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The experiences of mineworkers interacting with driverless trucks: risks, trust and teamwork

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KEYWORDS

Haul truck automation
Automation hazards
Mineworkers
Human-machine interface
Trust and Teamwork

ABSTRACT

Driverless haul trucks represent a significant transformation for the mine site workers in the Western Australian (WA) Mining Industry. Research within the industry is yet to explore the experiences of frontline workers who are mining with this new technology. The aim was to investigate the practical experiences of miners working with driverless trucks in a broader evaluation of safety incidents. A stratified sample of workers, from a WA mine site, were interviewed face-to-face using a mixture of open and close-ended questions. A convergent parallel design developed a comprehensive understanding of various risk perspectives. Interpretive data collected from multiple cases were analysed thematically through cross-case displays. The results indicate new hazards and risks are introduced through automation. Despite this, miners developed high levels of trust for technology through predicted pathways, adherence to instructions and exercising diligence when stopping for objects. The driverless trucks were perceived to play their part; however, technology does not assist others and engage in team play. Therefore, the worker perspectives highlight the introduction of new risks, high levels of trust and the narrow focus of driverless technology.

1. INTRODUCTION

Driverless haul trucks have been involved in several mine site incidents since 2013 (Department of Mines and Petroleum, 2014). This kind of events are unconventional and are new to the Western Australian (WA) Mining Industry (Department of Mines and Petroleum, 2015a). Although they account for a small number of total incidents across the industry, the plans to expand the technology across Australia could see those numbers increase. The expansion is not only the case in the Mining Industry; with driverless vehicles being involved in public road incidents across the United States (National Transportation Safety Board, 2017; 2018). Despite recent reports of incidents involving driverless haul trucks, they provide little insight into the experiences of mineworkers who are now working with this technology. The experiences of people interfacing with automated systems across high-risk industries appear to be well known in aviation (Billings, 2018), maritime (de Vries, 2017), manufacturing (Frohm et al., 2006) and railroad (Gschwandtner et al., 2010). Experiences reported through the interactions with automated equipment include automation surprises (De Boer & Dekker, 2017), machine literalism (Billings, 2018) and opacity (Wessel et al., 2019) to name a few.

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What is most concerning, however, is the fact that automated systems are often evaluated on what they have been programmed to do, not what they should have been programmed to do (McKinnon, 2019). Such inward thinking will hinder the improvement cycle of human-machine systems, leaving the frontline to continue to make local improvisations to soothe the practical constraints of pre-programmed machines.

Open-cut mining represents a unique and high-risk environment, with mine workers performing various tasks with a variety of tools and equipment. Moving haul trucks creates a particular risk, due to the mobility, size and speed of the machine. In addition to this, mining companies are now replacing their truck drivers with automated systems. This substitution represents a transformation in the nature of tasks completed on mine sites, and associated risks, with the integration of human and machine activities. Moreover, there are also specific risks associated with computer interfaces, which are linked to feedback loops and system warnings (Dixon et al., 2007; Parasuraman & Manzey, 2010). Lastly, supervisors and users of automated technology are often the last lines of defence, applying local adaptions to avoid incidents and recover systems from failure (Reason, 1990).

Several studies have made connections to the nature and causes of human-machine breakdowns, which attempt to investigate the effects of automation on human performances. There have been reports that automation can be challenging to track and linked opaque interfaces to its contribution (Sarter & Woods, 1992). More recent studies have explored the effects of the unawareness of machine modes and associated features (Björklund et al., 2006; Feldhütter et al., 2019, August 26-30). Specifically, a lack of mode awareness emerging from an overreliance on automation than visual attention. Mode awareness has been argued to be a more complex phenomenon than merely eye-tracking. In addition, there are also links to the level of trust that is extended to automated systems and the reliance that is placed upon them (Botsman, 2017; Körber et al., 2018; Lee & See, 2004).

Despite the extensive amount of human factors research conducted in the Aviation Industry, there has been little research undertaken in the WA Mining Industry. A Code of Practice (COP) by the Department of Mines and Petroleum (2015a) indicated that there are unique risks associated with automating mobile equipment. However, there is no mention of trust or reliance issues that have been linked to automation (Hoff & Bashir, 2015). Although the COP does, however, note the risk of human intervention, system overriding, survey mismatches and mode switching. Research examining the attentional demands of automation suggests that monitoring automation can create out-of-the-loop problems for humans (Endsley, 2017). Moreover, a study in automated driving identified that individual trust levels influence how humans monitored the surrounding environment (Körber et al., 2018). Therefore, there is a real need to determine the trust levels of miners and whether attentional demands are leading to out-of-the-loop problems (Department of Mines and Petroleum, 2015b).

There is a significant body of knowledge that evaluates whether automated systems are team players. Team players have been defined as agents that cooperate (sharing, observable, directable) and participate (fluent, coordination) in team play (Christoffersen & Woods, 2002). Within the Aviation Industry, there is a powerful link between new surprising problems and human-machine breakdowns; for instance, how automated systems managed to get into a particular mode (Sarter & Woods, 1995). The characteristics of a team player are that humans must be able to cooperate with driverless trucks and share similar priorities. If the automated system is to be redirected, relative to operational demands, it can be achieved quite fluently. Finally, the effectiveness of feedback and awareness improves team play and minimises the significant problems with human-machine interactions (Sarter & Woods, 1997). The high-risk environment of driving trucks suggests that improving team play is equally important in mining. However, there is still no research conducted on how driverless trucks can become better team players.

The research aimed to explore the practical experiences of mining personnel working with a driverless haulage system. This aim was achieved by facilitating face-to-face interviews with workers using semi-structured questions. The technique enabled the researchers to gather quantitative and qualitative data on the perspectives and lived experiences of worker interactions. Data that was transcribed was analysed using a pattern matching technique, identifying the themes across the sample group to represent the experiences of workers.

2. METHOD

2.1. Design

A simplified haulage system represents a number of components that work seamlessly together to load, haul and dump. Reductionism distinguishes between what the system has and what it does, achieving simplicity through what it excludes. The practice also distinguishes between what humans and machines undertake as well (Dekker, 2014). The simplification of haulage systems rests on the belief that components operate independently, without non-linear interactions disrupting the flow of the cycle. This is achieved by breaking down the system into its most basic parts, re-allocating tasks to either human or machine (Pritchett et al., 2013). The system is then put back together again, with isolated components that operate independently. This enables engineering to contain incidents and serious breakdowns in the design of the haulage cycle.

The reductionist approach aims to understand each components of the cycle individually within the system (Hamada & Saito, 2018). A simplified system improves upon knowing the behaviours of the constituent parts and being able to lock-in the productive methodologies for automation. It removes the variability and increases the predictability in what the system will perform. Haul trucks in a simplified system will therefore appear to be foreseeable and controlled in the way they execute the tasks. Therefore, trucks working within the design parameters will ultimately improve workplace safety and haul truck productivity. This constitutes the set of appearances that sit behind a much simpler haulage system.

2.2. Participants

The population of the study involved employees and contractors who work with driverless haul trucks. The size of the population was approximately 450 people who performed specific functions and characteristics pertinent to the research. A single-stage sampling procedure provided the investigation with direct access to the participants and the population under study (Teddlie & Tashakkori, 2009). The characteristics of the population were understood to enable stratification to occur. Therefore, the following roles and features identified: control room operators who monitor the performance of the trucks and make decisions via computer interfaces; pit technicians who attend to truck recoveries and system builders who build and verify the virtual mine model; ancillary and haul class operators manually controlling equipment; supervisors of system-based roles and auxiliary equipment operators who check and inspect work; and the professionals who include the designers and specialist in the function and pre-programming of the trucks. Specific characteristics targeted by random selection may not represent the entire population (Creswell, 2014a). There was saturation by recruiting 25 participants, which represented 5.5% of the operation when validating results.

