REVIEW REPORT:

Collision Management Systems Technical Specification Guideline (SME and UME) REV 7

(I.E., WORK PACKAGE 9,) OF THE

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

Service Agreement No 21/001

Technical Specification Guideline Review Report Acceptance			
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1. Definitions and abbreviations

The following definitions and abbreviations are relevant to this document.

CMS	Collision Management System – The overall combination of preventative controls, mitigation, recovery and supporting controls implemented by a mine site to prevent TMM collisions.
CPS	Collision Prevention System: The product system that complies with the regulatory (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 effective warning or collision avoidance functionality.
Ecosystem	A **business ecosystem** is the network of organizations—including suppliers, distributors, customers, competitors, government agencies, and so on—involved in the delivery of a specific product or service through both competition and cooperation.
Element/Sub System	A member of a set of elements that constitutes a system. A system element is a discrete part of a system that can be implemented to fulfil specified requirements. A system element can be hardware, software, data, humans, processes (e.g., processes for providing service to users), procedures (e.g., operator instructions), facilities, materials, and naturally occurring entities (e.g., water, organisms, minerals), or any combination. (ISO/IEC 15288:2015)
Emergency stopping	In the case of an emergency situation, the machine needs to slow down and stop as quickly as possible, without losing control (meaning directional stability) and without any immediate negative health and safety impact on the operator.
EMESRT	Earth Moving Equipment Safety Round Table
EMI	Electromagnetic interference (EMI) is a phenomenon that may occur when an electronic device is exposed to an electromagnetic (EM) field.
EMC	Electromagnetic Compatibility, also known as EMC, is the interaction of electrical and electronic equipment with its electromagnetic environment, and with other equipment. All electronic devices have the potential to emit electromagnetic fields.

Functional Specification:	Specifications that define the function, duty or role of the product. Functional specifications define the task or desired result by focusing on what is to be achieved rather than how it is to be done.
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/PRF TS 21815-2. 2. The user interface – Also sometimes referred to as the Graphic User Interface (GUI) if 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 (V2V), vehicle-to-pedestrian (V2P) or vehicle-to-infrastructure (V2I). 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, 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/EMC challenges.
Loss of control	The uncontrolled movement of a TMM due to operator, machine or environmental reasons. Note: Section 8.10.3 pf MHS Act. Loss of control may result in several scenarios: • Machine failure – park brake or service brake, tyre blowout or • Operator disabled – fatigue, medical condition, inattention, distraction, non-compliance with TMP rules (e.g. over speeding on decline, overloading).
MHS Act	Mine Health and Safety Act No. 29 of 1996 and Regulations
MOSH	Mining Industry Occupational Safety and Health
PDS*	Proximity Detection System – see CxD. *
Project	Industry Alignment on TMM Collision Management Systems Project: **CAS READINESS PHASE**
Quality Assurance	Verifying a process, product or service; usually conducted by a person experienced in the specific field.

Reasonably practicable measure	Reasonably practicable means practicable having regard to: (a) the severity and scope of the hazard or risk concerned; (b) the state of knowledge reasonably available concerning that hazard or risk and of any means of removing or mitigating that hazard or risk; (c) the availability and suitability of means to remove or mitigate that hazard or risk; and (d) the costs and the benefits of removing or mitigating that hazard or risk; (from MHS Act)
SAMI	South African Mining Industry
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.
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/PRF TS 21815-2 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.
Stop*	ISO/PRF TS 21815-2 provides for two definitions, an emergency stop and a controlled stop, both of which are considered to be 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 situation. 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.
Sub-system	See Element.

System	A combination of interacting elements organized to achieve one or more stated purposes (ISO/IEC/IEEE 2015).
Systems Engineering	Interdisciplinary approach and means to enable the realization of successful systems. Expanded definition: Interdisciplinary approach governing the total technical and managerial effort required to transform a set of user needs, expectations, and constraints into a solution and to support that solution throughout its life.
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.
This document	Collision Management Systems Technical Specification Guideline SME and UME REV 5 – Review Report.
TMM	Trackless Mobile Machine. (Machine, vehicle, etc.)
TMM COP	Guideline for the compilation of a Mandatory Code of Practice for Trackless Mobile Machines.
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)
Vicinity (Surface TMMs)	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, then and one or both does not take action 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
Vicinity (Underground TMM and pedestrians)	The distance of a TMM from a pedestrian, such that if the operator of the TMM and the pedestrian does not take action to prevent a potential collision then emergency slow down and stopping of the TMM can successfully be 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.

2. Purpose of this document

The report sets out the review comments, implications, gaps and proposed actions to enhance and align the specification and testing documents with the TMM regulations in South Africa.

Background: Two technical specification guidelines generated by the CM&EE TMM Task Team in November 2018 have been accepted by the mining industry as the foundation guidelines for collision avoidance system selection, procurement, testing and implementation in South Africa.

This report summarises the review of the above documents and sets out the major findings of the review.

The purpose of this document is therefore to:

- Summarise the current state of the above documents,
- Summarise the gaps between the current state and required alignment with this project objectives, and
- Propose ways to fill those gaps in compliance with the South African regulatory framework.

3. Scope of review

The primary scope of the review is the two Collision Management Systems Technical Specification Guidelines:

- Opencast / Open Pit / Surface Mining Operations, Prepared by the CM&EE TMM Task Team, (Rev A.6); and
- Underground Mining Operations, Prepared by the CM&EE TMM Task Team, (Rev A.6).

Since any gaps that may exist in the functional specifications will automatically imply gaps in the testing specifications only **general review** comments are made with respect to the testing documents.

At the end of the report a section is dedicated to record observations and aspects that the review team believe might be of interest, concern or opportunity to the Minerals Council SA. The section includes aspects such as developments and observations in other mining jurisdictions of which the review team took note and consider relevant, a view of the effectiveness of the regulation, and the like.

Whilst this report will primarily focus on the gaps that have been identified, it is important to note that the work done to date is acknowledged and will be used to the maximum in the deliverables to be produced.

4. Context of the review

The review was performed in the context of the **INDUSTRY ALIGNMENT ON TMM REGULATIONS; SPECIAL PROJECT OF THE MINERALS COUNCIL SOUTH AFRICA** and in particular to the **CAS READINESS PHASE,** the primary objectives of which are:

- To ensure technology (Products) with functionality that will comply with the RSA TMM **regulations** is developed by ensuring complete and unambiguous requirements for such products,
- To enable large scale rollout of the "CAS" technology to enable timeous compliance as per the regulatory requirements.

5. Background to the Collision Management Systems Technical Specification Guideline

It is important to consider the background to the Collision Management Systems Technical Specification Guidelines. The guidelines were developed as outputs of the Earth Moving Equipment Safety Round Table (EMESRT) collision management initiative. EMESRT developed the now well-known and widely used nine level collision management framework as shown in figurer 1.

Figure 1: EMESRT Control Levels (1-9)

EMESRT developed the initial versions of the guidelines and made them available to the South African mining industry for use. Since South Africa was the only jurisdiction at the time that regulated Level 9 intervention controls, EMESRT decided around 2015/6 to dedicate its **initial** efforts to Levels 1 to 6 of the framework and support the ICMM's Vehicle Interaction initiative.

6. Alignment of definitions and abbreviations

Based on the above background, terminology, definitions and abbreviations throughout the guidelines are not consistent with RSA regulatory terms, definitions and abbreviations. Despite the alignment challenge that it may pose the review team concluded that it needed to write this report based on terms, definitions and abbreviations used and derived from RSA TMM "CAS" regulations while taking into account other abbreviation and definitions in use by other initiatives, such as EMESRT, the ISO/PRF TS21815 working group and the ICMM VI initiative.

Key findings with regards to terms, definitions and abbreviations used in the Specification Guidelines

The CMS specification guidelines defines, **CMS** = **Collision Management System** – "The overall combination of preventative controls, mitigation, recovery and supporting controls implemented by a site to reduce exposure to hazardous vehicle interactions".

