ACCELERATED TESTING PLAN FOR COLLISION PREVENTION SYSTEMS

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

REV 3

CPS Readiness Criteria Acceptance			
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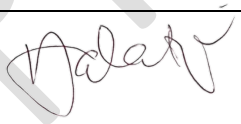
Stanford Malatji		**Minerals Council**	20 June 2022

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1 Purpose of this document

This document sets out the accelerated test plan for Collision Pretension Systems

2 Definitions and abbreviations

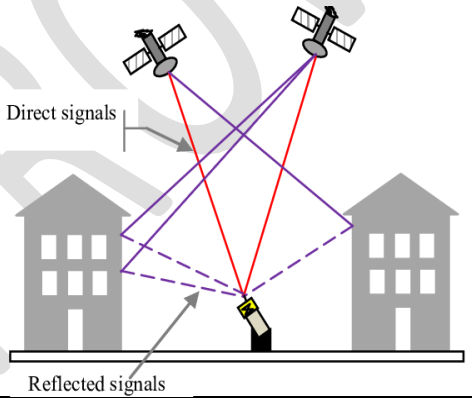
The following definitions and abbreviations will be used to create a common approach for all deliverables. (Note: The rationale for some of the terms and definitions is set out in the CMS Technical Specification Guideline Review Report).

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.)
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
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.
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.
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 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: CPS READINESS PHASE.

3 Executive Summary

Verification of conformance to the functional requirements of CPS products is important to ensure successful introduction of the technology into the SAMI. Testing is the primary method of verification of functions of CPS products. SECDI (PTY) LTD has been mandated to develop an integrated TESTING REGIME as well as a CPS TESTING FACILITY NEEDS REPORT as part of the Industry Alignment on TMM Regulations: Special Project of The Minerals Council South Africa.

The TESTING REGIME defined a systematic logical and integrated approach to testing, based on the maturity growth of a CPS product. The internationally recognised Technology Readiness Level framework (9 level) is used to structure the testing regime.

One of the enhancements of the "CAS readiness project" is the introduction of a User Requirements specification. The specification defines several specific operational scenarios that the CPS products need to be able to deal with. For surface TMM CxD testing, these scenarios require a bigger and different test facility than what was used in the past.

The CPS TESTING FACILITY NEEDS REPORT identified three potential options for CPS TESTING FACILITIES. A project risk assessment indicated that two of the options have significant schedule and uncertainty risk for the project. The third option in itself has some risk, however, significantly less than the others. This is because:

- it is part of an existing initiative that has already started,
- the project management team is able and willing to prioritise CPS testing needs, and
- the project management team is able and willing to prioritise the development of the facility elements required to do the CPS testing.

This option, option 3, is the University of Pretoria Engineering 4.0 (E 4.0) project.

The Minerals Council mandated SECDI to develop a testing plan based on Option 3 and the plan described in this document has been developed in response to the Minerals Council Board's request to explore options to reduce the duration for CPS readiness.

The business case for investing in E 4.0 is fairly strong and is also the lowest risk option. It is proposed that investment to develop E 4.0 for CPS testing will be shared amongst the collaborators with the Minerals Council co-ordinating donations and contributions from mining companies.

The facility development and construction cost for the project that will enable CPS testing was reported in the Test Facility Needs Report as R 210 million. After a re-evaluation of the cost estimate and including the needs for CPS testing, the current estimate is R 136 million excluding VAT.

The specific cost for the Minerals Council members will be the outcome of negotiations between the collaborators such as the Minerals Council, University of Pretoria, TMM OEMs, CxD developers and the other parties collaborating on E 4.0 including CSIR and SANRAL. The Mandela Mining Precinct Modernisation and Mechanisation projects will also benefit from collaboration.

The accelerated test plan includes several prioritised and concurrent testing approaches that will reduce the overall time to test all the CPS products. It incorporated minimising the need for, and/or number of tests to be performed on mining sites (pilot mines). In the case of underground TMM CPS it includes some enhancements at the E 4.0 test facility that will eliminate the need for TRL 7 testing on pilot mines. In the case of surface TMMs it includes a single pilot mine (unused quarry).

