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The Minerals Council South Africa: Understanding the potential unintended consequences on operators within the context of the South African Mining Industry's introduction of Collision Prevention Technology

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1. Executive summary

1.1. The project objectives

- The Mine Health and Safety Act (MHSA) 1996 has stipulated important standards to be achieved for the safe utilisation of Trackless Mobile Machinery (TMM), including the use of Collision Prevention Systems (CPS) of TMM for safe operations.
- This project seeks to investigate the negative/unintended effects (if any), on the physical and mental state of an Operator of a diesel-powered vehicle, when the vehicle automatically slows down and stops without the Operator's intervention on an ongoing basis. The aim is for the industry to prepare adequate change management to mitigate against any detrimental effects that may be introduced by CPS to the Operator when the Regulator lifts the suspension on the said regulations. The study may also necessitate the need to generate training material that contains some of the key lessons learnt to create an awareness for TMM operators.
- In particular, this study will take a behavioural based approach that looks at:
  - Potential physical injury introduced by emergency stopping technology.
  - Potential negative psychological effects due to the knowledge of the presence of automatic intervention by the TMM in emergency situations.

1.2. Project Scope

The scope of this project is to:

- Collate relevant information from all stakeholders and role-players to define and risk analyse the introduction of the emergency stopping technology.
- Facilitate discussions amongst role-players and stakeholders of how risks may be mitigated.
- Conduct a human factors engineering study including but not limited to the make-or break issues on the introduction of the emergency stopping technology.
- Document potential controls and create a change management framework/guideline for sharing with mines in the South African mining industry (SAMI) for consideration when introducing CPS.
- Identify possible training and training material generation that may be necessitated by the study.

1.3. Key findings

- *Unintended consequences* is defined as the "outcome of purposive actions that are not intended or foreseen." These consequences can fall within three groups:
    - Positive – usually referred to as luck, serendipity, or a windfall.
    - Negative - an unexpected result occurring in addition to the desired benefit.
    - Perverse - a contrary effect to what was originally intended, e.g., makes a problem worse.
- Few studies have looked, specifically, at the unintended consequences of CPS implementation. Literature that does reference these consequences within the context of mining automation (incl. CPS) has been done predominantly in the Australian mining industry. While this is of value for the purposes of this study, it does provide a comprehensive understanding of the issue within the South African mining industry due to a multitude of unique human factors that face South African mines.
- A broad range of potential unintended consequences exist and can be classified under the 6 human factor themes: Psychological, Cognitive and Sensory (Internal Human Factors); Physical, Procedural and Socio-Cultural (External Human Factors).
- The likelihood of an unintended consequence being realised during the implementation of CPS is largely dependent on a variety of contextual factors.
- The following contextual factors have a significant influence on the impact of potential unintended consequences: Culture and Leadership, Change and Communications, Reward and Remuneration, Behavioural Characteristics, Skills and Training, Organisational Design, Financial Health, Quality of the Technology, and Environment.
- The following provides brief insight into some of the key unintended consequences, a more comprehensive list and description can be found in *section 4:*
    - Loss of trust
    - Reduction in job stress due to perception of increased safety for operator and pedestrians
    - Loss of situational awareness
    - Over-reliance on the technology
    - Operator alarm fatigue
    - Injuries or physical discomfort due to the force of the braking system
    - Peer enforced accountability
    - Increase in overall safety culture
    - Assumption of risk mitigation

- This study identified the physical and psychological unintended consequences on TMM operators, to ensure the effective mitigation of these potential outcomes requires effective change management.

- Change management is distinct from the management of change as it deals specifically with the people-side of change. A change management blueprint, developed by the *Mandela Mining Precinct* specifically for the purposes of the implementation of modern technologies, has been included to support mining operations with their implementation processes. This is a comprehensive framework that includes supporting tools and guides.

1.4. Implications for mining houses yet to implement CPS

- Any technological change or enhancement is likely to impact its users in positive and negative ways.
- It is imperative that the leadership of a mining operation systematically consider the potential outcomes of implementing a technology such as CPS.
- The findings in this report provide leaders with the likely scenarios as well as a framework to consider other unintended consequences.
- Mining operations should do their own risk analysis to determine the likelihood of these outcomes occurring due to the unique context in which each mine operates within.
- Overall, no change should be viewed in isolation from the broader system or environment. Therefore, leaders should ensure that they understand the systemic nature of change and especially the impact on the end user as this is a key step in realising the intended benefits of the change and potentially other positive unintended outcomes.

2. Background and context

Trackless mobile machinery (TMM) regulations were promulgated under notice N.R. 125 in the Government Gazette, on the 27th of February 2015. The TMM Regulations form part of chapter 8 of the regulations made under the Mine Health and Safety Act, 1996 (Act No. 29 of 1996, as amended) (MHSA). The regulations came into operation three (3) months after the date of publication in the Government Gazette, except for sub-regulations 8.10.1.2 (b) and 8.10.2.1 (b), which deal with the automatic slowing down and stopping of diesel-powered TMM.

Notably, proximity detection and warning systems (PDS) have been widely installed in the industry, however, there remains a challenge with finding suitable collision prevention systems (CPS) for diesel-powered TMM. The Minerals Council South Africa remains committed to the vision of Zero Harm and is currently investigating the potential impact and opportunities presented whilst taking a risk-informed, phased approach towards the introduction of the suspended regulations which will not only save lives but also save livelihoods, and possibly create new livelihoods. For this reason, the CEO Zero Harm Forum has approved a dual strategy of advocacy and continued investment in assisting members in the adoption of this complex technology.

