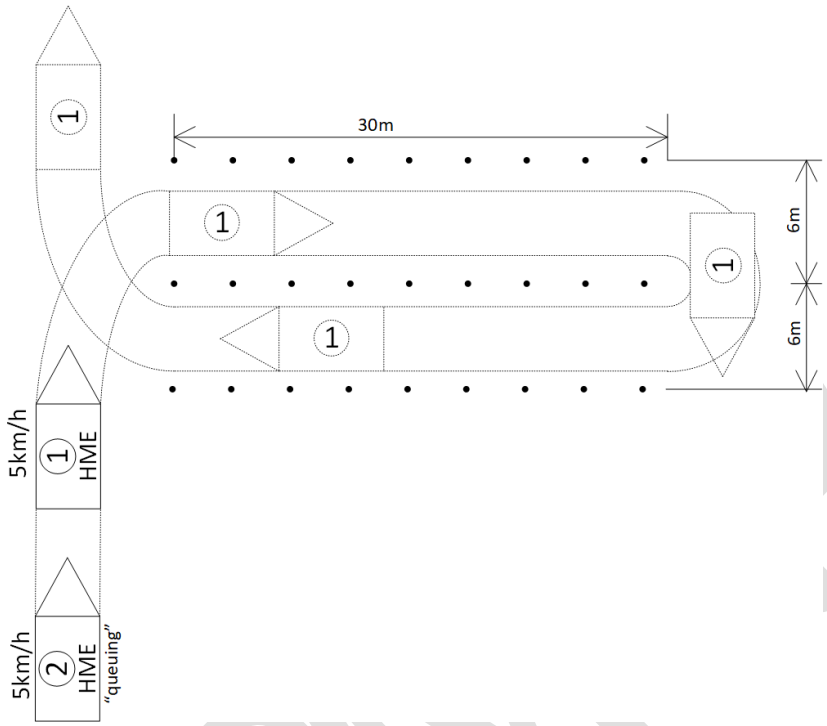
6.15.8. Confirm that test vehicle 1 has no alerts and NOP

6.15.9. Have test vehicle 2 take-off and attempt to exit the hard-park at a speed of 10km/h

6.15.10. Confirm that test vehicle 2 has slow-EW and auto-slow response

6.15.11. Repeat 3 times

6.16. Test configuration 15: 90deg ramp access



6.16.1. Set up test area to simulate a 90-degree access brake ramp as depicted in the figure
6.16.2. Test vehicle 1 is HME and outside vicinity of test vehicle 2
6.16.3. Test vehicle 2 is HME, outside vicinity and in "queuing" status
6.16.4. Have test vehicle 1 enter the brake ramp, continue along at 5km/h, and stop at the turnaround point
6.16.5. Have test vehicle 2 disengage "queuing" status and attempt to enter the brake ramp
6.16.6. Confirm that test vehicle 2 has stop-EW and stop response
6.16.7. Have test vehicle 2 clear the exit of the brake ramp and park outside of test area
6.16.8. Confirm that CPS checks for correct gear selection
6.16.9. Have test vehicle 1 continue along at 5km/h and exit the brake ramp
6.16.10. Repeat 3 times

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
7.4.1. the proposed deviation
7.4.2. reason for the proposed deviation and
7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 27: **Example** of test results and noted machine responses*

Firmware versions	
CxDC	3.1.4
CxDI	2.7.1.8
CxDLK	1.6.1.8
Test results	
TC1 – TC15	2.6 CxD Surface Appendix A

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

10.1. TC1 Restricted areas

10.1.1. For LDV restricted area:

10.1.1.1. HME can pass through restricted area, AND

10.1.1.2. LDV auto-slows and stop before edge of zone, AND

10.1.1.3. LDV has stop-EW active between 2.5-3.0s before auto-slow and stop intervention, AND

10.1.1.4. LDV has MI after coming to a stop, AND

10.1.2. For HME restricted area:

10.1.2.1. LDV can pass through restricted area, AND

10.1.2.2. HME auto-slows and stop before edge of zone, AND

10.1.2.3. HME has stop-EW active between 2.5-3.0s before auto-slow and stop intervention, AND

10.1.2.4. HME has MI after coming to a stop, AND

10.1.3. For three runs at that speed

10.2. TC2 Escorted vehicle

10.2.1. Front LDV receives stop-EW and auto-slow and stop

10.2.2. Rear LDV receives stop-EW and auto-slow and stop

10.2.3. HME receives immediate stop-EW and MI response

10.2.4. For three test runs at that speed

10.3. TC3 Speed limited zone

10.3.1. Vehicle has NOP response when below limit-speed in speed limited zone, AND

10.3.2. Vehicle has slow-EW and auto-slow response when attempting to enter above limit speed, AND

10.3.3. Vehicle is at limit speed before entering speed limit zone when attempting to enter above limit speed, AND

10.3.4. Vehicle has slow-EW and auto-slow response in speed limited zone when attempting to exceed limit speed in zone, AND

10.3.5. Vehicle has slow-EW active between 2.5-3.0s before intervention, AND

10.3.6. 5, 10km/h test runs: All runs at that speed, AND

10.3.7. 30km/h test runs: Vehicle has slow-EW and auto-slow response when exceeding global speed limit for all test runs

10.4. TC4 Dove-tail & overtaking
- **10.4.1.** Dove-tailing vehicle has slow-EW active between 2.5-3.0s before intervention, AND
- **10.4.2.** Dove-tailing vehicle auto-slows to match leading vehicle's speed, AND
- **10.4.3.** Overtaking vehicle has NOP response, AND
- **10.4.4.** Leading vehicle has proximity-EW and NOP response during dove-tailing, AND
- **10.4.5.** Leading vehicle has NOP response during overtaking, AND
- **10.4.6.** For three test runs at that speed combination

10.5. TC5 Curving dove-tail
- **10.5.1.** Dove-tailing vehicle has slow-EW active between 2.5-3.0s before intervention, AND
- **10.5.2.** Dove-tailing vehicle auto-slows to match leading vehicle's speed, AND
- **10.5.3.** Leading vehicle has proximity-EW and NOP response, AND
- **10.5.4.** For three test runs at that speed combination

10.6. TC6 T-junction
- **10.6.1.** Vehicle on non-prioritised intersecting road:
  - **10.6.1.1.** has stop-EW active between 2.5-3.0s before intervention, AND
  - **10.6.1.2.** has stop-EW and auto-slows and stop response when approaching with other vehicle on priority road, AND
  - **10.6.1.3.** has proximity-EW and NOP response when waiting for traffic on priority road to pass, AND
  - **10.6.1.4.** has immediate stop-EW and MI response when attempting to disrupt traffic on priority road, AND
  - **10.6.1.5.** returns to NOP when priority road clears, AND
- **10.6.2.** Vehicle on priority road:
  - **10.6.2.1.** Has proximity-EW and NOP response, AND
- **10.6.3.** For three test runs

10.7. TC7 Priority road with multiple interactors
- **10.7.1.** Non-prioritised vehicles have stop-EW active between 2.5-3.0s before intervention, AND
- **10.7.2.** Non-prioritised vehicles have auto-slow and stop response, AND
- **10.7.3.** Non-prioritised vehicles have NOP response when priority traffic clears the intersection, AND
- **10.7.4.** Prioritised vehicle has proximity-EW and NOP response, AND
- **10.7.5.** For three test runs

10.8. TC8 Head-on & passing
- **10.8.1.** Inside danger zone:
  - **10.8.1.1.** Both vehicles have stop-EW active between 2.5-3.0s before intervention, AND
  - **10.8.1.2.** Both vehicles have stop-EW and auto-slow and stop response, AND
  - **10.8.1.3.** Both vehicles have MI after stop, AND
  - **10.8.1.4.** Stop intervention only issued at safe speed, AND
- **10.8.2.** Outside danger zone:
  - **10.8.2.1.** Both vehicles have NOP, AND
- **10.8.3.** For three test runs at that speed combination

10.9. TC9 Multi object overtake
- **10.9.1.** For overtaking slow moving TMM:

10.9.1.1. HME has NOP response during overtake, AND
10.9.1.2. FEL/grader/dozer has NOP response during overtake, AND
10.9.1.3. Bowser has slow-EW active between 2.5-3.0s before intervention, AND
10.9.1.4. Bowser has slow-EW and auto-slow response when attempting to overtake FEL/grader/dozer, AND

10.9.2. For overtaking broken down TMM:
10.9.2.1. HME has NOP response when overtaking below the overtaking speed, AND
10.9.2.2. HME has slow-EW and auto-slow response when attempting to overtake bowser above overtaking speed, AND
10.9.2.3. Bowser has NOP response when overtaking below the overtaking speed, AND

10.9.3. For three test runs

10.10. TC10 Curved head-on & passing
10.10.1. Inside danger zone:
10.10.1.1. Both vehicles have stop-EW active between 2.5-3.0s before stop intervention, AND
10.10.1.2. Both vehicles have stop-EW and auto-slow and stop response, AND
10.10.1.3. Both vehicles have MI after stop, AND
10.10.1.4. Stop intervention only issued at safe braking speed, AND
10.10.2. Outside danger zone:
10.10.2.1. Both vehicles have NOP response, AND
10.10.3. For three test runs at that speed combination

10.11. TC11 Motion inhibit and override
10.11.1. LDV approaching HME without safe park engaged:
10.11.1.1. LDV has stop-EW active 2.5-3.0s before intervention
10.11.1.2. LDV auto-slow and stops within safe distance from HME
10.11.1.3. HME has immediate stop-EW and MI response
10.11.2. LDV approaching HME with safe park engaged:
10.11.2.1. Both HME and LDV has proximity-EW and NOP response
10.11.3. LDV in close proximity when safe park is disengaged:
10.11.3.1. LDV has immediate stop-EW and MI response
10.11.3.2. HME has immediate stop-EW and MI response
10.11.4. Activation of override:
10.11.4.1. LDV and HME has proximity-EW and NOP response
10.11.5. For three test runs

10.12. TC12 Dump
10.12.1. Dumping-dozing-entering:
10.12.1.1. Dumping vehicle has no warnings/alerts and is NOP
10.12.1.2. Dozing vehicle has no warnings/alerts and is NOP
10.12.1.3. Entering vehicle has no warnings/alerts and is NOP
10.12.1.4. Dust supressing vehicle has no warnings/alerts and is NOP
10.12.2. Exiting-reversing-queuing:
10.12.2.1. Reversing vehicle has no warnings/alerts and is NOP
10.12.2.2. Dozing vehicle has no warnings/alerts and is NOP
10.12.2.3. Exiting vehicle has no warnings/alerts and is NOP

10.12.2.4. Dust supressing vehicle has no warnings/alerts and is NOP

10.12.3. Dust suppression-dumping:

10.12.3.1. Dumping vehicle has proximity-EW and is NOP

10.12.3.2. Dozing vehicle has proximity-EW and is NOP

10.12.3.3. Dust supressing vehicle has no warnings/alerts and is NOP

10.12.3.4. Vehicle that has exited the dump has no warnings/alerts and is NOP

10.12.4. Violation of dump rules:

10.12.4.1. Dust supressing vehicle proximity-EW and is NOP

10.12.4.2. Dumping vehicle has immediate stop-EW and MI

10.12.4.3. Dozing vehicle has immediate stop-EW and MI

10.12.4.4. Vehicle that has exited the dump has no warnings/alerts and is NOP

10.13. TC13 Pit

10.13.1. Loading-queuing:

10.13.1.1. Loading vehicle can park in close proximity to FEL

10.13.1.2. FEL can approach loading vehicle with loading gap

10.13.1.3. FEL receives stop-EW and auto-slow and stop when closer than loading gap to loading vehicle

10.13.1.4. Queuing vehicles can move up in queue

10.13.2. Exiting-entering-LDV in pit:

10.13.2.1. LDV receives proximity-EW when exiting safe-zone

10.13.2.2. Stationary FEL receives proximity-EW

10.13.2.3. Queuing vehicle receives proximity-EW

10.13.2.4. Entering vehicle receives stop-EW auto-slow, stop and MI

10.13.2.5. Exiting vehicle receives stop-EW auto-slow, stop and MI

10.13.3. Over speeding in pit:

10.13.3.1. Over speeding vehicle receives speed-limit-EW and auto-slow

10.13.3.2. All other vehicles are in NOP

10.14. TC14 Parking area

10.14.1. Departing out of turn:

10.14.1.1. 2nd priority departure vehicle receives immediate stop-EW and MI response

10.14.1.2. All other vehicles proximity-EW and remains in NOP

10.14.2. 1st Priority departs

10.14.2.1. 1st priority vehicle departs with no warnings and NOP

10.14.2.2. All other vehicles receive no warnings and remains in NOP

10.14.2.3. 1st priority vehicle can pass safe-parked vehicle in close proximity

10.14.3. 2nd priority vehicle departs in turn

10.14.3.1. 2nd priority vehicle can pass safe-parked vehicle in close proximity

10.15. TC15 90deg access brake ramp

10.15.1. Vehicle accessing the ramp with another vehicle inside receives immediate stop-EW and auto stop response

10.15.2. Vehicle inside ramp has NOP response when correct gear is selected

10.15.3. Vehicle inside ramp has stop-EW and stop response when incorrect gear is selected

10.15.4. Vehicle exiting ramp receives speed-limit-EW with auto-slow and stop response when over speeding

11. Outcome of this test

*Table 28: **Example** outcome for CxDC Surface logic test*

	FWD			REV			
	5	10	30	5	10	30	MI
TC1 Restricted areas	Yes	Yes	Yes				Yes
TC2 Escorted vehicle							
TC3 Speed limited zone	Yes	Yes	Yes				
TC4 Dove-tail & overtaking	Yes	Yes	Yes				
TC5 Curving dove-tail	Yes	Yes	Yes				
TC6 T-junction			Yes				Yes
TC7 Crossing with multiple TMMs		Yes					
TC8 Head-on and passing	Yes	Yes	Yes				
TC9 Multi object overtake			Yes				
TC10 Curved head-on & passing	Yes	Yes	Yes				
TC11 Motion inhibit & override							Yes
TC12 Dump	Yes	Yes	Yes				
TC13 Pit	Yes	Yes	Yes				
TC14 Parking area	Yes	Yes	Yes				
TC15 90deg access brake ramp	Yes	Yes	Yes				

12. Applicable document

See separate file: **2.6S_CxD_CxDC_Surface_test_protocol_Appendix_A_28Jan**

Appendix 16: TRL 4 Underground CxD Scenario Test

TRL4 Stage Gate: CxD Interactive scenario:
CxDC UG logic test protocol (CxDC)

1. Purpose

The 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.

2. Preceding test

- **2.1.** CxD ISO21815 Bench test
- **2.2.** CxD log-keeping test
- **2.3.** CxD Self-diagnostics test
- **2.4.** Effective warning test
- **2.5.** Basic detection and tracking test

3. Test facility/site

Site where two fully commissioned CxD systems are available on two test vehicles. Tests are highly dynamic and adequate space for run-up, interaction and run-off is required.

4. Instrumentation

- **4.1.** 2x test vehicles with CxD installed
- **4.2.** 2x brake robots
- **4.3.** 2x HP GNSSs
- **4.4.** 1x SP GNSS with self-recorder
- **4.5.** 2x DAQs with ISO/TS 21815-2 interface
- **4.6.** 12 pedestrian tags
- **4.7.** 1 mannequin onto which pedestrian tag is fitted during test

5. Test preparation

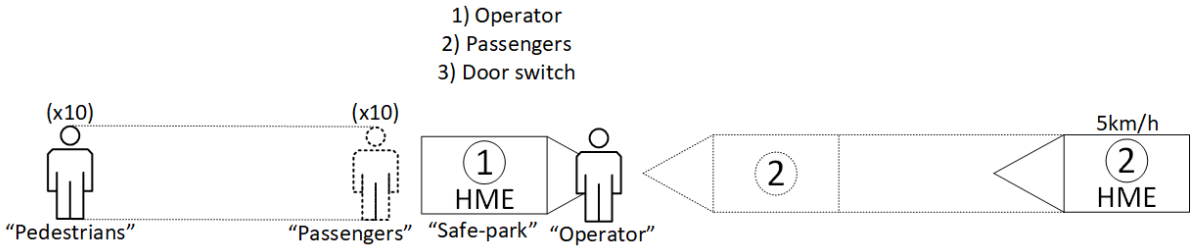
- **5.1.** The client will supply sufficient CxDs in working order, correctly configured for each TMM type to be tested. An authorized person (technology provider representative) will sign-off that the supplied CxD is in working order as designed that has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the CxD will be allowed once testing has commenced.
- **5.2.** Fence off test area. Ensure all aspects in Safety protocol is adhered to.
- **5.3.** Install HP GNSS on each test vehicle and ensure good satellite reception is obtained.
- **5.4.** Connect DAQ to the CxD CAN-harness via the ISO21815 connector.
- **5.5.** Complete negotiation sequence between CxD and Machine Emulator.
- **5.6.** Set slowdown and stop decelerations on brake robot to 0.2g and 0.4g respectively.
- **5.7.** Set machine delay on brake robot to 0.5s.
- **5.8.** Ensure all personnel, equipment and all obstacles are removed in front and behind of the test vehicles.

5.9. Pedestrian tags not being used must be kept in area where it will not interfere with the test being conducted

6. Test method

6.1. Note firmware versions of CxDC, CxDI, CxDLK

6.2. Test configuration 1: Operators and Passengers (S1, S2, S3, R6)

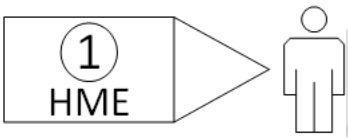


6.2.1. Test vehicle 1 is in safe parking status
6.2.2. Test vehicle 2 is outside vicinity
6.2.3. Scenario 1: Operator pairing with vehicle
6.2.4. 1 Pedestrian tag is inside test vehicle 1 footprint
6.2.5. Confirm that test vehicle 1 has proximity-EW
6.2.6. Pair pedestrian tag inside footprint as "operator"
6.2.7. Confirm that test vehicle 1 has no alerts and NOP response
6.2.8. Confirm that operator tag has no alerts
6.2.9. Scenario 2: Passengers pairing with vehicle
6.2.10. Test vehicle 1 is still in safe parking status
6.2.11. Have 10 pedestrian tags enter the danger zone
6.2.12. Confirm that test vehicle 1 has proximity-EW
6.2.13. Confirm that all 10 pedestrian tags have danger-EW
6.2.14. Pair 10 pedestrian tags as "passengers"
6.2.15. Confirm that test vehicle 1 has no alerts and NOP response
6.2.16. Confirm that both operator tag and passenger tags have no alerts
6.2.17. Have test vehicle 2 with paired operator enter danger zone
6.2.18. Confirm that both test vehicles 1 and 2 have no alerts and NOP response
6.2.19. Confirm that both operator tags and all passenger tags have no alerts
6.2.20. Have test vehicle 2 exit vicinity
6.2.21. Scenario 3: Door switch and un-pairing
6.2.22. Test vehicle 1 is still in safe parking status
6.2.23. Activate door switch
6.2.24. Confirm that test vehicle 1 has proximity-EW
6.2.25. Confirm that both operator tag and passenger tags have proximity-EW
6.2.26. Restore door switch
6.2.27. Have test vehicle 1 disengage "safe-park" status
6.2.28. Activate door switch
6.2.29. Confirm that test vehicle 1 has immediate stop-EW and MI response
6.2.30. Restore door switch
6.2.31. Have test vehicle 1 re-engage "safe-park" status
6.2.32. Confirm that test vehicle 1 has no alerts and NOP response

6.2.33. Un-pair 10 passenger tags
6.2.34. Confirm that test vehicle 1 has immediate proximity-EW
6.2.35. Confirm that all pedestrian tags have immediate proximity-EW
6.2.36. Repeat 3 times

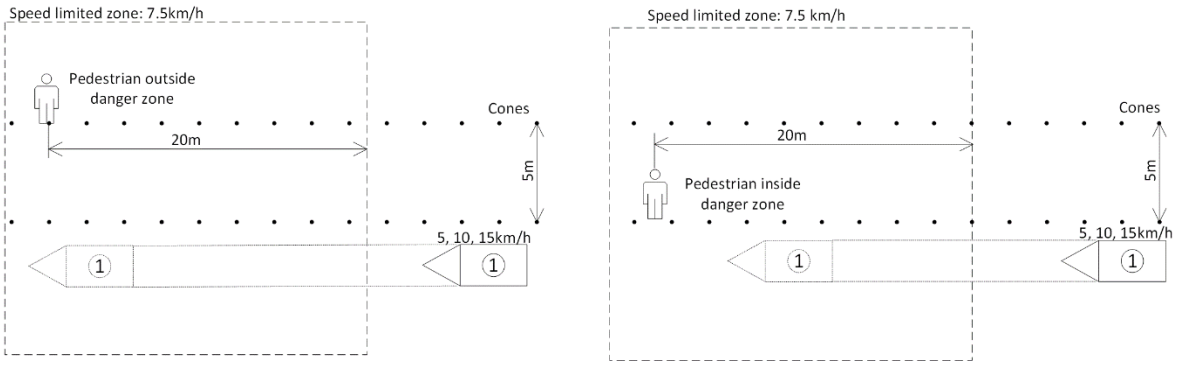
6.3. Test configuration 2: Motion Inhibit and override (S4, R11, R13)