The accelerated testing plan is supported by a project planner (tool) that allows for considering the impact of specific testing durations on the overall readiness date. The planner not only shows the interrelationships of the tests and the proposed action plan based on current assumptions; it also enables a real-life schedule based on improved assumptions and actual progress against the plan.

The accelerated testing schedule drivers are:

1. The date on which testing can start
2. The number of CPS products, i.e. CxD and TMM combinations.
3. The duration of the CxD development and the TMM CPS development to meet the user requirement specifications.
4. The number of legacy TMMs that will require physical changes to their braking mechanisms and upgrading of their existing controllers.
5. The duration of EMC testing.
6. The number of test teams with sufficient technical skill, test equipment and experience to conduct the various tests.

4 Context of this document

This document forms part of the deliverables of the Industry Alignment on TMM Regulations Collision Management Systems Special Project of The Minerals Council South Africa: CPS TECHNOLOGY READINESS PHASE work.

5 Background

As part of Work Package 10: Testing Facilities, of the Industry Alignment on TMM Regulations Collision Management Systems Special Project of The Minerals Council South Africa: CAS TECHNOLOGY READINESS PHASE work, a CPS Test Facilities Needs Report was developed.

The need for extensive CxD testing at TRL 4 has been motivated in the report and three potential options have been proposed for the verification testing.

Simulation

Whilst simulation would be a credible option, the time it will require for development and validation, and the related schedule and cost uncertainty makes it a high project risk option. This option should be explored in parallel to any physical test facility development, but this falls outside of the scope of the current project.

Gerotek Upgrade

To date CxD testing has been done at Gerotek. With the additional testing facility requirements as defined in the CPS Test Facilities Needs Report, construction upgrades are needed on the Gerotek Test Facility. Since the Gerotek facility is used by several clients, including international car manufacturers, there are specific constraints for this option. Amongst them are:

- Unavailability of the facility when international car manufacturers are testing new models.
- Uncertainty as to how long and when any upgrades will be able to be done as it might imply unavailability of testing during such a period.
- Uncertainty of the duration it will take to obtain approval for any facility upgrades.

Given the project schedules this option is considered to be a high risk.

University of Pretoria Engineering 4.0 project

The University of Pretoria started the development of a new building on its Hillcrest Campus in 2016. The first phase of the project, consisting of an educational laboratory, SANRAL national reference laboratory, offices and an auditorium was completed in 2020. A master plan for further developments was developed during the initial planning phase. Included in this master plan is a test track that will be used for autonomous vehicle development and testing by the Vehicle Dynamics Group at UP.

The request of the Minerals Council Board to accelerate the CPS development prompted the SECDI team to approach the University of Pretoria regarding the possibility of expediting the test track construction at Engineering 4.0 with a view to enhance the test track to include the needs of the CPS testing. The UP team seized the opportunity and the current status is as follows:

- Construction of the original test track was due to be the final phase slated for 2025 and beyond. This has now been revised and can be started immediately.

- The design of the test track was updated to accommodate the specific CPS test facility needs. This test track can be used to test all surface and underground interaction scenarios at the TRL4 stage gate. The test track can also be used to test 'lighter' surface TMMs (such as small ADTs, FELs and graders) instrumented with CPS. This will test the detection robustness of surface CxDs.
- Possibilities of maximizing the potential of a test facility dedicated to the verification of CPS were explored. The aim is to limit the number of tests to be conducted on a pilot mine to limit the loss of production. The exact details are still being refined, but the idea is to construct a mine mock-up that can be used to test UG CPS systems in representative environments at the Engineering 4.0 test facility.
- Quantity Surveyor estimates of the cost and duration of construction have been obtained. These estimates include escalation during the construction period.
- Environmental impact studies were conducted during the initial planning phase. The environmental impact studies will have to be expanded to include the revised design. The impact of this on the construction schedule is uncertain, however, given the fact that it is an amendment and not a new application, it is expected that the impact will be limited.
- The Hillcrest Campus is currently zoned as educational. The CPS verification testing to be conducted falls within the scope of educational use.

The disadvantages of the E 4.0 option are; the time that it will take to construct the test facility, as well as the time that it may take to secure the necessary funds, given the number of potential collaborators.

The development of the University of Pretoria's Engineering 4.0 project is the lowest risk option for the project and as such is the recommended way forward.