The project has both a technology and operational readiness focus with very specific outcomes and milestones that need to be achieved. Over and above the application of physical controls to reduce the risk of TMM collision wherein persons may be injured, mines where the risk of collision remains significant are in the process of deploying CPS as a last measure to prevent such collisions. A particular challenge on the introduction of such technology is what unintended consequences it may present to TMM Operators from a physical, psychological, or other point of view.

2.1. Intended Outcomes for the Work

This project seeks to investigate the positive and negative unintended effects (if any), on the physical and mental state of an Operator of a diesel-powered vehicle, when the vehicle automatically slows down and stops without the Operator's intervention on an ongoing basis. The aim is for the industry to prepare adequate change management to mitigate against any detrimental effects that may be introduced by CPS to the Operator when the Regulator lifts the suspension on the said regulations. The study may also necessitate the need to generate training material that contains some of the key lessons learnt to create an awareness for TMM operators.

In particular, this study will take a behavioural based approach that looks at:

- Potential physical injury introduced by emergency stopping technology.
- Potential negative and positive psychological effects due to the knowledge of the presence of automatic intervention by the TMM in emergency situations.

The overall aim of this project is to prepare mines with the required knowledge, tools and frameworks to identify and mitigate against any detrimental effects as well as to leverage any positive effects that may be introduced by CPS.

3. Approach and Ground Covered

This section provides a detailed overview of the methodical approach followed throughout the course of the project. It further illustrates the complete approach as to how the data was gathered.

3.1. Project Approach and Timelines

With a specific focus on the unintended consequences of implementing Level 9 CPS devices onto TMM equipment, the approach is detailed and methodical, whilst also allowing the flexibility to learn and adapt.

3.2. Data Gathering Approach

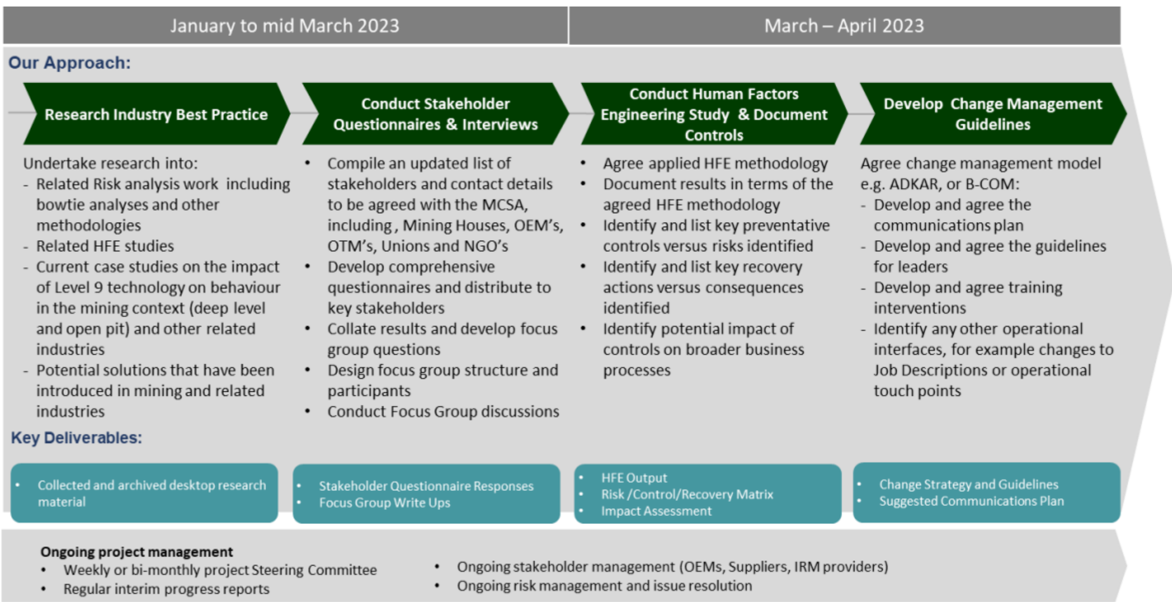

Figure 1 - Data Gathering Approach

Due to the significant number of Subject Matter Experts (SMEs) the project team needed to engage with, the variety of information that needed to be gathered and the challenge experienced by the project team to secure meetings and responses to requests for information, the following multipronged approach was used when collecting the required data:

1. **Interviews** - Semi-structured interviews were conducted via *MS Teams, Google Meets* or *Zoom* with various stakeholders from the relevant Original Technology Manufacturers (OTMs), Original Equipment Manufacturers (OEMs) and mining houses. The approach was to ensure the project team conducted interviews with SMEs from the major OTMs, OEMs and mining houses. In addition, selected mining houses made certain of their affected employee groupings available, most particularly:

a. Operators
b. Pedestrians
c. Supervisors
d. Organised Labour Representatives
e. Safety Officers
f. Senior Management

2. **Online questionnaires** - Online questionnaires were developed using *Google Forms* to assist with the gathering of the required information and were sent to a group of OTMs, OEMs and Mining Houses. This approach was also used to secure information from SMEs that the project team were not able to secure an interview with.

3. **Desktop Research** - To gather and validate the required information to support this study, desktop research was conducted by the project team using on-line resources as well as informal discussions with stakeholders within the industry.

The following table (Figure 2) shows the response rate of OTMs, OEMs, Mining Houses and other stakeholders that contributed to the findings detailed in this report, either through online interviews, the completion of an online questionnaire or focus groups.