2.3 Data collection

Semi-structured interviews were digitally recorded and took appropriately 45 minutes to 1.5 hours to complete. Participants were interviewed one-on-one between January 2018 and February 2019. The

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interviews were conducted on the research site and held in a quiet room. Every meeting was digitally recorded and was transcribed by one of the researchers verbatims.

During face-to-face interviews, participants were asked whether automating the haul trucks introduced new hazards and risks. Participants that believed new dangers and risks emerged were offered to elaborate on what they were and what contributed to them. Secondly, participants were asked to provide a trust level rating and what underpinned their level of trust. Thirdly, whether the interviewees observed driverless perform something that they did not anticipate. Did their trust level reduce after facing an incident or unanticipated situation? Fourth, did the system inform them adequately of what mode and function the truck is performing. Lastly, are driverless trucks team players, and whether they had ever instructed a truck to do something, yet it undertook something different. The set of questions (Table 1) remained consistent for all participants across the stratified sample.

Table 1: Interview questions specific to risk, trust and teamwork when working with driverless haul trucks

Topic	Question
Risk	– Do you believe new hazards and risks have been introduced through haul truck automation? – What do you think is contributing to incidents involving driverless haul trucks?
Trust	– What rating out of 10 would you say your trust level was towards the driverless trucks? – Have you observed a driverless truck perform something that you did not anticipate? – Did your trust level change after an incident or unanticipated situation? – How confident are you in redirecting or overriding obstacle detections?
Teamwork	– Does the system inform you adequately of what mode or function the driverless truck is performing? – Have you instructed a driverless truck to do one thing, yet it performed something different? – If the driverless trucks were team players, how would you describe them?

2.4 Data analysis

Interview data was uploaded and transcribed into an online database. Interpretive data collected from multiple cases analysed through a cross-case display. The display compared the interview responses for patterns and themes when coding abductively (Tashakkori & Teddlie, 2010). A mixed-method analysis provided statistical and analytical generalisations about the phenomenon (Creswell et al., 2011). Descriptive analysis organised and summarised the responses to enhance understanding of worker experiences. The technique was applied to represent natural clusters, grouping and dimensions (Onwuegbuzie & Combs, 2010). Statistical results were, therefore justified rather than predicted, comparing different perspectives drawn from qualitative and quantitative data (Creswell, 2014b).

Participants rated their understanding of the systems' modes and features, comparing their reasons why with responses that may have been higher. An inclusive design framework calculated statistics from data themes. Therefore, the numerical properties of the results stemmed from the stratified sample taken in the population (Onwuegbuzie & Combs, 2010). Cross-case analysis facilitated the simultaneous facilitated the analysis of multiple perspectives to avoid being bound by individual

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contributing factors (Onwuegbuzie & Combs, 2010). Raw data were sorted into groups and did not distinguish between independent and dependent variables (Miles & Huberman, 1994).

Furthermore, to enhance the investigation, this approach enabled the researcher to identify patterns and variables. The variables compared against the participants' perspectives working with driverless haul trucks (Wainer, 2005). A graphical analysis reported the results and highlight how they relate to the questions, which assisting in presenting the statistical information in visual form. Bar graphs developed for the visualisation of practical significance and trends in the worker experiences.

2.5 Ethical considerations

The research was approved by the University Research Ethics Committee (HRE2017-0844). The participants were provided with written information about the study. The researcher undertaking the interviews was an employee on the mine site. Therefore, the researcher informed participants of the researcher's role before commencing discussions. Participants provided written consent to participate in the research and were given to opportunity to choose the interview location. The interviewees were assured that interviewed records were kept confidential, with the participants allowed to cease the interview at any time.

3. RESULTS

The findings of miners' experiences working driverless trucks were synthesised into three themes. Those three themes include; the introduction of new hazards and risks, higher levels of trust for haul trucks and the narrow focus of driverless technology. The headings describe the workers' primary response to the question of their thoughts and personnel experiences.

3.1 New hazards and risks introduction through automation

3.1.1 Hazards and risks

A majority of participants reported that new hazards and risks had been introduced through automation. Participants explained how it used to be enough to train people how to drive haul trucks. However, since the replacement of truck drivers, coordinating the truck fleet is much more complicated. Driverless trucks were said to perform everything that is instructed, yet they will not perform tasks humans do not ask. New hazards, such as complacency, were reported to have emerged in anticipation of a trucks' next move. An expectation that the trucks will repeat the exact performances every single time. However, it was explained that there are factors outside the design parameters that can influence the trucks' performances. For example, truck settings and speed zones can be applied to change the truck's response to a situation. Local adaptions are required since the technology expects a particular operating environment; requiring roads to be dry and survey information to be accurate. When there is a distinction between the virtual and physical environment, the driverless system is restricted in how it can respond. As a result, without speed restrictions and accurate survey information in place, trucks' can drive full speed in wet weather and reverse beyond windrow boundaries. Therefore, humans must be a step ahead of the system to put controls in place to avoid incidents.

A humans' complacency towards driverless trucks was raised as a particularly significant hazard. Since automated trucks were considered so 'predictable', the frontline workers had developed a high level of trust. In particular, when participants compared their experiences in manual truck operations. Despite this, high levels of trust drove practices that were not observed in a manual environment. For example, graders working head on to an oncoming haul trucks until they stopped, pulling away at the last minute.

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These practices place a high dependence on the trucks' lasers, sensors and GPS systems to work:

> *You still have to respect the blue light. They are a big machine, no one in them, could be doing 60 km/h. They are not just going to stop on a dime [abruptly].* [P23]

If a vehicle turns in front of a travelling haul truck, it was reported that a driverless truck could not stop in time. The eyes and ears of truck drivers are said to be far different from the lasers and sensors that substitute them. Personnel now monitors a 3D world through a 2D display, which requires a high frequency of verifications to validate the virtual model. Participants raised the importance of checks to avoid truck backing through windrows. Virtual mine models must be 'real' to prevent penetrating the boundary:

> *Had a truck back through a windrow to get to another windrow behind that, because someone had not surveyed it in. A grade operator has come up and said, 'no, it's all clear'.* [P21]

Now that mine controllers supervise multiple trucks; it was noted that an enormous amount of responsibility had been placed on a single person to manage numerous trucks. Since there is no longer direct communication with a haul truck, mine controllers rely on computer interfaces. Controllers set goals for the shift, allocate trucks and redirect the fleet where they are needed. When it comes to manually operated equipment, the machines must be connected to the network to be visible in the system. Vehicles without communications are escorted through the mine, which has created escort splits and unintended interactions in the past. Furthermore, participants reported that personnel rely heavily on this technology to recognise their vehicle and rarely observe in-cab displays. In addition, their reliance drove new methods of managing the truck operation:

> *[Driverless] truck breaks down on a ramp. Truck stops. We put a virtual zone around it.... In the manned world, if that had have happened. Someone would have to stay in the [manual] truck; we would put a barrier behind the truck, we would put cones there, we would probably put a lighting plant there to shine on the truck... We are comfortable with virtual controls, as opposed to hard controls.* [P15]

There were situations reported where personnel were unable to create a dump plan without turning off all the exclusion zones. An exclusion zone prevents driverless trucks from driving into that area. The problem with zones in dump plans, however, is that some people were not turning them back on. Personnel tend to rely on sensors that do not always recognise objects. Moreover, it was noted that people are still learning how to interact with the trucks properly:

> *In general, I think it is safer, but it's that learning around working with the system properly. I guess, what it does and what it doesn't do.* [P25]

While ever people are interacting with a 400-tonne truck, participants noted that there will always be associated with risks. For example, there are people still on the ground refuelling and mode changing driverless trucks. If the mode changing process is not followed, there was said to be a chance that a driverless truck could drive away while someone is nearby. However, when comparing hazards to manual truck operations, participants maintained that the risks had been reduced.