6 The UP Engineering 4.0 Business Case

Investment into initiatives related to the Fourth Industrial Revolution (4IR) in general can make a positive contribution to the future of South Africa. Such investment will also provide specific benefits to the mining industry:

- Although autonomous TMMs in the mining industry is not something envisaged for the near future, the introduction of Collision Prevention Systems as a regulatory requirement has placed the SAMI at the forefront of CPS related technologies and their application in the global mining industry.
- The regulatory requirement for CPS has pedestrian and operator safety as its objective. CPS on TMMs in mining operations is directly linked to the SAMI's objective of eliminating fatalities on mines.
- Investment into ensuring full functionality of CPS products allows for real cost avoidance related to TMM related fatalities and serious injury in the

SAMI. The need for extensive testing is one of the learnings from current CPS initiatives.

- Investment into an initiative that can assist a wider mining industry vision and goal than just CPS will ensure a return beyond just the CPS project.
- Collaboration with other SAMI initiatives such as Modernisation and Mechanisation will increase the value of the return on investment.

Revenue

Besides the lower schedule and uncertainty risk of the E 4.0 CPS test facility option, it also provides for revenue generation options to recover all or a part of the investment.

The University of Pretoria confirmed that commercial mechanisms do exist to facilitate such and indeed have been used before.

For the purpose of the business case only revenue opportunities directly related to CPS products will be considered.

CxD Stage Gate Testing

The CPS integrated testing regime requires progressive testing of CxDs at TRL 4 and TRL 7 by a 3rd Party Testing Organisation. These tests need to be done on a test facility such as E 4.0. The CxD testing will therefore include a facility fee. A portion of this fee can be used as revenue towards the investment and operating expenses of the test facility.

CPS Provider Development and Conformance Testing

The CPS Integrated Testing Regime requires CPS providers to demonstrate conformance to the specified functional requirements. These tests are not the Stage Gate tests and are to be planned and executed by the CPS providers themselves, prior to Stage Gate testing. It is expected that CPS providers will want to make use of the facilities at E 4.0 or indeed have the tests conducted by the same organisation doing the 3rd party Stage Gate testing. Similar to the Stage Gate testing, a portion of the facility fee can be allocated as revenue.

Cost Avoidance

Advanced CxD tests for Underground TMM CPS products are planned to be done at TRL 7. If these tests are done on the Pilot Mines, of which there are to be eight each of the pilot sites will require to set up a mock-up of an underground mine. By building the mock-up on the E 4.0 facility it would be possible to do the advanced CxD tests at E 4.0 and not at a pilot mine. If four specific types of underground TMM (LHD, ADT, Telehandler, and personnel carrier) can be made available for underground testing at E 4.0 the underground CxD testing at TRL 7 on pilot mines can be avoided with resulting significant cost and time saving.

The only additional requirement for underground TRL 7 testing on a pilot mine would be rock penetration testing. That test can successfully be moved to just before the underground TRL 8 tests start.

For Surface TMM CPS testing the cost avoidance component by making use of the E 4.0 facility is very significant. This is due to the nature of the tests that will have to be done on pilot mines (if a dedicated pilot mine cannot be found) Pilot mine testing implies the use of production TMMs and TMM operators with the related loss of production opportunity cost. Typical costs are defined in the Testing Facility Needs Report.

Facility Cost

Appendix A provides a detail cost breakdown of the revised test track construction cost.

Including a 5% contingency and excluding VAT the cost for the entire construction with the revise d scope is R 136 million.

Return on Investment/Cost Recovery

The quantification of the return on the investment in terms of Rand will be possible once the following information becomes available:

- The portion of the R 136 million that will be required from the SAMI. This will be the outcome of negotiations between the collaborators.
- Any large mining company donor contributions have been considered.
- The 3rd party CPS Stage Gate testing organisation has provided a quotation for the CPS Stage Gate Tests.
- Anybody who contributes to the cost will get a discount/preferential rate.

The E 4.0 facility is the lowest risk option and the only option with a business case.

7 The Accelerated Plan

In response to the Minerals Council Board's request to reduce the duration of the period for the mining industry to be ready for the uplifting of the suspended TMM regulatory clauses, the Minerals Council mandated SECDI Pty (Ltd) to develop an accelerated plan for Stage Gate testing of CPS products. The accelerated plan presented herein is:

Prioritising the CPS testing facility requirements and development within the current Engineering 4.0 project.