It defines **CMS Strategy** as: "The overall combination of Level 1-6 site controls and PDS providing awareness and advisory information to the operator (Levels 7-8), an interface with the machine, and an implemented intervention via a controller (Level 9 solutions only)"

The above definitions refer to the holistic approach (L1-L9). However, it defines **CMS Solution** as "The technology or combination of technologies providing Level 7-9 controls meeting the technical specifications of the collision management system" The CMS Solution is very specific and excludes any technology except that providing L7-L9 functionality. This creates confusion.

The guidelines define **CAT = Collision Avoidance Technology** as – "technologies with intelligence that scan for other equipment and/or personnel in close proximity providing 'slow down and stop' instructions to the machine to automatically take control from the operator and slow down or stop the machine – a safety **system** that takes over control from the operator" It is noteworthy that the guidelines do not provide a definition for CAS though.

The term **CAS** is used in the Earth-moving machinery -- Collision warning and avoidance – Technical Specification **ISO/PRF TS 21815-2**. It defines **CAS = Collision Avoidance System**; system which is able to detect objects in the collision risk area, evaluate the collision risk level and take interventional collision avoidance action.

For whatever reason the term CAS is widely used in the South African mining industry although the RSA regulations use the term **prevent** and not **avoid**.

Given the fact that the RSA regulatory requirements are very specific and not the same as the ISO definition it will create **confusion** if the term CAS is also used for the RSA scenario.

The review team therefore proposes that the term used for the RSA scenario is:

CPS = Collision Prevention System defined as: A Product System that comprises the functionality and characteristics that comply with the **RSA TMM collision prevention regulations**.

The specification guideline further defines **PDS** = **Proximity Detection System** as a PAT, PDT or CAT fitted to mobile equipment, carried by a person or placed in a location to demarcate a hazard, implemented as part of the CMS solution. These terms and definitions are not generally used in South Africa. In the last few years, the ISO/PRF TS 21815-2 has been developed as a draft international standard. The team proposes that the project as far as practically align with the definitions of ISO/PRF TS 21815-2 and only deviate from it where RSA regulations dictate. This will ensure future alignment with the international community. The terms, definitions and acronyms defined in this report are the ones that are proposed for use in this project.

It is important to further note that Level "7, 8 and 9" are not consistent with RSA TMM regulations. The TMM regulations do not distinguish between L7, L8 and L9 and do not use that terminology at **all**. More importantly, the functionality that is assigned to the different levels does not align with the RSA TMM regulations. This is elaborated on later in this report.

Above are explanations of a few specific examples to demonstrate the importance of terms and definitions to be used in the RSA regulatory environment to motivate why realignment are necessary.

Note: Unless specifically referring to the EMESRT definition the term CPS will be used in the rest of this document.

7. Alignment of the overall approach with RSA regulatory environment.

The EMESRT approach was rightly informed by a non-regulatory commercial, market driven approach. Functionalities were identified and derived from TMM and pedestrian interaction risk. This is not the case with the RSA TMM regulations. The RSA TMM regulations were not informed by a **formal** vehicle interaction risk assessment.

The RSA TMM regulations do not require **vehicle to pedestrian** functionality for surface mining operations, although many fatalities on surface mines are pedestrians. It also does not require **vehicle to vehicle** functionality for underground operations and also no vehicle to infrastructure functionality for either surface or underground operations. The local regulations are primarily concerned with automatic stopping of TMMs to prevent collisions between TMMs for surface operations and TMMs and pedestrians for underground operations.

This has the implication of making entire sections of the specification guidelines **non applicable** for the purpose of this project.

An even more impactful difference of the EMESRT approach and that of the RSA challenge is the regulatory nature itself. In the absence of regulations, the EMESRT approach is rightly driven by a normal technology market offering and the evolutionary development of functionality and products, driven by market needs. This inevitably means that **every mine** must define its **own requirements** based on its **own priority, technology vision and risk profile**.

By implication it means that the rate of development, need for testing, cost of testing and risk related to the quality of development and testing are entirely that of **a specific mine** or a mining group. The development of a **specification guideline** that can be used by individual mines is therefore appropriate.

Such an approach is not ideal and not feasible for the regulatory challenge that the RSA mining industry faces. This is due to:

- Regulations require compliance of many organisations (mines) on a specific date/period with potential negative consequences for non-compliance. (Mine can be closed)
- It requires an entire ecosystem to be established timeously to ensure that at the effective date of regulation, the demand for the technology can be met.
- Regulations dictate specific and implied functionality requirements.
- It elevates the importance of functionality and reliability significantly. In a normal commercial technology cycle, a mine can simply switch off the technology if it is found to be too unreliable or its functionalities are inadequate. For regulated technology this would mean a mine must stop operations or obtain temporary exemption from the regulations.
- As a safety system that ultimately takes away the control of a TMM from an operator, specific functional and system requirements are required that must be agreed upon between stakeholders and must be ensured to minimise the potential disruption of the introduction of such technology to an entire industry.
- Due to the limited window to develop the ecosystem it requires an order of magnitude better collaboration, co-ordination and alignment between all relevant stakeholders including technology providers and machine OEMs.
- Even if mines have funds to perform all required tests on their own and at their own premises, the demand of all mines in a short window of execution will be overwhelming to all suppliers whether TMM or CPS suppliers.
- The implication of the regulation is that all mines must comply on a specified date. Many mines do not have the financial resources to procure systems, let alone funds to conduct testing of novel products that may require many iterations of retesting.

The South African challenge requires an ecosystem optimised approach.

As indicated above the RSA challenge requires the establishment of an entire ecosystem. The approach proposed for the local challenge is that of a **collaborative technology development and testing approach** informed by the TMM population, the number of mines, the regulatory implementation window and an optimised approach for least overall cost and interruption of mines.

This approach by implication means a **centralised requirements specification** and **testing** as far as practically possible.

8. Legislation

The following legislation determines all requirements in the deliverables of this project:

Reference	Description
MHSA	Mine Health and Safety Act No. 29 of 1996 and Regulations.
TMM COP	Guideline for the compilation of a Mandatory Code of Practice for Trackless Mobile Machines.

9. General alignment of functionality with RSA regulations

The CPS functional requirements of the local TMM regulations are very specific. This is further elaborated on in section 10. In general, the EMESRT approach has structured the CAT functionality into 3 levels:

Level 7 is the **"proximity awareness"** functionality; providing TMM operators and pedestrians with general warnings, alerts, and awareness of the proximity of other TMMs and or pedestrians.

Level 8 is the **"advisory controls"** functionality that provides TMM operators with advice related to detected TMMs and pedestrians in the vicinity.

Level 9 is the **"intervention controls"** functionality that automatically apply an emergency braking action to TMMs.

In a non-regulatory scenario, this structure, correctly, enables a mine to choose what level of functionality it requires. A similar freedom does not exist in the South African regulatory context. The requirements of the RSA CPS regulations are for "Level 9" equivalent solutions, i.e. automatic stopping. The fact that the automated stopping functionality (clauses 8.10.1.2(b) and 8.10.2.1(b)) are suspended seems to have created the impression at mines that an EMESRT L7 functionality is acceptable for complying with regulations 8.10.1.2(a) and 8.10.2.1(a). This is unfortunately not the case, specifically as a result of the implied requirements for "vicinity" and "effective warning" (see sec 10) and the implication of this reality is that almost all of the current “L7” systems **do not comply** with the RSA regulations.

10. Specific TMM Regulatory CPS functionality (explicit and implied)

As part of this review, a TMM regulatory analysis was performed. This analysis considered all the relevant aspects related to TMMs. The diagram is attached as a separate **Pdf file** in order to enable readability of the diagram.

Figure 2 shows the result of the analysis.