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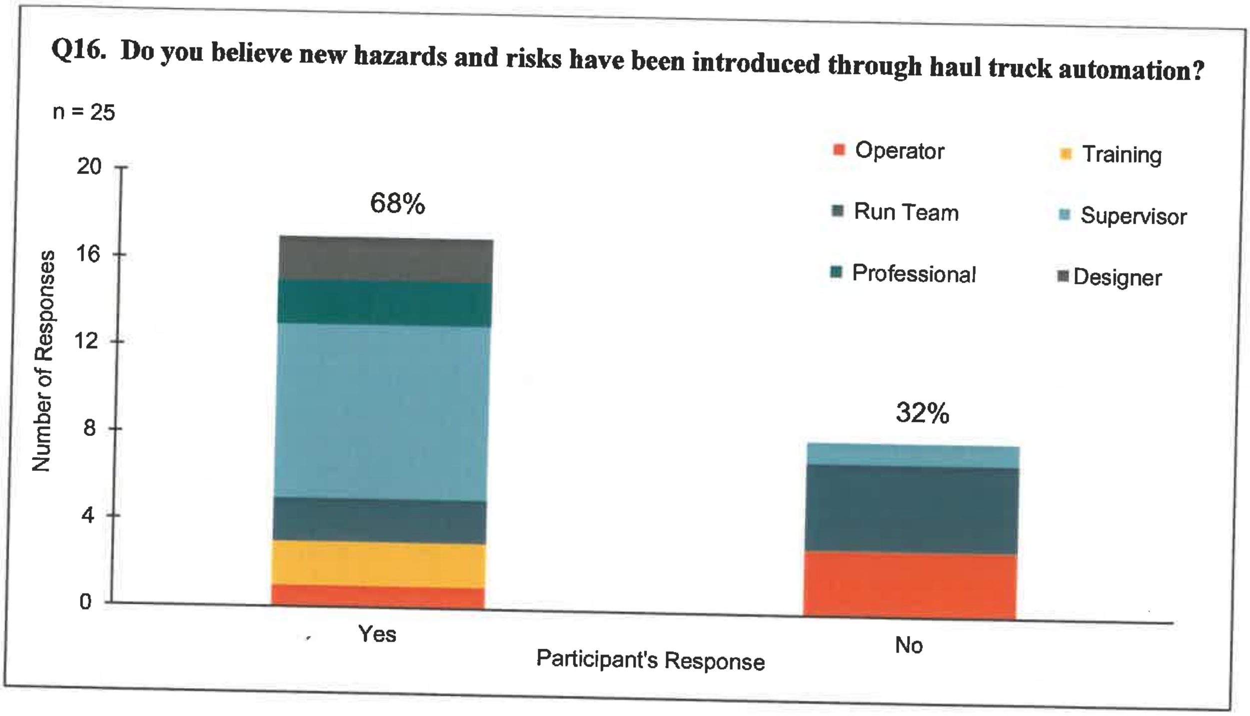

Figure 1. Responses to question whether new hazards and risks have been introduced through haul truck automation. Data collected through one-on-one interviews

Participants reinforced that the positives of driverless technology far outweigh new hazards and risks. Where priority rules breaches used to be the most common risk, a now reported to be virtually non-existent. Therefore, replacing the truck driver removed some of the typical event types:

> *The amount of incidents we used to have with priority rules breaches with truck on truck. Things like that, that's just disappeared. We don't have it. Pos comms (positive communication) breaches as well.* [P18]

Despite most participants reporting that there are new hazards, there was a much small number of participants that stated there were no new hazards. Those participants claim that removing people simply left nothing to worry about:

> *I think it's a much safer environment to drive around in, than if there were humans driving around in the trucks. Because you can see exactly where they're going, and you just stay out of their way, basically.* [P5]

Driverless operations were reported to be a lot safer than manual, which was referenced by the improvements in recordable injuries. Participants recalled the hazards and risks that observed in the driverless operations. The hazardous conditions had elements of human and technology. The primary concerns were the difference in the virtual and physical world, complacency and limited experience with automation:

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And then this comes back to knowledge of people in the pit... grader operator didn't look for that windrow being surveyed in and all that sort of stuff. Where if he had a bit more knowledge before that event, he would have known... that windrow is not surveyed in, don't back that truck in there. [P21]

3.1.2 Humans are contributing to driverless incidents

When asked what is contributing to incidents involving driverless trucks, a majority of participants (n = 16) reported that it was 'humans'. The events were argued to be a perfect representation of the mining culture embedded in the WA Mining Industry. Participants claim that people who are so focused on the dirt can quickly look past things. There is much more detail now required to run a truck operation. Moreover, it was argued that people are not verifying situations in enough depth:

Especially with the truck going through the bund, everyone assumes when that occurred, it was just a little rock that was there that the truck had seen. They didn't go into the in-depth detail to look at it a little bit further and actually really check. [P2]

Participants explained that when a truck identifies a reverse object, rather than just looking for a physical object. People must compare what they are observing to the virtual mine model. When detected objects are cleared from a distance, there is no way to identify whether there are objects behind the truck. Personnel need to make themselves aware of their surroundings, including communicating with others to verify and explain what is being observed. The trust extended to the system is very high, with an expectation that the truck will not do anything outside of its design parameters. When people perceive that they are being rushed, it was reported that they perform tasks outside of the procedure. The low operating discipline on behalf of the human is claimed to lead to the frontline not following standards and avoiding ownership. As a result, people have more faith in computer literalism than human cognition, with the belief that the system is perfect:

What I believe is that the system is perfect. We are the ones that slow it down or make it fault. So, human error... [P18]

Participants reported that personnel become comfortable with what driverless trucks can perform. If people do not look at their in-cab displays, they will not observe truck assignments. When people are not concentrating, it was reported that people rush into tasks and create incidents. These conditions include lapses in judgement or not focusing on the things around them. The inexperience of working with driverless systems has led to actions that conflict with the situation. Moreover, as the operation has expanded, it was reported that more people were brought over from the manual truck operation with less experience:

It's just the skill set of operators. A lot of operators have moved around; we are bringing in a lot of other operators at this point in time. They're experienced operators, but not all have autonomy experience. [P22]

Surveys that do not match the physical mine leave virtual distinctions that the trucks accept as an accurate representation. When people do not respond quick enough to downpours of rain, trucks can be left operating at full capacity without speed or traction controls (Jamasmie, 2019). Moreover, water cart operators have applied too much water on the road, creating slippery conditions for a driverless truck. The lack of knowledge with truck capability has led to people removing controls while believing other functions were in place.

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It is essential to know how to read and use the information outputted by the system correctly. Some conditions were considered to be influencing people's actions, mainly manually operated equipment interacting with the trucks. Without physical demarcation, it is challenging to identify an intersection that exists in the virtual mine model. Unless in-cab displays are observed, there is nothing to indicate intersections exist. Participants explained can be confused when a truck stops for no physical obstruction in the truck's lane.

Participants reported that workers could become comfortable with driverless technology, regardless of what it does. Participants noted that the people assume driverless trucks will always identify them. This assumption drives relaxed behaviours when in the field. Moreover, in the beginning, the operation did not have all their systems and processes to support people. As the technology was evolving and people were learning, those processes were just being developed. Therefore, the operation relied heavily on the manufacturer to coach them on how to interact with the driverless fleet.