To ensure soonest test facility availability the following are necessary:

- Negotiate a participation agreement with the E 4.0 collaborators and provide funding for the development and construction of Engineering 4.0 test track.
- Finalize the scope of the mine mock-up.
- Complete detailed designs of the test track and underground mine mock-up.
- Revise the environmental impact study in the light of the revised designs. Start off with the existing zoning for educational purposes. Conduct initial tests within the scope of the current contract research & development use authorisation.

- Rezone the facility for commercial use to facilitate future income generation. Start the rezoning to commercial zoning as soon as possible.
- Synergise efforts with the approved Centre for Mining Mechanisation project (this project is a collaboration between UP and the Mandela Mining Precinct).

Prioritising TMM CPS testing

From a testing perspective it is important to consider the nature of the testing of the two major elements of a CPS product, namely the CxD and the TMM CPS.

At the TRL 4 Stage Gate, a CxD is tested on instrumented LDVs, while for the TMM the actual TMM must be tested. At TRL 5 the TMM and the CxD are physically integrated and integration verified. At TRL 6 the integrated CxD and TMM (CPS), amongst others, does an EMC test. These differences have major schedule and cost implications for the overall CPS project;

- There are around 20 CxD providers implying a minimum of 20 tests at TRL 4.
- There are at least 399 different models of TMMs in the mining industry (excluding legacy equipment), implying much more than 399 TMM CPS tests, if every TMM, brand type and model must be tested.

Even with a reduced number of TMMs to be tested the overall test duration for TMM CPS testing will take much longer than for CxD testing. This is not only due to the much bigger numbers of tests but also because:

- As required by SANS 1589(UG) and ISO 3450(SME) the TMM CPS TRL 4 tests require brake testing to be done by an Accredited Test Laboratories (ATL) if changes have been made to the braking mechanisms or the machine braking system has been rebuilt. Currently the SANS 1589(UG) and ISO 3450(SME) brake tests for **new or rebuilt** vehicles, where braking components are affected by modifications, are done at Gerotek's brake testing facility. There are two ATLs beside Gerotek and they also make use of Gerotek's test facility.
- The logistics (such as transporting TMMs from OEMs/rebuilders/mines and back) will most likely take longer than the actual testing. The overall duration of an individual TMM CPS test will therefore be longer than an individual CxD test.

Prioritising TMM CPS development and testing will ensure the shortest overall time required for CPS readiness. It also allows time for constructing the E 4.0 test facilities required for CxD testing, without impacting the overall readiness date.

Expediting CxD/TMM Pairing

A significant technology challenge for the accelerated CPS development initiative is the communication between CxD – TMM OEM products. Where V2X communication is standardised, the two elements can be developed and tested independently, and a mine will be able to choose any CxD brand for its TMM fleet (even having specific CxD providers associated with specific TMM OEMs).

The mines have decided to overcome the current lack of standardised V2V communication (lack of interoperability) by using a sole CxD provider per mine for all the TMM brands, types and models requiring CPS solutions on that mine.

Even only having to test each of the 399 TMMs with 20 CxD products will imply at least 7980 tests, (excluding legacy equipment) if all combinations are tested. This is for obvious reasons impractical.

Above implies that mines, CxD providers and TMM OEMs must agree **upfront** who will provide the CPS solution for every specific mine, in order for the CxD providers to be able to develop their products for all the TMM types and models that specific mines require. The agreement of these arrangements and the resulting contractual agreements proved to have taken substantial time up to now and will have to be prioritised in order for the development to start.

It is therefore imperative that all mines complete their Traffic Flow and risk analysis and provide this project with their TMMs that will require CPS solutions, by no later than the end of January 2022.

Prioritising the TMM CPS development for unintelligent (Legacy) UG TMMs
Having demonstrated the need for prioritising TMM CPS development and testing in general, with the amount of development and manufacturing work required for unintelligent (legacy) TMMs, being significantly more than for intelligent TMMs, and the related additional brake testing that potentially has to be done at a brake test facility, a further overall schedule benefit will be realised if the development of the unintelligent underground TMMs are prioritised over the intelligent ones.