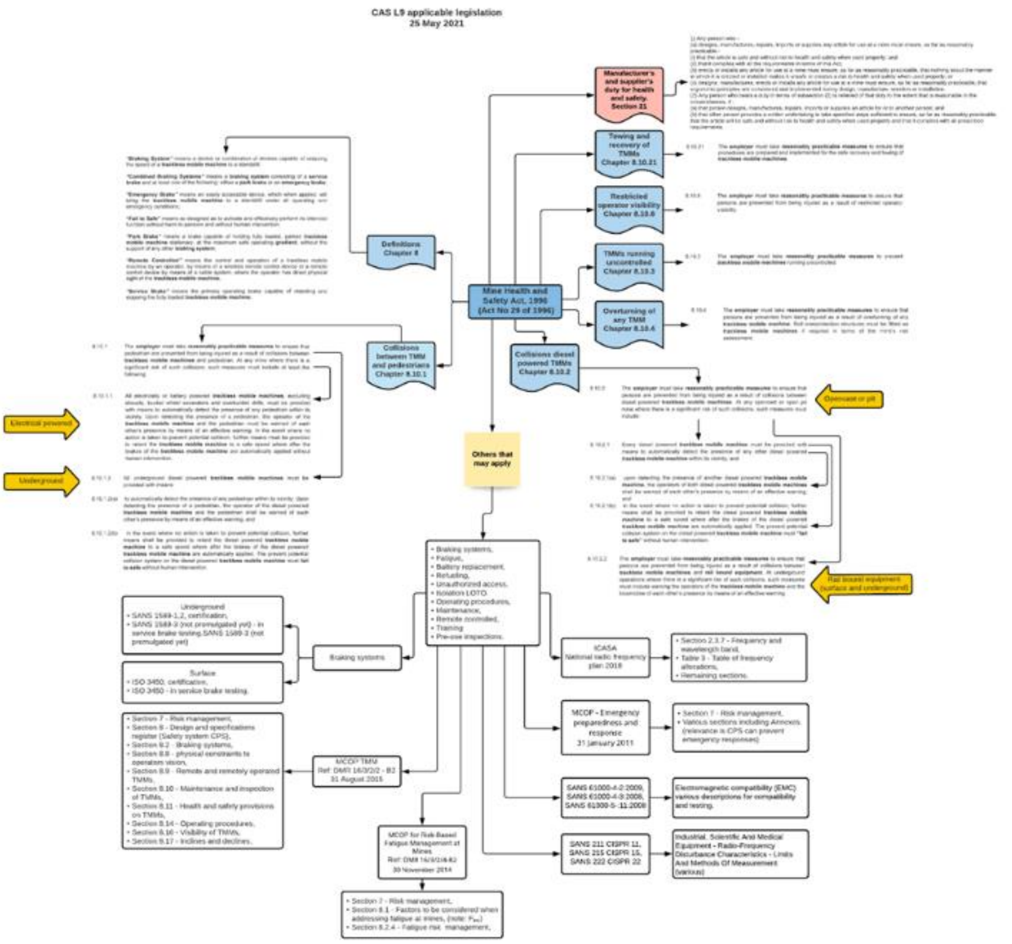

Figure 2 TMM regulatory analysis (see Appendix for a legible diagram)

As stated before, the RSA TMM CPS regulations (8.10.1 and 8.10.2) are the specific scope and foundation of this project. Whilst fig 2 depicts multiple aspects of the regulations, this section will only focus on the CPS regulations. Analysing and aligning between all stakeholders on the direct and implied requirements of the regulations are therefore critical for project success. Other relevant aspects identified during the regulatory analysis will be discussed in a later section of the report.

Below is the review team's interpretation of the requirements of the CPS regulations.

General (Applicable to open pit/cast and underground mines)

The regulation states (8.10.1and 8.10.2) that: *The employer must take* ***reasonably practicable*** *measures to ensure that* ***pedestrians/persons*** *are* ***prevented*** *from being* ***injured*** *as a result of collisions between diesel powered trackless mobile machines and pedestrians/collisions between diesel powered trackless mobile machines. At any mine, where there is a* ***significant risk*** *of such collisions (collisions wherein pedestrians or persons can be injured) such measures must include…*

Consider **"reasonably practicable"**

Reasonably practicable with reference to the Act, which means practicable having regard to:

- the severity and scope of the hazard or risk concerned,
- the state of knowledge reasonably available concerning that hazard or risk and of any means of removing or mitigating that hazard or risk,
- the availability and suitability of means to remove or mitigate that hazard or risk, and
- the cost of removing or mitigating that hazard or risk in relation to the benefits deriving therefrom.

Reasonable practicability involves weighing-up the risks and balancing these against the resources necessary to control them. (If risk is high, less weight can be placed on costs to implement controls than if risk is low.)

8.10.1 refers to … such measures shall include **at least** the following: At least can be defined as "not less than; at the minimum" – this clause may imply that CPS is the minimum that is required.

Consider "**prevent"**

Prevent means to stop something from happening or someone from doing something (prevent, avoid, stop, avert, prohibit, check). In terms of occupational health and safety management, prevent means the application of preventative controls that are either objects or systems or practices.

Given the momentum involved when a TMM collides with a pedestrian, 'prevented from being **injured"** is almost impossible when a collision occurs. This is most likely the reason why the DMRE is so keen that employers introduce automatic stopping of all TMMs as it will prevent TMM collisions with pedestrians as well as other TMMs.

Consider "**significant risk"**

The term "Significant" is defined in the Oxford Dictionary as being **"noteworthy**, of considerable amount or considerable effect or considerable importance"

The TMM COP guideline DMR 16/3/2/2-B2 issued by the Chief Inspector of Mines. States:

The objective of this guideline is to enable the employer at every mine to compile a COP, which, if properly implemented and complied with, would improve health and safety in connection with the use of ***trackless mobile machines*** at a mine.

Section 11 of the MHSA requires the employer to identify and assess the health and safety **hazards** to which employees may be exposed while they are at work, and record the **significant hazards identified and risks assessed**. The **COP** must address how the **significant risks** identified in the risk assessment process **must be dealt with**, having regard to the requirements of sections 11(2) and 11(3) that, as far as reasonably practicable, attempts should first be made to **eliminate** the risk, thereafter, to **control** the risk at source.

The SAMRASS codebook defines **risk as "the likelihood that occupational injury or harm to persons will occur"** The above definition read together with "**prevent** collisions" and the reality that a TMM collision will most of the time result in an injury to a "pedestrian or a person" leads to the conclusion that **all** TMM collisions are "noteworthy" / significant and must be **prevented**.

A mine therefore must **identify all the places** on the mine where a TMM collision with a pedestrian is possible and decide how collisions at that **specific** place will be "eliminated" and, if not eliminated, "addressed" i.e. what controls will be introduced to prevent the collision.

If the mine introduces **any** measures/controls to eliminate or prevent the collision at that specific place or the measures/controls that are introduced can prevent (are effective) that potential collision then there is no "significant risk" that a collision can happen and the mine does not have to introduce Collision Prevention Systems that will comply with the requirements of the regulations. Conversely if the mine does not introduce such measures/controls then the mine must introduce a CPS that complies with the requirements of the regulation.

The inclusion of the **significant risk** condition into the regulations has a major implication for a mine as it provides the mine with an opportunity to not introduce CPS but to introduce other controls to prevent TMM collisions.

Reading of the TMM CPS regulations in conjunction with the TMM COP Guideline places an obligation on a mine to introduce **all** controls in accordance with the hierarchy of controls. This is significant in terms of the DMRE's challenge to employers to introduce "low hanging fruit" controls.

An analysis of the specific requirements for surface mines (open cast and open pit) are discussed below.

<u>**For Surface Mines**</u> the regulation states: *At any **opencast** or **open pit** mine, where there is **a significant** risk of such collisions (collisions wherein persons can be injured as a result of TMM collisions) such measures **must** include:*

*8.10.2.1 Every **diesel powered trackless mobile machine** must be provided with means to automatically detect the presence of any other **diesel powered trackless mobile machine** within its **vicinity** and:*

*8.10.2.1 (a) upon detecting the presence of another diesel powered trackless mobile machine, the operators of **both** diesel powered trackless mobile machines shall be warned of each other's presence by means of an **effective warning**;*

The direct functionality requirements derived from above are:

- Detection when within each other's **vicinity**

- **Both** TMMs to detect each other
- **Both** operators to be warned
- Warnings to be **effective warnings**

Whilst bullets 2 and 3 are clear, bullets 1 and 4 require further interpretation in order to be unambiguous and needs further analysis and interpretation.