Organisation Type	Type of engagements	% response
Mining House	Interviews	62,5%
OTM	Interviews	38%
OEM	Interviews	0%
OTM	Online Questionnaire	10%
OEMs	Online Questionnaire	0%
Other (e.g., Academic institutions, consultants, etc.)	Online Questionnaire	75%

Figure 2 – Participant Response Rate

4. Literature Review

SETTING THE STAGE

The question that became clear was whether the findings from the interviews and questionnaires were going to validate what was apparent from the literature on the subject. The approach when gathering the data from literature was to establish the stage for the findings to be presented; whether that meant that the interviews/questionnaires provided data that either refuted or supported what had been previously reported.

To begin with, an understanding of automation was key as well as how to define the concept of unintended consequences particularly as how it relates to automation using a human factors engineering approach. This approach allowed for a broader understanding of unintended consequences of automation before homing in on the unintended consequences of CPS in TMMs in mining.

The key part at the beginning of this research was to understand what models and definitions exist relating to this study and using that to inform the model used in categorising the data below. Most importantly for this research is that it is focussed on the South African mining context, which unlike other countries where CPS has been implemented, is plagued by issues/factors that are unique to each mine and surrounding communities. This is not to say that the information and data that has been gleamed from sources focussing on mining beyond South Africa's borders is not relevant. The requirements for developing mitigating factors for these unintended consequences are such that it considers the diverse social and cultural landscapes of South Africa. Thus, the solutions presented by a paper based on an Australian mining context needs to be seen as less compatible, whilst still providing some key insights that are useful.

Perhaps a key finding to come out of the literature on the subject was a baseline. This allows the findings from questionnaires and interviews to be placed within a greater global context, while still allowing for all the nuances that exist in the South African mining environment.

SETTING THE STAGE: DEFINING KEY TERMS

Unintended Consequences

Unintended consequences replaced the concept of unanticipated consequences which was popularised by Robert Merton, an American sociologist, in 1936. It is defined as the "outcome of purposive action that are not intended or foreseen." These consequences can fall within three groups (Link):

> "Positive – usually referred to as luck, serendipity, or a windfall Negative - an unexpected result occurring in addition to the desired benefit, ex.

> Perverse - a contrary effect to what was originally intended, ex. makes a problem worse, ex.”

Having this understanding of the groupings allows for better classification of the unintended consequences of CPS in TMMs. In this study, it is not as simple as determining whether an action has a positive, negative, or perverse consequence, but mitigating factors and/or solutions need to be able to be developed and this requires further information.

Human Factors Engineering

As this study’s focus is on the psychological and physiological unintended consequences of CPS in TMMs, understanding these consequences through a lens focussed on human factors is paramount.

Human factors engineering is a discipline concerned with the design of tools, machines and systems that consider human capabilities, limitations, and characteristics. Its goals are to design for safe, comfortable, and effective human use. This is key with the advent of automation, as for humans, the nature of work has changed and will continue to do so.

The purpose of this joint approach of looking at the unintended consequences of CPS in TMMs through a human factors lens is to effectively assess where areas of concern need to be addressed and how to address them.

Automation and Mining

Automation has largely been hailed as an enemy of workers. Many activities that are needed to perform tasks in production have been moved from the control of humans to being automated. The reasons for this switch range from the removal of human error to efficiency and the prevention of workplace accidents. To a plant or factory worker, this could bring about concerns about job security among others. To a large extent, there is evidence showing that the switch to automation leads to job cuts, and with production being the main concern of many businesses, it comes at the cost of jobs. This tends to be the case in many industries, including mining, but is less so in South Africa. The introduction of automation through safety tech on machinery and TMMs represents a different motivation other than production.

One can posit that the goal of safety on the mines is the real motivation and perhaps to some degree this is true. During discussions with various key stakeholders, the goal of safety appeared to not be universally shared on the mines. From these discussions it seemed that production was the main goal, at least from a top-down view. This point will be expanded further on later.

Automation is defined as the removal/reduction of human input in the operation of a task. In the case of this study, automation takes the level 7 early detection safety systems used on TMMs and adds in an intervention, i.e., automated emergency braking, changing it to a level 9 safety system, if the Operator does not respond to the early warning (Level 8) .

Safety and Elimination of Risks – Hierarchy of controls

In all work environments, workers' safety is paramount, especially in hazardous work environments such as mines, the safety of all personnel should not be minimised. Using the Hierarchy of Controls, the exposure to the risks and hazards that are present in a hazardous working environment can be controlled. There are five levels of control which are ranked from most effective to least effective as per below shown in *Figure 3.*