1) Override



6.3.1. Test vehicle 1 with paired operator is stationary with safe-park status disengaged
6.3.2. Test vehicle 2 with paired operator is outside vicinity and does not partake in test
6.3.3. 1 Pedestrian tag is inside danger zone of test vehicle 1
6.3.4. Confirm that test vehicle 1 has danger-EW
6.3.5. Confirm that pedestrian tag has stop-EW
6.3.6. Activate override on test vehicle 1 and start timer for cool down
6.3.7. Confirm that test vehicle 1 has proximity-EW and NOP response
6.3.8. Confirm that pedestrian tag has danger-EW
6.3.9. Wait until override cool down runs out and note duration
6.3.10. Confirm that test vehicle 1 have immediate stop-EW and MI response
6.3.11. Confirm that pedestrian tag still has danger-EW
6.3.12. Repeat 3 times

6.4. Test configuration 3: TMM in speed limited zone (S5, S6, R7, R8)



6.4.1. Set up a zone with a speed limit of 7.5km/h as depicted in the figure
6.4.2. Note GPS coordinates of edge of speed limited zone
6.4.3. Test vehicle 1 with paired operator is outside vicinity
6.4.4. Test vehicle 2 with paired operator is outside vicinity and does not partake in test
6.4.5. Place mannequin with pedestrian tag outside the danger zone
6.4.6. Note GPS coordinates of pedestrian tag

6.4.7. Have test vehicle 1 enter the speed limited zone at speeds of 5, 10 and 15km/h and attempt to maintain that speed inside the speed limited zone

6.4.8. Have test vehicle 1 pass the pedestrian and note for each test run:

6.4.8.1. Distance between edge of speed limited zone and position at which limited speed is achieved

6.4.8.2. Confirm that test vehicle 1 has speed-limit-EW and auto-slow response when attempting to enter speed limited zone above limit speed

6.4.8.3. Confirm that test vehicle 1 has proximity-EW and NOP response when passing pedestrian inside speed limited zone

6.4.8.4. Confirm that pedestrian tag has proximity-EW

6.4.8.5. Confirm that vehicle can speed up after exiting the speed limited zone

6.4.8.6. Repeat 3 times

6.4.9. Place pedestrian tag inside the danger zone

6.4.10. Note GPS coordinates of pedestrian tag

6.4.11. Have test vehicle 1 enter the speed limited zone at speeds of 5, 10 and 15km/h and note for each speed:

6.4.11.1. Distance between edge of speed limited zone and position at which limit speed is achieved

6.4.11.2. Confirm that test vehicle 1 has speed-limit-EW alert and auto-slow response when attempting to enter speed limited zone above speed limit

6.4.12. Have test vehicle 1 attempt to pass pedestrian and note:

6.4.12.1. Confirm that test vehicle 1 has stop-EW, auto-slow and stop response

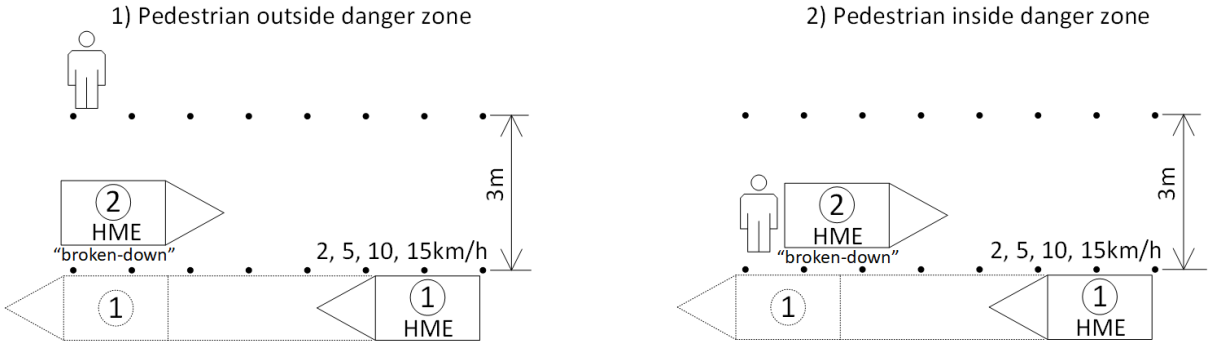
6.4.12.2. Confirm that test vehicle 1 has MI response after stopping

6.4.12.3. Confirm stop gap is between 2.5 and 3.0m

6.4.12.4. Confirm that pedestrian tag has danger-EW

6.4.12.5. Repeat 3 times

6.5. Test configuration 4: Broken-down TMM (S6)



6.5.1. Setup test area to simulate a mechanic attending to a broken-down TMM as depicted in the figure

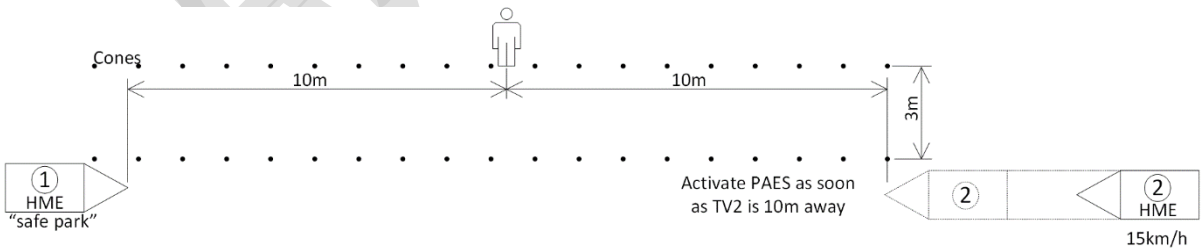
6.5.2. Test vehicle 1 with paired operator is outside vicinity of test vehicle 2 and pedestrian

6.5.3. Test vehicle 2 with paired operator is in broken-down status and outside vicinity of test vehicle 1 and pedestrian

6.5.4. Scenario 1: Pedestrian inside crawl zone

6.5.5. Place mannequin with pedestrian tag outside danger zone
6.5.6. Note GPS coordinates of pedestrian tag
6.5.7. Have test vehicle 1 pass pedestrian at a speed of 2km/h
6.5.8. Confirm that test vehicle 1 has proximity-EW and NOP response
6.5.9. Confirm that pedestrian has proximity-EW
6.5.10. Repeat 3 times
6.5.11. Have test vehicle 1 pass pedestrian at speeds of 5, 10 and 15km/h
6.5.11.1. Confirm that test vehicle 1 has stop-EW and auto-slow and stop response
6.5.11.2. Confirm that pedestrian tag has danger-EW
6.5.11.3. Repeat 3 times
6.5.12. Scenario 2: Pedestrian inside danger zone
6.5.13. Place one pedestrian tag such that test vehicle 1 will pass within the danger zone
6.5.14. Note GPS coordinates of pedestrian tag
6.5.15. Have vehicle 1 approach pedestrian tag and attempt to pass at speeds of 2, 5, 10 and 15km/h and note for each speed:
6.5.15.1. Distance when stop-EW on test vehicle1 and danger-EW on pedestrian tag is issued
6.5.15.2. Distance when auto-slow is activated
6.5.15.3. Distance when stop is activated
6.5.15.4. Confirm that stop-EW on test vehicle 1 is active between 2.5 and 3.0s before activation of auto-slow and stop
6.5.15.5. Confirm that danger-EW on pedestrian tag is active between 2.5 and 3.0s before activation of auto-slow and stop
6.5.15.6. Confirm that stop is activated only after test vehicle 1 has reached safe braking speed
6.5.15.7. Confirm that test vehicle 1 has MI response after stopping
6.5.15.8. Confirm stop gap is between 2.5m and 3.0m
6.5.15.9. Repeat 3 times

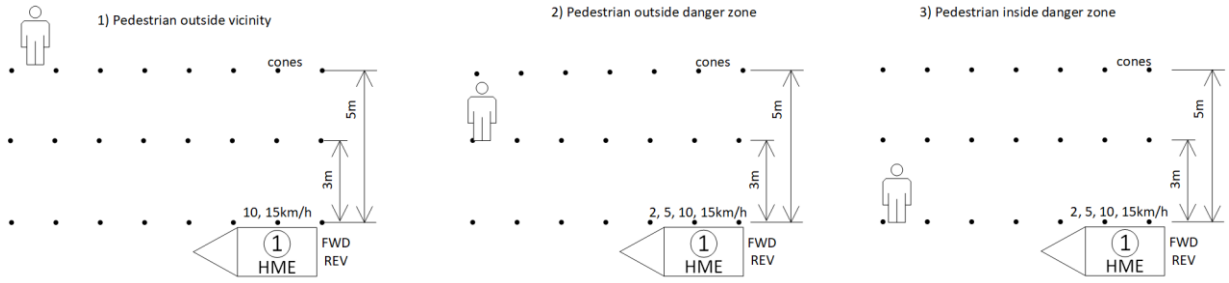
6.6. Test configuration 5: Pedestrian activated emergency stop (S7, R10)



6.6.1. Setup test area to simulate a pedestrian activating an emergency stop as depicted in the figure
6.6.2. Test vehicle 1 with paired operator is in safe parking status and 10m away from pedestrian tag
6.6.3. Test vehicle 2 with paired operator is sufficiently far away from pedestrian tag to speed up to 15km/h

6.6.4. Pedestrian tag is outside the danger zone of both test vehicles
6.6.5. Have test vehicle 2 approach test vehicle 1 head-on at a speed of 15km/h
6.6.6. Activate pedestrian activated emergency stop as soon as test vehicle 2 is 10m away from pedestrian
6.6.7. Confirm that test vehicle 1 has stop-EW and MI response
6.6.8. Confirm that test vehicle 2 has stop-EW and auto-slow and stop response
6.6.9. Confirm that stop is activated only after test vehicle 2 has reached safe braking speed
6.6.10. Confirm that test vehicle 2 has MI response after stopping

6.7. Test configuration 6: Pedestrian approach and passing (S8, S11, R1, R2, R3, R4)



6.7.1. Set up test area as depicted in the figure
6.7.2. Test vehicle 1 with paired operator is outside vicinity
6.7.3. Test vehicle 2 with paired operator is outside vicinity and does not participate in test
6.7.4. Scenario 1: Pedestrian outside vicinity
6.7.5. Place mannequin with pedestrian tag outside vicinity
6.7.6. Note GPS coordinates of pedestrian tag
6.7.7. Have test vehicle 1 pass pedestrian at speeds of 10 and 15km/h and note for each speed:
  6.7.7.1. Confirm that test vehicle 1 has no alerts and NOP response
  6.7.7.2. Confirm that pedestrian tag has no alerts
  6.7.7.3. Repeat 3 times
6.7.8. Scenario 2: Pedestrian outside danger zone
6.7.9. Place pedestrian outside danger zone
6.7.10. Note GPS coordinates of pedestrian tag
6.7.11. Have test vehicle 1 pass pedestrian at a speed of 2km/h
6.7.12. Confirm that test vehicle 1 has proximity-EW and NOP response
6.7.13. Confirm that pedestrian has proximity-EW
6.7.14. Repeat 3 times in both directions
6.7.15. Have vehicle pass pedestrian at speeds of 5, 10 and 15km/h
  6.7.15.1. Confirm that test vehicle 1 has stop-EW and auto-slow and stop response
  6.7.15.2. Confirm that pedestrian tag has danger-EW
  6.7.15.3. Repeat 3 times in both directions
6.7.16. Scenario 3: Pedestrian inside danger zone
6.7.17. Place one pedestrian tag such that test vehicle 1 will pass within the danger zone

6.7.18. Note GPS coordinates of pedestrian tag

6.7.19. Have vehicle 1 approach pedestrian tag and attempt to pass at speeds of 2, 5, 10 and 15km/h and note for each speed:

6.7.19.1. Distance when stop-EW test vehicle1 and danger-EW on pedestrian tag is issued

6.7.19.2. Distance when auto-slow is activated

6.7.19.3. Distance when stop is activated

6.7.19.4. Confirm that stop-EW on test vehicle 1 is active between 2.5 and 3.0s before activation of auto-slow and stop

6.7.19.5. Confirm that danger-EW on pedestrian tag is active between 2.5 and 3.0s before activation of auto-slow and stop

6.7.19.6. Confirm that stop is activated only after test vehicle 1 has reached safe braking speed

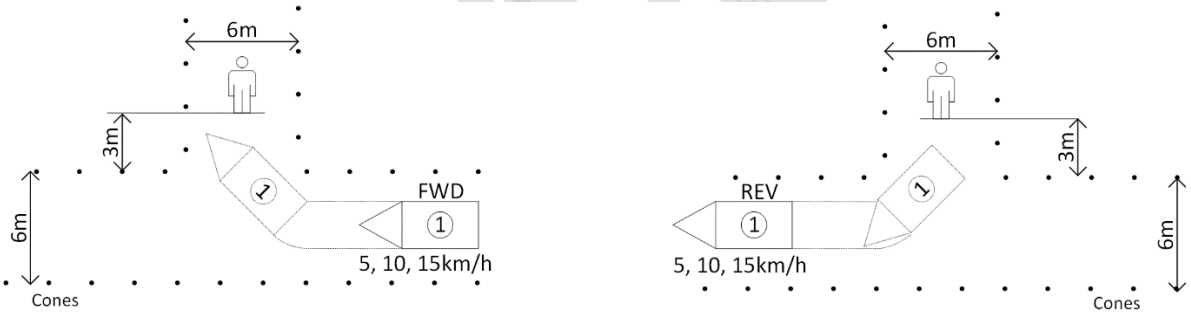
6.7.19.7. Confirm that test vehicle 1 has MI response after stopping

6.7.19.8. Confirm stop gap is between 2.5m and 3.0m

6.7.19.9. Repeat 3 times

6.7.19.10. Repeat for FWD and REV directions

6.8. Test configuration 7: TMM turning to obscured pedestrian (S9, R5)



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

6.8.2. Test vehicle 1 with paired operator is outside of vicinity

6.8.3. Test vehicle 2 with paired operator is outside of vicinity and does not partake in the test

6.8.4. Position pedestrian in centre of board, 3m away from perpendicular board

6.8.5. Have test vehicle 1 approach corner and steer towards obscured pedestrian at speeds of 5, 10 and 15km/h and note for each speed:

6.8.5.1. Distance when both stop-EW on test vehicle 1 and danger-EW on pedestrian is issued

6.8.5.2. Distance when auto-slow is activated

6.8.5.3. Distance when stop is activated

6.8.5.4. Confirm that stop-EW on test vehicle 1 is active between 2.5-3.0s before any intervention

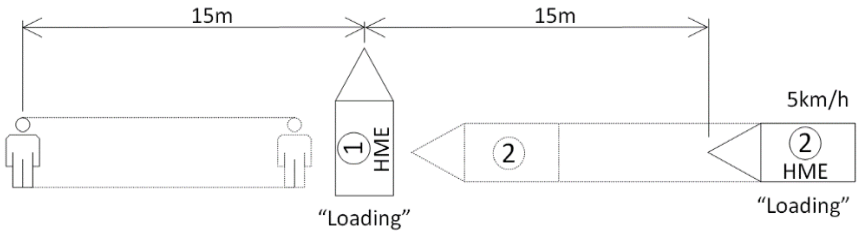
6.8.5.5. Confirm that danger-EW on pedestrian is active between 2.5-3.0s before any intervention

6.8.5.6. Confirm that stop gap is between 2.5m and 3.0m

6.8.5.7. Repeat 3 times

6.8.5.8. Repeat for both FWD and REV directions

6.9. Test configuration 8: Multiple TMMs with pedestrian approaching (S10, R8)



6.9.1. Test vehicle 1 with paired operator is in centre of test area in loading status
6.9.2. Test vehicle 2 with paired operator is outside vicinity in loading status
6.9.3. Pedestrian tag outside vicinity
6.9.4. Have a countdown or trigger event so that the following 2 instructions can be performed concurrently to simulate a pedestrian approaching an underground loading scenario:
6.9.4.1. Have pedestrian approach test vehicle 1 from the left hand side at a walking pace
6.9.4.2. Have test vehicle 2 approach test vehicle 1 from the right hand side at a speed of 5km/h
6.9.5. Note GPS coordinates of moving pedestrian
6.9.6. Distance when both stop-EW on test vehicle 1 and danger-EW on pedestrian is issued
6.9.7. Note distance between pedestrian and test vehicle 1 when MI response is activated
6.9.8. Distance when both stop-EW on test vehicle 2 and danger-EW on pedestrian is issued
6.9.9. Note distance between pedestrian and test vehicle 2 when auto-slow and stop is issued
6.9.10. Confirm that test vehicle 1 has stop-EW and motion inhibit response
6.9.11. Confirm that test vehicle 2 has stop-EW and motion inhibit response
6.9.12. Have pedestrian tag exit the vicinity of test vehicle 1
6.9.13. Confirm that both test vehicles 1 and 2 has no alerts and NOP response

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
7.4.1. the proposed deviation
7.4.2. reason for the proposed deviation and
7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 29: **Example** of noted machine response to introduced failure modes*

Firmware versions	
CxDC	3.1.4
CxDI	2.7.1.8
CxDLK	1.6.1.8
Test results	
TC1 - TC8	2.6 CxD Appendix A

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

10.1. TC1 Operators & passengers:

10.1.1. Vehicle and pedestrian tag no alerts and NOP with operator paired, AND

10.1.2. Vehicle and pedestrian tags no alerts and NOP with passengers paired, AND

10.1.3. Vehicle, operator and passengers tags no alerts and NOP with second vehicle and operator in vicinity, AND

10.1.4. Vehicle proximity-EW and NOP response with door switch activated when in safe-park status, AND

10.1.5. Vehicle immediate stop-EW and MI response with door switch activated when not in safe-park status, AND

10.1.6. Vehicle has immediate proximity-EW and when pedestrian tags unpaired as passengers when in safe-park status, AND

10.1.7. Pedestrians immediate proximity-EW with pedestrian tags unpaired as passengers, AND

10.1.8. For all test runs

10.2. TC2 Motion Inhibit and override

10.2.1. Vehicle has stop-EW and MI response with pedestrian tag in danger-zone, AND

10.2.2. Pedestrian has danger-EW with pedestrian tag in danger-zone, AND

10.2.3. Vehicle has proximity-EW and NOP with override, AND

10.2.4. Pedestrian has danger-EW with override, AND

10.2.5. Vehicle has immediate stop-EW and MI response when override timer runs out, AND

10.2.6. For all test runs

10.3. TC3 TMM in speed limited zone

10.3.1. Vehicle has no alerts and NOP when below - limit speed, AND

10.3.2. Vehicle has speed-limit-EW and auto-slow before entering speed limit zone when above limit speed, AND

10.3.3. Vehicle is below limit speed before entering speed limit zone, AND

10.3.4. Vehicle has proximity-EW and NOP when passing outside danger zone of a pedestrian inside speed limit zone, AND

10.3.5. Pedestrian has proximity-EW with vehicle passing outside danger zone, AND

10.3.6. Vehicle has stop-EW and auto-slow and stop with pedestrian inside danger zone, AND

10.3.7. Vehicle has stop-EW active between 2.5-3.0s before any intervention, AND

10.3.8. Pedestrian has danger-EW active between 2.5-3.0s before any intervention on vehicle, AND

10.3.9. Vehicle stop only at safe braking speed, AND

10.3.10. Vehicle has MI response after stopping, AND

10.3.11. Stop gap is between 2.5-3.0m, AND

10.3.12. For all runs at that speed

10.4. TC4 Broken-down TMM

10.4.1. Vehicle has proximity-EW and NOP with pedestrian outside danger zone while below 3km/h, AND

10.4.2. Pedestrian has proximity-EW with vehicle passing outside danger zone, AND

10.4.3. Vehicle has stop-EW and auto-slow and stop response with pedestrian inside danger zone

10.4.4. Vehicle has stop-EW active between 2.5-3.0s before any intervention, AND

10.4.5. Pedestrian has danger-EW active between 2.5-3.0s before any intervention on vehicle, AND

10.4.6. Vehicle stop only at safe braking speed, AND

10.4.7. Vehicle has MI response after stopping, AND

10.4.8. Stop gap is between 2.5-3.0m, AND

10.4.9. For all runs at that speed

10.5. TC5 Pedestrian activated emergency stop

10.5.1. Stationary vehicle has stop-EW and MI response after emergency stop activated, AND

10.5.2. Moving vehicle has stop-EW and auto-slow and stop response when emergency stop activated, AND

10.5.3. Auto-slow and stop is issued within 1s of emergency stop activation, AND

10.5.4. Pedestrian has danger-EW active after emergency stop activated, AND

10.5.5. Vehicle stop only at safe braking speed, AND

10.5.6. Vehicle has MI response after stopping, AND

10.5.7. For all runs

10.6. TC6 Pedestrian approach & passing

10.6.1. Vehicle has no alerts and NOP when passing outside vicinity of a pedestrian, AND

10.6.2. Pedestrian has no alerts with vehicle passing outside vicinity, AND

10.6.3. Vehicle has proximity-EW and NOP with pedestrian outside danger zone and vehicle below 3km/h, AND

10.6.4. Pedestrian has proximity-EW with vehicle passing outside danger zone

10.6.5. Vehicle has stop-EW and auto-slow and stop with pedestrian inside danger zone, AND

10.6.6. Pedestrian has danger-EW with vehicle passing inside danger zone, AND

10.6.7. Vehicle has stop-EW active between 2.5-3.0s before any intervention, AND

10.6.8. Pedestrian has danger-EW active between 2.5-3.0s before by intervention on vehicle, AND

10.6.9. Vehicle stop only at safe braking speed, AND

10.6.10. Vehicle has MI response after stopping, AND
10.6.11. Stop gap is between 2.5-3.0m, AND
10.6.12. For all runs in that direction at that speed

10.7. TC7 TMM turning to obscured pedestrian
10.7.1. Vehicle has stop-EW and auto-slow and stop response, AND
10.7.2. Vehicle has stop-EW active between 2.5-3.0s before any intervention, AND
10.7.3. Pedestrian has danger-EW active between 2.5-3.0s before any intervention on vehicle, AND
10.7.4. Vehicle stop only at safe braking speed, AND
10.7.5. Vehicle MI after stop, AND
10.7.6. Stop gap between 2.5-3.0m, AND
10.7.7. For all runs in that direction and at that speed

10.8. TC8 Multiple TMMs with pedestrian approaching
10.8.1. Moving vehicle has stop-EW and auto-slow and stop response, AND
10.8.2. Stationary vehicle has stop-EW active between 2.5-3.0s before any intervention, AND
10.8.3. Moving vehicle has stop-EW active between 2.5-3.0s before any intervention, AND
10.8.4. Pedestrian danger-EW active between 2.5-3.0s before intervention, AND
10.8.5. Both vehicles MI with pedestrian in danger zone of stationary vehicle, AND
10.8.6. Both vehicles NOP with pedestrian outside vicinity of stationary vehicle, AND
10.8.7. For all runs

11. Outcome of this test

*Table 30: **Example** outcome for CxDC UG logic test*

	FWD				REV				
	2	5	10	15	2	5	10	15	MI
TC1 Operators & passengers									Yes
TC2 Motion Inhibit & override									Yes
TC3 TMM in speed limited zone		Yes	Yes	Yes					
TC4 Broken-down TMM		Yes	Yes	Yes					
TC5 Pedestrian activated emergency stop									Yes
TC6 Pedestrian approach & passing	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
TC7 TMM turning to obscured pedestrian		Yes	Yes	Yes		Yes	Yes	Yes	
TC8 Multiple TMMs with pedestrian approaching									Yes

12. Applicable document

See separate file: 2.6U_CxD_CxDC_UG_test_protocol_Appendix_A_28Jan

Appendix 17: TRL 4 Underground CxD Robustness Test

TRL4 stage gate: CxD Detection robustness:
CxD UG Detection robustness test protocol (D&T)

1. Purpose

The D&T subsystem 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 representative environment.

