READINESS CRITERIA FOR COLLISION PREVENTION SYSTEMS DEVELOPMENT

PART 2: MANUFACTURING

(I.E., WORK PACKAGE 8)

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

REV 3

CPS Readiness Criteria Acceptance			
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1. Purpose of this document

This document sets out the criteria for the progressive readiness stages for the supply of CPS products.

2. Definitions and abbreviations

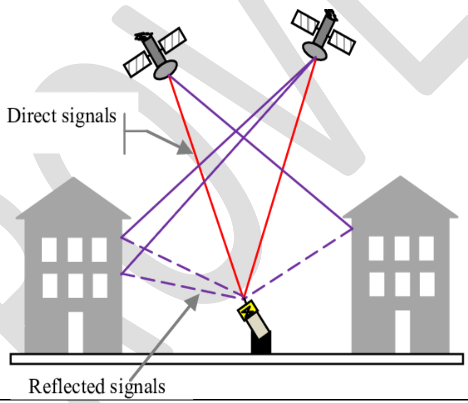
The following definitions and abbreviations will be used to create a common approach for all deliverables. (Note: The rationale for some of the terms and definitions is set out in the CMS Technical Specification Guideline Review Report).

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.
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.
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 highly relevant examples: 1. CxD-machine interface – The interface between a Collision Warning and Avoidance System Device (CxD) and the machine. This interface is described in ISO/DTS21815-2. 2. The user interface – Also sometimes referred to as the Graphic User Interface (GUI) 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".
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 Zone Functionality and Sensor Fusion Report.
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	Underground: Indicating that a specific aspect is applicable to underground TMMs/operations.
UTC	Coordinated Universal Time.
V2X	Vehicle to anything.
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 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 8: Readiness Criteria, of the Industry Alignment on TMM Regulations Collision Management Systems Special Project of The Minerals Council South Africa: CAS TECHNOLOGY READINESS PHASE work.

The document will be released in 4 parts:

- Part 1 Functional Readiness.
- Part 2 Manufacturing Readiness (this document).
- Part 3 Operation Readiness.
- Part 4 Commercial Readiness.

Part 2 of the deliverable must be read with Part 1.

4. Background

TMM regulations for the SAMI have been 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 and manufacturing criteria are needed, and must be conformed to, in order to minimise the potential disruption of the introduction of CPS products to the entire mining industry.

5. The CPS Life Cycle System (Ecosystem)

The CPS Life Cycle System (ecosystem) is defined in Part 1 of the CPS Readiness Criteria document. It is partially repeated here for purposes of context.

The CPS Life Cycle System is shown in figure 1.