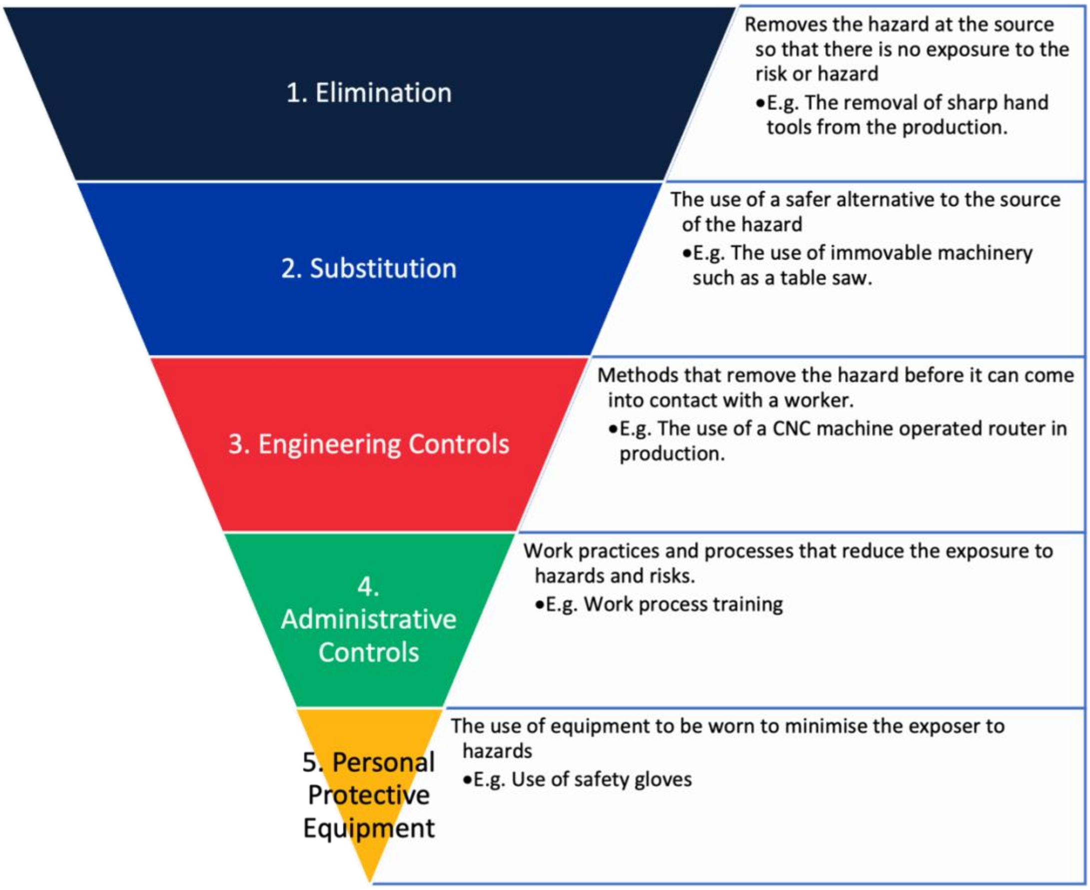

Figure 3 – Hierarchy of Controls

It is difficult to implement the first two levels of control into existing processes effectively. These stages are best implemented at the development stage of processes and when implementing new equipment and procedures. This is then a more proactive level of control when dealing with risks and hazards.

On mines, as the hazards and risks can be fatal, the use of the correct controls are vital. The use of CPS in TMMs on mines as well as the adequate training would fall within Levels 3 and 4 in the hierarchy of controls. The purpose of CPS is to go one step further than providing a collision warning. It is also to provide an intervention in the case where the human operator's reactions may not suffice, essentially removing the human factor and having the system brake automatically.

Specifically, level 7 systems on mines were introduced as an engineering control that required human intervention and level 9 is a progression of that, removing human control in the event of a potential collision.

BEYOND THIS STUDY - FROM GLOBAL TO LOCAL

Having defined the key terms and developing a fundamental understanding of the subject, a view into previous work done on automation and mining is required. Furthermore, a view into work done on the unintended consequences of automation in mining, with a focus on CPS, is what is key. Whilst occupying its own niche, it may seem as though there may be very little literature, however the issue of safety on mines is not only a concern held by the South African mining community. Although the motivation for the use of safety tech is different beyond South Africa's borders, the lessons learned should not be ignored. Although this may contradict what has been said earlier in this study, it is key to remember that the lessons can still be applied whilst applying them for a South African mining context.

The work that has been done on the subject beyond South Africa's borders has led to several subject matter experts. Two who have written substantially on the subject are Tim Horberry and Robin Burgess-Limerick. Whilst they may not focus specifically on the unintended consequences of CPS in TMMs on mines, they do deal with the design and use of machinery on mines from a human centred design focus. The outcomes of their work have unintentionally (pun intended) yielded some unintended consequences of automation on mines. Bear in mind that their field of view is of the Australian mining industry, thus the importance of the distinction between the different mining contexts. Perhaps it would be best to place the South African mining context within the cultural landscapes it exists in to understand why this distinction is important. Globally, the introduction of CPS is largely linked to the high rate of collisions between mining vehicles, however in South Africa, and more importantly, in this study, it is more prudent to focus on the rate of incidents that involve pedestrians.

With the use of collision prevention systems on mines in Australia, the motivation to implement an Radio Frequency Identification (RFID) tag system was to monitor production, the positive consequence of this action was an easier gateway to implement systems that would ultimately reduce the risk of collisions between vehicles.

South Africa has a rich mining history. It is one of the countries with the richest mineral deposits, from gold to diamonds to coal and everything in between, South Africa's economy would not exist as it does today without the mining industry. The mining industry has also helped shape the cultural landscape of South Africa. The main economic hub of South Africa and arguably, Africa, sits on old gold mines, aptly nicknamed the Egoli, the city of gold, Johannesburg arguably would not exist as it does without mining. Mining in South Africa forms a significant part of the national GDP, where in 2008, the mining sector contributed 8%. Thus, even economically, mine safety is paramount to keep the industry operating. In South Africa the goal of mine safety is perhaps best assessed when looking at the objectives of mine mechanisation. This is shown below as per the extract from the paper "Human factors in mine mechanization.":

> The objectives of mine mechanization are varied, but typically include one or more of the following:
>
> - To improve safety performance by minimizing the number of people exposed to the most dangerous areas underground (which are typically at the mining faces)
> - To facilitate the achievement of workplace gender transformation and the accommodation of workers suffering from HIV, by using machines to perform more physically demanding work
> - To improve productivity (in terms of mass of mineral per employee)
> - To reduce direct mining costs by concentrating mining activities
> - To improve working conditions and the quality of work through the provision of more intellectually stimulating and satisfying work processes.