2. Preceding test

- **2.1.** CxD ISO21815 Bench test
- **2.2.** CxD log-keeping test
- **2.3.** CxD Self-diagnostics test
- **2.4.** CxD Effective warning test
- **2.5.** CxD Basic detection and tracking test
- **2.6.** CxD CxDC logic test

3. Test facility/site

Site where board and pillar mock-up and two TMMs with CPS is available. Tests are highly dynamic in narrow spaces and need adequate space for run-up, conducting the test and run-off. Mock-up mine surface needs to be level for all test configurations, except for TC9 Blind approach on decline where a 15deg decline is required.

4. Instrumentation

- **4.1.** 1x LHD machine with CPS installed
- **4.2.** 1x ADT machine with CPS installed
- **4.3.** 2x DAQs with ISO/TS 21815-2 interface
- **4.4.** 1x Lidar or Radar synchronised with UTC
- **4.5.** 12 pedestrian tags
- **4.6.** 10 mannequins onto which pedestrian tags are fitted during test

5. Test preparation

- **5.1.** Test vehicles to be fully instrumented with CxD and any required peripherals needed as determined by supplier. An authorized person (technology provider representative) will sign-off that the supplied CxDs and peripherals are in working order as designed and that Equipment Under Test has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the CxD will be allowed once testing has commenced.
- **5.2.** Fence off test area. Ensure all aspects in Safety protocol is adhered to.
- **5.3.** Connect DAQ to CAN-harness so that messages between CxDI and MCI can be logged.
- **5.4.** Ensure that operators understand the objective of each test.
- **5.5.** Ensure that test engineer has effective method of communicating to operators in an emergency such that machines can be stopped immediately (air horn for example).
- **5.6.** All personnel must be within designated safe area when vehicles are moving.
- **5.7.** Ensure all personnel are wearing all the necessary PPE.

5.8. Ensure all personnel, equipment and all obstacles are removed in front and behind of the machine.

5.9. Start machines and let idle.

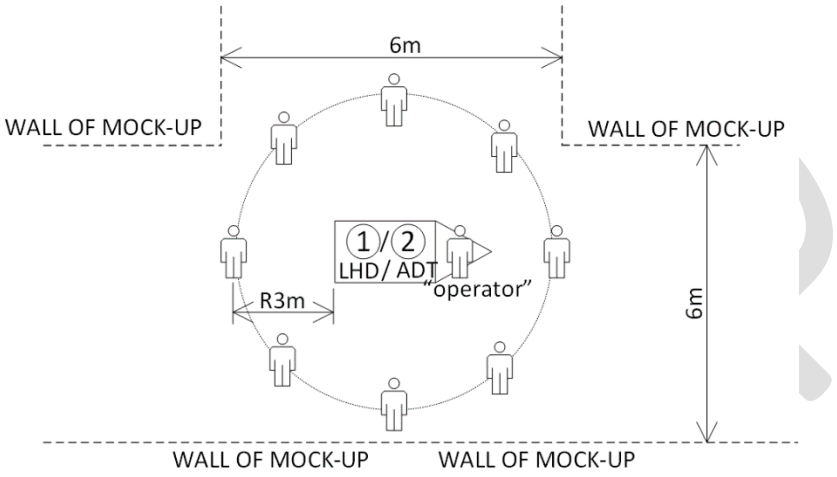
6. Test method

6.1. Note firmware versions of CxDC, CxDI, CxDLK, MCI, MC

6.2. Note OEM, model and serial number of machine

6.3. Note unique IDs of operator tags

6.4. Test configuration 1: Drop-out and status change test



6.4.1. In board and pillar mock-up mine, set up test area as depicted in the figure

6.4.2. Instruct operator to position machine 1 in the centre of the intersection

6.4.3. Machine 2 with paired operator is outside vicinity and does not partake in the test

6.4.4. Place 8 mannequins with pedestrian tags around machine 1 at a radius of 3m

6.4.5. Machine should have proximity-EW and NOP response

6.4.6. Pedestrians should have proximity-EW

6.4.7. Start recording on machine 1

6.4.8. Instruct operator to cycle between all available statuses of the machine

6.4.9. Instruct operator to articulate machine and lift bucket up and down

6.4.10. Note any drop-out of pedestrian proximity-EWs

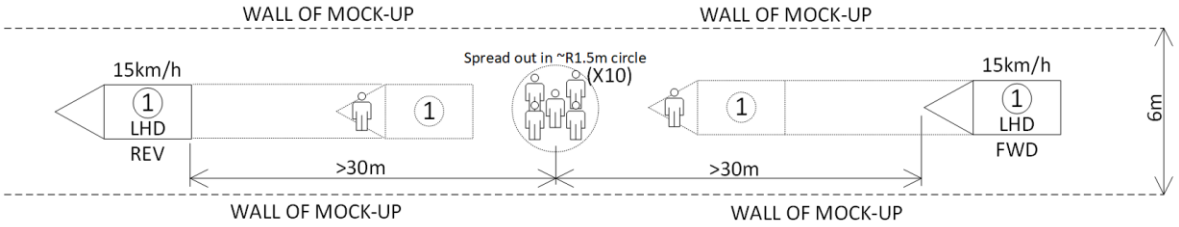
6.4.11. Stop recording on machine 1

6.4.12. Download log from CxDLK and note continuous detection of 8 pedestrian tags in Additional Continuous message in log file

6.4.13. Repeat 3 times

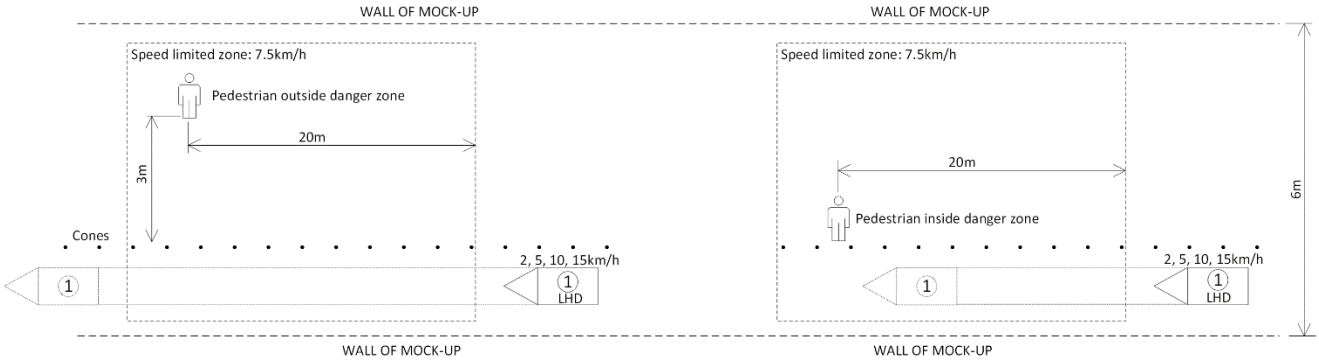
6.4.14. Repeat with machine 2

6.5. Test configuration 2: Multiple object test



6.5.1. In board and pillar mock-up, set up test area as depicted in the figure
6.5.2. Machine 1 with paired operator is outside vicinity and has scoop full of material
6.5.3. Machine 2 with paired operator is outside vicinity and does not participate in test
6.5.4. Place 10 mannequins with pedestrian tags in the centre of the board
6.5.5. Pedestrian tags should be spaced to fit inside a R1.5m circular area such that it represents a group of pedestrians standing close together
6.5.6. Have machine 1 approach group of pedestrians from a distance of at least 30m at a speed of 15km/h in both the FWD and REV directions
6.5.7. Note distance at which stop-EW is issued on machine
6.5.8. Note distance at which auto-slow response was activated
6.5.9. Note distance at which stop response was activated
6.5.10. Confirm stop gap is between 2.5-4.0m to the closest pedestrian
6.5.11. Confirm machine has MI response after stopping
6.5.12. Download logs and note detection of 10 pedestrian tags in Additional_Continuous message on log file
6.5.13. Note the maximum distance at which all 10 pedestrians are detected at speed
6.5.14. Repeat 3 times

6.6. Test configuration 3: TMM in speed limited zone (S5, S6, R7, R8)



6.6.1. In mock-up board and pillar mine, set up a zone with a speed limit of 7.5km/h as depicted in the figure
6.6.2. Note position of edge of speed limited zone
6.6.3. Machine 1 with paired operator is outside vicinity of the speed limited zone
6.6.4. Machine 2 with paired operator is outside vicinity and does not partake in test
6.6.5. Scenario 1: Pedestrian outside danger zone

6.6.6. Place mannequin with pedestrian tag inside the speed limited zone, such that the machine will pass it outside the danger zone

6.6.7. Note position of pedestrian tag

6.6.8. Have machine 1 enter the speed limited zone and pass the pedestrian at a speed of 2km/h and note:

6.6.8.1. Confirm that machine has NOP response before entering speed limited zone

6.6.8.2. Confirm that machine has proximity-EW and NOP response when passing pedestrian

6.6.8.3. Confirm pedestrian has proximity-EW

6.6.8.4. Confirm that vehicle can speed up after exiting the speed limited zone

6.6.9. Have machine 1 approach and enter the speed limited zone at speeds of 5, 10 and 15km/h

6.6.10. Attempt to maintain approaching speed inside speed limited zone and note for each speed:

6.6.10.1. Confirm that machine 1 has speed-limit-EW and auto-slow response when attempting to enter speed limited zone above limit speed

6.6.10.2. Distance between edge of speed limited zone and position at which limit speed is achieved

6.6.10.3. Confirm that speed limit is enforced inside speed limited zone

6.6.10.4. Confirm that pedestrian tag has danger-EW

6.6.10.5. Confirm that machine 1 has stop-EW and auto-slow and stop response when attempting to pass pedestrian

6.6.10.6. Confirm machine has MI after stopping

6.6.10.7. Confirm stop gap is between 2.5 and 4.0m

6.6.10.8. Repeat 3 times

6.6.11. Scenario 2: Pedestrian inside danger zone

6.6.12. Place pedestrian tag inside the danger zone

6.6.13. Note position of pedestrian tag

6.6.14. Have machine 1 enter the speed limited zone and attempt to pass pedestrian at a speed of 2km/h and note:

6.6.14.1. Confirm machine has stop-EW and stop response

6.6.14.2. Confirm pedestrian has danger-EW

6.6.15. Have machine 1 approach and enter the speed limited zone at speeds of 5, 10 and 15km/h

6.6.16. Attempt to maintain approaching speed inside speed limited zone and note for each speed:

6.6.16.1. Confirm that pedestrian tag has danger-EW

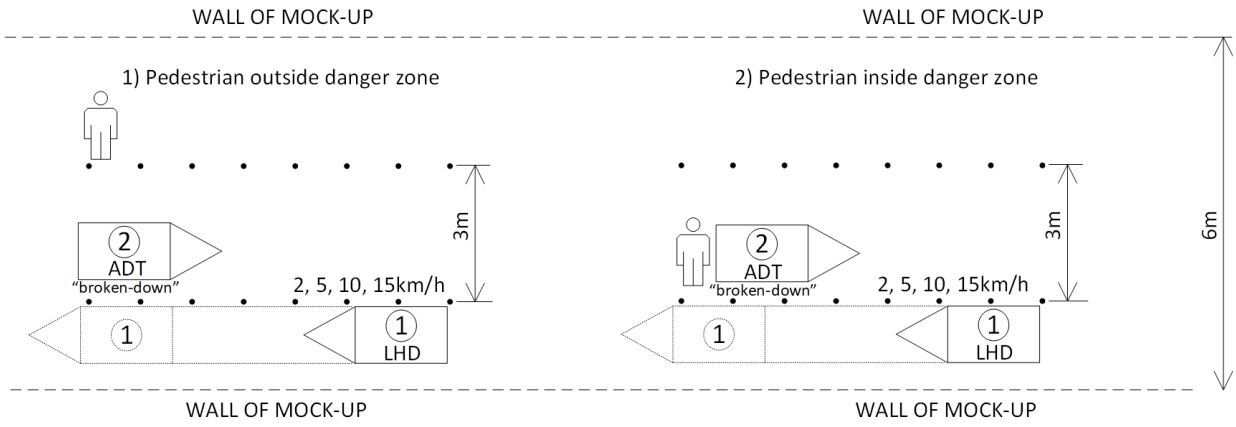
6.6.16.2. Confirm that machine 1 has stop-EW and auto-slow and stop response when attempting to pass pedestrian

6.6.16.3. Confirm machine has MI after stopping

6.6.16.4. Confirm stop gap is between 2.5 and 4.0m

6.6.16.5. Repeat 3 times

6.7. Test configuration 4: Broken-down TMM (S6)



6.7.1. In mock-up board and pillar mine, setup test area to simulate a mechanic attending to a broken-down TMM as depicted in the figure

6.7.2. Machine 1 with paired operator is outside vicinity of machine 2 and pedestrian

6.7.3. Machine 2 with paired operator is in broken-down status and outside vicinity of machine 1 and pedestrian

6.7.4. Scenario 1: Pedestrian outside danger zone

6.7.5. Place mannequin with pedestrian tag inside the speed limited zone, such that machine 2 will be between pedestrian and machine 1 as it passes outside the danger zone

6.7.6. Note position of pedestrian tag

6.7.7. Have machine 1 enter the speed limited zone and pass the pedestrian at a speed of 2km/h and note:

6.7.7.1. Confirm that machine has NOP response before entering speed limited zone

6.7.7.2. Confirm that machine has proximity-EW and NOP response when passing pedestrian

6.7.7.3. Confirm pedestrian has proximity-EW

6.7.7.4. Confirm that vehicle can speed up after exiting the speed limited zone

6.7.8. Have machine 1 approach and enter the speed limited zone at speeds of 5, 10 and 15km/h

6.7.9. Attempt to maintain approaching speed inside speed limited zone and note for each speed:

6.7.9.1. Confirm that machine 1 has speed-limit-EW and auto-slow response when attempting to enter speed limited zone above limit speed

6.7.9.2. Distance between edge of speed limited zone and position at which limit speed is achieved

6.7.9.3. Confirm that speed limit is enforced inside speed limited zone

6.7.9.4. Confirm that pedestrian tag has danger-EW

6.7.9.5. Confirm that machine 1 has stop-EW and auto-slow and stop response when attempting to pass pedestrian

6.7.9.6. Confirm machine has MI after stopping

6.7.9.7. Confirm stop gap is between 2.5 and 4.0m

6.7.9.8. Repeat 3 times

6.7.10. Scenario 2: Pedestrian inside danger zone

6.7.11. Place mannequin with pedestrian tag inside the speed limited zone, such that machine 2 will be between pedestrian and machine 1 as it passes inside the danger zone

6.7.12. Note position of pedestrian tag

6.7.13. Have machine 1 enter the speed limited zone and attempt to pass pedestrian at a speed of 2km/h and note:

6.7.13.1. Confirm machine has stop-EW and stop response

6.7.13.2. Confirm pedestrian has danger-EW

6.7.14. Have machine 1 approach and enter the speed limited zone at speeds of 5, 10 and 15km/h

6.7.15. Attempt to maintain approaching speed inside speed limited zone and note for each speed:

6.7.15.1. Confirm that pedestrian tag has danger-EW

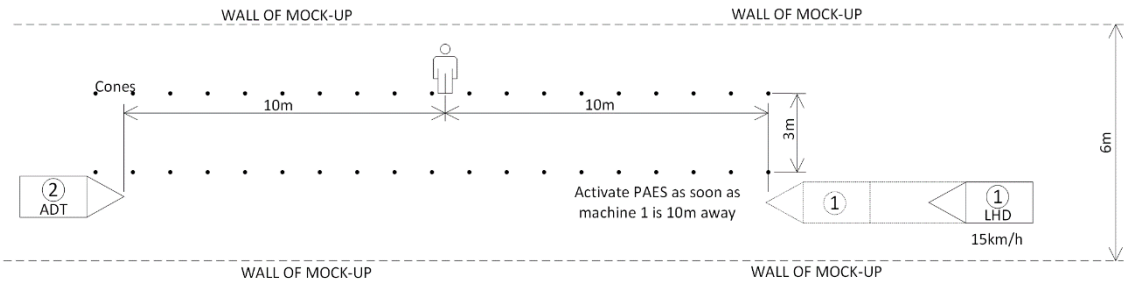
6.7.15.2. Confirm that machine 1 has stop-EW and auto-slow and stop response when attempting to pass pedestrian

6.7.15.3. Confirm machine has MI after stopping

6.7.15.4. Confirm stop gap is between 2.5 and 4.0m

6.7.15.5. Repeat 3 times

6.8. Test configuration 5: Pedestrian activated emergency stop (S7, R10)



6.8.1. In mock-up board and pillar mine, setup test area to simulate a pedestrian activating an emergency stop as depicted in the figure

6.8.2. Machine 1 with paired operator is sufficiently far away from pedestrian tag to speed up

6.8.3. Machine 2 with paired operator is stationary and 10m away from pedestrian tag

6.8.4. Pedestrian tag is outside the danger zone of both test vehicles

6.8.5. Have machine 1 approach machine 2 head-on at a speed of 15km/h

6.8.6. Activate pedestrian activated emergency stop as soon as test machine 1 is 10m away from pedestrian

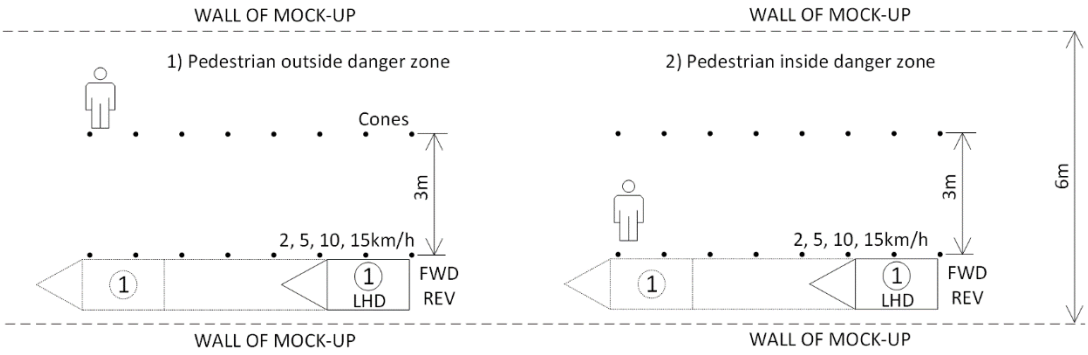
6.8.7. Confirm that machine 1 has stop-EW and MI response