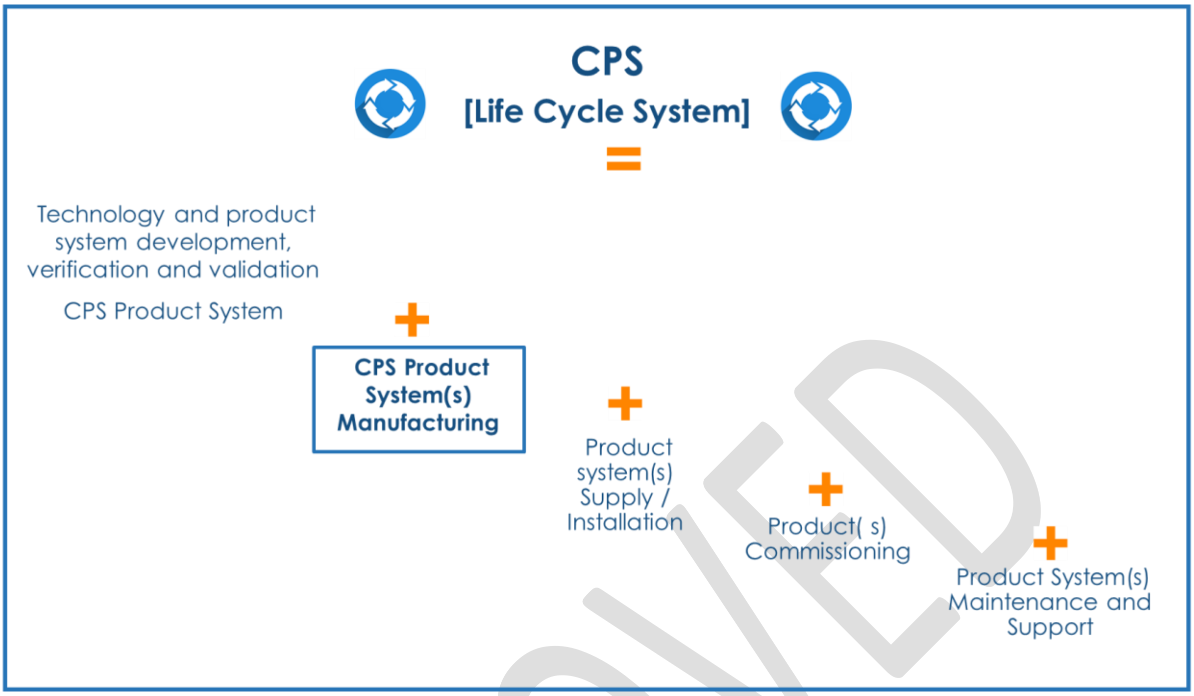


Figure 1: The CPS Life Cycle System

The CPS product manufacturing life cycle element relates to the procurement and manufacturing of CPS products.

6. CPS Product Manufacturing Overview

The CPS Product Manufacturing element relates to all aspects of manufacturing of CPS products, based on specific supply chain and localisation strategies. It applies both to the individual CPS supplier and CPS supply as an element of the CPS ecosystem.

Opportunities

Although, as highlighted in many of the CAS Readiness Phase project deliverables, the development challenge of CPS products is significant, it also comes with opportunities:

- **Developing-world market**

Since South Africa is forced by regulation to be at the forefront of CPS product development, it affords the country an opportunity to leverage this downside as an opportunity to become a dominant player in CPS product supply in developing countries.

To date the local CPS market has been left to normal supply and demand forces. Some Tier 1 TMM OEMs have partnered with international based CxD providers for current RSA fleets, although there might still be opportunities for partnerships.

Local CPS provider's appetite for investment in manufacturing and supply capability and capacity, can be stimulated by export potential. This however is something that the Minerals Council should facilitate in collaboration with local mining equipment suppliers such as MEMSA. It is however important that the ecosystem level strategies be firmed up early in the CPS manufacturing drive, since it will have a big impact on individual CPS product provider supply strategies.

- **Component demand aggregation**

The DMRE,s expectation for local manufacturing and beneficiation in the mining sector is well known. Within the limits of competition law, another opportunity that may be explored is that of component demand aggregation for local manufacturing. It can be readily accepted that a number of CPS product components to be supplied by different CPS providers, can be manufactured by similar, if not the same manufacturing processes. By aggregating the demand and having it manufactured by a local manufacturer that has existing capability, may result in cost benefits, as well as creating more sustainable job opportunities.

Risks

At a time of a significant decline in the local manufacturing capacity and capability in South Africa, the immense time pressure under which CPS products will have to be manufactured, holds a number of risks for the CPS supply ecosystem element. Some of these are:

- **Short window of supply**

In terms of current regulatory expectations, as well as the Minerals Council ambition for accelerated readiness of CPS products, the likely supply window will be 12 to 18 months, with a significant drop in demand thereafter. Since demand is not market driven, but forced by regulatory requirements, the business risk (return on investment) associated with such a short manufacturing window may in all likelihood beyond the appetite of most of the potential CPS providers. Whilst verified CPS products might be available in a year, it will be produced at rates that makes economic sense to the CPS providers. History has shown that unnatural demand, with associated supply shortages, might result in huge price penalties, making CPS products that are already relatively expensive, beyond the reach of smaller and marginal mining operations. This will be defeating the regulatory objective of CPS products.

- **Demand uncertainty**

The very short CPS product supply window implies significant demand for CPS products over a short period of time. If CPS providers does not have visibility of the demand for specific CPS solutions (economies of scale), early enough to make informed business decisions they might be less willing to invest in solution development. Unlike the CMS approach, where a mine had a choice of introducing different levels of collision management technology (the so-called Level 7,8 or 9), a CPS is a single-specification product, that includes, auto slow-down and stop functionality.