The regulations further state:

8.10.*2.1 (b) in the event where no action is taken to* ***prevent*** *a potential collision,*

This clause also provides the implied requirements with regards both **vicinity** and **effective** warning.

Vicinity:

The law expects the operators of both machines to **take action** to **prevent** a potential collision. This means that vicinity is defined as:

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 take action then the CPS will be able to prevent the potential collision.

Vicinity therefore cannot be a fixed value; it is scenario dependent. It is not 50m or 30m or even 10m because we don't want operators to take **any action** if they are still 50m or 30m apart or in some instances, not even 10m, when it is necessary for normal operation as it will for example prevent TMMs from passing each other on a narrow haul roads.

"Vicinity" thus depends on specific circumstances and operational scenarios.

(Note: In the absence of specific operational scenarios and the relevant circumstances it is almost impossible to develop CPS Product Systems that will comply with the regulations.)

Effective Warning:

The regulation states that the operators of both TMMs **must** take action to avoid a potential collision. The operator of a TMM must always stay in control of her/his TMM. The intention of the TMM regulation is clearly to uphold that principle. The regulations are specifying technology to enable emergency braking of TMMs to prevent collisions, but it **upholds** the obligation of the operator to remain in control of the TMM. This is an important consideration as this requirement delays the time to trigger the automating stopping of the TMM.

The regulations do not call for a **general warning** or an **awareness warning**, or an instruction to stop the TMM, it calls for an **effective warning**.

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.**

An effective warning is conditional, depending on speed, relative position, road design, road condition etc.

If the **operator** is expected to take action to avoid a potential collision, she/he must be granted a "fair"/reasonable opportunity to take the action. An effective warning therefore also includes the time that an operator is given to respond to the effective warning to avoid a potential collision.

8.10.*2.1 (b …….further means shall be provided to retard the diesel powered "trackless mobile machine" to a* ***safe speed*** *where after the brakes of the diesel powered "trackless mobile machine" are automatically applied. The system on the diesel powered "trackless mobile machine" must "fail to safety" without human intervention.*

A **safe speed** is a speed below which the automatic emergency stopping intervention can be initiated without increasing the risk of a collision or causing other unintended consequences that may lead to personal injury.

When considering the TMM regulations it is important to also note that where there are "places of potential collision" that a CPS will not prevent a potential collision or if the CPS cannot comply with the requirements of the regulation it does not absolve the mine to introduce other preventive controls.

Two practical examples of this are where commercial LDVs are used on roads where Heavy Mining Vehicles work. If a regulatory compliant CPS does not exist for that LDV then that LDV must be prevented from a potential collision by other reasonably practicable controls such as berm separation or separate LDV roads.

Further, if a CPS does not exist that can prevent two haul trucks moving in opposite direction on a haul road from a potential collision, then the two haul trucks must be prevented from a potential collision by other reasonably practical controls such as a centre berm or a one directional road.

An analysis of the specific requirements for electric powered trackless mobile machines are only mentioned and not discussed since the promulgation of the regulation is not postponed due to technical difficulties.

For Electric and Battery powered machines

8.10.1.1 All electrically or battery powered trackless mobile machines, excluding shovels, bucket wheeled excavators and overburden drills must be provided with means to automatically detect the presence of any pedestrian within its vicinity. Upon detecting the presence of a pedestrian, the operator of the trackless mobile machine and the pedestrian must be warned of each other's presence by means of an effective warning. In the event where no action is taken to prevent the potential collision, further means must be provided to retard the trackless mobile machine to a safe speed where after the brakes of the trackless mobile machine are automatically applied without human intervention."

An analysis of the specific requirements for surface mines (open cast and open pit) are discussed below

<u>**For Underground mines**</u> the regulation states: *<u>"8.10.1.2 All underground diesel powered trackless mobile machines must be provided with means:</u>*

*<u>8.10.1.2.(a) To automatically detect the presence of a **pedestrian** within its **vicinity**. Upon detecting the presence of a pedestrian, the **operator** of the diesel-powered trackless machine and the **pedestrian** shall be warned of each other's presence by means of an **effective** warning;</u>*

The direct functionality requirements derived from above are:

- Detection when within each other's **vicinity**
- **Only the** TMMs to detect the pedestrian
- **Both** the operators and the pedestrian to be warned
- Warnings to be **effective warnings**

Whilst bullets 2 and 3 are clear, bullets 1 and 4 require further interpretation in order to be unambiguous and needs further analysis and interpretation.

The regulations further state:

8.10*<u>.2.1 (b) in the event where no action is taken to **prevent** a potential collision,</u>*

This clause also provides the implied requirements with regards both **vicinity** and **effective** warning.

Vicinity:

The law expects the operator of the machines to **take action** to **prevent** a potential collision. This means that vicinity is defined as:

the distance/time/ of a TMM from the point of a potential collision with a pedestrian, such that if the operator of the machine are instructed to take action to prevent a potential collision and does not take action then the CPS will be able to prevent the potential collision.

Vicinity therefore cannot be a fixed value; it is scenario dependent. It is not 15m or 10m because we don't want an operator to take **any action** if a pedestrian is still within its proximity for normal operation as it will prevent TMMs from working at low speed in face areas as well as workshop areas.

"Vicinity" thus depends on specific circumstances and operational scenarios.

(Note: In the absence of specific operational scenarios and the relevant circumstances it is almost impossible to develop CPS Product Systems that will comply with the regulations.)

Effective Warning:

The regulation states that the operator of the TMMs and the pedestrian **must** take action to avoid a potential collision. The operator of a TMM must always stay in control of her/his TMM. The intention of the TMM regulation is clearly to uphold that principle. The regulations are specifying technology to enable emergency braking of TMMs to prevent collisions, but it **upholds** the obligation of the operator to remain in control of the TMM. This is an important consideration as this requirement delays the time to trigger the automating stopping of the TMM.

The regulations do not call for a **general warning** or an **awareness warning**, or an instruction to stop the TMM, it calls for an **effective warning for both the operator and the pedestrian**.

The expected outcome of the pedestrian and the operator action is that the potential collision is prevented, therefore an **effective warning must inform the operator of the TMM what the appropriate action(s) are to prevent the potential collision** as well as the pedestrian.

An effective warning is conditional, depending on operational area/process, speed, relative position, road design, road condition etc.

If the **operator** is expected to take action to avoid a potential collision, she/he must be granted a "fair"/reasonable opportunity to take the action. An effective warning therefore also includes the time that an operator is given to respond to the effective warning to avoid a potential collision, likewise the pedestrian must also be given a "fair"/reasonable opportunity to take the action. An effective warning therefore also includes the time that a pedestrian is given to respond to the effective warning to avoid a potential collision

8.10.*2.1 (b …….further means shall be provided to retard the diesel powered "trackless mobile machine" to a* ***safe speed*** *where after the brakes of the diesel powered "trackless mobile machine" are automatically applied. The system on the diesel powered "trackless mobile machine" must "fail to safety" without human intervention.*

A **safe speed** is a speed below which the automatic emergency stopping intervention can be initiated without increasing the risk of a collision or causing other unintended consequences that may lead to personal injury.

11. Alignment with a Systems Engineering Approach

Development of technology, products and systems of a complex nature such as CPS should be done and governed in accordance with recognised international standards and methodologies so as to avoid the pitfalls that is so common when not using such approaches. The Systems Engineering approach and standards have originated from the failures of many projects challenged with complex solutions/systems development.