6.8.8. Confirm that machine 2 has stop-EW and auto-slow and stop response

6.8.9. Confirm that stop is activated only after test vehicle 1 has reached safe braking speed

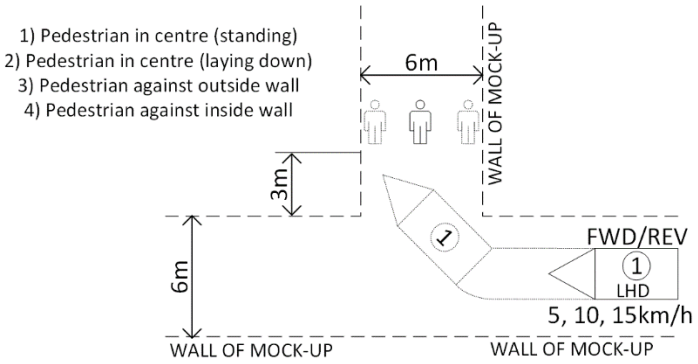
6.8.10. Confirm that machine 2 has MI response after stopping

6.9. Test configuration 6: Pedestrian approach and passing (S8, S11, R1, R2, R3, R4)



6.9.1. In board and pillar mock-up, set up test area as depicted in the figure
6.9.2. Machine 1 with paired operator is outside vicinity
6.9.3. Machine 2 with paired operator is outside vicinity and does not participate in test
6.9.4. Scenario 1: Pedestrian inside crawl zone
6.9.5. Place mannequin with pedestrian outside danger zone
6.9.6. Note position of pedestrian tag
6.9.7. Have machine pass pedestrian at a speed of 2km/h
6.9.8. Confirm that machine 1 has proximity-EW and NOP response
6.9.9. Confirm that pedestrian has proximity-EW
6.9.10. Repeat 3 times in both directions
6.9.11. Have machine pass pedestrian at speeds of 5, 10 and 15km/h
6.9.11.1. Confirm that machine 1 has stop-EW and auto-slow and stop response
6.9.11.2. Confirm that pedestrian tag has danger-EW
6.9.11.3. Repeat 3 times in both directions
6.9.12. Scenario 2: Pedestrian inside danger zone
6.9.13. Place mannequin with one pedestrian tag such that machine 1 will pass within the danger zone
6.9.14. Note position of pedestrian tag
6.9.14.1. Have machine 1 approach pedestrian tag and attempt to pass at speeds of 2, 5, 10 and 15km/h and note for each speed: Distance when EW on both machine and pedestrian is issued
6.9.14.2. Distance when auto-slow is activated
6.9.14.3. Distance when stop is activated
6.9.14.4. Confirm danger-EW on pedestrian is active between 2.5-3.0s before intervention on machine 1
6.9.14.5. Confirm stop-EW on machine 1 is active between 2.5-3.0s before intervention
6.9.14.6. Confirm that machine 1 has MI response after stopping
6.9.14.7. Confirm stop gap is between 2.5m and 4.0m
6.9.14.8. Repeat 3 times
6.9.14.9. Repeat for FWD and REV directions

6.10. Test configuration 7: TMM turning to obscured pedestrian (S9, R5)



6.10.1. In board and pillar mock-up, set up test area to simulate an obscured pedestrian as depicted in the figure

6.10.2. Machine 1 with paired pedestrian is outside of vicinity and has scoop filled with material

6.10.3. Machine 2 with paired pedestrian is outside of vicinity and does not partake in the test

6.10.4. Scenario 1: Pedestrian in centre (standing)

6.10.5. Position mannequin with pedestrian tag in centre of board, 3m away from perpendicular board

6.10.6. Have machine 1 approach corner and steer towards obscured pedestrian at speeds of 5, 10 and 15km/h and note for each speed:

6.10.6.1. Distance when both stop-EW on machine and danger-EW on pedestrian is issued

6.10.6.2. Distance when auto-slow is activated

6.10.6.3. Distance when stop is activated

6.10.6.4. Confirm danger-EW on pedestrian is active between 2.5-3.0s before intervention on machine 1

6.10.6.5. Confirm stop-EW on machine 1 is active between 2.5-3.0s before intervention

6.10.6.6. Confirm that stop gap is between 2.5m and 4.0m

6.10.6.7. Repeat 3 times

6.10.6.8. Repeat for both FWD and REV directions

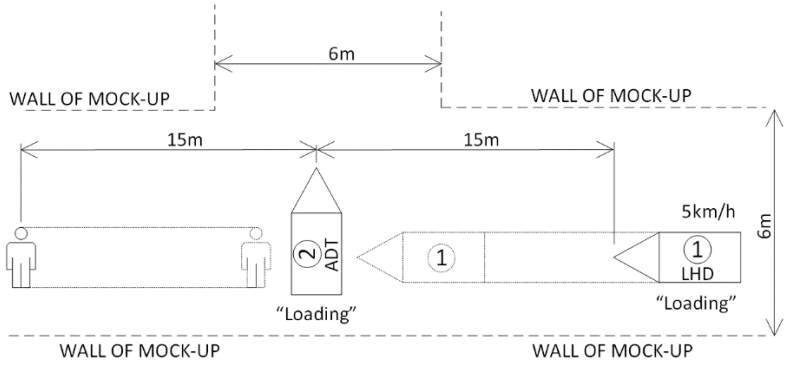
6.10.6.9. Repeat all of the above for the following scenarios:

6.10.6.9.1. Scenario 2: Pedestrian in centre (laying down)

6.10.6.9.2. Scenario 3: Pedestrian against outside wall

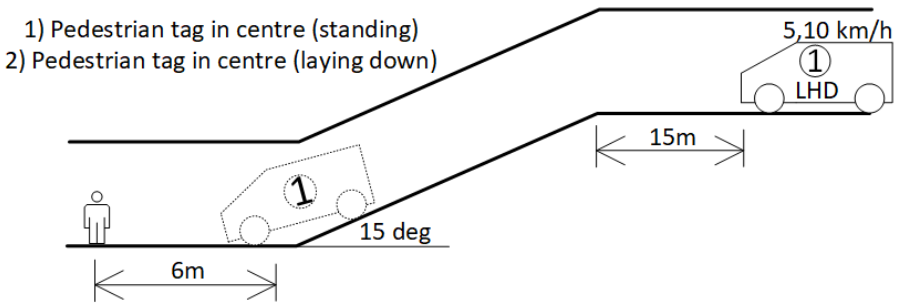
6.10.6.9.3. Scenario 4: Pedestrian against inside wall

6.11. Test configuration 8: Multiple TMMs with pedestrian approaching (S10, R8)



6.11.1. In board and pillar mock-up, set up test area as depicted in the figure
6.11.2. Machine 1 with paired operator is outside vicinity in loading status
6.11.3. Machine 2 with paired operator is in centre of test area in loading status
6.11.4. Pedestrian tag is outside vicinity
6.11.5. Have a countdown or trigger event so that the following 2 instructions can be performed concurrently to simulate a pedestrian approaching an underground loading scenario:
6.11.5.1. Have pedestrian approach machine 1 from the left hand side at a walking pace
6.11.5.2. Have machine 2 approach machine 1 from the right hand side at a speed of 5km/h
6.11.6. Note position of moving pedestrian
6.11.7. Note distance when both danger-EW on pedestrian and stop-EW on machine 2 is issued
6.11.8. Note distance when both danger-EW on pedestrian and stop-EW on machine 1 is issued
6.11.9. Note distance between pedestrian and machine 1 when auto-slow and/or stop is issued
6.11.10. Confirm that machine 2 has stop-EW and MI response
6.11.11. Confirm that machine 1 has stop-EW and MI response
6.11.12. Have pedestrian tag exit the vicinity of machine 2
6.11.13. Confirm that both machines 1 and 2 has no alerts and NOP response

6.12. Test configuration 9: Blind approach on decline



6.12.1. Place mannequin with pedestrian tag at the bottom of the decline, in the centre of the board, 6m away from apex
6.12.2. Note position of pedestrian.
6.12.3. Machine 1 is at top of incline, 15m from apex with a fully loaded bucket
6.12.4. Scenario 1: Pedestrian standing (900mm off the ground)
6.12.5. Have machine approach decline apex and descend to approach pedestrian head-on at speeds of 5 and 10km/h and note for each speed:
6.12.5.1. Distance between vehicle and pedestrian when effective warning is issued
6.12.5.2. Distance between vehicle and pedestrian when auto-slow and stop is issued
6.12.5.3. Confirm machine stop-EW is active between 2.5-3.0s before any intervention
6.12.5.4. Confirm pedestrian danger-EW is active between 2.5-3.0s before any intervention on machine
6.12.5.5. Confirm stopping distance is between 2.5-4.0m
6.12.5.6. Repeat 3 times
6.12.6. Scenario 2: Repeat all of the above with pedestrian tag on the ground

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
7.4.1. the proposed deviation
7.4.2. reason for the proposed deviation and
7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

Table 31: Example of noted machine response to introduced failure modes

Firmware versions	
CxDC	3.1.4
CxDI	2.7.1.8
CxDLK	1.6.1.8
MCI	3.1.4
MC	2.7.1.8
Test results	
TC1 – TC9	2.7 CxD Appendix A

9. Influence of deviations on outcome

Example: None

10. Acceptance criteria for this test

10.1. Drop-out and status change test:

10.1.1. Detect all pedestrian tags for duration of test, AND

10.1.2. In all machine statuses, AND

10.1.3. For all machine types, AND

10.1.4. For all three runs

10.2. Multiple objects test

10.2.1. Detect all 10 pedestrian tags, AND

10.2.2. Detect all pedestrian tags at a distance of at least 25m, AND

10.2.3. Machine stop-EW is active between 2.5-3.0s before any intervention, AND

10.2.4. Pedestrian danger-EW is active between 2.5-3.0s before any intervention, AND

10.2.5. Stop gap is between 2.5-4.0m to closest pedestrian, AND

10.2.6. Machine has MI after stopping, AND

10.2.7. Machine stops below safe braking speed, AND

10.2.8. In both directions, AND

10.2.9. For all runs

10.3. TMM in speed limited zone

10.3.1. Machine is NOP when below limiting speed, AND

10.3.2. Machine has speed-limit-EW active between 2.5-3.0s before entering speed limited zone if attempting to do so above limit speed, AND

10.3.3. Machine enters speed limited zone below limit speed if attempting to do so above limit speed, AND

10.3.4. Speed limit is enforced inside speed limited zone, AND

10.3.5. Machine has proximity-EW and NOP when passing pedestrian outside danger zone below 3km/h, AND

10.3.6. Pedestrian has proximity-EW with machine passing outside danger zone below 3km/h, AND

10.3.7. Machine has stop-EW and auto-slow and stop response when attempting to pass pedestrian outside danger zone above 3km/h, AND

10.3.8. Pedestrian has danger-EW outside danger zone when machine attempts to pass above 3km/h, AND

10.3.9. Machine has stop-EW and auto-slow and stop response when attempting to pass pedestrian inside danger zone, AND

10.3.10. Pedestrian has danger-EW when machine attempts to pass inside danger zone, AND

10.3.11. Machine has MI after stop, AND

10.3.12. Stop gap is between 2.5-4.0m, AND

10.3.13. Machine stop-EW is active between 2.5-3.0s before any intervention, AND

10.3.14. Pedestrian danger-EW is active between 2.5-3.0s before any intervention on machine, AND

10.3.15. Machine can speed up after exiting speed limit zone, AND

10.3.16. For all three runs at that speed

10.4. Broken-down TMM

10.4.1. Machine has proximity-EW and NOP when passing pedestrian outside danger zone below 3km/h, AND

10.4.2. Pedestrian has proximity-EW with machine passing outside danger zone below 3km/h, AND

10.4.3. Machine has stop-EW and auto-slow and stop response when attempting to pass pedestrian outside danger zone above 3km/h, AND

10.4.4. Pedestrian has danger-EW outside danger zone when machine attempts to pass above 3km/h, AND

10.4.5. Machine has stop-EW and auto-slow and stop response when attempting to pass pedestrian inside danger zone, AND

10.4.6. Pedestrian has danger-EW when machine attempts to pass inside danger zone, AND

10.4.7. Machine has MI after stop, AND

10.4.8. Stop gap is between 2.5-4.0m

10.4.9. Machine stop-EW is active between 2.5-3.0s before any intervention, AND

10.4.10. Pedestrian danger-EW is active between 2.5-3.0s before any intervention on machine, AND

10.4.11. For all three runs at that speed

10.5. Pedestrian activated emergency stop

10.5.1. Pedestrian tag has immediate danger-EW, AND

10.5.2. Stationary machine has immediate stop-EW and MI response, AND

10.5.3. Moving machine has immediate stop-EW and auto-slow and stop response, AND

10.5.4. Moving machine only stops below safe braking speed, AND

10.5.5. Moving machine has stop-EW and MI response after stopping, AND

10.5.6. For all three runs

10.6. Pedestrian approach and passing

10.6.1. Machine has proximity-EW and NOP when passing pedestrian outside danger zone below 3km/h, AND

10.6.2. Pedestrian has proximity-EW with machine passing outside danger zone below 3km/h, AND

10.6.3. Machine has stop-EW and auto-slow and stop response when attempting to pass pedestrian outside danger zone above 3km/h, AND

10.6.4. Pedestrian has danger-EW outside danger zone when machine attempts to pass above 3km/h, AND

10.6.5. Machine has stop-EW and auto-slow and stop response when attempting to pass pedestrian inside danger zone, AND

10.6.6. Pedestrian has danger-EW when machine attempts to pass inside danger zone, AND

10.6.7. Machine has MI after stop, AND

10.6.8. Stop gap is between 2.5-4.0m

10.6.9. Machine stop-EW is active between 2.5-3.0s before any intervention, AND

10.6.10. Pedestrian danger-EW is active between 2.5-3.0s before any intervention on machine, AND

10.6.11. For all three runs at that speed

10.7. TMM turning to obscured pedestrian

10.7.1. Machine has stop-EW and auto-slow and stop response, AND

10.7.2. Pedestrian has danger-EW, AND

10.7.3. Machine has MI after stop, AND

10.7.4. Stop gap is between 2.5-4.0m, AND

10.7.5. Machine stop-EW is active between 2.5-3.0s before any intervention, AND
10.7.6. Pedestrian danger-EW is active between 2.5-3.0s before any intervention on machine, AND
10.7.7. For all positions of pedestrian tag at that speed, AND
10.7.8. For all three runs at that speed

10.8. Multiple TMMs with pedestrian approaching
10.8.1. Pedestrian has danger-EW, AND
10.8.2. Stationary machine has stop-EW and MI response, AND
10.8.3. Moving machine has stop-EW and auto-slow and stop response when pedestrian is inside stationary machine's vicinity, AND
10.8.4. Moving machine has MI after stop, AND
10.8.5. Machine stop-EW is active between 2.5-3.0s before any intervention, AND
10.8.6. Pedestrian danger-EW is active between 2.5-3.0s before any intervention on machine, AND
10.8.7. Both machines NOP after pedestrian has exited vicinity of stationary machine, AND
10.8.8. For all three runs

10.9. Obscured pedestrian at bottom of decline
10.9.1. Machine has stop-EW and auto-slow and stop response, AND
10.9.2. Pedestrian has danger-EW, AND
10.9.3. Machine has MI after stop, AND
10.9.4. Stop gap is between 2.5-4.0m, AND
10.9.5. Machine stop-EW is active between 2.5-3.0s before any intervention, AND
10.9.6. Pedestrian danger-EW is active between 2.5-3.0s before any intervention on machine, AND
10.9.7. For all positions of pedestrian tag at that speed, AND
10.9.8. For all three runs at that speed

11. Outcome of this test

*Table 32: **Example** outcome for machine controller response test*

	FWD				REV				
	2	5	10	15	2	5	10	15	MI
TC1 Drop out and status change									Yes
TC2 Multiple object									Yes
TC3 TMM in speed limited zone		Yes	Yes	Yes					
TC4 Broken-down TMM		Yes	Yes	Yes					
TC5 Pedestrian activated emergency stop									Yes
TC6 Pedestrian approach & passing	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
TC7 TMM turning to obscured pedestrian		Yes	Yes	Yes		Yes	Yes	Yes	
TC8 Multiple TMMs with pedestrian approaching									Yes
TC9 Obscured pedestrian at bottom of decline		Yes	Yes						

12. Applicable document

See separate file: 2.7U_CxD_Detection_robustness_test_protocol_Appendix_A_28Jan

10. TRL 6 Tests

Appendix 18: TRL 6 Surface CPS Integration Test

TRL6 CPS systems integration stage gate
CPS Surface systems integration protocol (CxD + TMM)

1. Purpose

The CxD and TMM subsystems have been tested in isolation are now integrated to form the CPS. The purpose of this test is to ensure that the subsystems are fully compatible and that the complete system performs as expected.

2. Preceding tests

- **2.1.** ISO3450 test
- **2.2.** TMM ISO21815 Bench test
- **2.3.** TMM log-keeping test
- **2.4.** TMM Machine sense test
- **2.5.** TMM Self-diagnostics test
- **2.6.** TMM Machine controller response protocol
- **2.7.** CxD ISO21815 Bench test
- **2.8.** CxD log-keeping test
- **2.9.** CxD self-diagnostics test
- **2.10.** CxD Effective warning test
- **2.11.** Basic detection and tracking test
- **2.12.** CxD CxDC logic test
- **2.13.** SANS 13766 test
- **2.14.** Section 21 file including:
  - **2.14.1.** Layout drawings of CxD and all components on TMM (including interface ISO/TS 21815-2)
  - **2.14.2.** OEM approval for all additional fittings for CxD components placement on TMM
  - **2.14.3.** Installation checklist, testing, commissioning and sign off / handover to production procedure of CPS
  - **2.14.4.** CPS risk assessment
  - **2.14.5.** CPS operation and maintenance technical specification

3. Test facility/site

Site where CPS is available on TMM. Tests are dynamic and need adequate space for run-up, conducting the test and run-off. Surface needs to be level.

4. Instrumentation

- **4.1.** 2x CPS system on TMMs
- **4.2.** 1x DAQ with ISO/TS 21815-2 interface
- **4.3.** 1x HP GNSS

5. Test preparation

5.1. Equipment under test will be supplied in working condition by systems integrator. An authorized person (systems integrator representative) will sign-off that the supplied EUT is in working order as designed that has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the EUT will be allowed once testing has commenced.

5.2. Fence off test area. Ensure all aspects in Safety protocol is adhered to.

5.3. Install HP GNSS on two machines and ensure good satellite reception is obtained.

5.4. Connect DAQ to CAN-harness so that messages between CxDI and MCI can be logged

5.5. Ensure all personnel, equipment and all obstacles are removed in front and behind of the machine.

5.6. Start machines and let idle.

5.7. Instruct operator that during each test run AND unless unsafe:

5.7.1. The accelerator pedal must stay depressed during the entire duration of the test run

5.7.2. Manually operated brakes may not be used at any time during the test run

5.7.3. Take-off is only required to be gradual, slow and short since MI is being evaluated

6. Test method

6.1. Note firmware versions of MC and MCI, MLK, CxD, CxDI, CxDLK

6.2. Note OEM, model and serial number of the machine

6.3. Scenario 1: Fail to safe for communication and power interruption

6.3.1. With machine stationary and in NOP, disconnect the CAN communication interface between the CxD and the machine

6.3.2. Instruct operator to attempt to take-off in both FWD and REV directions and note MI response

6.3.3. Reconnect the CAN interface and instruct operator to take-off in FWD and REV directions and note NOP

6.3.4. With machine stationary and in NOP, disconnect the power supply to the CxD

6.3.5. Instruct operator to attempt to take-off in both FWD and REV directions and note MI response

6.3.6. Reconnect the power supply to the CxD and instruct operator to take-off in FWD and REV directions and note NOP

6.3.7. Repeat 3 times

6.4. Scenario 2: MI, override & NOP

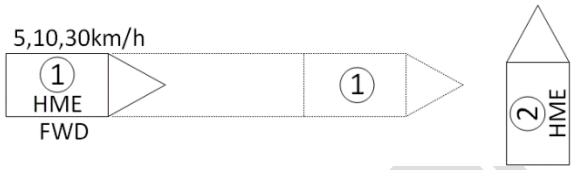
6.4.1. With machine stationary and in NOP, introduce machine 2 into danger zone

6.4.2. Instruct operator to attempt to take-off in both FWD and REV directions and note MI

6.4.3. Attempt to activate override on machine 1 with non-authorised person and note response of system

6.4.4. Activate override on machine 1 with authorised person and start timer
6.4.5. Note proximity-EW and NOP response of machine 1
6.4.6. Wait until system returns to MI and note duration
6.4.7. Remove machine 2 from danger zone
6.4.8. Instruct operator to take-off in both FWD and REV directions and note NOP
6.4.9. Repeat 3 times

6.5. Scenario 3: Decelerations and delays to slowdown and stop commands



6.5.1. Set up test area as depicted in the above figure
6.5.2. Instruct operator to drive machine 1 head-on towards machine 2 at the following speeds:
6.5.2.1. 5km/h
6.5.2.2. 10km/h
6.5.2.3. 30km/h
6.5.3. For each speed, note:
6.5.3.1. Time delay between slowdown command and 5% speed reduction (i.e. machine delay to slowdown command)
6.5.3.2. Deceleration between 5% speed reduction and 5% above safe braking speed (i.e. slowdown deceleration)
6.5.3.3. Distance between machines and position where slowdown command was issued
6.5.3.4. Time delay between stop command and 5% speed reduction (i.e. machine delay to stop command)
6.5.3.5. Deceleration between 5% above safe braking speed and 1km/h (i.e. stop deceleration)
6.5.3.6. Distance between machines and position where stop command was issued
6.5.3.7. Stop gap
6.5.3.8. If MI is maintained after machine has come to a stop
6.5.4. Repeat 3 times for each speed-direction combination

