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From truck driver to systems engineer: transforming the human contribution

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Role transformation.
Human-machine interface.
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Mineworkers.
Residual workload and local adaption.

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 transitioning to driverless truck operations. The study aimed to investigate the role transformation of mineworkers, their residual workloads and local adaptions when working with automated systems. A sample of 25 employees, from a WA mine site, were interviewed face-to-face on the research site using a mixture of open and close-ended questions. A comprehensive understanding of the risk perspectives was developed through a convergent parallel design. Multiple cases were analysed thematically through cross-case displays, utilising complex reasoning to accommodate the emerging themes. Participants reported the introduction of new roles, while conventional roles were redefined. The residual work included building virtual mine models, clearing detected objects and calling trucks into the loading area. Although truck driving drastically reduced, new technology and computer-based skills developed. The results confirm that haul truck automation transforms mining roles, with residual tasks that require local adaptions to overcome non-designed situations.

1. INTRODUCTION

The introduction of automated technology marks the beginning of the replacement of truck drivers for machines. This alternative intends to substitute driving activities that have been reversed engineered into a computer. Engineering maturity has enabled mining haul trucks to drive from A to B, which appears on the surface to be performing the task like a truck driver. What is not always visible are the inputs and local adaptions that make driverless performances possible. Local adaptions fulfilled by residual roles help the technology through non-designed situations. Despite recent reports of mineworkers removed from the mining operation, there are still routine and adaptive tasks performed to make driverless technology a reality. Therefore, there is a real need to understand the transformation of functions and skills required to complete tasks post-automation.

Driverless technology requires numerous data inputs to perform, with goals and fleet allocations determined at the start of the shift. Not only must the technology be pre-programmed to perform truck driving tasks, but the system-based role must also provide instructions on what material is to move.

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Material movement includes the tonnes required from each load unit and associated destinations. For this to occur, the driverless system requires a virtual mine model to operate. Driverless trucks need these data points to compare incoming LiDAR, radar and GPS data with the virtual model. The mining model contains travel lanes, intersections, active mining areas, exclusion areas and speed zones. These digital aspects must be computer generated and designed by new formed roles, which then physically verify data in the field. Once the model is available, the driverless trucks can operate within that model, providing it has loading sources and associated dump locations. From there, the system can generate truck assignments between those locations. Within the cycle, a truck may be confronted with an object in the lane, which requires a human to clear. Those objects can be centre dividers that are not surveyed, wildlife, spillage or vehicles that lost communications. Trucks may also lose connections, which requires the machine to be recovered by humans. Once the haul truck arrives at the loading source, the excavator must call the truck into a loading bay designated by the operator. The operator must then press a button when the truck is fully loaded. The driverless machine can then travel at full speed unless restricted otherwise by speed zones. For example, a speed zone may be in place near potholes or slippery roads conditions from a downpour of rain. These are just some examples of the types of inputs, which locally adapt to the changes and complexities in the practical constraints of a mining environment.

Through the substitution of personal work for a machine, research has investigated the repercussions of residual tasks on humans. Leftover jobs are often unspecified and require human supervisors to overcome the situation (Dekker & Woods, 2002). Furthermore, automated systems can provide little feedback on what is happening and rarely offer a safe way forward (Reason, 1990). Therefore, not only is the human suddenly reintroduced back into the control loop, they must determine how to safely proceed within the confines of the system's design (Banks & Stanton, 2016). Automation may not even hand back control, functioning beyond the parameters that requires humans to take control (Endsley, 2019). Therefore, double-binds can emerge, where humans may intervene to create an incident, or fail to intervene to allow an incident to occur (Dekker, 2003). The human is therefore, monitoring the performance of the system, with skills in performing designed tasks, yet developing improvised skills only in times of malfunction.