This is an important alignment to be achieved between TMM OEMs and the Minerals Council as it is natural for TMM OEMs (and mines) to want to start with and focus on the easier challenge of intelligent machines.

Since mines can only start TRL 8 testing when all the TMMs required to have CPS for the pilot operation (mining section) are available, it will not be of benefit for the overall schedule (or for a mine, unless all the CPS requiring machines on a mine are intelligent) to prioritise and focus on the intelligent machines. A detailed development schedule for every OEM's TMMs CPS will have to be developed based on the quickest overall completion date of the project.

Prioritising TMM CPS testing in general, and for unintelligent underground TMM development specifically, combined with the plan for CxD testing (discussed below) could result in the SAMI being ready for the upliftment of the suspended TMM regulations for underground TMMs much earlier than for surface TMMs. This will demonstrate not only commitment from the SAMI but also addresses the significantly riskier TMM collisions between pedestrians and underground TMMs when compared to surface TMM collisions with other TMMs. It gives practical effect to a holistic risk-based approach for the regulatory compliance.

Doing the Underground TRL 4 TMM element tests as early as possible and concurrently

In support of the prioritisasion of underground TMM CPS products, functional performance of some TMM CPS elements (MCI, MLK) can be verified at existing test facilities before physical integration on the TMM itself. This will prevent time lost due to functional failure of components after physical integration of the TMM CPS elements to be tested at TRL 4. MC and MS testing will have to be done only after physical integration.

Prioritising Underground CxD Testing

In support of the plan to prioritise CPS readiness for underground TMMs, further prioritisation of CxD testing, due to the relative simplicity of the CxD tests will add additional time benefits.

The regulatory requirements for underground TMMs are for V-P only, resulting in simpler CxD functionality and, hence, testing requirements. No permanent facility upgrades at Gerotek are needed for underground TMM CxD testing. This means that TMM testing can start as soon as the first underground TMM OEM provider can demonstrate conformance to TRL1-4 functional readiness criteria.

Doing advanced CxD D&T and Detection Robustness tests for Underground TRL7 at the same time and place as TRL 4

Although schedule benefit can be gained from just focussing on doing the CxD TRL 4 tests at Gerotek, a further and bigger schedule, as well as cost saving can be achieved by doing advanced D&T testing that will be done at TRL 7 at the pilot mine at the same place and time as the CxD TRL 4 tests. This can be done if a temporary board and pillar mine mock-up is constructed.

The construction of a temporary board and pillar mine mock-up at Gerotek has both cost and schedule risks due to the required approval process and potential extra facility fees. Construction can however be done at the **already** completed Engineering 4.0 facility with minimal approval challenges and at no extra facility fees. Construction of the temporary mock-up at E 4.0 will require funding as would be the case if doing it at Gerotek. Adding the CxD D&T robustness test to the advanced CxD D&T tests and doing it at the same time and place as the CxD tests at TRL 4 will have a further and significant cost and schedule benefit.

D&T robustness testing at a mine mock-up will require actual UG TMMs (an **LHD,** an **ADT** and a **personnel carrier**) that are CPS-ready.

The effect of this approach will be that the only tests to be done at TRL 7 for underground TMMs are the CxD rock penetration tests. By doing this test as the 1st test before TRL 8 starts, eliminates the need for doing any TRL 7 tests on pilot mines.

This approach has major schedule and cost benefits. Doing the tests at the pilot mines (8 mines) with operational TMMs will have significant production loss

opportunity cost implications, as well as actual test cost due to logistic requirements. This element of the plan can only be done at the E 4.0 test facility.

Doing Surface TMM TRL7 testing on a single pilot site.
Surface TMM TRL7 testing can be considered as an advanced CxD test. The value of the Surface TMM TRL7 test is demonstrating that the CxD remains functional in a representative mining environment. The representative environment consists of:

- Typical mining roads and infrastructure, such as berms, high walls, dust, etc.
- Congested areas (dump, pit, hard park).
- Ramps & declines
- Varied machinery working in close proximity (e.g. RDT, ADT, FEL and LDV in dump area).