7. Deviations from protocol

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accepted in writing?
7.4.1. the proposed deviation
7.4.2. reason for the proposed deviation and
7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 1: **Example** of noted machine response to introduced failures.*

	Vel km/h	Run1	Run2	Run3
Firmware versions				
MC		Version 2.7.1.8		
MCI		Version 3.1.4		
CxD		Version 1.6.1.8		
Machine details				
OEM		CAT		
Model		785D		
Serial number		13327		
Scenario1: FTS				
Communication interrupted		MI	MI	MI
Communication restored		NOP	NOP	NOP
Power interrupted		MI	MI	MI
Power restored		NOP	NOP	NOP
Scenario2: MI, override & NOP				
Machine with hazard		MI	MI	MI
Articulation with hazard		MI	MI	MI
Attachment with hazard		MI	MI	MI
Non-authorised override		MI	MI	MI
Authorised override		Limited to 5km/h	Limited to 5km/h	Limited to 5km/h
Override duration		50s	51s	50s
Return to NOP		Yes	Yes	Yes
Scenario 3: Decelerations and delays to slowdown and stop command				
Decel 5% speed reduction to 5% above safe braking speed (slowdown decal)	**5**	0.10g	0.12g	0.11g
	10	0.12g	0.11g	0.10g
	15	0.10g	0.12g	0.11g
Delay 5% speed reduction for slowdown command	**5**	0.45s	0.55s	0.42s
	10	0.49s	0.52s	0.5s
	15	0.45s	0.45s	0.57s
Decel 5% speed reduction to 1km/h (stop decal)	**5**	0.35	0.34	0.36
	10	0.37	0.35	0.36
	15	0.36	0.34	0.34
Delay 5% speed reduction for stop command	**5**	0.45s	0.55s	0.42s
	10	0.49s	0.52s	0.5s
	15	0.45s	0.45s	0.57s
MI after stop	**5**	Yes	Yes	Yes

	10	Yes	Yes	Yes
	15	Yes	Yes	Yes

9. Deviations from protocol

None

10. Acceptance criteria for this test

10.1. Fail to safe: communication interruption
- **10.1.1.** System immediately responds with motion inhibit when CAN communication is severed between CxD and Machine, AND
- **10.1.2.** System restores to NOP when CAN communication is restored, AND
- **10.1.3.** For all three test runs

10.2. Fail to safe: Power interruption
- **10.2.1.** System immediately responds with motion inhibit when power is interrupted between CxD and Machine, AND
- **10.2.2.** System restores to NOP when power is restored, AND
- **10.2.3.** For all three test runs

10.3. Motion inhibit
- **10.3.1.** Machine is MI when machine 2 is introduced in danger zone, AND
- **10.3.2.** For all three test runs

10.4. Override
- **10.4.1.** Can only be activated by authorised person, AND
- **10.4.2.** Proximity-EW is active, AND
- **10.4.3.** Limits machine to emergency speed, AND
- **10.4.4.** Only active for a limited time duration, AND
- **10.4.5.** For all three test runs

10.5. NOP
- **10.5.1.** System returns to normal operation when hazard is removed from vicinity, AND
- **10.5.2.** For all three test runs

10.6. Deceleration and delays to slowdown commands
- **10.6.1.** Slowdown deceleration rate within OEM's spec, AND
- **10.6.2.** Machine delay between slowdown command and response within OEM's spec, AND
- **10.6.3.** For all dynamic test runs

10.7. Deceleration and delays to stop commands
- **10.7.1.** Stop deceleration rate within OEM's spec, AND
- **10.7.2.** Machine delay between stop command and response within OEM's spec, AND
- **10.7.3.** Motion inhibit is maintained after machine has come to a stop, AND
- **10.7.4.** For all dynamic test runs

11. Outcome of this test

*Table 33: **Example** outcome for machine controller response test*

		Pass
FTS Communication	Fail to safe with communication interruption	Yes
FTS Power interruption	Fail to safe with power interruption	Yes
MI	Machine response to hazard in danger zone	Yes
Override	Machine response to authorised override	Yes
NOP	Machine response to removal of hazard	Yes
Slowdown commands	Machine response to slowdown command	Yes
Stop commands	Machine response to stop command	Yes

*Table 34: **Example** response of machine*

	Value
Average machine delay to Slowdown	0.5 s
Average machine delay to Stop	0.5 s
Average machine deceleration to Slowdown	0.13 g
Average machine deceleration to Stop	0.35 g

Appendix 19: TRL 6 Underground CPS Integration Test

TRL6 Stage Gate CPS systems integration

CPS UG systems integration protocol (CxD + TMM)

1. Purpose

The CxD and TMM subsystems have been tested in isolation are now integrated to form the CPS. The purpose of this test is to ensure that the subsystems are fully compatible and that the complete system performs as expected.

2. Preceding test

- **2.1.** SANS1589
- **2.2.** TMM ISO21815 Bench test
- **2.3.** TMM log-keeping test
- **2.4.** TMM Machine sense test
- **2.5.** TMM Self-diagnostics test
- **2.6.** TMM Machine controller response protocol
- **2.7.** CxD ISO21815 Bench test
- **2.8.** CxD log-keeping test
- **2.9.** CxD self-diagnostics test
- **2.10.** CxD Effective warning test
- **2.11.** CxD Basic detection and tracking test
- **2.12.** CxD CxDC logic test
- **2.13.** CxD Detection robustness test
- **2.14.** SANS 13766 test
- **2.15.** Section 21 file including:
  - **2.15.1.** Layout drawings of CxD and all components on TMM (including interface ISO 21815)
  - **2.15.2.** OEM approval for all additional fittings for CxD components placement on TMM
  - **2.15.3.** Installation checklist, testing, commissioning and sign off / handover to production procedure of CPS
  - **2.15.4.** CPS risk assessment
  - **2.15.5.** CPS operation and maintenance technical specification

3. Test facility/site

Site where CPS is available on TMM. Tests are dynamic and need adequate space for run-up, conducting the test and run-off. Surface needs to be level.

4. Instrumentation

- **4.1.** 1x CPS system on TMM
- **4.2.** 1x DAQ with ISO 21815-2 interface
- **4.3.** 1x HP GNSS
- **4.4.** 1x pedestrian tag
- **4.5.** 1x mannequin onto which pedestrian tag is fitted during test

5. Test preparation

5.1. Equipment under test will be supplied in working condition by systems integrator. An authorized person (systems integrator representative) will sign-off that the supplied EUT is in working order as designed that has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the EUT will be allowed once testing has commenced.

5.2. Fence off test area. Ensure all aspects in Safety protocol is adhered to.

5.3. Install HP GNSS on machine and ensure good satellite reception is obtained.

5.4. Connect DAQ to CAN-harness so that messages between CxDI and MCI can be logged

5.5. Ensure all personnel, equipment and all obstacles are removed in front and behind of the machine.

5.6. Start machine and let idle.

5.7. Instruct operator that during each test run AND while it remains safe to do so:

5.7.1. The accelerator pedal must stay depressed during the entire duration of the test run

5.7.2. Manually operated brakes may not be used at any time during the test run

5.7.3. Take-off is only required to be gradual, slow and short since MI is being evaluated

6. Test method

6.1. Note firmware versions of MC and MCI, MLK, CxD, CxDI, CxDLK

6.2. Note OEM, model and serial number of the machine

6.3. Test configuration1: Fail to safe for communication and power interruption

6.3.1. With machine stationary and in NOP, disconnect the CAN communication interface between the CxD and the machine

6.3.2. Instruct operator to attempt to take-off in both FWD and REV directions and note MI response

6.3.3. Reconnect the CAN interface and instruct operator to take-off in FWD and REV directions and note NOP

6.3.4. With machine stationary and in NOP, disconnect the power supply to the CxD

6.3.5. Instruct operator to attempt to take-off in both FWD and REV directions and note MI response

6.3.6. Reconnect the power supply to the CxD and instruct operator to take-off in FWD and REV directions and note NOP

6.3.7. Repeat 3 times

6.4. Test configuration 2: MI, override & NOP

6.4.1. With machine stationary and in NOP, introduce pedestrian tag into danger zone on the side of the machine

6.4.2. Instruct operator to attempt to take-off in both FWD and REV directions and note MI

6.4.3. If available, instruct operator to attempt to articulate vehicle and note MI

6.4.4. If available, instruct operator to attempt to operate attachment and note MI

6.4.5. Attempt to activate override on machine with non-authorised person and note response of system

6.4.6. Activate override with authorised person and start timer

6.4.7. Note proximity-EW and NOP response of machine

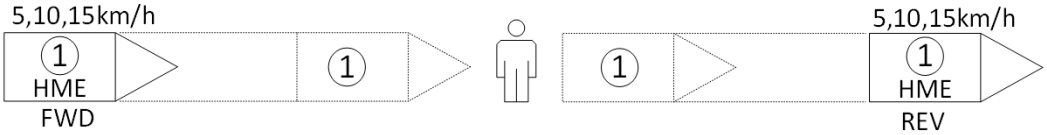
6.4.8. Wait until system returns to MI and note duration

6.4.9. Remove pedestrian tag from danger zone

6.4.10. Instruct operator to take-off in both FWD and REV directions and note NOP

6.4.11. Repeat 3 times

6.5. Interaction scenario 3: Decelerations and delays to slowdown and stop commands



6.5.1. Set up test area as depicted in the above figure

6.5.2. Position mannequin with pedestrian tag in centre of test area and note GPS coordinates

6.5.3. Instruct operator to drive machine head-on and reverse-on towards the pedestrian tag at the following speeds:

6.5.3.1. 5km/h

6.5.3.2. 10km/h

6.5.3.3. 15km/h

6.5.3.4. Or maximum speed in each gear

6.5.3.5. In FWD and REV directions

6.5.4. For each speed, note:

6.5.4.1. Time delay between slowdown command and 5% speed reduction (i.e. machine delay to slowdown commands)

6.5.4.2. Deceleration between 5% and 5% above safe braking speed (i.e. slowdown deceleration)

6.5.4.3. Distance between pedestrian and position where slowdown command was issued

6.5.4.4. Time delay between stop command and 5% speed reduction (i.e. machine delay to stop commands)

6.5.4.5. Deceleration between 5% and 1km/h (i.e. stop deceleration)

6.5.4.6. Distance between pedestrian and position where stop command was issued

6.5.4.7. Stop gap

6.5.4.8. If MI is maintained after machine has come to a stop

6.5.5. Repeat 3 times for each speed-direction combination

7. Deviations from protocol

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accepted in writing?
  7.4.1. the proposed deviation
  7.4.2. reason for the proposed deviation and
  7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 35: **Example** of test results*

	Vel km/h	Run1	Run2	Run3
Firmware versions				
MC		Version 2.7.1.8		
MCI		Version 3.1.4		
CxD		Version 1.6.1.8		
Machine details				
OEM		Komatsu		
Model		WX18H		
Serial number		14414		
Scenario1: FTS				
Communication interrupted		MI	MI	MI
Communication restored		NOP	NOP	NOP
Power interrupted		MI	MI	MI
Power restored		NOP	NOP	NOP
Scenario2: MI, override & NOP				
Machine with hazard		MI	MI	MI
Articulation with hazard		MI	MI	MI
Attachment with hazard		MI	MI	MI
Non-authorised override		MI	MI	MI
Authorised override		Limited to 5km/h	Limited to 5km/h	Limited to 5km/h
Override duration		50s	51s	50s
Return to NOP		Yes	Yes	Yes
Scenario 3: Decelerations and delays to slowdown and stop command				
Decel 5% speed reduction to 5% above safe braking speed (slowdown decal)	**5 FWD**	0.10g	0.12g	0.11g
	10 FWD	0.12g	0.11g	0.10g
	15 FWD	0.10g	0.12g	0.11g
	5 REV	0.10g	0.12g	0.11g
	10 REV	0.12g	0.11g	0.10g
	15 REV	0.10g	0.12g	0.11g

Delay 5% speed reduction for slowdown command	**5 FWD**	0.45s	0.55s	0.42s
	10 FWD	0.49s	0.52s	0.5s
	15 FWD	0.45s	0.45s	0.57s
	5 REV	0.45s	0.55s	0.42s
	10 REV	0.49s	0.52s	0.5s
	15 REV	0.45s	0.45s	0.57s
Decel 5% speed reduction to 1km/h (stop decel)	**5 FWD**	0.35g	0.34g	0.36g
	10 FWD	0.37g	0.35g	0.36g
	15 FWD	0.36g	0.34g	0.34g
	5 REV	0.35g	0.34g	0.36g
	10 REV	0.37g	0.35g	0.36g
	15 REV	0.36g	0.34g	0.34g
Delay 5% speed reduction for stop command	**5 FWD**	0.45s	0.55s	0.42s
	10 FWD	0.49s	0.52s	0.5s
	15 FWD	0.45s	0.45s	0.57s
	5 REV	0.45s	0.55s	0.42s
	10 REV	0.49s	0.52s	0.5s
	15 REV	0.45s	0.45s	0.57s

9. Deviations from protocol

Example: None

10. Acceptance criteria for this test

10.1. Fail to safe: communication interruption

10.1.1. System immediately responds with motion inhibit when CAN communication is severed between CxD and Machine, AND

10.1.2. System restores to NOP when CAN communication is restored, AND

10.1.3. For all three test runs

10.2. Fail to safe: Power interruption

10.2.1. System immediately responds with motion inhibit when power is interrupted between CxD and Machine, AND

10.2.2. System restores to NOP when power is restored, AND

10.2.3. For all three test runs

10.3. Motion inhibit

10.3.1. Machine is MI when pedestrian tag is introduced in danger zone, AND

10.3.2. If available, articulation is MI when pedestrian tag is introduced in danger zone, AND

10.3.3. If available, attachment is MI when pedestrian tag is introduced in danger zone, AND

10.3.4. For all three test runs

10.4. Override

10.4.1. Can only be activated by authorised person, AND

10.4.2. Proximity-EW is active, AND

10.4.3. Limits machine to emergency speed, AND

10.4.4. Only active for a limited time duration, AND
10.4.5. For all three test runs

10.5. NOP
10.5.1. System returns to normal operation when hazard is removed from vicinity, AND
10.5.2. For all three test runs

10.6. Deceleration and delays to slowdown commands
10.6.1. Slowdown deceleration rate within OEM's spec, AND
10.6.2. Machine delay between slowdown command and response within OEM's spec, AND
10.6.3. For all dynamic test runs, AND
10.6.4. In both directions

10.7. Deceleration and delays to stop commands
10.7.1. Stop deceleration rate within OEM's spec, AND
10.7.2. Machine delay between stop command and response within OEM's spec, AND
10.7.3. Motion inhibit is maintained after machine has come to a stop, AND
10.7.4. For all dynamic test runs, AND
10.7.5. In both directions

11. Outcome of this test

*Table 3637: **Example** outcome for machine controller response test*

		Pass
FTS Communication	Fail to safe with communication interruption	Yes
FTS Power interruption	Fail to safe with power interruption	Yes
MI	Machine response to hazard in danger zone	Yes
Override	Machine response to authorised override	Yes
NOP	Machine response to removal of hazard	Yes
Slowdown commands	Machine response to slowdown command	Yes
Stop commands	Machine response to stop command	Yes

*Table 3738: **Example** response of machine*

	Value
Average machine delay to Slowdown	0.5 s
Average machine delay to Stop	0.5 s
Average machine deceleration to Slowdown	0.13 g
Average machine deceleration to Stop	0.35 g

11. TRL 7 Tests

Appendix 20: TRL 7 Surface TMM Advanced CxD Test

TRL7 Stage Gate: Pilot site interaction (surface): **CxD Surface pilot site test protocol (CxD + TMM)**

1. Purpose

The 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 a surface mining operation. The purpose of this test is to determine if the logic of the CxDC is able to provide effective collision prevention in the 15 defined surface scenarios in an environment that is representative of where the CxD will be used.

2. Preceding test

2.1. ISO3450 test
2.2. TMM ISO21815 Bench test
2.3. TMM log-keeping test
2.4. TMM Machine sense test
2.5. TMM Self-diagnostics test
2.6. TMM Machine controller response protocol
2.7. CxD ISO21815 Bench test
2.8. CxD log-keeping test
2.9. CxD self-diagnostics test
2.10. CxD Effective warning test
2.11. CxD Basic detection and tracking test
2.12. CxD CxDC logic test
2.13. SANS 13766 test
2.14. Systems integration test

3. Test facility/site

Pilot mine where fully commissioned CPS systems on 2 HMEs and 2 LDVs are available. An additional LDV with no CPS installed is also required. Test area must be representative of a surface mining operation where system is intended to be used at. Site must have level, hard and dry surface. A decline of 10% (6 degrees) is also required with a hard and dry surface. Tests are highly dynamic and adequate space for run-up, interaction and run-off is required.

4. Instrumentation

4.1. 1x RDT installed with CPS
4.2. 1x ADT installed with CPS
4.3. 2x LDVs installed with CPS
4.4. 1x LDV without CPS installed
4.5. 3x HP GNSSs
4.6. 3x DAQs with ISO/TS 21815-2 interfaces
4.7. 1x SP GNSS with self-recorders

5. Test preparation

5.1. Equipment under test will be supplied in working condition by CPS supplier. An authorized person (systems integrator representative) will sign-off that the supplied EUT is in working order as designed that has passed all preceding tests as stipulated in Point 2 above. No modifications to any aspect of the EUT will be allowed once testing has commenced.

5.2. Fence off test area. Ensure all aspects in Safety protocol is adhered to.

5.3. Machine 1 is RDT, machine 2 is ADT, vehicles 3, 4 and 5 are LDVs.

5.4. Install HP GNSSs on machines 1, 2 and on vehicle 3. Ensure good satellite reception is obtained.

5.5. Install SP GNSS with self-recorder on vehicle 4. Ensure good satellite reception is obtained.

5.6. Connect DAQ to CAN-harness so that messages between CxDI and MCI can be logged.

5.7. Ensure that operators understand the objective of each test.

5.8. Ensure that test engineer has effective method of communicating to operators in an emergency such that machines can be stopped immediately (2way radio for example).

5.9. All personnel must be within designated safe area when vehicles are moving.

5.10. Ensure all personnel are wearing all the necessary PPE.

5.11. Ensure all personnel, equipment and all obstacles are removed in front and behind of the machine.

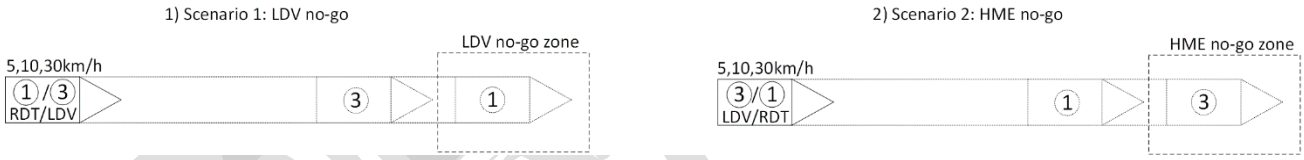
5.12. Start machines and let idle.