3.2 High levels of trust developed with driverless technology

3.2.1 Participant trust levels

Participants reported a high level of trust towards the driverless fleet (median = 9), claiming that if a truck drove somewhere that it did not instruct it to, then it is a person's fault. For example, driverless trucks that park too far away from the excavator have had the loading point placed there by the operator. Furthermore, it was explained that driverless trucks could reverse over rocks or up the dig face when instructed. Driverless trucks were claimed to be reasonably accurate, which resulted in high levels of trust. Particularly when compared to a manual truck environment, with one participant adding that they would rate humans low on a good day. With 12-hour shifts, driverless trucks are reported to perform safely for 12 hours, where truck drivers did not:

> *A man truck might be spot on after his smoko [cigarette break] and his coffee, but 5 hours down the track, he could be thinking about fishing or something like that. An autonomous truck is not thinking about that.* *[P10]*

Trust increased through the introduction of in-cab displays which highlight haul truck travel paths. In addition, the frontline could control driverless trucks from their light vehicle. Moreover, driverless trucks were claimed to not drive out of their assigned lane like a manual truck driver. As a result, with blue paths indicating where trucks are travelling, participants trust that the truck is going to go straight and not veering off in front of them. As time went on, people's trust level had increased, with a realisation they were not going to hurt them. The truck will just stop. Despite the potential for truck slides, interviewees reported that driverless haul trucks losing control turn their wheels to the outside windrow to avoid oncoming traffic. It is these sorts of practices and observed vigilance that increased trust:

> *When you watch them give way to a cow on a haul road... Come to a stop in a space that no way a human could pull a truck up in, safely. And a cow walks across the road in front of it, and the truck drives off in the end. And you go, wow.* *[P4]*

Driverless trucks are usually attempting to correct themselves and avoid oncoming traffic. It is these responses that participants observed in the mine. It was also noted that through virtual playbacks, when participants watched truck movements, the machines were never found performing something unsafe. Although personnel may question why a truck is driving from one location to another, one participant claimed that they never observed a truck do something unpredictable:

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> *I've never seen a truck do anything in an unsafe manner that I couldn't say wasn't predictable... But I've never seen it do something unpredictable. There's always been a reason why it has always done what it has done.* *[P3]*

It was argued that there is always a reason why a truck performs something or is redirected. Participants have observed trucks waiting in the queue and suddenly execute a U-turn to travel to another loading source. It was noted that people might find this action unpredicted. Yet it was suggested that this might be unexpected, but not unpredictable. The assignment engine can simply re-assign a truck elsewhere, with the U-turn lanes already available for the trucks. The more participants observed trucks performances and understood the assignment engine, the more they trusted the system.

Participants reported that trust is built through learning what the trucks will and will not perform. Understanding the controls and the systems that are in place, particularly how driverless trucks respond to situations. Recognising that it is an algorithm, participants reported that trucks would simply repeat the observable functions. This function is underpinned by in-cab displays that highlight the intended travel path, which is non-existent in a manual truck operation. Moreover, it was reported that participants have the sense that trucks will remain in their lane. If a truck touches or slightly breaches the path, it will stop. A manual truck is reported to have less certainty:

> *You don't have the uncertainty of a manned driver, that can go off over windrows, can go bush, can go anywhere, if they wanted to... You know a truck is going to stay in its lane, and it's going to travel that path, and if deviates slightly, it's going to stop.* *[P19]*

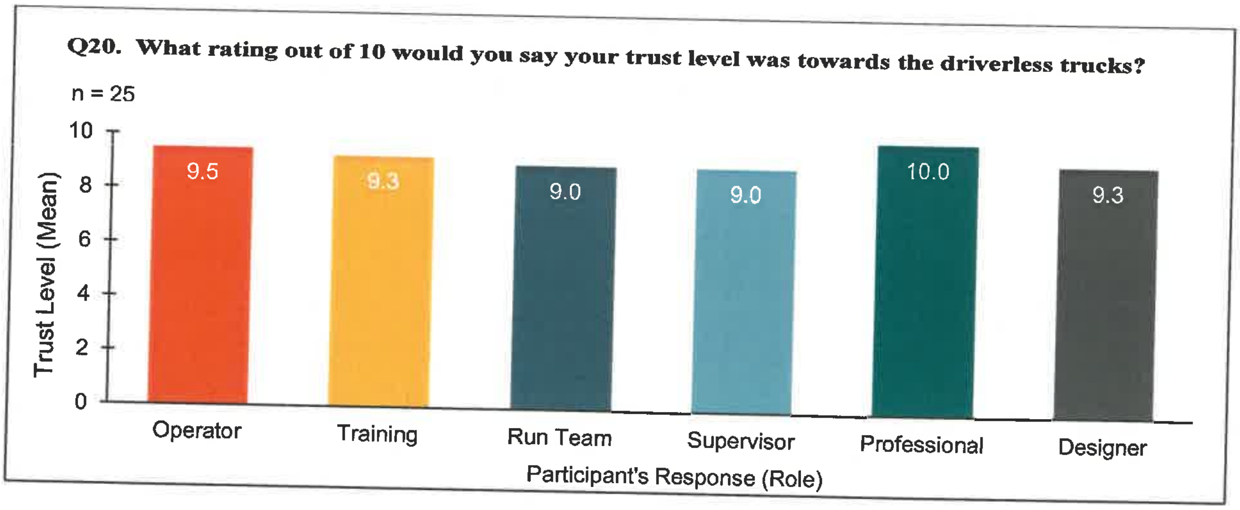

Figure 2. Median trust level out of 10 towards the driverless trucks by role. Data collected through one-on-one interviews with personnel on mine site

Driverless trucks had built trust by stopping when they lose communication. The fact that the system stops when the situation is 'not right', made participants feel like safety was taken seriously. Moreover, manually operated equipment that lose communication generates an exclusion bubble, which expands a zone that stops trucks until the vehicle has found a safe location. The safety mechanisms and their effectiveness underline the high level of trust was realised. In addition, the trucks are reported to behave the way a truck is supposed to, responding to situations similar to a truck driver, if not better. Driverless trucks travel to where they are supposed to and park where loading units wants them.

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The human factor was argued to have been removed, with priority rules and communication breaches no longer a risk. One of the significant dangers reported was fatigue, where truck indicators were never trusted. Participants noted that they would never drive out, claiming that it was unknown whether the driver was paying attention. In comparison, the technology had introduced layers of controls to maintain a safe distance between people and haul trucks, including avoidance boundaries and emergency stop devices. However, the participants did note that they would never walk out in front of a truck. With an understanding of what a truck is capable of performing, the only trust issues were highlighted in wet weather:

> *But, road conditions, weather permitting and all that stuff. Where a dump truck could potentially slide down a ramp into an LV or a car or something, yeah, that's a bit of a different question... If we don't put a zone lock on in time, then stuff can get pretty hairy."* *[P12]*

3.2.2 Driverless trucks performed unanticipated tasks

Driverless haul trucks were observed by participants to perform tasks that were not expected. A driverless truck 'wobbling' aggressively side-to-side was one example. Although it can now be explained that is was a steering fault, at the time, participants were left confused. Driverless trucks can also drive away without explaining its intentions to manually operated equipment. This reinforces the point made earlier by a participant who noted that manual machines could no longer make direct contact with a haul truck driver. On the pit floor, driverless trucks are given the flexibility to generate their pathway to being loaded. For a dozer operator, they can be surprised when a truck arrives behind them without notice:

> *All of a sudden, the digger moved to a certain spot and the trucks had to come back in behind me, and I didn't realise... I came out, and this blinkin' thing is right behind me on the dozer, going 'barrrrrrrrrp' (sound of the truck horn).* *[P5]*