By the time a CxD is tested at TRL7, it has proven a large part of the specified functionalities (although in a controlled test environment). This reduces the scope of testing at TRL7. The TRL7 tests are used to validate the results obtained at TRL4 and verify the outstanding functionality.

Instead of requiring 15 Surface TRL 7 Pilot mines with the associated use of production TMMs and resulting loss of production, a single TRL 7 pilot mine for surface TMM testing can be used if 7 surface TMMs can be made available as testing vehicles. The following surface TMMs will be needed; a **RDT, two ADTs, a FEL, a grader** and **three of the LDVs** used at TRL 4 can be used if the schedule allows for it. The TMMs must pass the TMM TRL4 stage gate before TRL7 testing can commence.

An ideal pilot site will be a currently non-operational or only partially operational quarry near Pretoria or Johannesburg where a pilot test setup can be established for around 6 to 12 months. Finding a place close to Johannesburg or Pretoria will reduce the subsistence and travelling cost for the 3rd Party Testing organisation as well as for the CxD providers that are mostly situated inside the area of Johannes burg and Pretoria (East Rand, Centurion, Midrand)

Depending on the status of the mine, it can be expected that the test site will be under the jurisdiction of the Mine Health and Safety Act. Appropriate safety measures will thus need to be in place (safety officer, safety declaration, risk assessment, licencing of operators, on-boarding of test personnel and technology provider personnel, maintenance crew and facilities, dust suppression etc.)

TRL8 and 9 Pilot Mines
The approach of a single TRL 7 pilot mine for surface TMMs and no TRL 7 pilot mine for underground TMMs does not imply similar for TRL 8 and 9.

Pilot mines are needed for TRL8 and TRL9 testing. The accelerated plan allows for TRL8 and TRL9 tests to be done as part of the CPS procurement processes of

mines that are ready for CPS deployment i.e., conform with the operational readiness criteria. TRL 9 "testing" is an operational verification of the specific CPS products. The "testing" is characterised by diligent data analysis, trending and an incident reporting and investigation processes. TRL 8 "testing" is the equivalent to cold commissioning, with the objective of verifying the full functionality of the system without the slowdown and stop functionality activated. TRL 8 is intended to verify that the mine's traffic management plan is effective and that the mine is operationally ready for the switching over to a CPS enabled operation.

Besides the availability of data analysts and a fulltime safety officer during TRL 8 and 9 testing, pilot mines will not need to expend anything. Sufficient Pilot mines should be available to represent all the CxD and TMM (CPS) combinations in the SAMI.

Summary of tests and locations

Table 1 provides a tabular summary of the proposed location of subsystem testing.

Table 1: Location of tests

Subsystem	UG			SME		
	TRL4	TRL7	TRL9	TRL4	TRL7	TRL9
D&T	E 4.0	E 4.0 mine mock-up & TRL8/9 pilot mines	TRL8/9 pilot mines	E 4.0	TRL7 pilot mine	TRL8/9 pilot mines
CxDC	E 4.0	-		E 4.0	TRL7 pilot mine	
EW	E 4.0	-		E 4.0	-	
V2XIF	E 4.0	-		E 4.0	-	
CxDLK	E 4.0	-		E 4.0	-	
CxDI	E 4.0	-		E 4.0	-	
MCI	Gerotek/ E 4.0	-	-	E 4.0	-	-
MC	Gerotek	-		Gerotek/ E 4.0/OEM/ TRL8/9 pilot mines[1]	-	-
MBS	Gerotek	-		Gerotek/OEM/ TRL8/9 pilot mines[1]	-	
MS	Gerotek	-		Gerotek/ E 4.0/OEM/ TRL8/9 pilot mines[1]	-	
MLK	Gerotek/ E 4.0	-		Gerotek/OEM/ TRL8/9 pilot mines[1]	-	

[1] OEM/TRL8/9 pilot mine needed for legacy equipment case

8 Test Planner

A planner has been developed to assist with the planning and management of the accelerated CPS testing.