More recent studies analysed the role of humans in self-driving cars (Fridman, 2018; Wessel et al., 2019), yet these findings are vastly different from a haul truck with no safety driver. Despite recent guidance and warnings surrounding driverless haul truck technology, there is little understanding of the transformation of support roles (Department of Mines and Petroluem, 2014; 2015). The original assumption was that the replacement removed the human contribution (Glover, 2016). However, when comparing residual human tasks across various high-risk industries, it is clear that human tasks and skills continue to play a significant role (de Visser et al., 2018; Lewis et al., 2018). Those skills include computer interfaces and data outputs to monitor the performance of the system (Sarter et al., 2007). For the mining industry, this represents a significant shift for operators who may never have used a computer before. In addition to learning new skills, existing conventional techniques can diminish overtime (Billings, 2018; Bravo Orellana, 2015). These techniques can include driving haul trucks or operating an excavator without an in-cab display. Therefore, it is evident that there is a need to explore the roles and skills changes that may be transforming the human contribution.

Research in aviation and manufacturing have analysed the residual tasks post-automation. Remaining duties include activities that designers are yet to automate. As a result, they are rarely conceived and developed with humans in mind (Reason, 1990). Human-centred approaches have advocated in designing human tasks that are leftover (Billings, 2018; Fridman, 2018). The design adopts skills and attributes from multiple disciplines, promoting the interests of humans in a joint system approach.

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What occurs, in contrast, is that the machine becomes the primary focus—optimising the pre-conceived ideas and efficiencies of the designers' one-best method, limiting the exploration, cooperation and learning capabilities (Giacomin, 2015). The workload can, therefore, be a residual set of tasks that are short and intensive, followed by long periods of inactivity (Ferris et al., 2010). After periods without activity, suddenly people are reintroduced to recover the system from failure. Research is yet to explore these experiences in a driverless truck operation, given that driverless technology is in early development in the mining industry.

The purpose of this research was to explore the role transformation of mine workers through the introduction of driverless technology. Face-to-face interviews were conducted on the mine site using semi-structured questions. The quantitative and qualitative aspects of the issues enable the research to gather the perspectives and lived experiences on the mine site. Data from the interviews were transcribed and analysed individually, then synthesised in themes to represent the participant views of the transformation.

2. METHOD

2.1 Design

A convergent parallel designed was used to develop a comprehensive understanding of different risk perspectives (Creswell & Clark, 2011). Multiple reasoning accommodated theory inductively for emerging themes and deductively for testing and validation. The process worked back and forth until data saturation and research significance were achieved (Creswell & Poth, 2017). The interview data were compared and contrasted for grouping and allocation of themes. Quantitative and qualitative methods were mixed to strengthened results by quantifying 'Yes' and 'No' responses. Quantified data was supported by the context and explanations contained in the qualitative data (Creswell, 2014a). The multi-method increased the likelihood of making empirical generalisations about the phenomenon, measuring qualitative variables and contextualising the quantitative aspects. The research did not attempt to over-generalise the population, therefore supporting each inference with distinct experience when concluding. This approach preserves the inherent complexity of each lesson by maintaining social context, with the raw expressions and perspectives on the transformation of roles (Miller & Crabtree, 2005).

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 a 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.

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2.3 Data collection

Interviews were digitally recorded on audiotape and took appropriately 45 minutes to 1.5 hours to complete. The duration depended on whether the participant elaborated on their experience relating to each question. Participants participated in interviews between January 2018 and February 2019. The interviews were conducted on the mine site itself and were held within a quiet room. Each meeting was digitally recorded and transcribed by one of the researchers verbatims.

During face-to-face interviews participants were asked to describe their role and whether it changed through automation. Participants elaborated on how it changed and what activities need to be completed. Moreover, each participant was provided with questions surrounding the workload of support roles, remedial actions, interpretation of system information and understanding of the systems' modes and features. Understanding local adaptions had participants asked whether they had confronted situations beyond procedures. Furthermore, how people remain in the loop with what is happening. The decision-making to determine whether to intervene or not when something does not seem correct. The set of questions (Table 1) remained consistent for all participants across the stratified sample.

Table 1: Interview questions specific to role, workload and adaptions when working with driverless haul trucks.