The local TMM regulations apply to all types of diesel driven TMMs. The regulations are however only requiring CPS products to be fitted to TMMs where there is a significant risk of collision. This aspect has been dealt with at length in the CMS Technical Requirements Specification Guideline Review Report. It is sufficient to repeat here, that the concept of vehicles being a "significant risk vehicle "is not justifiable from a regulatory requirements point of view. A significant portion of current CMS product demand is L7 or L8 CMS products fitted to LDVs, since they are considered "low risk" TMMs. With selective functionality (L7 or L8) not an option for CPS, and the unpracticality (even potential un roadworthiness for use on public roads) of auto slowdown and stop functionality on road going LDVs, the CPS demand may be sufficiently smaller than what CPS providers may estimate. This is because CPS providers may assume that because LDVs was previously fitted with L7 systems they all will have to be fitted with CPS,s

Information from the Minerals Council indicated that by far the biggest number of diesel driven TMM types in the SAMI is road going LDVs. A high-level collision risk analysis has also identified LDVs as the most collision vulnerable TMM Type.

As have been recommended before separation of LDVs from HMEs seems to be the most viable option for prevention of collisions between LDVs and HMEs on surface operations. If that position is taken by the SAMI the demand for CPS products will be significantly lower that what would be the case if the current L7 products are included in any estimate.

A further complicating aspect is that of legacy (unintelligent TMMs) that are currently widely used on mines in the SAMI.

Unavailability of accurate CPS product demand figures adds to the business risk for CPS providers, when it comes to estimation of manufacturing and supply demand of CPS products.

7. Approach to Manufacturing Readiness Criteria

The functionalities to be provided by CPS products are specified in detail in the F&TPR specification. CPS products are first of a kind product, even from a global perspective. It can be expected that CPS Product cost curves over product life cycle will be significantly higher during the initial (product novelty) stages. These are the very stages in which mines will be forced by regulation to purchase CPS products.

The CPS product manufacturing element of the CPS Lifecycle, (ecosystem) is a key make or break aspect of the successful introduction of CPS into SAMI. To manage the technical risks associated with CPS manufacturing a set of Manufacturing Readiness criteria are developed to govern the technical aspects of the element.

The objective of the CPS manufacturing readiness criteria is twofold:

- To ensure timeous CPS product availability to meet the TMM regulatory deadline.
- To ensure that CPS products consistently conform to the relevant general F&TP requirements. (CPS product quality).

These objectives apply to both intelligent and unintelligent (Legacy) TMMs

MRLs were developed to provide a maturity model based on acknowledged and proven principles and criteria for the successful supply of compliant products. It follows the same approach as that of TRLs.

As a result of the potential safety and production impact that non-conforming CPS products will have on mines and their employees, the mines have a legal obligation to ensure that CPS products do not negatively impact the health and safety of operators (surface TMMs) and operators and pedestrians (underground TMMs). CPS product reliability is directly linked to manufacturing quality, although it is not the only determinant of CPS product reliability.

Whilst a CPS product is technologically complex, it is physically quite simple. In all likelihood, detection systems (sensors) will be purchased off the shelf, and at best require improved encasements to deal with the harsh mining environment. Even for sensors it is likely that CxD developers will be able to source sensing devices that comply with the CxD robustness requirements. From a materials point of view, it is unlikely that novel materials will have to be developed. From a unit demand point of view, the aggregate local demand will in all likelihood be in the thousands and ten thousands and not in the hundred thousands and millions. Therefore, full-scale manufacturing automation are unlikely and will not be addressed.

Some of the CPS components will be sourced from abroad or from local agents. The focus of the criteria will therefore not be purely manufacturing but rather supply. Supply therefore includes component procurement or manufacturing, component acceptance verification, module assembly and factory acceptance testing.

Being safety systems, manufacturing quality and repeatability, are the highest priority aspects of CPS product supply.
Whilst the theoretical manufacturing readiness model has been retained, the criteria has been adjusted for the CPS product realities, as well as the local supply chain dynamics. Specific attention has been given to localisation since it does present some national opportunities

In the absence of a facilitated approach, the readiness criteria are focused on individual CPS providers.

Figure 2 depicts the manufacturing readiness model that will be used for structuring the readiness criteria.