A fundamental shortcoming of the specification guidelines with reference to a Systems Engineering approach is that they do not give any guidance as to **system development ownership**. Clear system development ownership is the starting point of the application of Systems Engineering. The system development owner is accountable for system concepts, system specification, system verification and validation. The system development owner is the **single** entity of accountability that the **end user** engages with.

The systems engineering approach follows a rigorous methodology for user requirements, system definition, system breakdown, verification and validation and the like. In the absence of a system development owner and a systems engineering approach, the purpose and scope of the existing guidelines are vague and ambiguous, system requirements are intermingled with user requirements and sub-system requirements, making a structured technology and product development effort very difficult.

A standard such as ISO/IEC/IEEE 15288:2015 as a basis for the development of CPS requirements specification guidelines was seemingly not followed by the developers of the guidelines.

If followed it would have highlighted the holistic nature of the development challenge and would have ensured that Life Cycle System Elements such as manufacturing, installation and commissioning as well as operational support were specifically identified as elements of a CPS Life Cycle System.

These elements, all forming a complete ecosystem, are required to successfully introduce CPS into the RSA mining industry within a specific timeframe.

Using a Systems Engineering approach would identify the sub systems/elements of the CPS Product System and structured requirements such that the relevant system requirements are allocated to the relevant element/sub system. This facilitates clear accountability for the different elements of the life cycle and the product system.

Requirements specification practices such as MIL-STD-490B have been developed to ensure unambiguous requirements that are quantifiable, can be verified, validated and demonstrated. A significant number of the requirements in the guideline are ambiguous and do not have nominal criteria with acceptance limits. Many however have been included in the test documentation.

It is proposed that, to the extent that it is practical, the principles and approaches of ISO/IEC/IEEE 15288:2015 are used for the definition of User Requirements as well as CPS Product Specifications.

The following System definition is proposed for the CPS Life Cycle System.

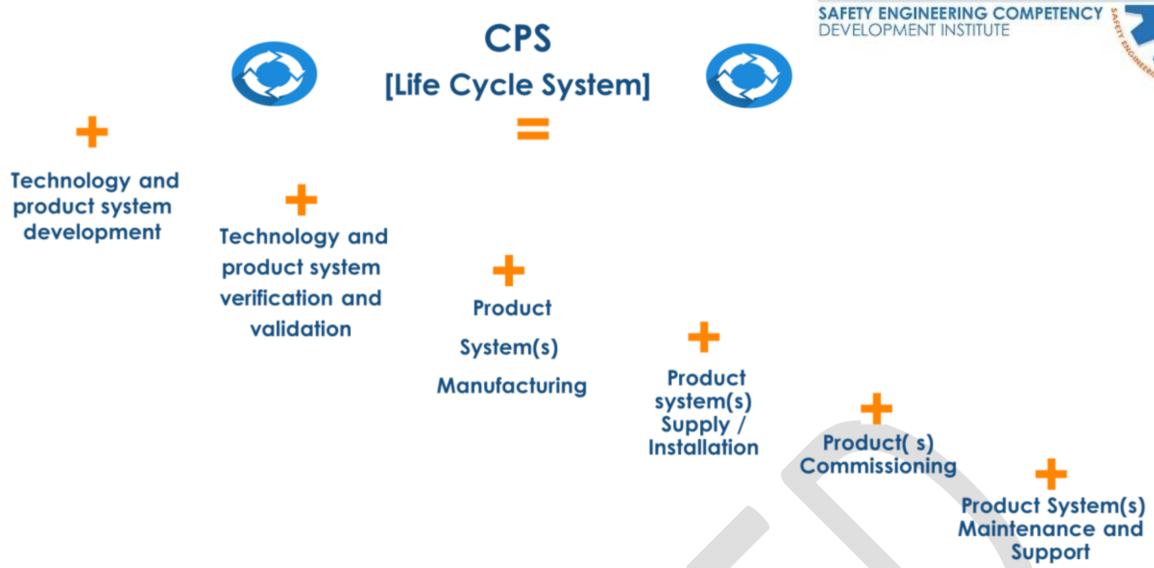

Figure 3: Proposed CPS Life Cycle System

The current specification guidelines do not address the CPS Life Cycle System at all and resultantly also do not identify the Life Cycle System development owner. The Minerals Council South Africa via its **INDUSTRY ALIGNMENT ON TMM REGULATIONS SPECIAL PROJECT** is the de facto CPS Life Cycle System development owner/facilitator. Whilst a third-party owner is not unusual, that organisation must be correctly enabled to successfully execute the role.

The existing specification guidelines also do not define the **CPS product system** or who owns it explicitly. Using a coal fired electricity power station as an analogy to explain the concept, the completed physical infrastructure with its supporting information constitutes the "Power Plant System". The "System" comprises elements/major sub systems such as the "Switch Yard" the Power Generation Units, the Cooling System, the Mills, the conveyor system etc. Normally an Engineering, Procurement and Construction Management Company **(EPCM)** is contracted as the Power Plant System provider to the Utility Company that is the owner/end user. A power plant's sub -systems and units in themselves are "systems" all logically comprising of physical and functional entities that are provided by multiple product and service providers. The EPCM is the "system development owner and integrator" until it is formally handed over to the Utility.

For systems that are products and not plants or facilities the same principles apply, and the review team proposes the following system definition for the CPS **Product** System.

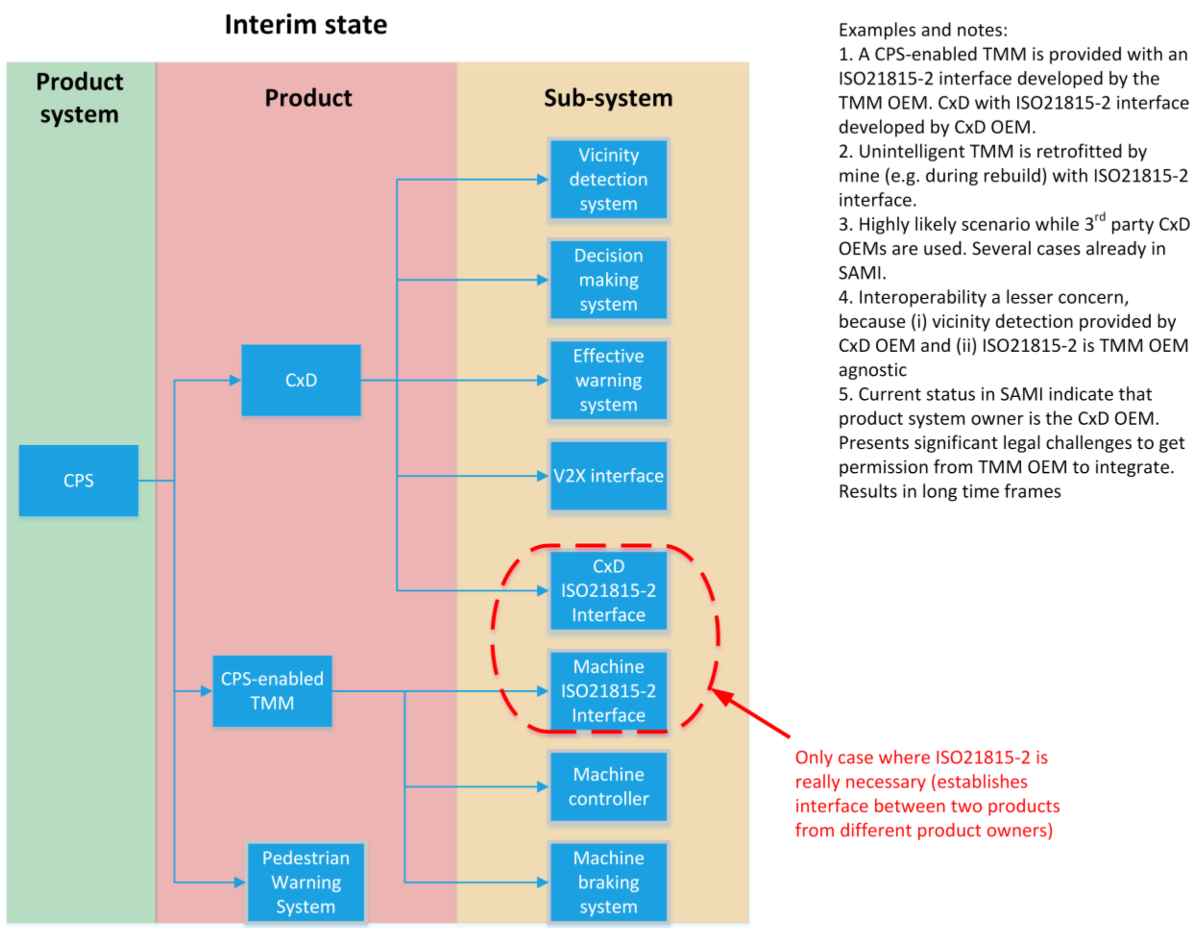

Figure 4: Proposed CPS Life Product System (Interim State)

The CPS product system shown in fig 4 represents the reality of most the surface solutions. There are variations of the system breakdown for legacy equipment as well as for the final state when CPS are incorporated into TMMs by TMM OEMs.