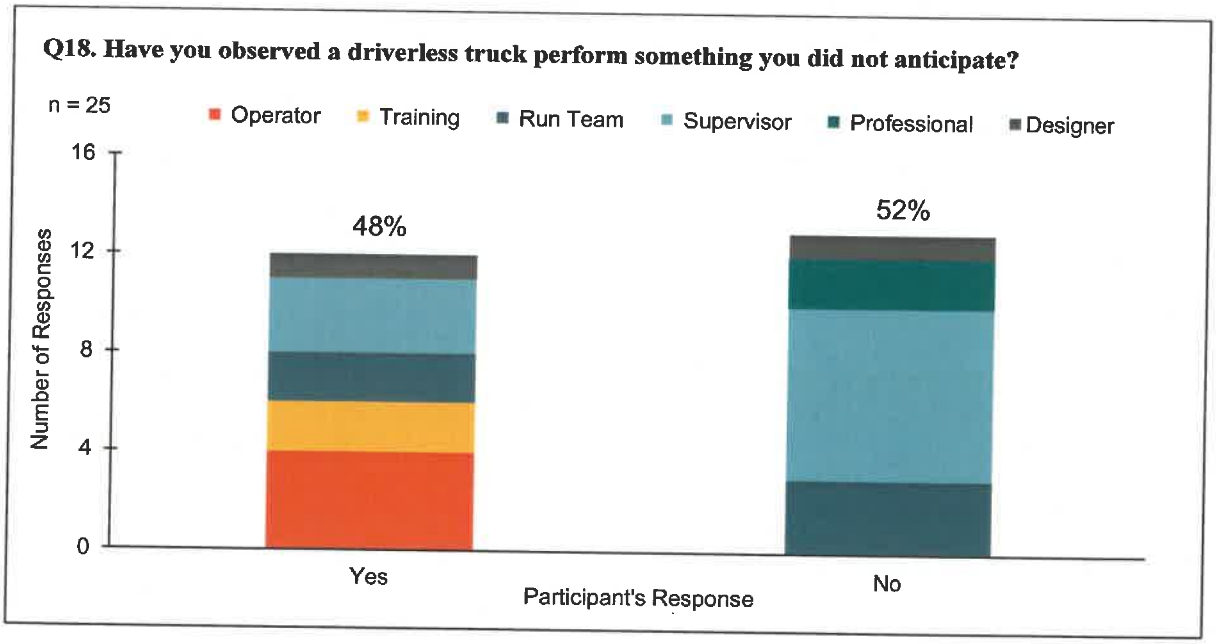

Figure 3. Responses to question whether participants had observed a driverless truck perform something that they did not anticipate. Data collected through one-on-one interviews

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Participants reported that driverless trucks could be found driving the longest haul route to the crusher. Several in-cycle delays on the haul route changed the average time taken, resulting in the trucks making a different way. However, at the time, the mine controller did not understand why this was being performed. Excavator operators have observed empty trucks driving off before loaded trucks as well. It was later found that the empty truck was higher up in the queue. Therefore, the system assigned the empty truck away, despite the other truck being loaded. Driverless trucks have also been observed travelling back to the loading unit with its tray in the air. Without a dump script in place, driverless trucks can drive away without being instructed to lower its tray.

Observing in-cab displays enables the frontline to be more informed of truck performances. The information highlights what a driverless truck is performing and what it is likely to do next. However, some functions are not described unless the designer previously explained it—for example, trucks driving through dust with its horn sounding. Although the algorithms are not visible, the data logs highlight a person's input or mechanical failure. With an explanation, participants explained how it could answer the uncertainty. Yet, not every role is provided with this level of information. Participants without this level of information learn through observing machine actions:

> *So, you learn how to interact with them... Figure out where the dump spots are, where the digger is loading from, and you just watch your screen to make sure they are going in the path, and you can move out of their way.* [P12]

Most of the truck activities were reported to be fairly structured. As a result, the trucks would not do much other than what was instructed. It was reported that there are always human decisions underlying why driverless truck do what they do. There are also different reasons why trucks slide out of their lane. Participants identified that birds were being detected as objects, which was leading trucks engaging the emergency brake. What was also surprising to participants, were driverless trucks trying to correct themselves. When faced with a wet road, driverless trucks will make every effort to remain on the centre line. The permission-based control system also enables two trucks to use an interaction at a time, which was never permitted in a manual operation. Despite participants observing practices that they had never seen before, once they had learned the parameters of the system, it had answered a lot of unanticipated situations.

3.2.3 Trust levels did not waver after incidents or unanticipated situations

Trust towards driverless trucks never wavered for the majority of participants. The participants reflected on incidents involving driverless trucks and explained how humans had instructed trucks to perform those tasks. Since the truck was only performing what was instructed, participants noted that their trust did not waver after such situations. What was even more profound, was that fact that some participants had increased their level of trust upon having the situation being explained:

> *When I found out it wasn't the truck's fault... it wasn't technology's fault, it was human error. So that just reiterated to me that I still had full trust in the system.* [P23]

The trucks only perform what has been instructed; therefore, the logic appears to be relieved of the consequences. As a result, with a person identified as the fault, participants found themselves comfortable with the actions of the computer. However, there were reports of participants becoming warier after being involved in an incident. Not necessarily with the system itself, more towards the clearing of objects and questioning the virtual representation. By developing a basic understanding of the safety features, participants were able to build a level of respect for the system. The experience of

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working long enough with the system establishes a level of knowledge for what a truck will and will not perform. For some participants, it has been a journey of watching the technology evolve overtime and ultimately improve.

Trust for a driverless system is reinforced when compared to manual truck operations. Participants reported truck drivers turning in front of them in a light vehicle in manual trucks operations. With people sitting in a truck for long periods, the risk is considered a lot higher:

> *I've always felt comfortable with them. Because I've had issues where people and trucks have pulled out on me when you least expect it. Because of the predictability of the AHT's, I've never really had those moments.* [P15]

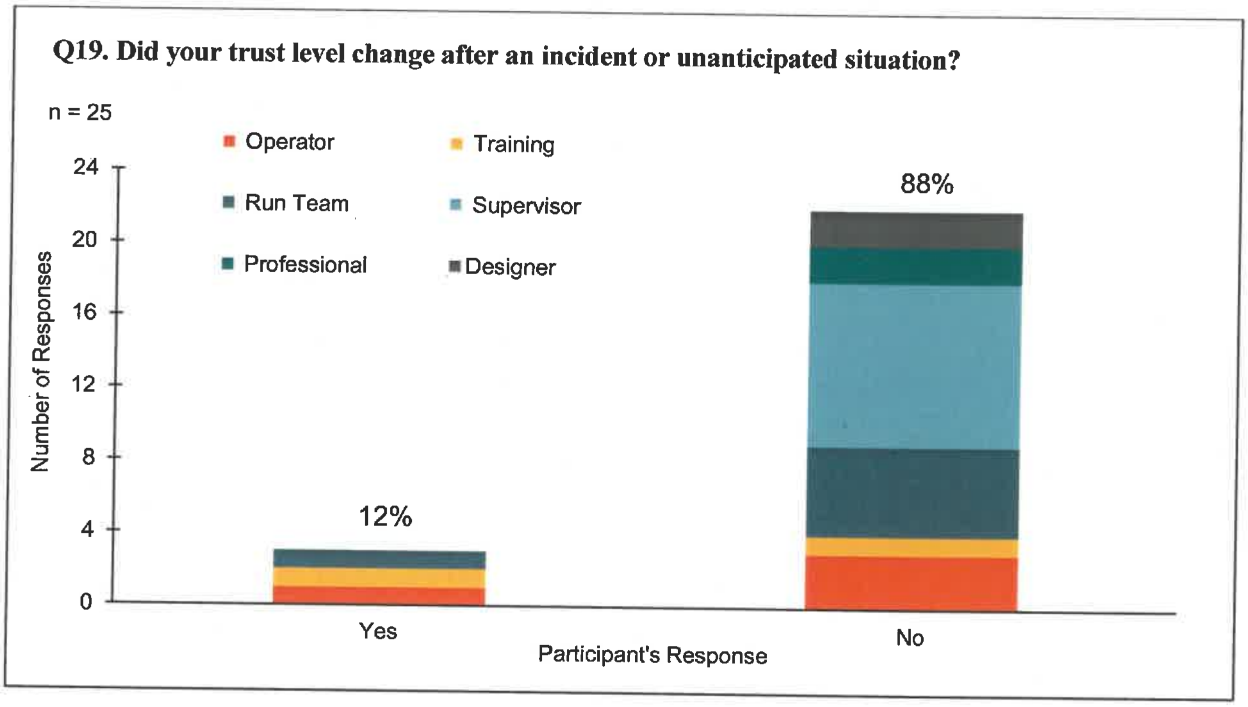

Figure 4. Responses to question whether participants' trust level changed after an incident or unanticipated situation. Data collected through one-on-one interviews

Providing an allocated pathway in the system has meant that participants avoided similar experiences in manual. For example, when approaching an intersection, the in-cab display indicates the intended path with blue coloured lane. This predictability results in people building trusting the trucks knowing what direction the truck is travelling. Some participants admit extending too much trust to the system. It is generally believed that the truck is built to keep people safe, with experiences reported that they had never faced a situation where a driverless truck has performed something they did not anticipate.