(T.S. HATTINGH, 2010)

This short view into the importance of the mining industry in South Africa does not even scratch the surface as to why the mining environment is so unique compared to those elsewhere.

Due to the need to comply with the regulations, the South African mining OTMs have been at the forefront of developing this technology. Due to South Africa often being classed as a third world country, one can often dismiss the technological prowess that exists within the borders. South Africa has been the inventors and pioneers of so many relevant medical and technological advances. The innovation therefore is taking place locally.

5. Findings

5.1. Human Factors Model

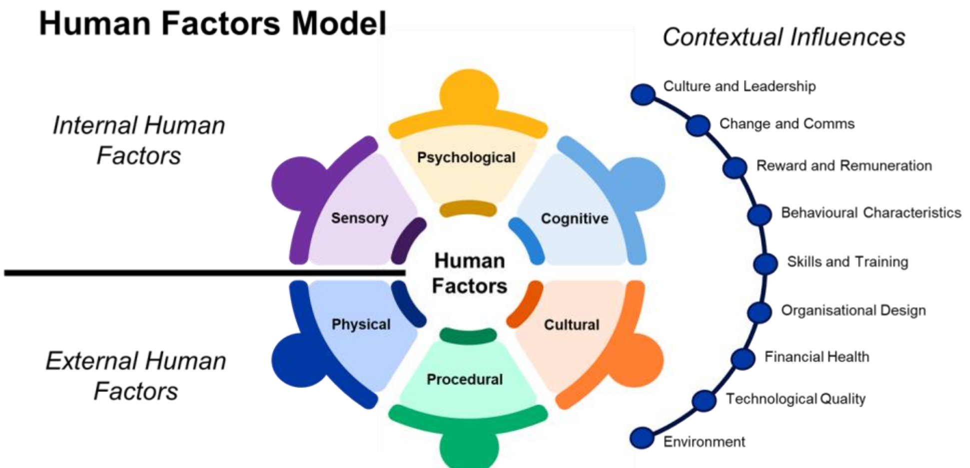

Figure 4 – Human Factors Model

The above diagram, (*figure 4*), outlines the elements of the Human Factors Model that was used to summarise the results of the research work. In broad terms the findings were categorised into Internal and External Human Factors. The Internal factors being further sub-categorised into Sensory, Psychological and Cognitive. The External factors sub-categorised into Physical, Procedural and Cultural. In addition, the Contextual Influences that impact on these factors were categorised as follows:

a. Culture and Leadership
b. Change and Communications
c. Reward and Remuneration
d. Behavioural Characteristics Skills and Training
e. Organisational Change
f. Financial Health
g. Technological Quality
h. Environment

5.2. Detailed Findings

This section outlines, in detail, a broad list of the potential unintended consequences uncovered from the research conducted, as described in Section 3 of this report.

While the list of unintended consequences is broad, it is unlikely that a mining operation that implements CPS on TMM will experience all these consequences. This is rather a list of potential risks or positive outcomes that may emerge depending on other contextual influencing factors. It is also likely that this is not a comprehensive list of unintended consequences. Given the contextual nature of how the implementation of CPS impacts an operational environment, operations may experience unintended consequences that were not uncovered during this research project - It is possible that the advancement of the technology or machinery may yield unintended consequences that have yet to be experienced.

Therefore, the intention of these outcomes is twofold: the first is to provide mining operations with a list of potential unintended consequences, based on previous lessons learned, so they can be prepared to mitigate or leverage. To support this, potential scenarios and mitigating factors have been provided for each unintended consequence. It is important to note that these mitigating factors serve as a general guide for mining operations. Mining operations must consider other suitable options, given their own unique circumstances, resources and capabilities that will have the most effective impact.

The second is to provide those responsible for implementing CPS with a framework that will enable them to consider potential immediate and future consequences. Therefore, enabling a proactive change and risk management mindset that will ensure they realise the highest possible positive impact of CPS and other technologies that may be implemented.

Finally, the list of unintended consequences below has been categorised into the six human factors as outlined in *figure 4.* As the list below is considered, it is important to consider the likelihood of unintended consequences being realised within a specific mining environment, as well as the effect one unintended consequence may have on another. This will ensure the effective use of resources in mitigating these outcomes.

5.2.1. Psychological

Definition

The psychological factor refers to the user’s emotional response towards the use of a system or technology. This is an important consideration as the strength and nature (positive or negative) of the emotion influences the likelihood of an individual behaving in a certain way.

For example, when we are faced with the introduction of automation into our roles, the user may have a positive emotional reaction as they perceive the new technology to enhance their direct working environment such as making them safer or productive. This positive emotional response is likely to increase the frequency and quality with which the job holder uses the technology. However, the counter is also true- an increase in negative feelings towards the technology is likely to lead to a flight (avoid the technology) or fight (abuse the technology) response.