Topic	Question
Role transformation	– How would you describe your role in the driverless operation? – Did your role change through the introduction of driverless trucks? – Have your skills changed or diminished through the introduction of driverless trucks?
Residual workload	– How would you describe the workload of system-based roles that support the driverless operation? – Are there activities that need to be complete because the driverless system is limited in what it can do? – Have you ever misinterpreted information that was given to you by the driverless system?
Local adaptions	– Have you ever been faced a situation that required you to think outside of a process or procedure? – How do you remain in the loop with what is happening in the driverless system? – How do you determine when to intervene or not when something doesn't seem right?

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).

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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 the emerging 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 factors (Onwuegbuzie & Combs, 2010). The 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 Curtin University Research Ethics Committee (HRE2017-0844) approved the study to be undertaken. The participants were all provided with written and verbal information about the study. Participants provided written consent to participate in the research and given to opportunity to choose the interview location. The interviewees assured that interviewed records were kept confidential, with the participants able to stop the interview at any time.

3. RESULTS

The findings of mineworkers' roles transformations were synthesised under three main headings. Those three headings include; the role changes through the introduction of automation, the residual workload and the local adaptions that occur to assist driverless trucks in non-designed situations. The headings describe the workers' primary response to the question of their thoughts and personnel experiences.

3.1 Role changes through the introduction of automation

3.1.1 Role description

Participants' role descriptions ranged from loading trucks to monitoring the performance of the system. Professionals developed reports from the system to analyse truck performances. The analysts work attempts to understand truck cycles and associated delays. The information was used to educate the operation on how to optimise the automated system. Training roles described their position upskill operators to transition from the manual to driverless truck operations. The upskilling involves teaching the additional layers and processes associated with automation. For example, setting a loading location and how to direct a truck into the bay. Therefore, people are taught how to react to a situation and how driverless systems are likely to respond. The activities that were described be more involved:

> *Quite a lot more involvement with the trucks from an autonomous standpoint, for a digger driver. You've got to put in spot points. Make sure you've got one called all the time. Make sure you're always thinking three or four trucks ahead as to where the truck is going to be…*
> [P4]

The most challenging component of this was explained to be the shift in responsibility. In particular, the operational and spatial awareness to be successful in those changes. An excavator operator, for instance, previously loaded trucks, maintained the bench and pulled batters. The introduction of driverless technology, however, introduced additional buttons and screens to interface with driverless trucks. When it comes to controlling the fleet, participants highlighted how they closely monitor the fleet to ensure machines perform as expected. The assignments are monitored to ensure the fleet is cycling through the loading units:

> *Mainly just watching the trucks. So just making sure that they're doing what they are supposed to be doing. Their assignments, their cycling through the diggers correctly, going to the correct dumps. Those sorts of things, yeah.* [P7]

Mine controllers described their role as directing the fleet across the mine in the most efficient way possible—the trucks controlled from a central location, which manages 25 machines for every control room operator. In comparison, machine operators are in charge of a single area. As a controller, one person can be responsible for multiples areas at any one time. Therefore, maintaining positive communication has been described as crucial step since truck drivers were removed. The daily plan, compliance, production, safety, and emerging issues all need to be managed. When breakdowns occur, the fleet is to swap around to maintain operations and completed manually. Controllers utilise field-based personnel to provide physical dump locations, including the validation of the virtual mine model to suite the physical mine:

> *All your processes, you got to ensure your onto your builders and make sure you've got somewhere for the trucks to go. The system at the start is pretty overwhelming; it's really complicated. But once you sort of figure it all out, it's pretty simple.* [P9]

Participants described how automation forced improvements in road compliance. Road compliance involved maintaining road standards, intersections and windrows. Additional technology layers require design standards to reflect the mine model. Virtual models that do not reflect the physical world creates risks and extra work for humans. Where a manual truck traditionally drove around road spillage, driverless systems identify the spillage as an object. However, the practice increased compliance as those conditions were unlikely to be raised by truck drivers. Production technicians attend to object that are identified in the field since driverless trucks are unable to classify objects. The role monitors and supervises truck cycles, mode changing machines and undertaking tasks that automation cannot perform:

> *Mode changing, manning them up when we had to go manned, to take them to the workshop, clearing obstacles. If we had to do manual tips, or refuelling... Taking care of the trucks, while not being in the truck.* [P11]

Wheel dozer operators keep the dumps pushed and the loading floor clean for driverless trucks. Areas around the crusher are maintained to remove built-up material that could be identified as an object. Despite a virtual model, physical dividers exist for separation and protection in the mine. More importantly, to prevent manually operated equipment from cutting corners and colliding with other machines. Supervisors monitor the performance of the truck system and oversee the mine plan to ensure the operation is meeting site targets. Since a large workforce remains, a significant portion of the supervisor's work is verifying the work that operators perform. Some tasks need to be allocated to people to provide an environment for automation to operate. As a result, verifications are frequent, and operators supervised to validate the entire system. Not only do supervisors oversee the work, but they also authorise to control trucks and build virtual models, playing a role in every discipline to ensure people have the tools and information they need:

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I do quite a bit of running around to make sure that people are getting the knowledge they need and helping them to perform their role properly. [P20]

The supervisor role described as being a role between every function. Communicating inside the control room and having a close connection to the pit. The pit described as being heavily reliant on the decisions that are made in the control room. Field roles require the virtual mine model to be build and maintained. Therefore, system-based duties are critical to running a driverless operation:

Without our role, the trucks don't run. So, we build all the road networks, all the dumps, get them into the digger and park ups, that sort of thing... We got to update surveys, make sure the trucks can do their thing. [P23]

The most crucial task is making sure the virtual mine matches up to the physical mine. It is identifying hazards or situations that could damage trucks or put personnel in danger. Therefore, new roles monitor and compare the model to validate against physical intersections, corners, ramps and dump locations.

3.1.2 New and transformed roles

New roles were explicitly designed for automation, while others transformed. Those roles included analysts and system-based roles, while conventional roles upskilled with new interfaces. Analysts taught themselves how to get into the system to understand automation. The data is analysed while replaying the actions of the machine. What has changed is the quality of data that comes with automation. Everything a driverless truck performs recorded and stored somewhere in the system, much more than a manual haul truck. Therefore, there is more to analyse and understand the technology-based layers. Similar experiences were shared with excavator operators, with far more involvement in how trucks enter the loading area:

Now you've got to put in your spot points, make sure you've got one called all the time. Make sure you are always planning 3 or 4 trucks as to where the trucks have to be and where its gotta go... looking at floor conditions, bench conditions... yeah, it's quite involved. [P4]

The most challenging component has been developing peoples' spatial awareness. Participants described having to think a lot more about their tasks. The trucks may be automated, yet they require humans to provide additional instructions in certain situations. This required manual equipment operators to learn how to plan for upcoming machines and how to coordinate them safely:

Yeah, you've got to plan where you want those trucks to a certain degree, but you just hang your bucket there, and the trucks come. With autonomy, you know, you've got to progress your spot point, you've always got to be putting where you are going to put the trucks. [P4]

In a manual truck operation, truck drivers would reverse themselves based on the excavator's position. However, now trucks are driverless; the excavator operator needs to physically identify where they would like trucks to be loaded. Excavator operators described this move as a positive step, enabling them to take responsibility for loading the trucks. Participants expressed enables them to know exactly where the trucks are going to travel:

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Previously, Betty could back over one part, and John could back over another part. There was an element of doubt sometimes where they were going to go.