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3.2.4 *Informing personnel of what mode or function trucks are performing*

When asked when the systems inform personnel of what mode or function trucks are performing, the participants responded favourably (n = 24). Blue lanes on in-cab displays were reported to indicate that trucks travelling in autonomous mode and their direction. When approaching a driverless truck, the mode lights located on the side of the truck indicate the machine's mode. Combining the visual reference with the virtual mine model, participants noted that personnel could identify what is around the truck and foresee potential interactions. More in-depth screen displays provide supervisors and run team members with diagnostics details and the performance of the fleet. When mode changing trucks, the lights change colour and flash to indicate the change in modes. Additional real-time information on in-cab displays highlights scripts and zones that can influence the function of the truck. It is in dumping and loading (dynamic) areas where participants experience surprises:

> *Sometimes they drive off by themselves. The controller didn't know what was happening. We put in a delay to have a clean-up, and it just backed itself up the ramp and took off.* *[P5]*

A dynamic area allows the trucks to utilise the space to reverse into the loading bay. On haul roads, participants reported that determining what the truck is performing is relatively clear. The blue light indicates the driverless mode and the blue lane identifies where it is heading. However, when in manual mode, a predicted pathway is not provided, requiring personnel to switch back to conventional priority rules. It was noted that at times mode lights could be challenging to change, which was described as a communication issue that can difficult to switch between functions. However, when asked whether the system informs personnel, one participant put simply:

> *It's blue, flashing blue, it's in autonomous mode. It's lifting its tray, it's dumping, it's backing under the digger, and it's going to get loaded.* *[P15]*

There was only a single participant who reported that the system does not adequately inform them. In contrast to observing mode lights or learning the repetitive elements of the haul cycle, it appeared the operator expected some level of feedback on what trucks are performing. The level of detail displayed on in-cab displays is dependent on the role, which manual haul class and ancillary equipment do not have. Despite this, there was personnel who considered the information adequate. For run team members, the status page provides additional functional information:

> *It tells you exactly what state the trucks in. Whether its travelling loaded, travelling empty, dumping... spotting at a dump, spotting at a digger, queuing... it tells you exactly what it is doing all the time."* *[P24]*

There are truck tiles that are coloured green, yellow or red, which indicate the health of the machine. Since the system was reported to log everything, system-based roles can see real-time modes of the entire fleet. The system is said to highlight what needs to be address and what is happening in the system. However, this is providing that personnel understand what they are looking to obtain.

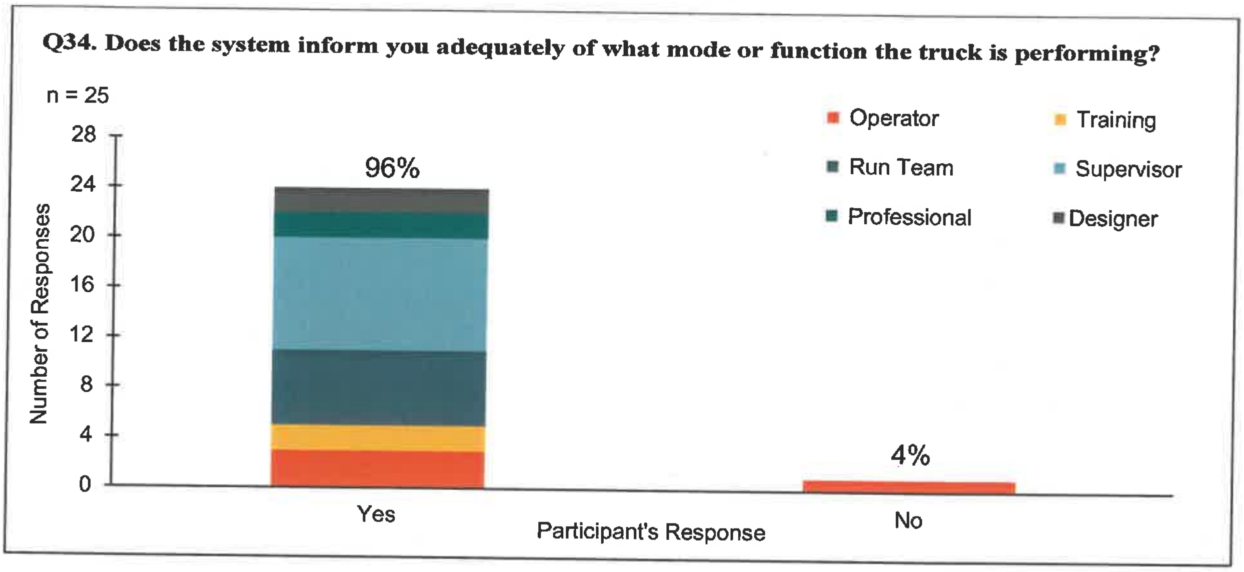

Figure 5. Responses to question whether the system informs participants of what mode or function a driverless truck is performing. Data collected through one-on-one interviews

The mode lights provide additional meaning, including communication losses that result in mode lights turning green. With the added benefit of a status page, participants reported that they are informed of what part of the cycle each truck is performing. Whether it be travelling empty, loading at source or dumping at the crusher, the information is available. Moreover, if a truck is facing issues such as wheel slippage, the system will highlight that this is occurring. In addition, the system is reported to display mechanical problems and increases in the truck's tyre temperature. When the truck is on delay, the truck icons turn grey to highlights that production is suspended. It was noted that a truck could only be in one of the five aspects of a cycle, which makes it easier to determine what the truck is performing:

> *... yeah because it's in, like travelling, spotting, loading, dumping, you know it's a cycle that it's in. It's only them five or six cycles that it can be in. So, you know which states it's in, and whether its autonomous or in manual mode."* *[P23]*

The data that indicates how many tonnes are on a truck, informing personnel whether the machine has been loaded. The real risk, however, was whether there was too much information for people to process to remain in-the-loop.

3.2.5 Driverless trucks may perform tasks that were not instructed

Participants reported that trucks had performed tasks that were not anticipated:

> *Yes, go the other way, without me seeing. Take a load of waste to the longest waste dump because of me not closing a particular dump off or taking a different route that I didn't want it to.* *[P8]*

They reported that if a truck is instructed to do something, it will just go ahead and do it. Rarely, that group argued, has a truck ever performed something that was not expected. A truck was more likely to do nothing than do something that was not instructed. To some participants, driverless trucks are the perfect truck driver:

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To me, they are the perfect trucky... If it went there, but it was supposed to go there, but I assigned it to go there. It's not the truck's fault; the truck's only doing what it got told to do. *[P13]*

In the participants' experience, if a truck is instructed to do something, it will go ahead and do it. A participant experienced a situation where a truck breached a windrow. It was noted that this occurs when the windrow is detected as an object. To the person clearing that object, there appears to be no obstruction to get to the windrow. However, since reverse locations can be mistakenly placed behind windrows, and if cleared, the truck will attempt to reverse over the windrow. There were also other examples experienced in the excavator, where pressing the incorrect button led to trucks parking out on the pit floor. The automated system can be re-assigned to perform a task numerous times; however, if old assignments exist, driverless trucks can difficult to direct:

We sent it out of the fuel bay. We sent it to go to park up in one of the park up bays. Done another loop again, come back around and parked up on the other side and sat there looking at us... It's done it three times before we got it to where we wanted it to go... *[P4]*

The participant explained that it was later identified that personnel had previously attempted to instruct a truck to the fuel bay. As a result, old assignments existed in the background and were being executed before performing the new instructions. In addition, trucks may hang onto scripts when the crusher light turns red as the truck is reversing into the bay. Trucks have then tipped shortly after being instructed to move forward away from the crusher bay. Participants reported that unanticipated situations could be glitches, rather than a truck performing different tasks. In contrast, trucks that take longer routes for no apparent reason are said to be recalculated routes after multiple stoppages, which increase the average travel time on main thoroughfares. More often than not, however, participants noted that a driverless truck is likely to remain stationary than perform something different.