As mentioned in the existing CPS technology and product development initiative there isn't an EPCM equivalent. Up to now every mine was expected to fulfil the role of the User and the EPCM, something very few mines/mining groups are capacitated to do. The Minerals Council **INDUSTRY ALIGNMENT ON TMM REGULATIONS SPECIAL PROJECT** is the closest "entity" to be an Engineering (E) facilitator of the equivalent of an EPCM. Third party product system owners/developers are not uncommon. However, to fulfil such a role the organisation must be correctly capacitated.

Senior representatives from mines and mining companies (CM&EE members) have long argued that TMMs should be supplied with integrated CPS product systems. In the draft TMM CPS regulations, 2019 was proposed as the year from which all TMMs supplied to mines in the RSA must be CPS product ready. With the regulations being promulgated without **all** the clauses this fell by the wayside. Considering the ICMM's ICSV VI initiative that has definitive involvement of TMM OEMs, the allocation of the TMM OEM as the CPS Product System owner makes logical sense.

Besides the above practical motivations, the RSA MHS Act further places the accountability with the TMM OEM.

MHS Act Section 21. Manufacturer's and supplier's duty for health and safety.

The act states that:

(1) Any person who -

(a) ***designs, manufactures, repairs, imports or supplies any article*** *for use at a mine must ensure, as far as reasonably practicable*

(i) that the article is ***safe and without risk to health and safety*** *when used* ***properly****; and*

(ii) ***that it complies with all the requirements in terms of this Act****;*

From the above it is clear that a TMM OEM must supply a TMM that complies with the TMM regulations. It is therefore reasonable to expect that all TMM suppliers to the RSA mining industry are actively working towards complying with the above requirement.

Even with legacy equipment and the challenge of back fitting CPS it seems that TMM OEMs are the best suited to fulfil the role of CPS product development owner.

A real challenge for the project is that currently, in the absence of the TMM OEMs taking up their role as CPS owners, CxD providers are fulfilling the role of CPS owners. **This reality is resulting in very limited commitment by TMM OEMs that has a significant, negative effect on the pace of CPS product development.** It is recommended that the Minerals Council SA seriously considers who the CPS product development owner for this project must be and agree such with the respective organisations.

Requirements Structure

As reported before the existing specification guidelines do not distinguish and allocate specific requirements explicitly to sub systems/elements. Based on Systems Engineering practice the following requirements structure for the product system development is proposed:

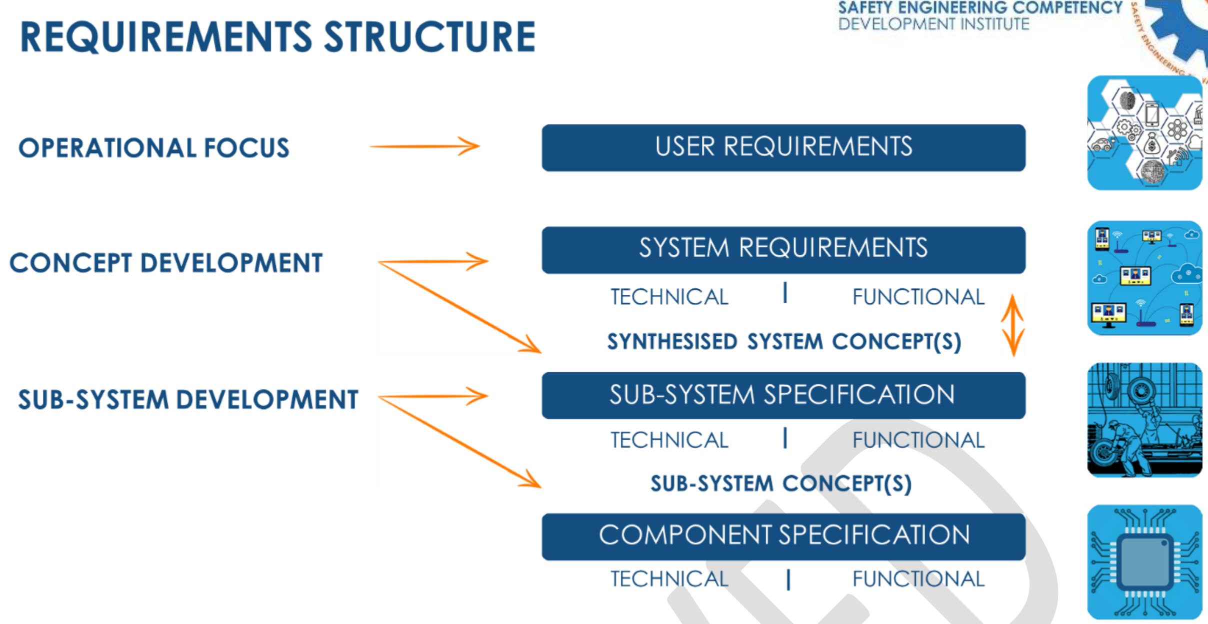

Figure 5: Proposed requirements structure

The extent to which it will be necessary to specify sub system components will only be determined during the specification process. In principle as little as possible component specifications should be dictated by end users in order to allow for the maximum degree of design freedom.

12. User requirements

The specification guidelines do not include a complete set of user requirements. The review team are aware of a document titled **"User Requirements for Collision Management Systems" Rev A.3.** The document is dated September 2017 and has the same structure and content as the CMS Technical Specification Guidelines. The document does not comply with the standard of a user requirements specification as per systems engineer practice.

Clear operational scenarios and the associated user requirements for CPS products to comply with are key elements of the successful introduction of CPS on a large scale.

The following example demonstrates the point. Typical haul roads widths range from around 8 meters to 40m on surface mines. In some cases, on smaller mines (quarries) a haul road can be 7 m wide. If a user requirement that states this range and the range of vehicles that uses these haul roads are not explicitly defined, CPS providers will not have clear functional requirements for the zone characteristics needed to ensure uninterrupted normal operation.

Where a CPS provider choses standard GPS technology as the basis for its CPS the detection inaccuracy/variance of +- 8m is too big to ensure that two haul trucks will always be allowed to pass each other on a haul road.

In underground mining this is even more important. Interaction distances are extremely confined and involve multiple close proximity interactions on a continuous basis as part of normal operation. CPS zone sizes that are determined by specific TMM functions and production processes are critical for developing CPS products that supports mine production and sustainability.

As part of the review the team performed a user identification analysis in order to identify the specific user profile based on the type of mining done. The analysis is shown in figure 6. The diagram is attached as a separate **Pdf file** to enable readability. The analysis revealed a number of mining types that are currently not included in the scope of the CAS Readiness Project. It is important that the Minerals Council consider the outcome and decide if any changes to the current scope is needed.