6. Test method

6.1. Note firmware versions of CxDC, CxDI, CxDLK, MCI, MC

6.2. Confirm that firmware versions are consistent with previous tests done

6.3. Test configuration 1: Restricted areas



6.3.1. Machine 1 is HME and outside vicinity of both vehicle 3 and restricted zone

6.3.2. Vehicle 3 is LDV and outside vicinity of both machine 1 and restricted zone

6.3.3. Machine 2 and vehicles 4 and 5 are outside vicinity and does not partake in the test

6.3.4. Scenario 1: Set up a restricted zone for LDVs

6.3.5. Note GPS coordinates of edge of restricted zone

6.3.6. Have machine 1 approach restricted zone head-on at speeds of 5, 10 and 30 km/h and note:

6.3.6.1. Confirm machine 1 has NOP response and notification as it passes through the restricted LDV zone

6.3.6.2. Repeat 3 times for each speed

6.3.6.3. Remove machine 1 from test area and introduce vehicle 3

6.3.7. Have vehicle 3 approach restricted zone head-on at speeds of 5, 10 and 30 km/h and note:

6.3.7.1. Confirm vehicle 3 has stop-EW and auto-slow and stop response

6.3.7.2. Confirm vehicle 3 has MI after stopping

6.3.7.3. Confirm stop gap between edge of restricted zone and vehicle 3 is between 10-12m

6.3.7.4. Repeat 3 times for each speed

6.3.8. Scenario 2: Set up a restricted zone for HMEs

6.3.9. Note GPS coordinates of edge of restricted zone

6.3.10. Have vehicle 3 approach restricted zone head-on at speeds of 5, 10 and 30 km/h and note:

6.3.10.1. Confirm vehicle 3 has NOP response as it passes through the restricted HME zone

6.3.10.2. Repeat 3 times for each speed

6.3.10.3. Remove vehicle 3 from test area and introduce machine 1

6.3.11. Have machine 1 approach restricted zone head-on at speeds of 5, 10 and 30 km/h and note:

6.3.11.1. Confirm machine 1 has stop-EW and auto-slow and stop response

6.3.11.2. Confirm machine 1 has MI after stopping

6.3.11.3. Confirm stop gap between edge of restricted zone and machine 1 is between 10-12m

6.3.11.4. Repeat 3 times for each speed

6.4. Test configuration 2: Escorted vehicle

6.4.1. Machine 1 is HME and outside vicinity of all other machines

6.4.2. Vehicle 3 is LDV and outside vicinity of all other machines and vehicles

6.4.3. Vehicle 4 is LDV and outside vicinity of all other machines and vehicles

6.4.4. Vehicle 5 is LDV and does not have CPS installed

6.4.5. Machine 2 are outside vicinity and does not partake in test

6.4.6. Pass gap between convoy and machine 1 is 6m

6.4.7. Have vehicles 3, 4 and 5 in tandem approach machine 1 at a speed of 5, 10 and 30km/h

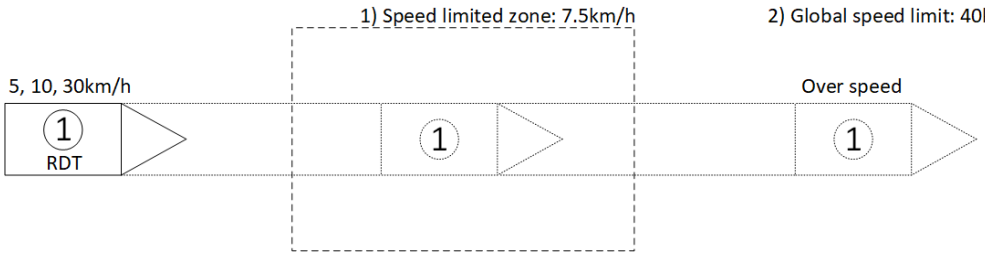
6.4.8. When vehicle 4 is in vicinity of machine 1, have machine 1 attempt to FWD take-off

6.4.9. Confirm immediate stop-EW and MI response of machine 1

6.4.10. Confirm immediate stop-EW and auto-slow and stop response of vehicle 3 and 4

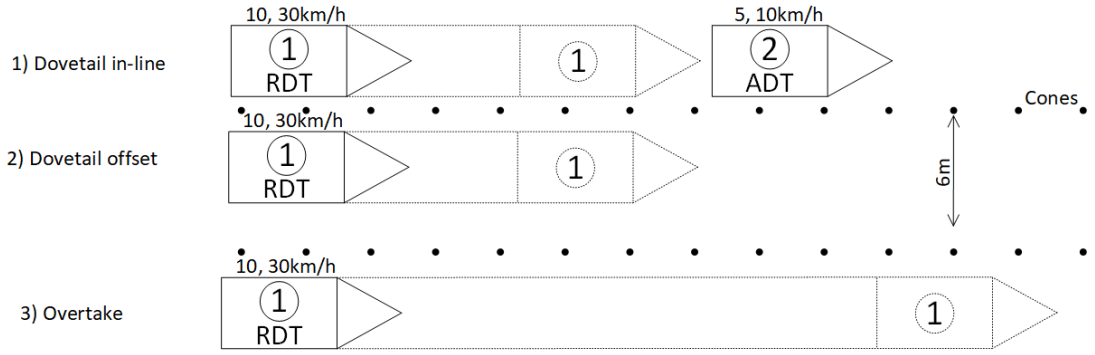
6.4.11. Repeat 3 times for each speed

6.5. Test configuration 3: Speed limited zone



6.5.1. Set up a speed limited zone of 7.5km/h as depicted in the figure
6.5.2. Note GPS coordinates of edge of speed limited zone
6.5.3. Set up global speed limit of 40km/h
6.5.4. Machine 1 is HME and outside vicinity of speed limited zone
6.5.5. Machine 2 and vehicles 3,4 and 5 are outside vicinity and does not partake in the test
6.5.6. Have machine 1 approach speed limited zone at speeds of 5, 10 and 30 km/h and note for each speed:
6.5.6.1. Distance between edge of zone and position at which speed limit is achieved
6.5.6.2. Confirm machine 1 has NOP response before entering the speed limited zone if below the limit speed
6.5.6.3. Confirm machine 1 has slow-EW and auto-slow response before entering the speed limited zone when attempting to enter above the limit speed
6.5.6.4. Confirm machine 1 has slow-EW and auto-slow response when trying to exceed the limit speed inside zone
6.5.6.5. Confirm machine 1 has NOP after exiting the speed limited zone
6.5.6.6. Repeat 3 times for each speed, and during the 30km/h runs:
6.5.6.6.1. Have machine 1 attempt to over-speed after exiting the speed limited zone and note:
6.5.6.6.2. Maximum recorded speed
6.5.6.6.3. Confirm machine has slow-EW and auto-slow response
6.5.6.6.4. NOP after reducing speed to below global limit

6.6. Test configuration 4: Dove-tail & overtaking



6.6.1. Set up test area with pass gap of 6m as depicted in the figure
6.6.2. Machine 1 is outside vicinity of machine 2 and can travel at 10 and 30km/h
6.6.3. Machine 2 is outside vicinity of machine 1 and can travel at 5 and 10km/h

6.6.4. Vehicles 3,4 and 5 are outside vicinity and does not partake in test

6.6.5. Scenario 1: Dovetail in-line

6.6.6. Have machine 1 approach machine 2 at combinations of 10-5, 30-5, 30-10 km/h respectively in dove-tail fashion directly in-line

6.6.7. Note for each speed combination:

6.6.7.1. Distance when effective warning on machine 1 is issued

6.6.7.2. Distance when auto-slow is activated on machine 1

6.6.7.3. Time difference between effective warning and activation of auto-slow on machine 1

6.6.7.4. Confirm that machine 1 has slow-EW and auto-slow response

6.6.7.5. Confirm that machine 2 has proximity-EW and NOP response

6.6.7.6. Confirm that machine 1 and 2 can platoon at the same speed

6.6.7.7. Distance between two machines when platooning

6.6.8. Scenario 2: Dovetail offset

6.6.9. Have machine 1 approach machine 2 at combinations of 10-5, 30-5, 30-10 km/h respectively in dove-tail fashion with a narrow pass gap offset

6.6.10. Note for each speed combination:

6.6.10.1. Distance when effective warning on machine 1 is issued

6.6.10.2. Distance when auto-slow is activated on machine 1

6.6.10.3. Time difference between effective warning and activation of auto-slow on machine 1

6.6.10.4. Confirm that machine 1 has slow-EW and auto-slow response

6.6.10.5. Confirm that machine 2 has proximity-EW and NOP response

6.6.10.6. Confirm that machine 1 and 2 can platoon at the same speed

6.6.10.7. Distance between two machines when platooning

6.6.11. Scenario 3: Overtaking

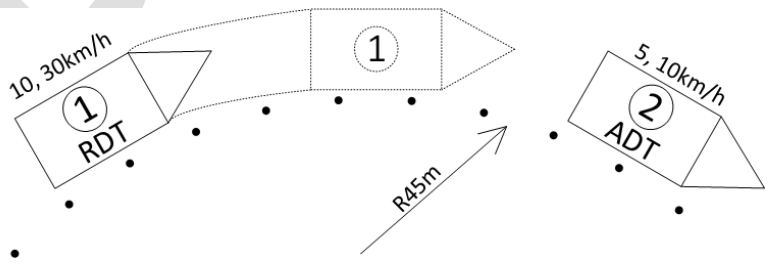
6.6.12. Have machine 1 approach machine 2 at combinations of 10-5, 30-5, 30-10km/h respectively in overtaking fashion (i.e. in outside lane)

6.6.13. Note for each speed combination:

6.6.13.1. Confirm no warnings and NOP of both machines during overtaking

6.6.13.2. Repeat 3 times for each speed combination

6.7. Test configuration 5: Curving dove-tail



6.7.1. Set up test area as depicted in the figure

6.7.2. Machine 1 is outside vicinity of machine 2 and can travel at 10 and 30km/h

6.7.3. Machine 2 can travel at 5 and 10 km/h

6.7.4. Vehicles 3, 4 and 5 is outside vicinity and does not partake in test

6.7.5. Have machine 1 approach machine 2 at combinations of 10-5, 30-5, 30-10 km/h respectively in dove-tail fashion and note for each speed combination:

6.7.5.1. Confirm that machine 1 has slow-EW and auto-slow response

6.7.5.2. Confirm that machine 2 has proximity-EW and NOP response

6.7.5.3. Confirm that machine 1 and 2 can platoon at the same speed

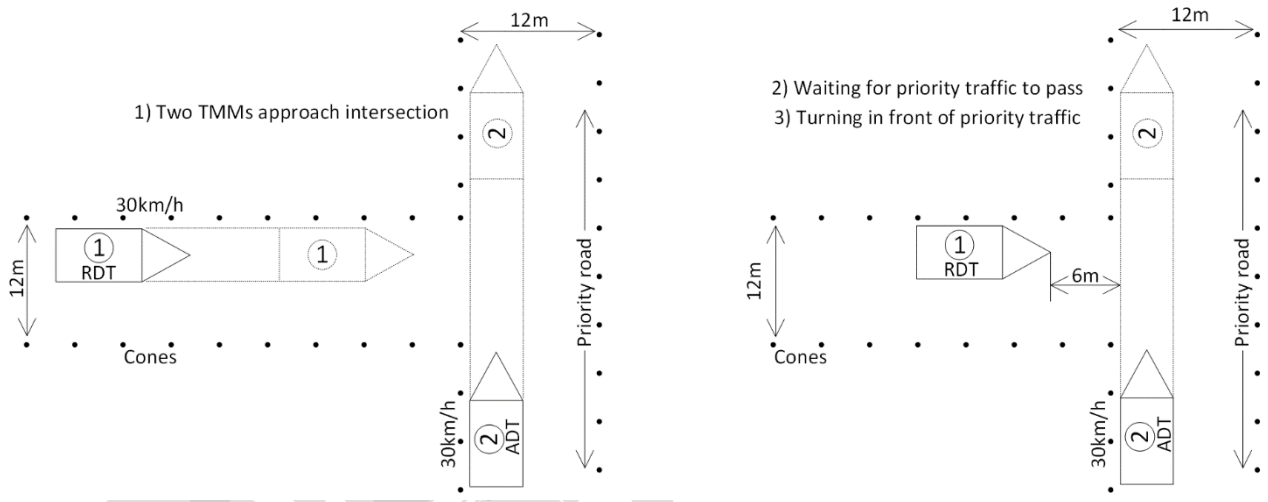
6.7.5.4. Straight line distance when both slow-EW on machine 1 and proximity-EW on machine 2 are issued

6.7.5.5. Straight line distance when auto-slow is activated on machine 1

6.7.5.6. Distance between two vehicles when platooning

6.7.5.7. Repeat 3 times for each speed combination

6.8. Test configuration 6: T-junction



6.8.1. Set up a T-intersection in test area with a priority road as depicted in the figure

6.8.2. Machine 1 is on the secondary road and outside the vicinity of both the intersection and machine 2

6.8.3. Machine 2 is on the continuous road and outside the vicinity of the intersection

6.8.4. Scenario 1: Have machine 1 and 2 approach one another at a speed of 30km/h such that the collision point will be inside the intersection

6.8.5. Confirm that machine 1 has stop-EW and auto-slow and stop response

6.8.6. Confirm that machine 2 has proximity-EW and NOP response

6.8.7. Confirm pass gap is at least 6m

6.8.8. Confirm NOP on machine 1 after machine 2 is out of vicinity

6.8.9. Repeat 3 times

6.8.10. Scenario 2: Position machine 1 6m away from intersection to simulate a vehicle waiting in the secondary road for traffic on the priority road

6.8.11. Have machine 2 approach the intersection at a speed of 30km/h

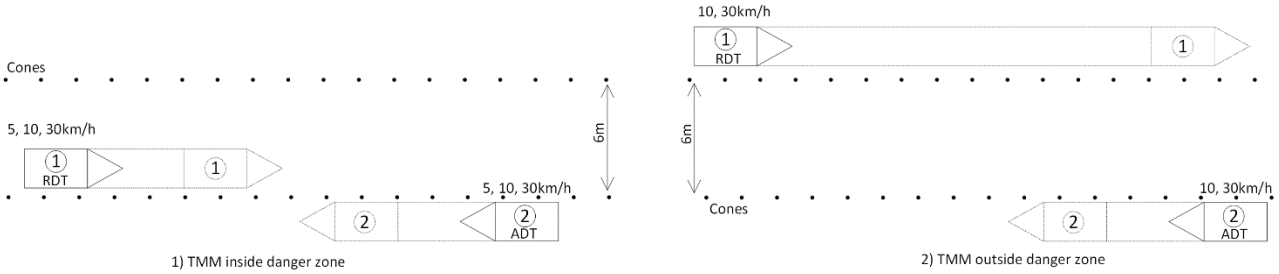
6.8.12. Confirm proximity-EW and NOP on machine 1

6.8.13. Confirm proximity-EW and NOP on machine 2

6.8.14. Repeat 3 times

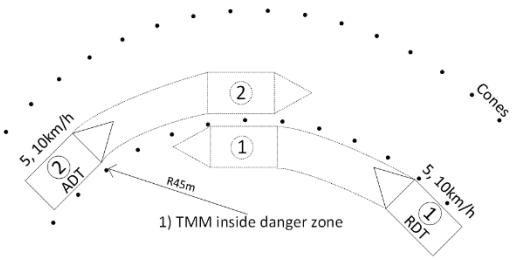
6.8.15. Scenario 3: Position machine 1 6m away from intersection to simulate a vehicle waiting and attempting to disrupt traffic on the priority road
6.8.16. Have machine 2 approach the intersection at a speed of 30km/h
6.8.17. When machine 2 enters the vicinity of the intersection, have machine 1 attempt to disrupt priority traffic by entering the intersection
6.8.18. Confirm that machine 1 has immediate stop-EW and MI response
6.8.19. Confirm that machine 2 has proximity-EW and NOP
6.8.20. Confirm NOP on machine 1 after machine 2 is out of vicinity
6.8.21. Repeat 3 times

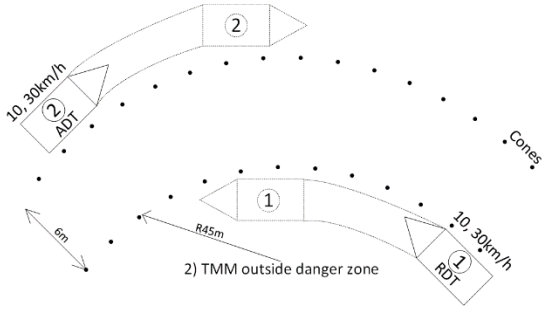
6.9. Test configuration 7: Head-on & passing



6.9.1. Set up test area as depicted in figure
6.9.2. Machine 1 is HME and outside vicinity of all other machines
6.9.3. Machine 2 is HME and outside vicinity of all other machines
6.9.4. Vehicles 3,4 and 5 is outside vicinity and does not partake in test
6.9.5. Scenario 1: Passing inside danger zone
6.9.6. Position machines 1 and 2 such that they will attempt to pass each other within the danger zone
6.9.7. Have machine 1 approach machine 2 head-on at speed combinations of 5-5, 10-5, 10-10km/h and note for each combination:
6.9.7.1. Distance when stop-EWs on both machines are issued
6.9.7.2. Distance when auto-slow is activated on machine 1
6.9.7.3. Distance when stop is activated on machine 1
6.9.7.4. Confirm stop-EW is active between 2.5-3.0s before any intervention
6.9.7.5. Confirm that stop gap is between 10-12m
6.9.7.6. Repeat 3 times for each speed combination
6.9.8. Scenario 2: Passing outside danger zone
6.9.9. Position machines 1 and 2 such that they will pass each other with a gap of 6m
6.9.10. Have machine 1 approach and pass machine 2 head-on at speed combinations of 10-10, 15-10, 30-10, 30-30km/h and note for each combination:
6.9.10.1. Confirm that both machines 1 and 2 have no alerts and NOP response
6.9.10.2. Repeat 3 times for each speed combination

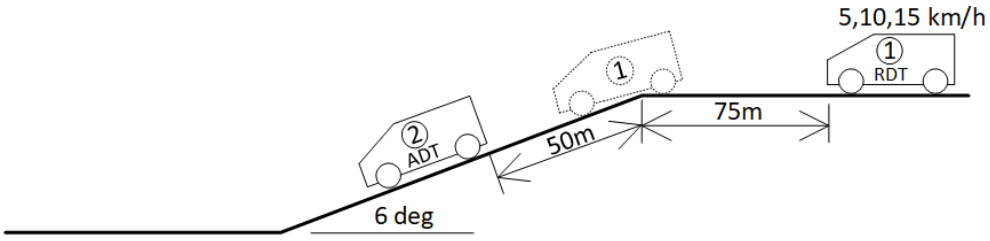
6.10. Test configuration 8: Curved head-on & passing





6.10.1. Set up test area as depicted in figure
6.10.2. Machine 1 is outside vicinity of machine 2
6.10.3. Machine 2 is outside vicinity of machine 1
6.10.4. Vehicles 3, 4 and 5 are outside vicinity and does not partake in test
6.10.5. Scenario 1: Passing within danger zone
6.10.6. Position machines 1 and 2 such that they will attempt to pass each other within the danger zone
6.10.7. Have machine 1 approach machine 2 head-on at speed combinations of 5-5, 10-5, 10-10km/h and note for each combination:
6.10.7.1. Confirm that both machines 1 and 2 has stop-EW and auto-slow and stop response
6.10.7.2. Distance when stop-EWs on both machines are issued
6.10.7.3. Confirm stop-EW is active between 2.5-3.0s before any intervention
6.10.7.4. Confirm that stop gap is between 10-12m
6.10.7.5. Repeat 3 times for each speed combination
6.10.8. Scenario 2: Passing outside danger zone
6.10.9. Position machines 1 and 2 such that they will pass each other outside the danger zone
6.10.10. Have machine 1 approach and pass machine 2 head-on at speed combinations of 10-10, 30-10, 30-30km/h and note for each combination:
6.10.10.1. Confirm that both machines 1 and 2 have no alerts and NOP response
6.10.10.2. Repeat 3 times for each speed combination

6.11. Test configuration 9: Blind approach on decline



6.11.1. On a decline of 10% (6 degrees) set up test area as depicted in the figure

6.11.2. Position machine 2 50m from top of decline with machine 1 being 75m from apex of decline. Ensure that machine 2 is offset to the side of the haul road with machine 1 being able to pass safely, to avoid a head on collision
6.11.3. Machine 1 is at top of decline and 75m from apex
6.11.4. Machine 2 is outside vicinity
6.11.5. Instruct operator of machine 1 to approach decline apex and descend to approach machine 2 head-on at speeds of 5,10 and 15km/h and note for each speed:
6.11.5.1. Distance between machines when effective warning is issued
6.11.5.2. Distance between machines when auto-slow and stop is issued
6.11.5.3. Confirm stop-EW is active between 2.5-3.0s before any intervention takes place
6.11.5.4. Stop gap
6.11.6. Repeat 3 times for each speed

7. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

7.1. What the deviation is
7.2. The reason for the deviation
7.3. How the deviation may affect the purpose of the test
7.4. Have all parties accept in writing:
7.4.1. the proposed deviation
7.4.2. reason for the proposed deviation and
7.4.3. motivation why the proposed deviation will not affect the purpose of the test

8. Test result

*Table 38~~39~~: **Example** of test results and noted machine responses*

Firmware versions	
CxDC	3.1.4
CxDI	2.7.1.8
CxDLK	1.6.1.8
MCI	3.1.4
MC	2.7.1.8
Test results	
TC1 – TC9	3.3 CPS Surface pilot site interaction test Appendix A

9. Influence of deviations on outcome

None

10. Acceptance criteria for this test

10.1. TC1 Restricted areas

10.1.1. For LDV restricted area:

10.1.1.1. HME can pass through restricted area, AND

10.1.1.2. HME has notification, AND

10.1.1.3. LDV auto-slows and stop before edge of zone, AND

10.1.1.4. LDV has EW active between 2.5-3.0s before auto-slow and stop intervention, AND

10.1.1.5. LDV has MI after coming to a stop, AND

10.1.2. For HME restricted area:

10.1.2.1. LDV can pass through restricted area, AND

10.1.2.2. LDV has notification, AND

10.1.2.3. HME auto-slows and stop before edge of zone, AND

10.1.2.4. HME has EW active between 2.5-3.0s before auto-slow and stop intervention, AND

10.1.2.5. HME has MI after coming to a stop, AND

10.1.3. For three runs at that speed

10.2. TC2 Escorted vehicle

10.2.1. Front LDV receives EW and auto-slow and stop

10.2.2. Rear LDV receives EW and auto-slow and stop

10.2.3. HME receives immediate EW and MI response

10.2.4. For three test runs at that speed

10.3. TC3 Speed limited zone

10.3.1. Machine has notification and NOP response when below limit speed in speed limited zone, AND

10.3.2. Machine has EW and auto-slow response when attempting to enter above limit speed, AND

10.3.3. Machine is at limit speed before entering speed limit zone when attempting to enter above limit speed, AND

10.3.4. Machine has EW and auto-slow response in speed limited zone when attempting to exceed limit speed in zone, AND

10.3.5. Machine has EW active between 2.5-3.0s before intervention, AND

10.3.5.1. 5, 10km/h test runs: All runs at that speed, AND

10.3.5.2. 30km/h test runs: Machine has EW and auto-slow response when exceeding global speed limit for all test runs