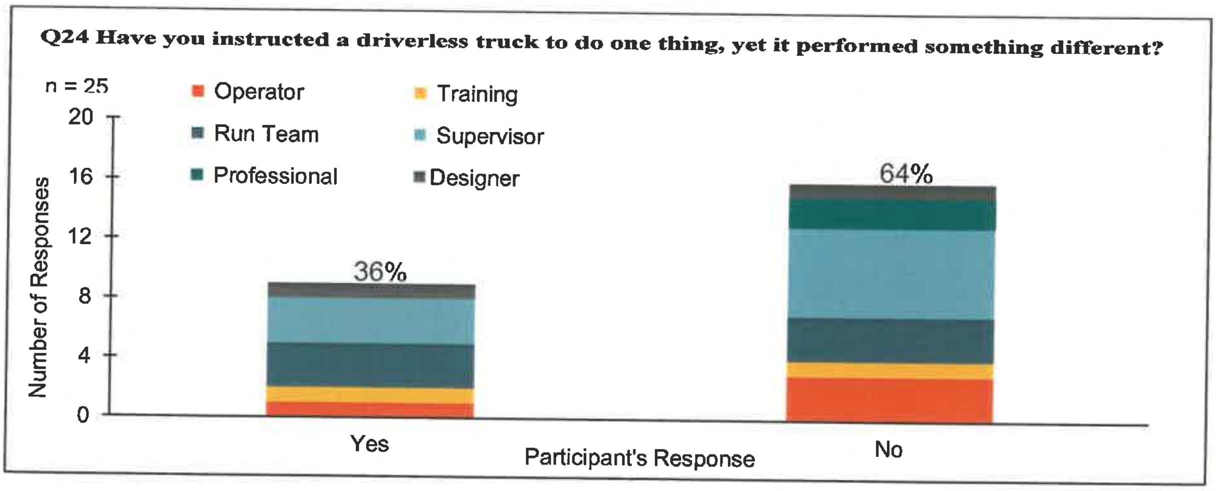

Figure 6. Responses to question whether participants have instructed a truck to do one thing, yet it had performed something different. Data collected through one-on-one interviews

3.3 Driverless trucks player their role, yet are not necessarily team players

3.3.1 *Team play*

Driverless trucks were described as the workhorse of the operation. To be a team player, however, participants noted that the correct goals and inputs must be provided to enable the system to succeed. These reports highlight how reliant the system currently is on human contributions. When describing whether the trucks are team players, participants explained how much harder they work than truck drivers. Driverless trucks perform what personnel want when they want it. Despite various responses, a majority were positive in how the fleet act as a unit. Yet, it was expressed that it would be nice if the trucks helped each other out. For example, if an object was already cleared for one truck, that information is not passed on. Therefore, the system does not learn from its experiences like truck drivers. Although participants described them as hard-working, the system also showed signs of independence, described them as being 'tonne hungry'. Driverless trucks were reported to drive as fast as they could and move as much material as possible:

> *There are no toilet breaks, no meals breaks, no hot seating, no crib breaks. They come in for a bit of fuel once a day, and away they go... They just do what I asked them to do, and they don't talk back.* [P11]

Driverless trucks were also described as performing tasks relatively the same. For example, if a speed or traction zone were put in place, every truck passing that zone would reduce their speed. Given their discipline to controls and instructions, participants highly regard their ability to play as team players. Participants noted that the trucks follow through with instructions when given to them, grinding away as their key player.

Despite the positives, there were, however, situations where participants observed literalism from the system. Driverless trucks may work hard, yet they focus on moving the dirt. Therefore, despite what is on the daily plan, trucks drive to loading units moving the most material. The driverless system is said to be geared towards utilising the most productive machines. If trucks are not overseen, the system only focuses on moving tons:

> *Like I said, if you give it the options, or if you know how to control the options you give it properly, it will play your game. But, if you let it do whatever it wants it to do, it will play its own game, and it's a production game.* [P20]

Although driverless trucks can move material quickly, some participants highlighted that they have to reign them in. Otherwise, the system will transfer material that personnel do not want to move. The control room is aiming to move material as per the plan; this can be at odds with how trucks are designed. It was argued that personnel need space to move the fleet freely between sources and destinations. Although they are primarily considered team players, they were not necessarily viewed as the captain. Instead, they fulfil the role of a half back, who would remain present before and after the game. As personnel learn to work them, participants noted that the relationship was improving. With the intricacies and complexities of such a system, a participant argued that it is bound not to work. If driverless trucks do not receive the right inputs, participants noted that driverless technology could not be expected to perform:

> *Well, it's not the system that changes, there's inputs... If there's a change in the priority, someone has to input that into the system, that's just basic. It's not artificial intelligence, it's just a system that we tell what to do...* [P15]

3.3.2 *Participants are confident in redirecting or overriding obstacle detections*

Depending on the participants' role, various experiences were shared with redirecting and overriding obstacles. Supervisors and designers were the most confident, given that they both have high levels of knowledge and information. Knowledge is coupled with field time, validating the virtual mine model with what is being observed. Participants reported that specific training is required to direct truck, which also comes technical in-cab displays. When it comes to clearing objects, every person was suggested to be capable of performing this. Despite this, some participant experiences tested their level of confidence:

> *The truck picked up the windrow, come up with an obstacle, I cleared the obstacle, and then the truck climbed over the windrow to get to where it was going.* *[P23]*

Although there was a high level of confidence across the participants, intervening is highly dependent on whether the foundations are in place—for example, the physical world matching the virtual system. Upon experiencing a situation where a truck breaches the boundary, it appears that participants were far more cautious in their approach. Despite this, participants still recorded a high level of confidence. The main reason for this was the driverless systems' adherence to instructions:

> *Well, they just do what I ask them to do mate, and they don't talk back, so yeah. [P11]*

Since the truck is only performing the instructions given, participants maintained that the trucks were not at fault. The reason why the professionals' confidence level was much lower was purely from a frequency perspective. With the majority of the participants' confidence levels being so high, it could be argued that their trust levels were also high. Given the participants' experiences in some incidents, it was noted that the task must also be performed within strict guidelines. Otherwise, personnel could find themselves experiencing unintended situations.