MRL 1	Manufacturing of CPS modules are feasible
MRL 2	The concepts to manufacture CPS modules are finalised
MRL 3	Manufacturing concepts for CPS modules are proven
MRL 4	Manufacturing of CPS modules was done in a workshop
MRL 5	CPS manufacturing components can be done in a production environment
MRL 6 & 7	CPS modules can be assembled and tested in a production environment
MRL 8	Low rate production pilot manufacturing elements tested
MRL 9	Low rate production demonstrated
MRL 10	Not envisaged for CPS products

Figure 2: Manufacturing Readiness Model for CPS Products

The CPS functional breakdown structure is defined in the CPS user requirements specification. Since every CPS developer will develop its own product breakdown structure for CxD and TMM combinations, there is no need for differentiated manufacturing readiness criteria between CPS modules. Readiness criteria are defined in generic terms, since it is not intended to prescribe to CPS developers how they should execute the supply and manufacturing of CPS modules.

Manufacturing Readiness Levels and their criteria are a risk mitigation for CPS project failure. The individual maturity levels are logical, progressive steps in maturing the supply and manufacturing element.

The number of levels is of lesser importance than the criteria itself. In figure 2, MRL 6 and 7 have been combined between sub-assemblies and sub systems due to the relative simplicity of CPS products.

Manufacturing readiness frameworks are developed to be applicable to a wide range of manufacturing scenarios. The readiness frameworks therefore provide for full scale/large scale manufacturing such as for Cell Phone components where production run into the 100 million units. MRL 10 provide for the application of Lean Manufacturing, that is the highest level of manufacturing readiness.

Due to the relatively limited number of CPS products that will need to be manufactured for each CPS provider large/full scale manufacturing is not envisaged. It is only envisaged that low rate production will be required. MRL 8 and 9 are therefore combined and no criteria will be set for MRL 10.

Based on the CPS breakdown structure and product modules, the relative simplicity of manufacture, and the fact that CPS modules have been supplied and manufactured for some years, the manufacturing readiness criteria may require only minimal adjustments from a CPS provider's current manufacturing and supply system. The number of MRLs is not an indication of complexity of the model. Some MRLs can be done in quick succession, or even concurrently and may require only limited time.

CPS providers have the obligation to demonstrate diligence in executing the required activities and provide proof of conformance.

The time pressure on manufacturing and supply of CPS products necessitates diligence in manufacture, while the MHS Act section 21 requirements places further obligations on CPS providers. The collaborative nature of the accelerated CPS initiative will benefit CPS providers significantly, since instead of every mine having to do its own oversight of the development and manufacturing of CPS products, a single 3rd party will be doing it on behalf of all mines. CPS providers will therefore only have to provide its portfolio of evidence once. Stage gates for manufacturing readiness have not yet been established for CPS, as it have to be agreed between the collaboration partners.

8. Readiness Criteria for CPS Module Manufacturing and Supply

MRL	Definition of the TRL	Description of Typical Activities	Success criteria to next maturity level (Evidence Description)
1	**Basic Manufacturing Implications Identified** Manufacturing of CPS modules are feasible	• Component manufacturing analysis. Based on the technology concepts chosen as well as the CPS commercial agreement(s) a formal manufacturing analysis must be done for the supply of each CPS product ie. the CxD and TMM CPS combination. • Off the shelf items and manufacturing items. (including harnesses) • Novel manufacturing challenges identified and planned.	CPS provider basic CPS manufacturing plan signed off, containing evidence of the supply strategy including CPS product supply partners, preliminary make or buy decisions at module and component level, and supply challenge analysis results.
2	**Manufacturing Concepts Identified** The concepts to manufacture are finalised	• 1st level demand estimates are developed • Localisation opportunities are considered, and decisions taken • Manufacturing component materials are selected, and cost trade-offs modelled. • Unit manufacturing cost based on reasonable material and manufacturing estimates. • Component material and manufacturing concepts decided. • A 1st generation of components are procured or manufactured inhouse or in collaboration with existing manufacturers of similar components. • Sample Off the Shelf items are sourced, based on item specification. • Off the shelf item manufacturing facility considered.	Enhanced CPS manufacturing plan signed off, containing evidence of: • localisation analysis and approach. • finalised list of make or buy items. • existence of cost models. Cost models do not have to be revealed or included in reports, only evidence to be provided that, models exist, and that cost is based on reasonable material and manufacturing estimates. • evidence of existence of off the shelf item specifications and manufacturer credentials • evidence of 1st items procured or manufactured. • Rev 1 manufacturing quality plan signed off
3	**Manufacturing Proof of Concept** Manufacturing concepts are proven	• The manufacturing processes are documented • Manufacturability analysis is performed • Component tolerances and characteristics are defined • Critical manufacturing characteristics are classified informed by formal FMECA results. • Validation and proof of conformance requirements are documented • Unit manufacturing cost based on actual material and manufacturing estimates. • Off the shelf components classified for criticality for module reliability and robustness requirements. • Off the shelf item component suppliers selected. • Off the shelf item manufacturing facility/reliability rating considered. • Components manufactured to prove manufacturing concepts	Enhanced CPS manufacturing plan signed off, containing evidence of all previous MRL criteria and evidence of: • manufacturing analysis including module assembly and installation on TMM. • component / item criticality ratings • component specifications/drawings with manufacturing tolerances • manufacturing process flow diagrams • component acceptance requirements and proof of conformance criteria • Demonstration of manufacturing concepts • Next Rev manufacturing quality plan signed off