10.4. TC4 Dove-tail & overtaking

10.4.1. Dove-tailing machine has EW active between 2.5-3.0s before intervention, AND

10.4.2. Dove-tailing machine auto-slows to match leading machine's speed, AND

10.4.3. Overtaking machine has notification and NOP response, AND

10.4.4. Leading machine has notification and NOP response during dove-tailing, AND

10.4.5. Leading machine has notification and NOP response during overtaking, AND

10.4.6. For three test runs at that speed combination

10.5. TC5 Curving dove-tail

10.5.1. Dove-tailing machine has EW active between 2.5-3.0s before intervention, AND

10.5.2. Dove-tailing machine auto-slows to match leading machine's speed, AND

10.5.3. Leading machine has notification and NOP response, AND
10.5.4. For three test runs at that speed combination

10.6. TC6 T-junction
10.6.1. Machine on non-prioritised intersecting road:
10.6.1.1. has EW active between 2.5-3.0s before intervention, AND
10.6.1.2. has EW and auto-slows and stop response when approaching with other machine on priority road, AND
10.6.1.3. has alert and NOP response when waiting for traffic on priority road to pass, AND
10.6.1.4. has immediate EW and MI response when attempting to disrupt traffic on priority road, AND
10.6.1.5. returns to NOP when priority road clears, AND
10.6.2. Machine on priority road:
10.6.2.1. Has notification and NOP response, AND
10.6.3. For three test runs

10.7. TC7 Head-on & passing
10.7.1. Inside danger zone:
10.7.1.1. Both machines have EW active between 2.5-3.0s before intervention, AND
10.7.1.2. Both machines have EW and auto-slow and stop response, AND
10.7.1.3. Both machines have MI after stop, AND
10.7.1.4. Stop intervention only issued at safe speed, AND
10.7.1.5. Stop gap is between 10-12m, AND
10.7.2. Outside danger zone:
10.7.2.1. Both machines have notification and NOP, AND
10.7.3. For three test runs at that speed combination

10.8. TC8 Curved head-on & passing
10.8.1. Inside danger zone:
10.8.1.1. Both machines have EW active between 2.5-3.0s before stop intervention, AND
10.8.1.2. Both machines have EW and auto-slow and stop response, AND
10.8.1.3. Both machines have MI after stop, AND
10.8.1.4. Stop intervention only issued at safe speed, AND
10.8.1.5. Stop gap is between 10-12m, AND
10.8.2. Outside danger zone:
10.8.2.1. Both machines have notification and NOP response, AND
10.8.3. For three test runs at that speed combination

10.9. TC 9: Blind approach on a decline
10.9.1. OWS active 2.5s before auto-slow or stop, AND
10.9.2. Stop gap > 10m, AND
10.9.3. Vehicle MI after stop, AND
10.9.4. Vehicle stop only at safe speed, AND
10.9.5. For all runs at that speed

11. Outcome of this test

*Table 3940: **Example** outcome for CPS pilot site interaction test*

	FWD			REV			
	5	10	30	5	10	30	MI
TC1 Restricted areas	Yes	Yes	Yes				Yes
TC2 Escorted vehicle							
TC3 Speed limited zone	Yes	Yes	Yes				
TC4 Dove-tail & overtaking	Yes	Yes	Yes				
TC5 Curving dove-tail	Yes	Yes	Yes				
TC6 T-junction			Yes				Yes
TC7 Head-on and passing	Yes	Yes	Yes				
TC8 Curved head-on & passing	Yes	Yes	Yes				
	FWD			REV			
	5	10	15	5	10	15	MI
TC9 Blind approach on decline	Yes	Yes	Yes				

12. TRL 8 Tests

Appendix 21: TRL 8 Surface CPS Test

TRL8 Stage Gate On site verification with partial CPS enablement

Note: If all the criteria as defined for the CPS development and introduction has been conformed to, and are effective, there should not be any negative production impact as a result of the introduction of the CPS to the mine. The mine should expect improved production throughput as a result of a more controlled operation.

1. Purpose

The purpose of this test is to ensure that the CPS will function as expected when fully operational and will have a minimal production impact when fully rolled out on the mine. There are four specific objectives during this Stage Gate:

1.1. On mine verification of all CPS documentation
1.2. Actual operation with auto slowdown and stop deactivated.
1.3. Confirmation that the implemented traffic management plan is effective to ensure safe operation of TMMs and not be the cause of any unnecessary Effective Warnings.
1.4. Verification of all the operational aspects on a pilot scale on the mine in order to minimise production impact and safety risk.

2. Preceding requirements

2.1. Preceding site controls implemented

2.1.1. Risk assessment for introducing CPS into the section.
2.1.2. Mine CPS Change Management Plan
2.1.3. Mine HPI (near miss) and accident reporting system
2.1.4. Traffic Management Plan for the section with associated Traffic flow analysis and risk analysis.
2.1.5. Related COPs and SOPs updated and signed off.
2.1.6. Formal change management and training plan and material available.
2.1.7. Infrastructure to auto download CPS data from TMMs
2.1.8. Hot spot dashboards.
2.1.9. CPS availability and reliability dashboard(s)
2.1.10. Methodology to implement actions emanating from the hot spot analysis
2.1.11. Section 21 file as per content specification
2.1.12. All CPS related operating manuals
2.1.13. All CPS fault finding manuals
2.1.14. All CPS inspection and maintenance manuals
2.1.15. CPS updated pre use inspection documentation

2.2. Preceding tests

The CPS provider will provide a certificate of conformance for the CPS fitted TMMs that will be operating within the selected operational section of the mine. This will include full on-mine commissioning tests. Once all the TMMs are signed off, the auto slow and stop functionality will be disabled while the Effective Warning will remain functional. All CPS installation and commissioning

documents used and verified during on-mine installation and commissioning will be updated and signed off by CPS provider and the mine legal accountable officer.

3. Test facility/site

A section of mine that is in full operation that can be used for monitoring of the CPS for such a period as is necessary to achieve full integration of the CPS into the specific session. All TMMs in the section must be installed with CPS. All traffic management rules must be obeyed. Production should continue as normal.

4. Instrumentation and Requirements

4.1. Infrastructure to facilitate automatic download of logs from all TMMs in section at the end of every shift.

4.2. A safety officer must be dedicated to the section fulltime to witness and record all effective warnings

4.3. A data analysist must be available to review the hot spot dashboard as well as the other logs and reports that the mine will use.

4.4. Mine team that can do any physical changes to roads etc. in response to hot spot analysis.

5. Typical Analysis

5.1. Analysis 1: Heat-maps and hot-spots for EWs

5.1.1. Process recorded effective warnings from CPS logs such that a heat-map can be generated to identify hot-spots where frequent warnings would occur if the CPS system was fully operational

5.1.2. For each hot spot identified:

5.1.2.1. Analyse data from concerning TMMs to conclude what the reasons may be for the occurrence of EWs at the hot spot

5.1.2.2. Formulate and implement potential improvements to the TMP to minimize EWs at the hot spot

5.1.2.3. Evaluate if implemented improvements has a positive effect on hot spots

5.1.3. Compare heat-map to reported near-miss incidents, TMP and risk assessment

5.1.4. Investigate any discrepancies

5.2. Analysis 2: Heat-maps and hot spots for interventions

5.2.1. Process recorded interventions from CPS logs such that a heat-map can be generated to identify hot-spots where frequent interactions would occur if the CPS system was fully operational

5.2.2. For each hot spot identified:

5.2.2.1. Analyse data from concerning TMMs to conclude what the reasons may be for the occurrence of interventions at the hot spot

5.2.2.2. Formulate and implement potential improvements to the TMP and risk assessment to minimize interventions at the hot spot

5.2.2.3. Evaluate if implemented improvements have a positive effect on hot spots

5.3. Analysis 3: Repeat offenders

5.3.1. Process recorded effective warnings and interventions such to identify if any particular operator or machine shows a statistically higher occurrence of EWs or interventions

5.3.2. For each repeat offender identified:

5.3.2.1. Analyse data from concerning TMMs to conclude what the reasons may be for the abnormally high number of offences

5.3.2.2. Formulate and implement potential improvements to address the concerned offender, including change management

5.3.2.3. Evaluate if implemented improvements have a positive effect on offender

5.4. Analysis 4: Daily number of EWs

5.4.1. Keep track and trend the number of daily would-be-EWs throughout the 3-month testing period

5.4.2. Evaluate continuous improvement of TMP to ultimately reduce the number of EWs as much as possible

5.5. Analysis 5: Daily number of interventions

5.5.1. Keep track and trend the number of daily would-be-interventions throughout the 3-month testing period

5.5.2. Evaluate continuous improvement of TMP and risk assessment to ultimately reduce the number of interventions as much as possible

5.6. Analysis 6: Impact analysis of number of interventions on safety, production and maintenance

5.6.1. Compare EW interactions to safety reports for the day or week (near misses etc).

5.6.2. Compare EW interactions in areas that can influence production with production for the day. Allocate a time frame to clear an auto retard and stop /safe park event and increase mining cycle times.

5.6.3. Verify possible impact on production

5.6.4. Compare EW interactions in areas that can influence auto stops for the day. Trend braking events and compare against braking history on CMMS.

5.6.5. Check for the number of false positives recorded each day and trend.

5.6.6. Log all maintenance interventions (call outs etc) and report on any overrides.

Appendix 22: TRL 8 Underground CPS Test

TRL8 Stage Gate: On site verification with partial CPS enablement

1. Purpose

Note: If all the criteria as defined for the CPS development and introduction has been conformed to, and are effective, there should not be any negative production impact as a result of the introduction of the CPS to the mine. The mine should expect improved production throughput as a result of a more controlled operation.

The purpose of this test is to ensure that the CPS will function as expected when fully operational and will have a minimal production impact when fully rolled out on the mine. There are four specific objectives during this Stage Gate:

1.1. On mine verification of all CPS documentation
1.2. Actual operation with auto slowdown and stop deactivated.
1.3. Confirmation that the implemented traffic management plan is effective to ensure safe operation of TMMs and not be the cause of any unnecessary Effective Warnings.
1.4. Verification of all the operational aspects on a pilot scale on the mine in order to minimise production impact and safety risk.

Due to a lack of representative environments two advanced CxD tests must be performed before TRL 8 starts:

1.5. Test configuration 1: TMM turning to obscured pedestrian and passing (S9, R5) with a specific focus on rock penetration
1.6. Test configuration 2: Blind approach on decline with a specific focus on rock penetration

2. Preceding requirements

2.1. Preceding site controls implemented

2.1.1. Risk assessment for introducing CPS into the section.
2.1.2. Mine CPS Change Management Plan
2.1.3. Mine HPI (near miss) and accident reporting system
2.1.4. Traffic Management Plan for the section with associated Traffic flow analysis and risk analysis.
2.1.5. Related COPs and SOPs updated and signed off.
2.1.6. Formal change management and training plan and material available.
2.1.7. Infrastructure to auto download CPS data from TMMs
2.1.8. Hot spot dashboards.
2.1.9. CPS availability and reliability dashboard(s)
2.1.10. Methodology to implement actions emanating from the hot spot analysis
2.1.11. Section 21 file as per content specification
2.1.12. All CPS related operating manuals
2.1.13. All CPS fault finding manuals
2.1.14. All CPS inspection and maintenance manuals

2.1.15. CPS updated pre use inspection documentation

2.2. Preceding tests

The CPS provider will provide a certificate of conformance for the CPS fitted TMMs that will be operating within the selected operational section of the mine. This will include full on-mine commissioning tests. Once all the TMMs are signed off, the auto slow and stop functionality will be disabled while the Effective Warning will remain functional. All CPS installation and commissioning documents used and verified during on-mine installation and commissioning will be updated and signed off by CPS provider and the mine legal accountable officer.

3. Test facility/site

A section of mine that is in full operation that can be used for monitoring of the CPS for such a period as is necessary to achieve full integration of the CPS into the specific session. All TMMs and pedestrians working in the section must be installed with CPS. All traffic management rules must be obeyed. Production should continue as normal.

4. Instrumentation

4.1. Reporting method to note all CPS related issues that is observed from operators, pedestrians, and managers during the testing period

4.2. Instrumentation requirement for test configurations 1 and 2:

4.2.1. 2x test vehicles with CPS installed

4.2.2. 2x DAQs with ISO 21815-2 interfaces

4.2.3. 1x pedestrian tag

4.2.4. 1x mannequin onto which pedestrian tag is fitted during test

4.3. Infrastructure to facilitate automatic download of logs from all TMMs in section at the end of every shift.

4.4. A safety officer must be dedicated to the section fulltime to witness and record all effective warnings

4.5. A data analysist must be available to review the hot spot dashboard as well as the other logs and reports that the mine will use.

4.6. Mine team that can do any physical changes to roads etc. in response to hot spot analysis.

5. Test preparation

5.1. Equipment under test will be supplied in working condition by CPS provider. An authorized person (CPS provider representative) will sign-off that the supplied EUT is in working order as designed that has passed all preceding tests as stipulated in Point 2.2 above. No modifications to any aspect of the EUT will be allowed once testing has commenced.

5.2. Install CPS on all TMMs being used in the identified section of the mine

5.3. Enable EW without automatic intervention activation while keeping all other functionalities

5.4. Ensure that operators and pedestrians understands that CPS, although installed on all TMMs, will not provide protection to them during this phase of testing

5.5. Ensure that operators and pedestrians understands the objective of the test

5.6. For test configurations 1 and 2:

5.6.1. Fence off test area. Ensure all aspects in Safety protocol is adhered to.

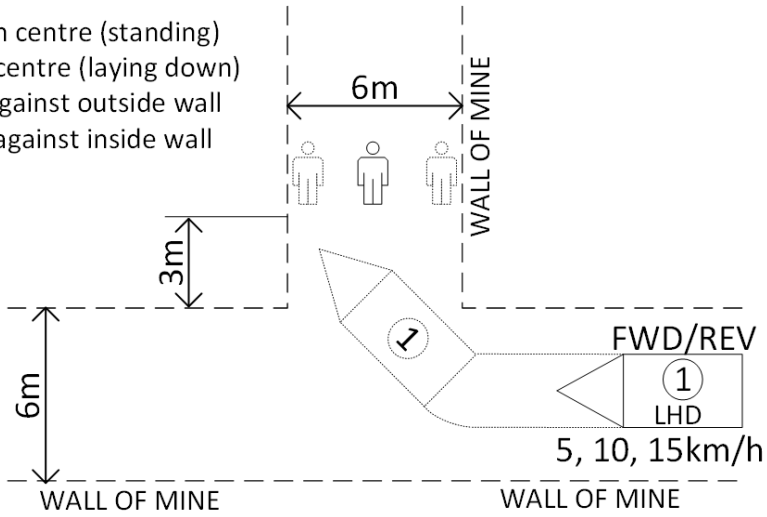
5.6.2. Connect DAQ to the CxD CAN-harness via the ISO21815 connector.

5.6.3. Ensure all personnel, equipment and all obstacles are removed in front and behind of the test vehicles.

6. Test method

6.1. Test configuration 1: Underground: TMM turning to obscured pedestrian and passing (S9, R5) with a specific focus on rock penetration

1) Pedestrian tag in centre (standing)
2) Pedestrian tag in centre (laying down)
3) Pedestrian tag against outside wall
4) Pedestrian tag against inside wall



6.1.1. In an underground mine, set up test area to simulate an obscured pedestrian as depicted in the figure

6.1.2. Machine 1 is outside of vicinity and has scoop filled with material

6.1.3. Machine 2 is outside of vicinity and does not partake in the test

6.1.4. Scenario 1: Pedestrian in centre (standing: 900mm off the ground)

6.1.5. Position mannequin with pedestrian tag in centre of board, 3m away from perpendicular board

6.1.6. Have machine 1 approach corner and steer towards obscured pedestrian at speeds of 5, 10 and 15km/h and for each speed:

6.1.6.1. Ensure operator has machine in safe park after CPS has brought it to a stop

6.1.6.2. Download logs from CxDLK and confirm stop-EW on machine 1 is active between 2.5-3.0s before intervention

6.1.6.3. Using a tape measure, confirm that stop gap is between 2.5m and 4.0m

6.1.6.4. Repeat 3 times

6.1.6.5. Repeat for both FWD and REV directions

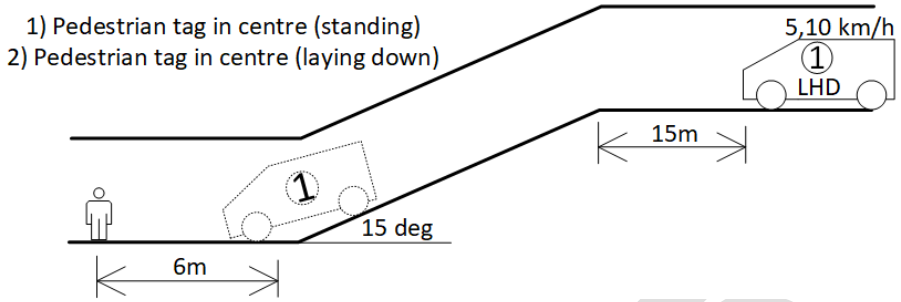
6.1.6.6. Repeat all of the above for the following scenarios:

6.1.6.6.1. Scenario 2: Pedestrian in centre (on the ground)

6.1.6.6.2. Scenario 3: Pedestrian against outside wall (900mm off the ground)

6.1.6.6.3. Scenario 4: Pedestrian against inside wall (900mm off the ground)

6.2. Test configuration 2: Underground: Blind approach on decline with a specific focus on rock penetration



6.2.1. Place mannequin with pedestrian tag at the bottom of the decline, in the centre of the board, 6m away from apex

6.2.2. Machine 1 is at top of incline, 15m from apex with a fully loaded bucket

6.2.3. Scenario 1: Pedestrian standing (900mm off the ground)

6.2.4. Have vehicle approach decline apex and descend to approach pedestrian head-on at speeds of 5 and 10km/h and for each speed:

6.2.4.1. Ensure operator has machine in safe park after CPS has brought it to a stop

6.2.4.2. Download logs from CxDLK and confirm EW on machine 1 is active between 2.5-3.0s before intervention

6.2.4.3. Confirm machine stop-EW is active between 2.5-3.0s before any intervention

6.2.4.4. Confirm pedestrian danger-EW is active between 2.5-3.0s before any intervention on machine

6.2.4.5. Using a tape measure, confirm stopping distance is between 2.5-4.0m

6.2.4.6. Repeat 3 times

6.2.5. Scenario 2: Repeat all of the above with pedestrian tag on the ground

6.3. All interaction scenario testing is now complete and the three-month main test can start

6.4. Obtain reported near-miss incidents

6.5. Analysis 1: Heat-maps and hot-spots for EWs

6.5.1. Process recorded effective warnings from CPS logs such that a heat-map can be generated to identify hot-spots where frequent warnings would occur if the CPS system was fully operational

6.5.2. For each hot spot identified:

6.5.2.1. Analyse data from concerning TMMs to conclude what the reasons may be for the occurrence of EWs at the hot spot

6.5.2.2. Formulate and implement potential improvements to the TMP to minimize EWs at the hot spot

6.5.2.3. Evaluate if implemented improvements has a positive effect on hot spots

6.5.3. Compare heat-map to reported near-miss incidents, TMP and risk assessment

6.5.4. Investigate any discrepancies

6.6. Analysis 2: Heat-maps and hot spots for interventions

6.6.1. Process recorded interventions from CPS logs such that a heat-map can be generated to identify hot-spots where frequent interactions would occur if the CPS system was fully operational

6.6.2. For each hot spot identified:

6.6.2.1. Analyse data from concerning TMMs to conclude what the reasons may be for the occurrence of interventions at the hot spot

6.6.2.2. Formulate and implement potential improvements to the TMP and risk assessment to minimize interventions at the hot spot

6.6.2.3. Evaluate if implemented improvements have a positive effect on hot spots

6.7. Analysis 3: Repeat offenders

6.7.1. Process recorded effective warnings and interventions such to identify if any particular operator, pedestrian or machine shows a statistically higher occurrence of EWs or interventions

6.7.2. For each repeat offender identified:

6.7.2.1. Analyse data from concerning TMMs to conclude what the reasons may be for the abnormally high number of offences

6.7.2.2. Formulate and implement potential improvements to address the concerned offender, including change management

6.7.2.3. Evaluate if implemented improvements have a positive effect on offender

6.8. Analysis 4: Daily number of EWs

6.8.1. Keep track and trend the number of daily would-be-EWs throughout the 3-month testing period

6.8.2. Evaluate continuous improvement of TMP to ultimately reduce the number of EWs as much as possible

6.9. Analysis 5: Daily number of interventions

6.9.1. Keep track and trend the number of daily would-be-interventions throughout the 3-month testing period

6.9.2. Evaluate continuous improvement of TMP and risk assessment to ultimately reduce the number of interventions as much as possible

6.10. Analysis 6: Impact analysis of number of interventions on safety, production and maintenance

6.10.1. Compare EW interactions to safety reports for the day or week (near misses etc).

6.10.2. Compare EW interactions in areas that can influence production with production for the day. Allocate a time frame to clear an auto retard and stop /safe park event and increase mining cycle times.

6.10.3. Verify possible impact on production

6.10.4. Compare EW interactions in areas that can influence auto stops for the day. Trend braking events and compare against braking history on CMMS.