The Gantt chart planner shown in figure 1 are based on the accelerated plan. It makes provision for:

- Test track development and construction time.
- Test equipment development, procurement, and commissioning.
- Development time required by technology providers to redesign/upgrade existing technology to meet the new CPS functional and technical specifications. There is a lot of uncertainty regarding the development time technology providers will need to meet the specifications.
- Time required for testing includes commissioning of Equipment under Test and test equipment setup, physical testing and reporting of the test results.
- Multiple test teams that can test the same sub-system concurrently (i.e., working in parallel). Multiple teams will require more test equipment and human resources.
- The potential number of CxD-TMM combinations are the biggest schedule constraint, significantly impacting the schedule. This has specific bearing at TRL6 for both physical integration verification and functional verification testing.
- It is at this point that it becomes evident that a risk-based approach will have to be followed to prevent schedule run away. The question that needs to be answered is: 'How many TMM types, models and variants are considered to be working in high collision risk operations and hence require CPS products. The team used the following basis for the schedule. (This to be validated by considering more views)
  - For UG mining operations, the number of combinations is expected to be quite low. The highest risk of interaction is between an LHD and pedestrian. For this reason, the number of CPS combinations have been estimated at 96. This makes provision for 8 CxD suppliers interfacing with 12 different LHD models and variants.
  - Surface mining operations represent a bigger challenge, because the risk of interaction between multiple machine types cannot be simplified to one class of machine (such as the case for UG). However, the challenges associated with SME is more related to decision-making in complex scenarios rather than detection and tracking of obstacles. Decision-making should not be affected by the machine size and shape; the number of combinations can thus be reduced. A size and shape study indicated that there are five basic classes: RDTs, ADTs, FELs/graders, LDVs and other smaller machines (such as forklifts). Combining the five classes with 15 CxD suppliers results in 75 combinations to be tested.

- It should be noted that we are not recommending that all TMMs that are to be fitted with CPS do not need to be tested. The Section 21 requirement mandates all suppliers/modifiers of machinery to ensure that the modifications (including CPS integration) are done properly and pose no safety risk to users of the machinery. The recommendation is to commence with TRL7 and TRL9 testing as soon as a reasonable number of TMMs fitted with CPS are available at pilot mines. Availability of CPS-enabled TMMs will depend on the first two bullet points above.

The assumptions used in the current version of the schedule are detailed in Table 2.

Table 2 – Timeline assumptions

	UG CPS	**Surface CPS**
Number of CxD providers	8	15
Number of TMM OEMs, models, types, variants[2]	200+	100+
Number of pilot mines	0	1
Haul cycle time [hrs]	0.5	1
R/ton of ore [R]	500	500
Ton/haul cycle	15 to 42	200

[2] Based on a review of the best known TMM OEMs' websites. This number excludes legacy equipment