Findings

Unintended Consequence	Description	Potential Outcome/Scenario	Mitigating Factors
Risk homeostasis	The introduction of CPS could lead to an increase in risk-related behaviours. This is in-line with the theory of risk homeostasis which posits that people aim to reduce the discrepancy between the current perceived risk and the amount of risk they are willing to take on. Therefore, people do not aim to minimise risk but rather optimise risk in order to realise the net potential benefit associated to that behaviour.	High risk homeostasis could lead to a decrease in operators adhering to traffic rules such as speed limits.	Effective communication regarding the actual consequences of increased risky behaviour. Enhance the true understanding of the net benefit.
Loss of role autonomy	The introduction of CPS impacts the users' feelings of autonomy over their role as they may now feel disempowered to make decisions.	Low role autonomy may lead to the following: ● Decrease in role engagement and discretionary effort. ● Sabotage of the system ● Breaking of rules to enhance imbalance of control over their role – potential increase in high-risk behaviour.	Effective change management and communication that enhances the understanding of why CPS has been installed. Inclusion of users throughout the implementation process; ensure their involvement in the decision-making process.
Loss of trust	People involved in the implementation	Sabotage of the system or hardware either through	Inclusion of users throughout the implementation

	of CPS reported that users do not initially trust the system as they feel that it is a tool that is used to "spy" on them or monitor their performance. Such feelings have led to the sabotage of the entire level 9 system. This also extends to how the data may be used such that managers could use the data to victimise certain operators.	deliberate abuse or not reporting/tending to maintenance requirements.	process to describe the functionality and intended use of system and data. Managers to demonstrate appropriate use of system data to enhance the effectiveness of CPS and to not use it as a performance management tool.
Role threat	A key challenge with any automation is the potential threat to jobs. While this is not a direct concern with CPS, as it only controls a certain aspect of the role under specific circumstances, users or unions may feel that this is the beginning of the transition to a more automated mining environment.	Resistance by unions. Poor commitment or adoption of the technology.	Effective change management and communication that enhances the understanding of why CPS has been installed and how it will impact roles.

5.2.2. Cognitive

Definition

Cognition refers to one's ability to use mental action and process to understand and perceive one's environment through thought. Key cognitive processes include thinking, remembering, directing attention, reasoning and problem solving. The mental or cognitive ability of an individual is largely influenced by previous experience and when one is suddenly faced with a new way of work and new types or volumes of information, their cognitive resources are depleted at a faster rate.

For example, when a machine operator has been working in a particular environment for extended period, their ability to understand and respond to their environment is often instinctual. Then when new technology becomes an additional information source about what is happening within that immediate environment, it takes that individual longer to process that information and then adequately respond to that information.

Findings

Unintended Consequence	Description	Potential Outcome/Scenario	Mitigating Factors
Cognitive overload	Too much information is presented to the operator rendering them unable to effectively complete their intended task.	Operators make decision or judgement errors due to lack of focus, which could lead to inefficiencies in completing the required task.	Minimise the number of interfaces and stimuli providing information to the operator to ensure their focus is drawn to the most salient information that will drive the highest value decision.
Operator task error – perception error / memory lapses/slip/ tech misunderstanding	Despite sufficient theoretical and practical training, operator errors are likely to occur.	Incident or activation of CPS slow or stop due to unintended misuse of the system.	Increased use and practice in low-risk environments.
Loss of situational awareness	Before the implementation of systems such as PDS and CPS, an operator would have to rely on their experience and spatial awareness to operate a TMM safely. Due to the implementation of PDS and subsequently CPS, the operator loses the need to rely on their experience and spatial awareness,	Should the CPS or PDS ever fail, the operator would need to rely solely on their situational awareness. Due to their loss of situational awareness, the operator may not be able to identify hazards as fast as they used to, leading to an incident.	Training using simulators to refresh the operator's safety-led behaviours in hazardous situations to ensure that should the CPS or PDS ever fail, they have the necessary skills and awareness to make the best decision to avoid/limit the hazardous situation.

	thus relying on the systems more.		
Accident migration or task transition	The use of CPS in certain situations may introduce unintended safety-led damaging behaviours in situations where CPS is not required.	Accidents take place off-site; whilst the operator is driving home or to another site.	Training on identifying the risks and hazards that the CPS is tasked to deal with and those risks that are not mitigated by CPS.
Over-reliance	Users are overly reliant on the functionality of the technology, which leads to overuse.	Operators allow the technology to slow or stop the TMM unnecessarily leading to overuse of the braking system and therefore faster rate of brake wear and tear. Potential system malfunction could lead to a higher risk of collisions. CPS induced slowing and stopping has been reported to have a higher impact on the physical discomfort on the operator.	Communication to the operators regarding the impact and risks associated to CPS induced slow down and stop. Apply separation (Machines and pedestrians) principles to minimise unnecessary emergency slow down and stop occurrences. Train or provide awareness to pedestrians about the unintended consequence that sudden stopping has on the machine operator.
Requirement of new skills	More experienced operators may struggle more to adapt to newer technologies or ways of work as they formed stronger habits to the previous ways of work.	Experienced operators may take longer to become accustomed to using the TMM fitted with CPS and the various skills and ways of work that the technology requires. They show greater resistance to the new technology.	Ensure training is aligned to the needs of the individual and identify where more dedicated training is required. Implement a thorough change management and identify resistance and

			ensure a resistance plan is in place.
Literacy Challenges	Images and diagrams easier to learn than systems that provide written information, due to literacy challenges.	Interfaces and training material that provide information in only English may result in poorer training and on-the-job performance.	Ensure information is communicated through images and diagrams that are universally understood.

5.2.3. Sensory

Definition

The sensory factor refers to information from our environment that is delivered by our senses and then how one makes sense or responds to this information. This is important to consider as the types of sensory inputs an operator is likely to receive will influence how they think (cognitive), feel (Psychological -emotional) and ultimately respond (procedural). Understanding the type and quality of sensory inputs delivered by a technological system is important to understanding how an individual is likely to behave.