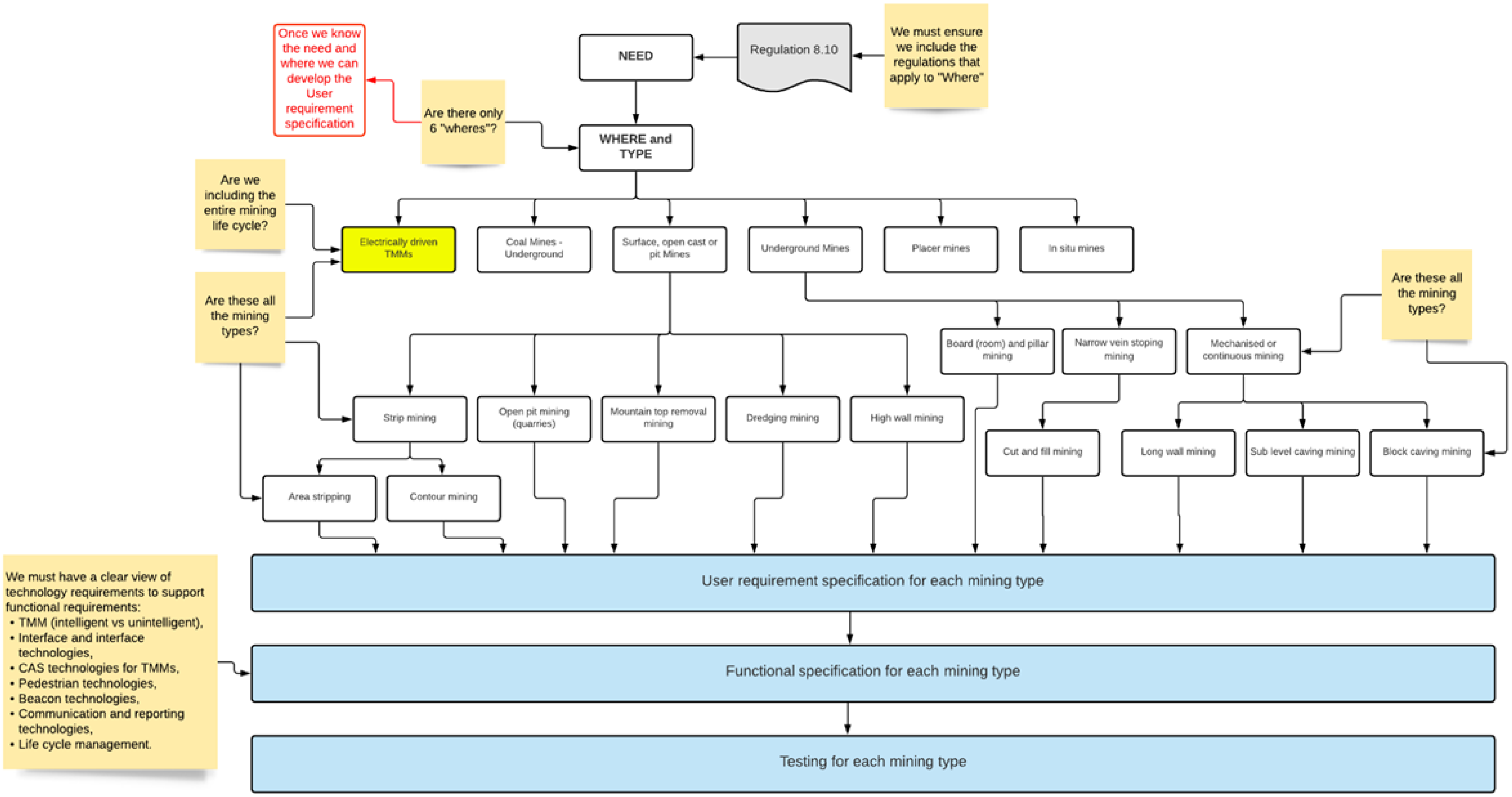

Figure 6: "Users" analysis diagram

The current contracted scope of work addresses diesel TMM only for open cast/open pit as well underground. Based on the outcomes from the holistic risk assessment this gap should be considered by the Minerals Council South Africa.

13. Other relevant TMM Regulations

With reference to Figure 2 and the regulatory analysis done, a number of CPS related regulations have been identified that might have an impact on the CPS development and the development of the CPS might likewise have an impact on the way that mines deal with these regulations. Considering only the CPS specific TMM regulations may result in conflicting and non-integrated user requirements.

The specific regulatory aspects identified are: Towing and recovery of TMMs, Restricted operator visibility, TMM running uncontrolled, Overturning of TMMs, Braking systems, Fatigue, Battery replacement, Refuelling, Unauthorised access, Isolation LOTO, Operating procedures, Maintenance of TMMs, Remote controlled TMMs, Training and Pre-use inspections.

It was therefore considered prudent to do a TMM regulatory analysis in order to identify any GAPs or opportunities that may exist.

14. Detail review: Surface Mobile Equipment Specification Guideline

The detail review comments are shown in the separate document with file name: 1812Dec20 CMS Technical Specification Guideline - SME (rev A.6.1.17) Reviewed. Revision B1.7 was later received and briefly verified for changes. In terms of the level of review done the changes were insignificant, however the latest revisions will be used in the remainder of the work.

15. Detail review Underground Mobile Equipment Specification Guideline

The detail review comments are contained in the separate document with file name: 1812Dec20 CMS Technical Specification Guideline - UME (rev A.6.1.17) TerreSauver review 15 May 2021. Revision B1.7 was later received and briefly verified for changes. In terms of the level of review done the changes were insignificant, however the latest revisions will be used in the remainder of the work

16. CMS Test Evaluation Guideline(s)

Although the primary focus of the review was the CMS Technical Specification Guidelines the team decided to share high level review comment in the report, specifically from the experience of the University of Pretoria's team.

The CMS Technical Specification Guidelines are accompanied by CMS Test Evaluation Guidelines and associated test reporting spreadsheets. These test guidelines and spreadsheets were used by the University of Pretoria to conduct performance evaluations of CPS offerings available in the SAMI. The test guidelines and reporting spreadsheets are exclusively based on the CMS Testing Evaluation Guidelines performance requirements.

16.1 Strengths Weaknesses Opportunities and Threats

UP conducted a SWOT analysis as part of its work, to identify strengths that should be built on, weaknesses that should be addressed, opportunities to be realised and threats that should be managed. The results are shown in the table in fig 7.

	Helpful	Harmful
Internal origin	**Strengths** 1. Established test methodology 2. Scalable approach (gradually increasing risk) 3. Very extensive (thorough) testing 4. Tests complete CPS solution (at product & product-system level) 5. More comprehensive than just the ZA legislation – can give an indication of performance for other, non-legislated opportunities (such as LoC, voids, obstacles, etc.)	**Weaknesses** 1. Focus on CMS Test Evaluation Guidelines scenarios, not focussed on ZA legislation, this includes requirement for L7, L8 & L9 2. Requires very expensive, high precision equipment for measurement 3. UG measurement equipment not ready for commercialisation 4. Labour intensive requiring highly technical personnel 5. Ambiguous pass/fail criteria – requirements not specified 6. Unclear connection between test configurations and scenarios 7. Sheer volume of testing required 8. Does not highlight technical reason for failure 9. Several gaps in evaluation, notably: o Multiple interactors o Interactions between different types of TMMs 10. Complicated reporting spreadsheet 11. Ignores remote object behaviour 12. Ignores number of objects CPS limitation (included in MOSH, not tested) 13. Pass/fail criteria not standardised 14. Tests not representative due to uncontrollable factors, such as operating conditions, operator delays, etc. 15. Tests are oversimplified, not representative of mining environment & mining machines 16. EMC testing not done 17. Lab-scale and single-machine tests do not consider false positive tests, focuses on false negatives (effective warning criteria not considered)

	Opportunities	Threats
External origin	1. Establishes a good baseline, can develop an improved approach without redefining the wheel 2. Reducing the number of test configurations to those required by ZA legislation (e.g.): 3. Establishment of unambiguous test specifications 4. Existing scenarios not included in ZA legislation can be tested as ‘Other opportunities’ o Loss of control o No-go area/void o Obstacles/infrastructure o Enforcing TMP 5. Apply a systems engineering approach to specifications	1. International standard that differs significantly from ZA approach is introduced 2. Non-adoption of new and improved approach (of this project) 3. New approach so complicated that nobody can meet the requirements 4. Weaknesses pointed out invalidate any tests conducted to date 5. Grandfather clause for systems already tested according to old approach (how to handle?)