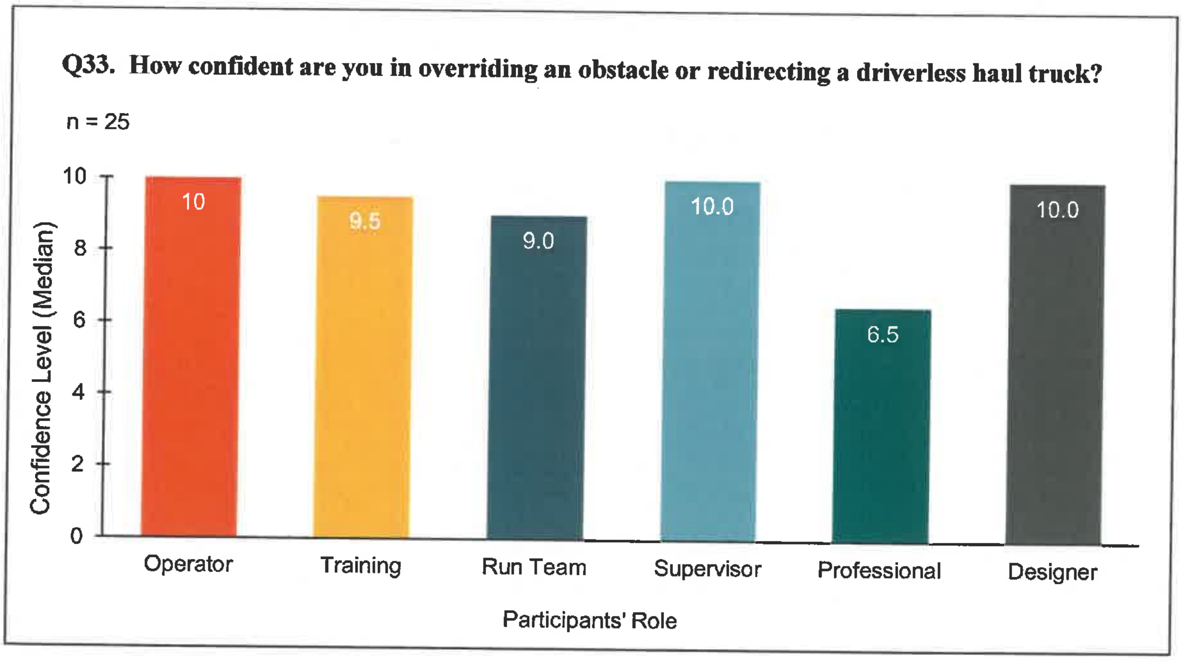

Figure 7. Median confidence level out of 10 towards the driverless trucks by role. Data collected through one-on-one interviews with personnel on mine site

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4. DISCUSSION

The study reflects similar experiences of humans interfacing with automated systems in high-risk industries (Billings, 2018; de Vries, 2017; Frohm et al., 2006). Study participants noted that new hazards and risks were presented through the introduction of driverless trucks. Despite this, participants developed a higher level of trust through observing predicted travel, diligent truck reactions and compliance to instructions. However, the high levels of confidence could be linked to the complacency contributing to driverless incidents.

New hazards and risks associated with driverless haul trucks were reported in the interviews. Driverless trucks require communications to operate; however, if those communications are lost, the sudden braking that occurs can cause trucks to slide. Moreover, the mismatches between the virtual model and the real mine resulted in trucks breaching windrows after objects were cleared. This experience reflects the literalism and opacity that comes with automation (Billings, 2018; Wessel et al., 2019). When it came to who was responsible for incidents, participants reported that humans were making the main contributions. The main reason was that the system was considered to be performing what it was instructed to do. A truck reversing over a windrow, it was noted could be cleared by a human to achieve a dump location place behind the windrow. However, the feedback loops and the transparency of the system need to be considered (Dixon et al., 2007; Parasuraman & Manzey, 2010). When verifying reverse objects in the field, there can appear to be no obstruction between the truck and the windrow. Yet, it is the windrow that is identified as the object. As a result, the object is cleared, and the truck passes through the windrow. In this scenario, humans are required to check the physical location against the mine model. Since a high level of trust that has developed, it appears humans do not anticipate that a truck would reverse over a windrow, even if there were potential mismatches.

A high level of trust had been developed towards driverless trucks by them only performing what was instructed. However, this trust could also be leading to a reliance on automated systems (Parasuraman & Riley, 1997). This comparison was made to the manual environment, where it was difficult to determine where a truck driver was heading. When it came to driverless trucks, the intended pathway on in-cab displays provided a level of transparency on the trucks' intentions. Predicted pathways removed a lot of anxiety for smaller equipment operators with manual trucks frequently turning in front of them, which increased their level of confidence. In addition, when dump or load location is set, driverless trucks reversed to that exact location. Manual trucks, in this instance, were reported to present a higher risk of reversing into excavators. More importantly, the additional concentration requirements to drive a truck for 12-hour shift. Despite being involved incidents and unanticipated situations with driverless trucks, a majority of participants' trust level did not waver. Therefore, the findings highlight that high levels of trust could be maintained if it can be demonstrated that driverless trucks performed what was programmed.

There were driverless observed performing tasks that were not anticipated. However, this was highly dependent on the persons' role and experience, which was realised in the operators' response. An operator has less detailed information on their screen interfaces, whereas supervisors, run team members and professionals had access to diagnostic and the assignment engine pages. These roles have the option and time to analyse the background information relating to performance. Therefore, the performance is matched to the mode or script at the time and increased human awareness of automated features (Björklund et al., 2006; Feldhütter et al., 2019, August 26-30). There were, however, participants in those roles that were surprised automation. Predominately, this experience was to do with algorithms and fleet management, which has featured in the surprises in the past (De Boer & Dekker, 2017). These results highlight that in-cab display information for operators could be improved, with additional explanations and training in the algorithms influencing the assignment engine.

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Participants reported that the system informs personnel of what mode or function a truck is performing, which is in stark contrast to other industry experiences (Feldhütter et al., 2019; Sarter & Woods, 1995) More specifically, the participants alluded to the mode lights located on the side of the truck. In addition, the blue lanes highlighted the truck's intended haul route reinforced that the truck is in an automated mode. Despite haul routes, there were operators surprised by the movements of driverless trucks in the loading area. Automation enables the trucks to generate a path, which can shift from one side to the other, depending on the location of the excavator. This situation had resulted in increased proximity detections due to operators being surprised by the trucks' presents. Operators are driven to observe their in-cab display more frequently to monitor the truck lane generation. This practice was a learned skill that was developed to avoid interactions and remain in-the-loop.

Driverless trucks were reported to perform something that had not been instructed rarely. Participants argued that the trucks are likely to do nothing than follow instructions. This response also underpins why a high level of trust has been extended to the system. In addition, there is no debate on whether the decision is an appropriate one, merely performing the task anyway. Participants reported that although trucks may deliver something that was not instructed, there are usually additional assignments or algorithms influencing in the background. This was highlighted in the fuel bay and more extended haul route examples when participants elaborated on what they had observed. Since driverless trucks were considered the workhorses and mostly team players, the trucks performed instructions when personnel wanted it, when they wanted it. Yet, when participants reflected on whether the trucks were team players, it was noted that they do not assist others in performing their tasks. In particular, when one truck had an object cleared safely, 5 minutes later, another truck could identify the same object. Although the trucks play their role and work hard, the experience reveals the narrow focus on automation to perform nothing else (Christoffersen & Woods, 2002; Klein et al., 2004). There was confidence in redirecting or overriding obstacles detected by driverless trucks. In particular, participants knew that despite what they performed; the trucks would only work within the confines of their parameters. Despite the belief that the trucks would never do something unsafe, the fact virtual and physical distinctions exist presented actual risks that any instruction could be taken literally (Billings, 2018). The difference means that although a person physically observes the edge of the windrow, the virtual system reference point may be further back. Therefore, the truck could perform activities based on the virtual mine model, not the physical representation, resulting in unintended consequences.

5. CONCLUSIONS

The research highlights the perspectives of mineworkers surrounding risk, trust and teamwork. New hazards and risk were introduced through automation, including virtual-physical world distinctions, communication losses and operator complacency. Humans were considered to be contributing to workplace incidents, which was explained by the belief that driverless trucks only perform what has been instructed. Therefore, despite the introduction of new hazards and risks, a high level of trust developed with driverless technology. High confidence was underpinned by predictable haul routes, adherence to instructions and diligence for stopping for small objects. More importantly, the trust did not waiver after participants had been involved in a driverless truck incident. The driverless trucks were considered team players concerning the execution of their role. However, when it came to assisting other teammates, the participants reported that the technology simply remains focused on its purpose. As a result, the system does not engage in team play to work as a team to resolve localised problems. The localised problems created situations where personnel needed to override or redirect the driverless fleet. Despite the confidence of participants in executing those adapting, human intervention has contributed to incidents involving driverless haul trucks. The response did not intend to result in

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unintended situations; however, the experiences have highlighted the consequences of introducing automation. Mineworkers experiences demonstrate the presents of new hazards and risks, as the dynamic of the human-machine relationship unfolds in trust and teamwork.

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