Findings

Unintended Consequence	Description	Potential Outcome/Scenario	Mitigating Factors
Operator alarm fatigue	Operators may experience false positives or alarm errors leading to unnecessary alarms that overwhelm the operator and lowers the intended impact of the alarm.	Operators ignore the alarm signal due to distrust in the system allowing the system to slow down and stop the TMM.	Regular and quality maintenance on the system to maintain and improve its efficacy.
Loss of visibility	Increase in technology interfaces has reportedly reduced operator visibility as the interfaces block operator line of sight.	Operators become over-reliant on the CPS to slow or stop due to loss of visibility.	Ensure alignment between the machine and technology to optimise operator visibility and the positive impact of the technology.

5.2.4. Physical

Definition

Physical human factors refer to the impact on the human body. Many roles within a mining environment require effective physical functioning as they put high demands on the human body. The consequences of automated systems on the physical body must be understood to ensure that individuals are kept physically safe.

Findings

Unintended Consequence	Description	Potential Outcome/Scenario	Mitigating Factors
Physical discomfort and/or injuries	When CPS technology is activated, operators have reported experiencing physical discomfort and/or injuries from the force of the braking system.	Operators are injured by the force of the braking system and are required to take sick leave.	Communicate the potential risks to the operators and pedestrians to ensure minimisation of over-reliance issues, improved traffic management adherence and situational awareness to reduce the chance of potential collisions and therefore activation of the CPS. Analyse CPS data to identify areas and situations of high activation to ensure mitigation actions are established to reduce potential collisions.
Technology functional errors (e.g., stalemate)	Interaction of different TMMs with differing CPS installed has led to vehicle "stalemates."	Slow down or loss in production until the stalemate is resolved.	Advancement of technology or Installation of CPS from a single technology provider. The MOSH Functional and

			Technical Performance Requirements has guidance on how to deal with this problem.
Brake wear and tear	The force associated with automatic slow down and stop leads to increased rate of brake wear and tear.	Increased rate of brake maintenance and replacement and therefore increased costs.	Reduce CPS over reliance through effective communication and change management. Communicate the potential risks to the operators and pedestrians to ensure minimisation of over-reliance issues, improved traffic management adherence and situational awareness to reduce the chance of potential collisions and therefore activation of the CPS.

5.2.5. Procedural

Definition

Procedural human factors refer to the required process of activities and actions performed by humans. When a new variable is introduced into a working environment, especially a highly rule-based environment, this can have an impact on how people respond to rules and requirements. New systems often bring new processes or add activities to existing processes. They also may enhance or inhibit the level of compliance to current procedures.

A thorough understanding of the procedural implications of collision prevention systems provides key insights into how operations can ensure sufficient adherence to the required procedures and therefore enhance the effectiveness of the system.

Findings

Unintended Consequence	Description	Potential Outcome/Scenario	Mitigating Factors
Non-compliance due to false positives	An operator will not respond accordingly if an alarm is constantly triggered when there is no explicit hazard.	If the CPS or PDS keeps on detecting hazards that are not explicit, the operator may ignore the alarm which may lead to an incident should there be a real hazard.	Dynamic calibration of systems and training aligned to the calibration of the systems will ensure that the false-positives are able to be identified and dealt with appropriately by the operator. The MOSH Functional and Technical Performance Requirements has guidance on how to deal with this problem.
Peer enforced accountability	Operators and pedestrians hold each other accountable to ensure the safety of all personnel on site.	Peer enforced accountability can lead to the avoidance of triggering the CPS leading to an investigation.	N/A
Increased adherence to traffic rules	In certain situations, the introduction of CPS has led to operators and pedestrians adhering to traffic rules to avoid the activation of the CPS.	Less vehicle and pedestrian interactions.	N/A
Procedural violations / procedural non-compliance	Contrary to the previous point, incidents have been noted of operators and pedestrians not adhering to procedure due to the perception that they operate in a zero-risk environment.	Pedestrians deliberately walking through exclusion zones and activating CPS.	Increased communication and change management to ensure understanding and impact of procedural violations.

5.2.6. Cultural

Definition

Cultural refers to the broader ecosystem of an operational environment. It reflects the organisational aspects such as values, leadership, organisational culture and also reflects other factors such community factors, regulatory and economic.

The introduction of any technology does not exist in isolation and there are many broader systemic factors that are impacted and must be understood to enhance the effectiveness of the system.

Findings

Unintended Consequence	Description	Potential Outcome/Scenario	Mitigating Factors
Increase in the overall safety culture	The implementation of CPS can lead to overall safer behaviours on mines as a result of personnel not wanting to cause unnecessary delays in production.	A pedestrian may be more aware of the TMMs and other machinery around them and will thus act accordingly.	N/A
Sabotage – nefarious and non-nefarious (creative ways established to deactivate the system)	To ensure that production does not lag, an operator/ pedestrian may choose to sabotage or bypass the safety systems on the TMMs to ensure that they can complete tasks with no impediments.	Operator and other mine personnel may elect to remove their RFID tags or caplamps, therefore making them invisible to the TMM thus enabling the operator to complete their task in a quicker manner.	Implementation of tamper alarms and regular health checks of systems to ensure no improper use. Safety behaviour-based incentives.
Assumptions of risk mitigation	Assumption that CPS is the safety “silver bullet” that reduces all risk across an operation.	Poor safety behaviour and increase in safety-related incidents.	Effective communication about the role of CPS and its potential impact and limitations.
Job losses due to mine closures (cannot afford to install CPS)	The adoption of CPS on mines is costly. The requirements for	Mine closures and job losses.	Implementation of controls that are higher up on the hierarchy of

	the mines to have their TMMs to have CPS on board, requires a large financial investment that some mining houses may not be able to afford.		controls so that the risk of collision is managed to remain below significant.