6.10.5. Check for the number of false positives recorded each day and trend.

6.10.6. Log all maintenance interventions (call outs etc) and report on any overrides.

6. Deviations from protocol during testing

If any deviation from the test protocol occurs for any reason, note:

6.1. What the deviation is
6.2. The reason for the deviation
6.3. How the deviation may affect the purpose of the test
6.4. Have all parties accepted in writing:
  6.4.1. the proposed deviation
  6.4.2. reason for the proposed deviation and
  6.4.3. motivation why the proposed deviation will not affect the purpose of the test

7. Test result

*Table 4041: **Example** of test results throughout the 3-month period*

Analysis 1: Heat-maps and hot-spots for EW					
Date	**Time**	**Interaction**	**Type**	**Location**	**Proposed improvement**
02-01-2022	08h42	V-P, P1	Proximity to pedestrians	Workshop 1	Increase passing gap between mechanics and traffic
03-01-2022	09h21	V-P, P1	Proximity to pedestrians	Intersection A3	Further increase passing gap
Analysis 2: Heat-maps and hot-spots for interventions					
Date			**Type**	**Location**	**Proposed improvement**
02-01-2022	06h20	V-P, P1	Proximity to pedestrians	Intersection A3	Increase passing gap between waiting traffic and priority traffic
02-01-2022	01h31				
Analysis 3: Repeat offenders					
Date			**Who**	**What**	**Proposed improvement**
03-01-2022	07h44	V-P P1	Proximity to pedestrians	Frequent proximity warnings at intersection A3	Inspect braking system and confirm SANS1589/ISO3450 compliance
04-01-2022	06h22	V-P P1	Pedestrian	Frequent proximity warnings at rock face	Train pedestrian to comply with machine interaction at the rock face
Analysis 4&5: Daily number of occurrences					
Date			**Number of EWs**	**Number of interventions**	
01-01-2022	06h00 - 09h00	V-P, P1	10	3	
02-01-2022			10	3	
03-01-2022			9	1	
04-01-2022			5	0	

05-01-2022			3	0	
…					
Impact on production					
Date	**Time**	**Interaction**	**TMM type**	**Mining cycle time increase**	**Tons lost**
02-01-2022	Various	V-V	Production (RDT)	220 minutes	14
Impact on maintenance					
Date	**Time**	**Interaction**	**TMM type**	**Events**	**Notes**
02-01-2022	Various	V-P	Production (RDT)	14 – braking events	Would not normally have braked
14-01-2022	Various	V-P	False positives,	11	
14-01-2022	Various	MTCE	Call out for break down or override	4	

8. Influence of deviations on result

Example: None

9. Acceptance criteria for this test

9.1. Test configuration 1: TMM turning to obscured pedestrian and passing (S9, R5)

9.1.1. EWs on both machine and pedestrian active 2.5s before auto-slow or stop, AND

9.1.2. Stop gap > 2.5m, AND

9.1.3. Vehicle MI after stop, AND

9.1.4. For all runs in that direction and at that speed

9.2. Test configuration 2: Blind approach on decline with a specific focus on rock penetration

9.2.1. EWs on both machine and pedestrian active 2.5s before auto-slow or stop, AND

9.2.2. Stop gap > 2.5m, AND

9.2.3. Vehicle MI after stop, AND

9.2.4. Vehicle stop only at safe speed, AND

9.2.5. For all runs at that speed

9.3. Partial CPS enablement for verification of impact on TMP, Risk Assessment and mine operations - test protocol (CPS**)**

9.3.1. Acceptable number of EWs after test period, AND

9.3.2. Acceptable number of interventions after test period, AND

9.3.3. No impact on production, AND

9.3.4. No increase in number of near misses

10. Outcome of this test

*Table 2: **Example** outcome for TC1, 2 and 3 tests*

	FWD			REV			
	5	10	15	5	10	15	MI
TC1 TMM turning to obscured pedestrian & passing	Yes	Yes	Yes	Yes	Yes	Yes	
TC2 Blind approach (decline)	Yes	Yes					

Table 3: Outcome of test given the example test result

Confirmation of TMP	Pass

13. TRL 9 Tests

Appendix 23: TRL 9 Surface CPS Validation

TRL9 Stage Gate: CPS Validation

1. Purpose

The purpose of TRL 9 is to validate the CPS over an extended period of operation on the **same** section of the mine by collecting sufficient data to make statistical inferences.

During TRL 8 it has been established that the CPS meets all the requirements, except for the auto slow and stop, - that is deactivated - in a real operational environment, on a section of the mining site, and the mine has resolved all operational aspects that could hamper operations, including all hot spots.

2. Preceding requirements

2.1. Successful completion of TRL 8.

2.2. Resolution of any CPS technical issues identified during TRL 8.

2.3. Auto slow and stop commissioning test after switching on the functionality again. (This is to ensure that before TRL 9 start all the TMMs are fully CPS functional).

3. Typical analysis

The same data as recorded for TRL 8 need to be collected for a period of at least 3 months or more depending on the statistical requirements. The data will be submitted to and analysed by the 3rd Party testing organisation to determine if the CPS has been validated against the Functional and Technical Performance Requirements.

The following are the minimum aspects to be covered:

3.1. Unnecessary Effective Warnings.

3.2. Interactions without Effective Warnings.

3.3. Reliability of the CPS and its individual elements.

3.4. Maintainability of the CPS and its elements.

3.5. Spares usage against the recommended spares lists.

4. Certification

The 3rd Party testing organisation will issue a short report and a conformance certificate once the CPS has achieved the validation criteria.

Appendix 24: TRL 9 Underground CPS Validation

TRL9 Stage Gate: CPS Validation

1. Purpose

The purpose of TRL 9 is to validate the CPS over an extended period of operation on the **same** section of the mine by collecting sufficient data to make statistical inferences.

During TRL 8 it has been established that the CPS meets all the requirements, except for the auto slow and stop, - that is deactivated - in a real operational environment, on a section of the mining site, and the mine has resolved all operational aspects that could hamper operations, including all hot spots.

2. Preceding requirements

2.1. Successful completion of TRL 8.
2.2. Resolution of any CPS technical issues identified during TRL 8.
2.3. Auto slow and stop commissioning test after switching on the functionality again. (This is to ensure that before TRL 9 start all the TMMs are fully CPS functional).

3. Typical analysis

The same data as recorded for TRL 8 need to be collected for a period of at least 3 months or more depending on the statistical requirements. The data will be submitted to and analysed by the 3rd Party testing organisation to determine if the CPS has been validated against the Functional and Technical Performance Requirements.

The following are the minimum aspects to be covered:

3.1. Unnecessary Effective Warnings.
3.2. Interactions without Effective Warnings.
3.3. Reliability of the CPS and its individual elements.
3.4. Maintainability of the CPS and its elements.
3.5. Spares usage against the recommended spares lists.

4. Certification

The 3rd Party testing organisation will issue a short report and a conformance certificate once the CPS has achieved the validation criteria.

14. Test Site General Safety Procedure

Appendix 25 Test Site General Safety Procedure

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 V-V and V-P interactions 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. Background to this procedure

In order to facilitate and enable the SAMI to meet the legislative deadline for CPS, the Minerals Council initiated a project to enable SAMI to select and implement CPS products based on proven and tested technologies and CPS enabled TMMs.

A significant part of the Minerals Council work package deliverables was focussed on testing the CPS at various stages (TRL levels 1-9) in the process to enable accelerated certification and approvals for the CPS into SAMI. Diagram 1 below shows the CPS system, elements, and sub-systems. Diagram 2 shows the testing TRL levels and stage gates.

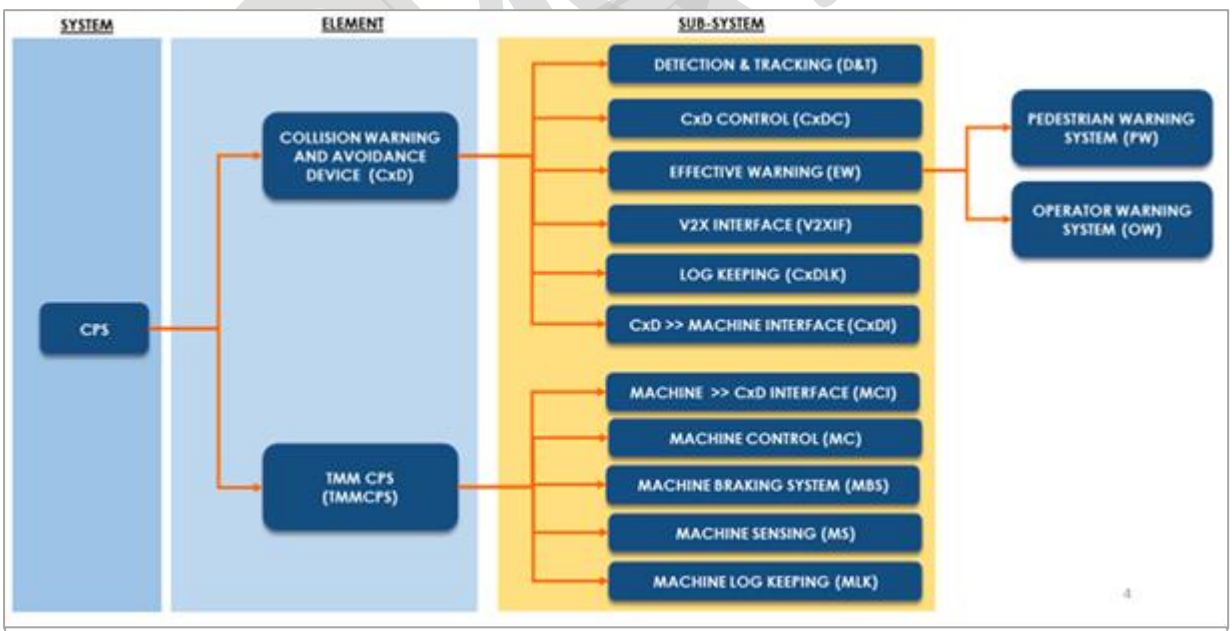


Diagram 1: CPS system, elements, and sub-systems

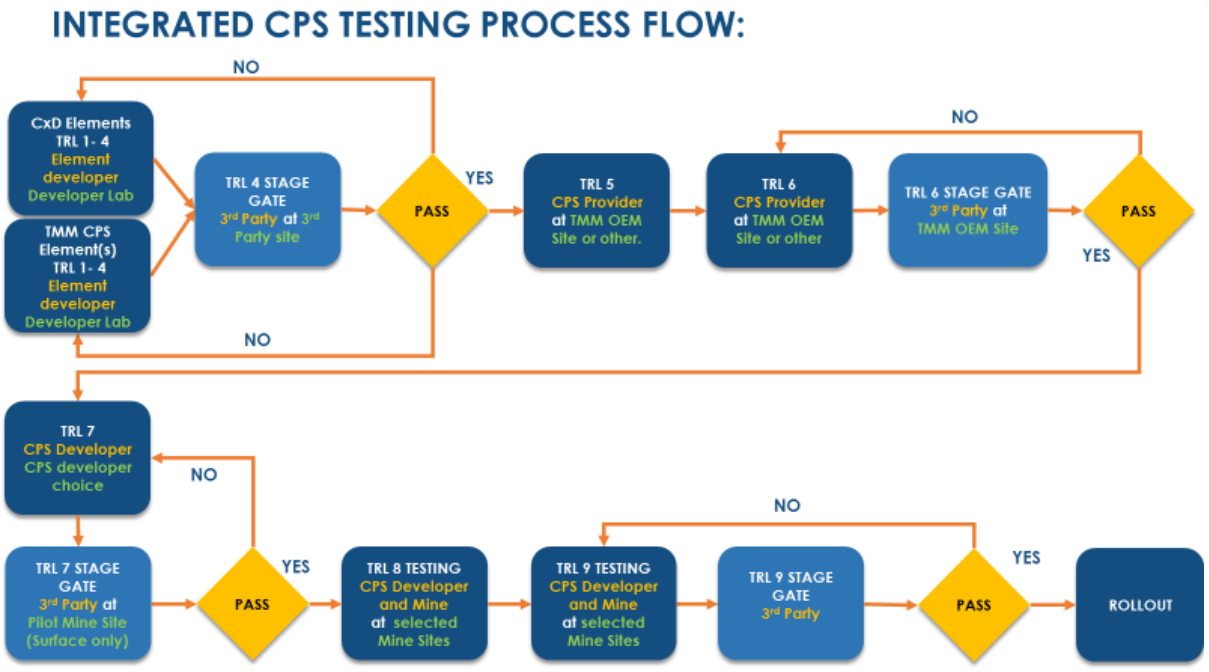


Diagram 2: CPS Stage Gate Testing Process

Testing and certification from the tests performed during the process in Diagram 2 above, requires that the testing will typically have TMMs interacting with one another and testing personnel (both operators and testing personnel). Wherever interactions of such a nature occur, the risk of injury exists and therefore all testing must be conducted without the risk to the health and safety of all people involved in the tests.

3. Scope

The scope of this document applies to the safety management for all CPS testing performed at the University of Pretoria Engineering 4.0 test site and at any pilot mines where the MHSA is not in force.

The scope of this document defines the following safety controls at the above testing sites:

- Access control and safety management during testing,
- Emergency management of the test site during CPS testing,
- Risk assessment completed for the testing,
- Test area layout including signage for the test area,
- Evacuation plan,
- Test plan for each test.

4. The test site

The test site is located …… The test site has the following main features:

- Current and future road layout
- Security access points
- Road access points (including abnormal loads)
- Private vehicle parking areas

- Test vehicle parking areas
- Fuel fill and storage areas
- Dust suppression storage areas
- Vehicle maintenance areas
- CxD fitment areas
- Pedestrian access points
- Male changerooms
- Female change rooms
- Meeting rooms
- Current area evacuation routes and assembly points
- Current emergency contact numbers
- Current emergency management plans and procedures
- Current radio channels used
- Current emergency equipment on site and location (ambulance, fire etc)
- Current first aid centres
- Equipment and spares storage containers or rooms
- Power supply (emergency power supply)
- Test management containers and document storage
- Current sign location and types

5. Pilot Mine

The test site is located ……. The test site shall have the following main features which are shown in the diagram:

- Current and future road layout
- Security access points
- Road access points (including abnormal loads)
- Private vehicle parking areas
- Test vehicle parking areas
- Fuel fill and storage areas
- Dust suppression storage areas
- Vehicle maintenance areas
- CxD fitment areas
- Pedestrian access points
- Male changerooms
- Female change rooms
- Meeting rooms
- Current area evacuation routes and assembly points
- Current emergency contact numbers
- Current emergency management plans and procedures
- Current radio channels used
- Current emergency equipment on site and location (ambulance, fire etc)
- Current first aid centres
- Equipment and spares storage containers or rooms
- Power supply (emergency power supply)

- Test management containers and document storage
- Current sign location and types

6. Safety approach during testing

Legal appointments (Where applicable). The appointments listed in the table is not exhaustive.

Legal appointee	Role	Name	Contact details
	Test site safety officer		
	Test site responsible engineer		

Risk assessment

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

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

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

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

All controls defined in the risk assessments must be implemented.

Pre-test risk assessment

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

Site entry register

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

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

7. Safety management

In accordance with the MHSA and the OHSA as well as the site SHERQ 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:

Morning before work begins:

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

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

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

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

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

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

Changes in risk during the day:

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

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

- heavy rainstorms, high wind where visibility is reduced due to dust,
- dark cloud that impinges visibility,
- tyre change,
- diesel spill that needs to be cleaned,
- pedestrians or vehicles inadvertently wandering on to the test site,
- severe road damage that requires repair,

- lightning,
- illness of someone who requires immediate treatment on site,
- injury on site,
- high environmental temperature that has a high risk of inducing heat stroke,
- TMM accident where persons are injured,
- Near misses where a high potential of interaction between TMM and TMM or TMM and pedestrian occurs.

Emergencies

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

Emergency number

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

Test site safety officer, and if not available then

Test site responsible engineer, and if not available then

The next highest-ranking test site employee on the test site.

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

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

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

COVID 19: COVID 19 good practice shall be employed on each test site. The following are these minimum standards:

- All personnel will be temperature screened when entering through the test site each day,
- COVID face masks are to be worn all the time while on the test site,
- Hand sanitizer is available at the site porta cabin for sanitizing before site entry, during testing, before eating and after completion of testing each day,
- Social distancing of 1,5 m applies on the test site.

- Any person showing any of the following symptoms must immediately report to the site safety officer who must direct the person to medical services for COVID screening and assessment:
  - Fever,
  - dry cough,
  - tiredness,
  - aches and pains,
  - sore throat,
  - diarrhoea,
  - conjunctivitis,
  - headache,
  - loss of taste or smell,
  - a rash on skin, or discolouration of fingers or toes,
  - difficulty breathing or shortness of breath,
  - chest pain or pressure,
  - loss of speech or movement.

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 personal who are not working on the vehicles: safety shoes, reflective vests, or other acceptable conspicuity apparel, (hat, cap or similar sunshade system is recommended),
- Persons working on the TMMs: overall (with conspicuity 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.

Insert diagram 6 here

8. Communication

Communication during testing will be via the following means:

- Two-way handheld radios on a frequency specifically for the test,
- Mobile communication via mobile phones,
- Data via a WiFi system flooded for the test area.

9. 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.

10. Environmental management

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

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

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

Smoking area

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

Afternoon when work ends for the day.

- The site test engineer shall declare work ended for the day,
- All TMMs will go to the test vehicle parking bay, where they will safely park, lock the vehicles and insert wheel chocks,
- 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,
- 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,
- The site safety officer shall check the attendance register and ensure that all employees have signed out for the day,

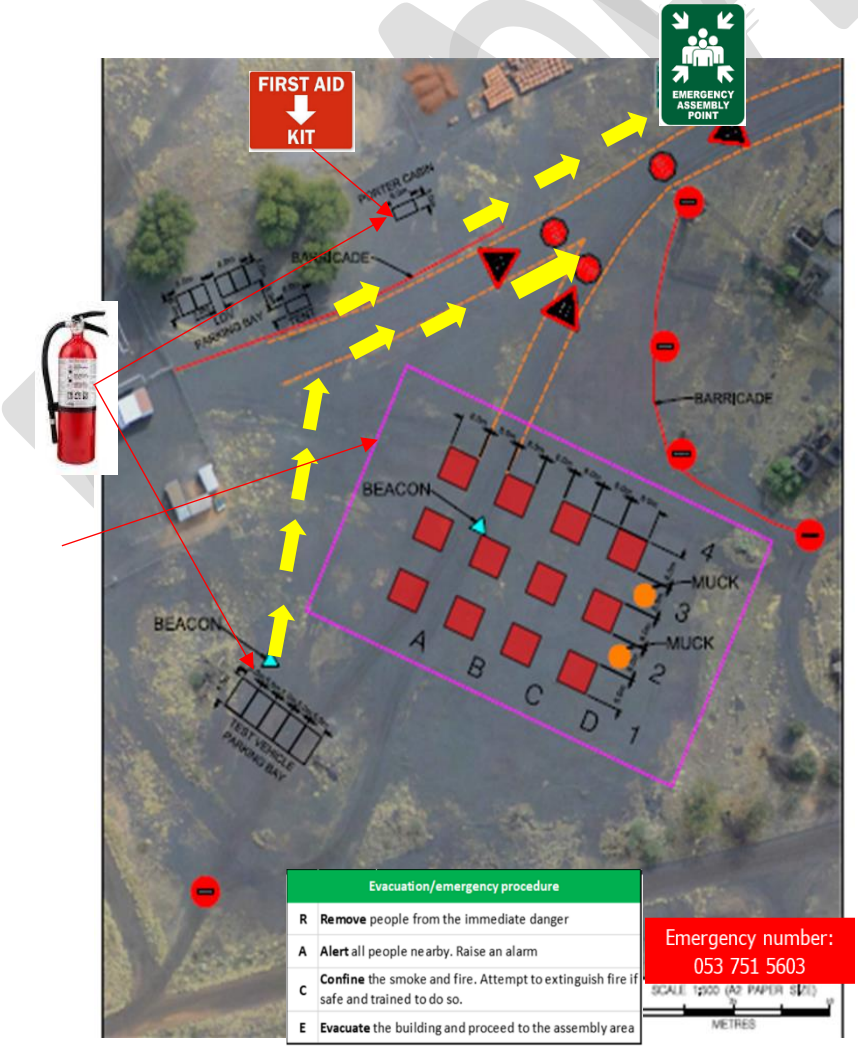
- The site safety officer shall check the site and declare it safe to be locked for the night and ensure that all employees are off site and shall lock the pedestrian gate.

11. Signage

Various signs are installed on the test site. They include the following:

12. Evacuation plan

An evacuation plan such as the one below shall be developed for each test site.



13. Test schedule - overall

The test schedules shall be included here for each test type.

Daily test schedule (Example)

06h30: Safety talk at Site office,

06h45: Test plan for the day discussion,

07h00: Operators perform pre-start check on TMMs and check fuel levels. Operators fill with fuel if required,

07h00: CPS technology providers and interface do final adjustments for the day,

07h30: First test for the day,

09h45: Tea break,

10h00: Test resume,

12h15: Lunch break,

13h00: Tests resume,

14h30: Tea break,

14h45: Test resume,

16h15: Test stop for the day unless otherwise agreed by all.