4	**Manufacturing of components and assembly of modules done in a workshop environment**	• Manufacturing and module assembly processes setup in workshop environment. • Sample components manufactured in workshop • Sample modules assembled in workshop • Special manufacturing and module assembly tools as well as in and out of cab TMM installation tools identified and designed • In process measurement/verification • Component and assembly identification and traceability requirements are finalised. • Factory Acceptance Testing (FAT) specified • FAT test equipment purchased • Human resource numbers available and skills requirements documented • Manufacturability assessment updated • Cost models finalised • Manufacturing Investment requirements finalised.	Enhanced CPS manufacturing plan signed off, containing evidence of all previous MRL criteria and: • Special tools lists and design drawings • Manufacturing quality plan (including traceability) • Module assembly drawings and documentation • Module in and out of TMM installation drawings and documentation, special tools documentation • FAT and on TMM testing documentation
5	**Capability to produce components in the final facility.** Components (including harnesses) manufacturing in the established production environment Components (including harnesses) testing in the production environment	• Manufacturing and FAT processes set up in final manufacturing facility(s) • Special tools manufactured and qualified • All facility construction or modification are completed • In process measurement/verification • Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on components in a production relevant environment. • Sufficient number of components produced for manufacturing process acceptance • Manufacturability assessment finalised (including module assembly and test and in and out of cab TMM installation and testing)	Enhanced CPS manufacturing plan signed off, containing evidence of all previous MRL criteria and: • Updated manufacturing quality plan • Demonstrate component manufacturing and testing against quality plan and component testing protocols • Component manufacturing process conformance certificate issued • Component testing process conformance certificate issued • Component materials supply chain verifiable • Manufacturing and testing skills certified
6&7	**Capability to assemble CPS modules with the established process in the final facility** Installation of trial CPS modules to TMMs	• Module assembly and FAT processes set up in final manufacturing facility(s) • Special tools for assembly manufactured and qualified • All assembly and test facility construction or modification are completed • In process measurement/verification • tooling and test equipment, as well as personnel skills have • been demonstrated on components in a production relevant environment • Sufficient number of modules assembled for assembly process acceptance	Enhanced CPS manufacturing plan signed off, containing evidence of all previous MRL criteria and: • Updated manufacturing quality plan • Demonstrate module assembly and testing against quality plan and module testing protocols • Module assembly process conformance certificate issued • Module testing conformance certificate issued

		• Sample modules fitted to specific TMMS to verify installation process and documentation • Module assembly and test assessment finalised • In and out of cab TMM installation and testing assessment finalised	• Component materials supply chain verifiable • Manufacturing and testing skills certified • TMM OEM CPS installation design and installation verified and signed off. • Module in and out of cab TMM installation process conformance certificate issued • Module in and out of cab TMM installation process conformance certificate issued
8 & 9	**Ready to begin production**	Demonstration of all aspects of manufacturing assembly and FAT completed All manufacturing inputs and process requirements are available in quantities as per the approved production plan. Materials and Off the shelf supply are available and supply chain is stable.	• Inhouse CPS manufacturing readiness certificate issued with the complete portfolio of evidence available to prospective clients. • Availability of all manufacturing inputs verifiable.
10	NA		