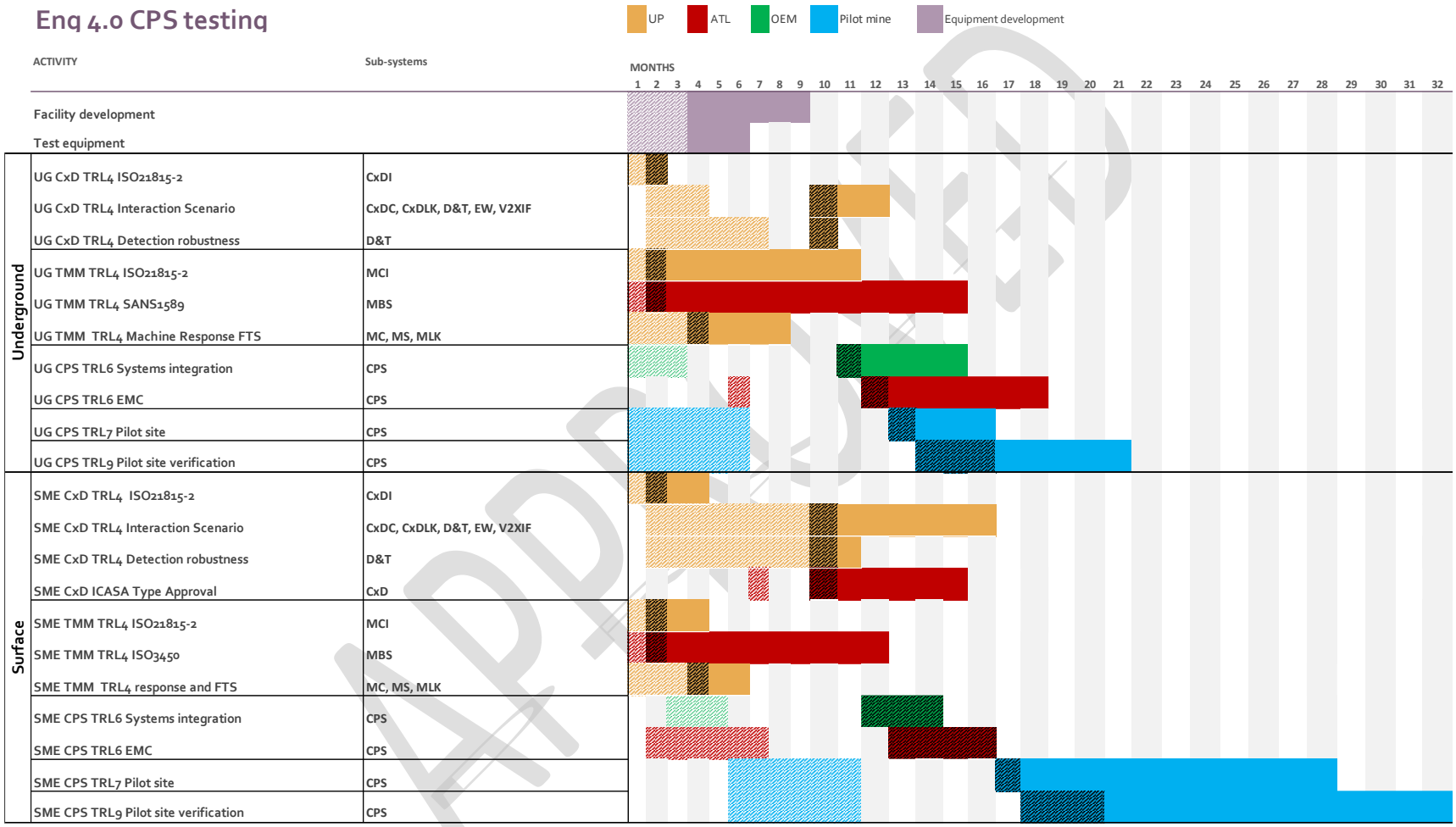


Figure 1: Testing timeline. Legend: Colour indicates where tests will be done; lightly hatched areas indicate development; dark hatched areas indicate when first system will have been tested once; solid fill indicates total test duration (excluding re-tests due to failures).

Appendix: A Detail Costing

ENGINEERING IV - TEST TRACK
UNIVERSITY OF PRETORIA
ORDFER OF MAGNITUDE ESTIMATE NO. 1

26-Oct-21

DESCRIPTION	TEST TRACK Area	Rate	Amount	Total
1 TEST TRACK				R 55 600 000.00
1.1 Connecting Road and Open Test Track	34 153.9	638	21 800 000	
1.2 Mechancal Straight Track	13 120.8	2 302	30 200 000	
1.3 Connecting Road to Engineering 4.0 delivery road	3 586	1 004	3 600 000	
2 UNDEROUND TEST MINE MOCK-UP				R 34 101 570.25
3 SUB-TOTAL				R 89 701 570.25
4 PRELIMINARIES		15%		R 13 455 235.54
5 SUB-TOTAL				R103 156 805.79
6 CONTINGENCIES		5%		R 5 157 840.29
7 TOTAL CURRENT CONSTRUCTION COST				R108 314 646.08
8 ESCALATION				
Pre-contract 01-Oct-21 to 01-Jun-22 8 months @ 0.50% pm				R 4 386 700.00
Post-contract 02-Jun-22 to 30-Nov-23 18 months @ 0.50% pm 0.51				R 5 230 500.00
9 TOTAL ESCALATED CONSTRUCTION COST				R117 931 846.08
10 PROFESSIONAL FEES		15%		R 17 689 776.91
Enabling / other				R 300 000.00
10.01 Land surveying		50 000		
10.02 Sundries		100 000		
10.03 Geotechnical		150 000		
11 TOTAL ESCALATED CONSTRUCTION COST (INCL. FEES & EXCL. VAT)				R135 921 622.99
12 VAT		15%		R 20 388 243.45
13 TOTAL FINAL CONSTRUCTION COST				R156 309 866.44