6. Conclusion and Change Management Approach

It is evident from the study and findings detailed above that mining operations that will implement CPS on their TMM fleet will likely experience several unintended consequences, as a result. The nature and volume of these consequences will largely depend on several contextual factors that may or may not be present at the mine. Therefore, it is important that the individuals responsible for implementing CPS on a particular operation have considered the likely consequences, positive and negative, that may impact TMM operators, pedestrians and other mining personnel.

While we have emphasised the contextual nature of these unintended consequences, what is consistent across all mining situations is the need for an effective and consistent change management approach. Many organisations underestimate the psychological impact any change, major or minor, has on their employees. The findings above as well as the findings of previous studies across the automation landscape emphasise the negative impact that poor or no change management has on the adoption of new technologies.

Therefore, to drive effective implementation and adoption of CPS through mitigation of unintended consequences detailed above or those unintended consequences yet to be identified, the following Change Management Blueprint has been developed by the Mandela Mining Precinct.

6.1. Change Management Blueprint for Adoption of New Technologies

As part of the SATCAP (Successful Application of Technology Centred Around People) project, the Mandela Mining Precinct established an "implementable change management blueprint for the adoption of modern technologies." It is important to emphasise that the blueprint is specifically designed for the "people side of change." In other words, it enables management to effectively influence the behavioural response of employees during the implementation of technical changes.

The blueprint was developed using a plant inspection platform as a case study and, to date, has not been applied to the implementation of CPS. However, the intention is for the blueprint to be applied to any project across the mining industry, that is implementing a modern technology.

To ensure that the blueprint is relevant to the adoption of modern technologies (including CPS) across the mining industry, the Mandela Mining Precinct incorporated the following design criteria:

- *Aligned to the **MOSH** Leading practice Adoption System (does not replace it)*
- *Aligned to or incorporates the relevant **Change Management models** and includes salient aspects of best practice of these change models.*
- *A **hybrid model** that incorporates both Management of Change and Change Management.*
- ***Agile** and **applicable** for use with other or existing change methodologies used within mining companies currently.*
- ***Aligned** to the latest safety, risk and/or legislative requirements.*
- *Simplified, practical and **user-friendly**.*
- *Applicable for the **adoption** of modern technologies.*
- *People-centric.*
- ***Scalable** to fit the level of change.*
- *Created for us, by us (**Co-created** with industry specialists and end-users).*

A key outcome of the study was the development of the following 5 step change management plan *(Figure 5),* referred to as the 3PRS:

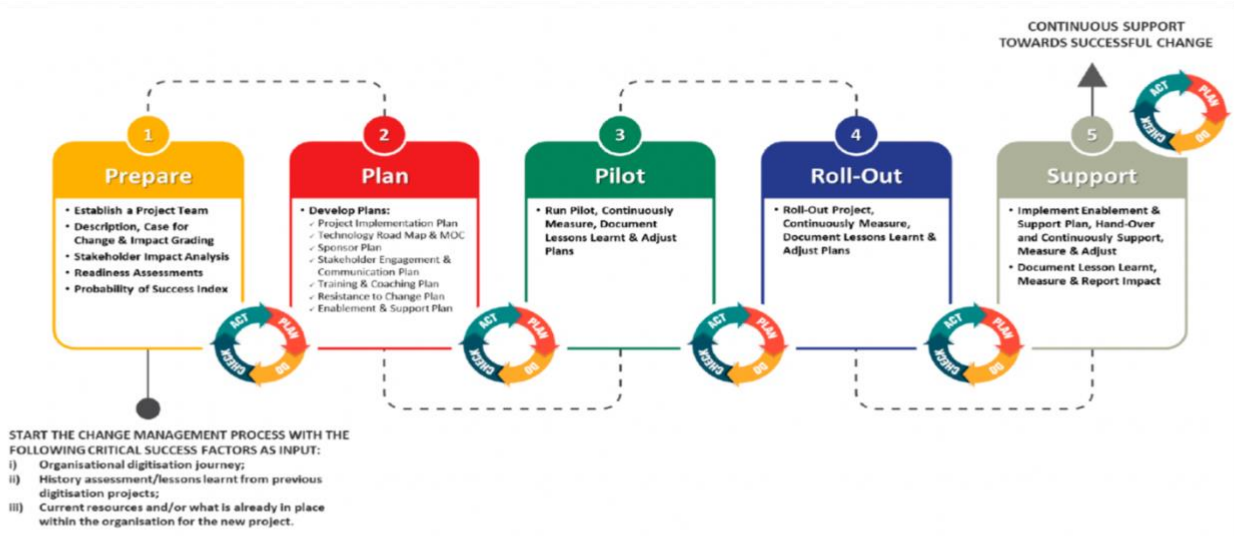

Figure 5 - Change Management Plan

To enable mining houses to drive effective change management the blueprint is supported by:

- *A poster version of The Blueprint that can be downloaded and shared*
- *Supportive templates*

- *A user-guide (i.e. Guideline explaining the use of the templates)*
- *An instructional video, giving step-by-step guidance on the use of the Change Management Blueprint*
- *Online portal: click Here*