Figure 7 Test evaluation SWOT outcomes

16.2 Alignment between CMS Test Evaluation Guidelines and South African Mine Health and Safety Act requirements

The current CMS Testing Evaluation guidelines are exclusively based on the CMS Test Evaluation Guidelines scenarios. It links the CMS Test Evaluation Guideline’s scenarios to test configurations that are then used to evaluate CPS performance. The CMS Test Evaluation Guideline’s scenarios are more extensive than the requirements of the TMM regulatory requirements (as mentioned earlier in this report).

The table in figure 8 compares the CMS Test Evaluation Guidelines scenarios with the minimum requirements of the TMM regulations. Note that, if a CMS Test Evaluation Guidelines scenario is not explicitly required by the TMM regulations, it may still be specified by a mine/mining house if it considers such functionality to be a reasonably practicable measure (RPM) to prevent injuries to persons.

Green areas in the table indicate where the TMM regulatory requirements and the CMS Test Evaluation Guidelines scenarios align. Unshaded areas indicate that CPS is not required for those scenarios.

Class	CMS Test Evaluation Guidelines scenario	Scenario description	UG mining requirement (and clause in Act)	Surface mining requirement (and clause in Act)
Vehicle to pedestrian	P1-Person (direct)	Person on foot (RO) in immediate vicinity around machine (LO)	CPS required 8.10.1.2(a) & (b)	RPM required 8.10.1
	P3-Person (indirect)	Person on foot that is a bystander in an interaction between machines and/or infrastructure	CPS required 8.10.1.2(a) & (b)	RPM required 8.10.1
	P4-Access and Egress	Person getting on or off stationary machine	CPS required 8.10.1.2(a), (b), 8.10.6 & 8.10.13	RPM required 8.10.1, 8.10.6 & 8.10.13

Vehicle to vehicle	L1-Head-on	RO directly in the path of a LO moving (or intending to move) forward	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	L2-Backup	RO directly behind a LO moving (or intending to move) in reverse	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	L3-Reverse-on	Two machines (LO and RO) reversing towards each other	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	L4-Dovetailing	LO following a RO with both moving in the forward direction	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	L5-Passing Head-on	Two machines (LO and RO) passing each other in opposite directions with both moving forward	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	L6-Passing Reverse-on	Two machines oriented in same direction with the forward-moving LO passing a stationary or reversing RO	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	L7-Overtaking	LO pulling out and overtaking a RO with both moving forward	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	L8-Blind approach	Forward-moving LO with limited or no visibility approaching a stationary or moving RO (blinded or obstructed)	RPM required 8.10.2 & 8.10.8	CPS required 8.10.1.2(a),(b) & 8.10.8
	C1-Curving Head-on	Two machines (LO and RO) approaching in opposite directions around a bend with both moving forward	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	C2-Curving Dovetail	Two machines (LO and RO) following each other around a bend with both moving forward	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	C3-Curving Reverse-on	LO approaching a stationary or reversing RO around a bend	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	T1-Merge	LO approaching a merge intersection with a RO travelling straight- through	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	T2-Crossover	LO intending to turn across path of oncoming RO	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	T3-Junction	LO approaching an tee intersection with RO travelling straight- through	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
	T4-Intersection	LO approaching a ~90 degree four-way intersection with RO travelling straight-through	RPM required 8.10.2	CPS required 8.10.1.2(a) & (b)
Others	R1-Swing	Machine with rotating body (LO) operating with another machine (RO) near-by – e.g. shovel-truck	RPM required 8.10.1 & 8.10.2	RPM required 8.10.1 & 8.10.2
	R2-Drop	Machine with elevated load (LO) transferring material to another machine (RO)	RPM required 8.10.1 & 8.10.2	RPM required 8.10.1 & 8.10.2

	O1-Obstacle	Machine (LO) approaching a fixed object (RO) – e.g. high-wall, foot-wall, hanging-wall, infrastructure	RPM required 8.10.1 & 8.10.2	RPM required 8.10.1 & 8.10.2
	V1-Void	Machine (LO) entering a no-go area (RO) - e.g. road or tip edge, limited clearance, soft barrier, electrical cable	RPM required 8.10.25	RPM required 8.10.25
	V4-Loss of Control	Operator not in control of machine (LO) and none of the above scenarios apply (P1,P3,L1-8,C1-3,T1-3,O1,R1-2,V1)	RPM required 8.10.3	RPM required 8.10.3
	V6-Congested Area	Machine (LO) operating with multiple (more than 2) other machines in close proximity – e.g. workshop area, LV/HV parking area	RPM required 8.10.2	CPS required 8.10.1.2(a) & 8.10.1.2(b)

Figure 8 TMM regulations vs CMS Test Evaluation Guidelines

As can be seen from the table there is a significant misalignment between the CMS Test Evaluation Guideline and the MHS Act TMM regulations. The implication of this is that less testing is required for compliance with the TMM regulations, but the current test regime and protocols need to be realigned with the TMM regulations.

The evaluation procedure follows a stage gate approach; CPSs have to demonstrate acceptable performance at each stage gate before they are allowed to proceed to the next. The University of Pretoria developed test equipment and a test procedure to independently assess a CPS solution's maturity. This needs to be realigned with any additional/different criteria that will be defined as part of Work Package 8 of the CAS Readiness Project.

The CMS Test Evaluation Guidelines and resulting procedures do have some technical shortcomings/gaps that need addressing. A gap analysis of the existing evaluation procedure was conducted.

16.3 CMS Test Evaluation Guidelines gap analysis

The test procedures followed by the University of Pretoria (UP) was based on the CMS Test Evaluation Guidelines.

The aim of the test evaluation was to determine the logical progression of a CPS technology maturity; the aim was not to fault find or debug CPSs. Lab-scale tests were conducted with light vehicles in controlled environments to provide a margin of safety during the early stages of CPS performance evaluation.

Crucial in any testing is the measurement capability against which pass/fail criteria are determined. The UP tests are supported by high-precision global navigation satellite systems (GNSS, colloquially known as a GPS) with a stated absolute measurement accuracy of 20mm. This resulted in the lab-scale testing done on surface and not underground for underground CPSs.

Single-machine test were conducted with TMMs, in controlled environments on mining sites (or representative sites), however in simplified operating conditions. As a result, the tests could not guarantee that a CPS would work in any and all mining environments. That given, these tests come at a fractional opportunity cost of testing in real operating environments and failure to pass the simplified tests means that a CPS would also not work in operational mining environments.

As part of the work to establish a test regime and plan for TMM regulatory compliance, a more detailed analysis is done to further identify gaps. The outcomes of that will be reported extensively in that deliverable.

The impact of the specifications that will be developed to ensure interoperability, EMI and all the zone functionalities as well as effective warning will also be determined as part of that work.

From an underground perspective the current CMS Test Evaluation Guideline does not make allowance for mine specific operating scenario-based user and functional requirements and related testing requirements. It also does not have clear acceptance criteria for testing of vehicles in their loaded and unloaded states, with or without articulation. The cost of testing at each specific mine will be very costly and time consuming especially if multiple suppliers are to be evaluated.

Currently, there is market confusion with regard to the requirements of the TMM regulations and the CMS Test Evaluation Guidelines. This leads to some mines requiring different functionality for their CPS than others and suppliers are subjected to multiple, often conflicting requirements.

17. Conclusion and Recommendation

The review team acknowledges that the analysis, interpretations and observations as reported are the result of its collective exposure, knowledge and insights. The team therefore recommends that the report be thoroughly reviewed to ensure full alignment of key role players.