But now you know exactly where they are going to go with the lanes and stuff that is generated on the screens. *[P5]*

Participants described how the floor conditions must be kept smooth in driverless operation. If floors are rough, the obstacle detection system will identify objects and stop short of the excavator. The positive is that there is far more data is available through in-cab displays. However, the operators had to learn how to observe and interpret the information displayed on the screen. The screen provides information and functions that allows operators to control the fleet. Participants explained how comfortable they have become now they have been empowered to manage the fleet. Driverless trucks that end up in the wrong loading position were explained to be the operators' fault, now that automation follows the instructions given by the operator. The screen also provides information about what trucks are doing and when they are coming. Operators can identify a loading location before trucks even arrive, which did not exist in manual:

Whereas, with a trucky, well he is sort of stopping there, he's waiting, you know. 'Oh, where do you want me to go?' And you're like come on get under the bucket here; this is where I want you. No more of that, you don't wait for the trucky, you tell the trucky exactly what you want him to do. *[P6]*

For participants who previously drove a truck, they explained how they were either trained in other equipment or upskilled in system-based roles. Therefore, the experiences were vastly different depending on where the participants transitioned. Participants were either taught how to operate other machines with in-cab displays, developing the virtual mine model and controlling the fleet:

Definitely, yeah. So, I was just driving trucks before. Very manual. It was physically driving the truck, refuelling and doing all the tasks that are involved with that. And then yeah, now it's just like sitting behind a computer, more technical-based, keeping the fleet online, those types of things... *[P7]*

Despite the transition, some participants believed similar mining principles still apply in automation. They're also fewer people to manage within the operation, therefore managing crib breaks and hot seating arrangements reduced. However, participants noted that driverless systems are far more labour intensive than manual trucks. Where a manual machine would drive around broken-down trucks, driverless trucks will stop and wait. In addition, if a driverless system loses communications, it must be manually recovered and relocated to a safe location. These were the types of additional practices learnt. More importantly, some of the roles in the manual operation described as reasonably simple in comparison. Moving from operating equipment in a manual to driverless meant the introduction of computer-based tasks and practices. As a result, if personnel moved into a system-based role, there were more changes involved:

Loading trucks like in the autonomous world, because you then became the truck driver as well the load unit operator... And in the sense of pit tech (technician), yeah, we didn't require those in the manned world. So, it was a new skill, new role. *[P11]*

Participants described how there were more aspects to take onboard. For instance, mode changing a truck and recovering it manually when it broke down. Operators also had to be mindful where the

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machines were driving, given that the system could not determine the type of terrain. Therefore, load unit operators were responsible for guiding driverless trucks into their loading position. Participants highlighted how new starters used to begin driving haul trucks. Since there are no more trucks drivers, operators need to be upskilled initially on more complex machinery. In addition to learning equipment functions, they must also learn how to interact with the driverless trucks. Despite this, driverless trucks were described to be more predictable in what they perform, with lanes indicating the direction of a machine. Participants involved in the early stages explain how they had to learn the system prior to developing safety procedures and inductions:

> *Number one I had to learn the system. Number two, then I had to go and start writing procedures, processes and inductions for autonomous operations... Because we actually had upgrades every, you know, twice/ three times a year... so, therefore, it changed processes and the way we actually operated. So, it did actually change the way I moved around, well part of my tasks within autonomy.* [P13]

Participants reported how the training documents needed to evolve with the operation. Despite the manufacturer offering a system, the site developed their ways of working. With software and functionality, upgrades came better safety and engineering controls. When the system was upgraded, the processes needed to be changed. Therefore, the practices required a shift in the way the mine site operated. When the procedures established the standard, those practices eventually stabilised. However, automation had introduced levels of complexity within existing processes. In manual truck operations supervisors relied heavily on the control room. Now with automation, people can monitor the activity much more closely:

> *Manned relied a lot on control in Perth to run the trucks and run the system. And we just kind of overseen what they were doing and contacting them. Whereas now with autonomy, we can actually see for ourselves what's going on, where the trucks are going, where the dig units are. And we can help assist them with it.* [P9]

Supervisors previously managed a lot of hot seating arrangements. The task is now limited to excavator operators, with the people who remain. For supervisors leading the operation, participants described how there was not a lot of change for them. Primarily their role is to supervise people doing the work, so unless they are actively participating in tasks, automation did not change a whole lot for supervision. However, they must still drive vehicles amongst driverless trucks and follow all the new processes introduced. Before the final development, supervisors were far more involved until the residual roles evolved:

> *It definitely changed. In the beginning it was more around problem-solving and sorting and understanding the system. And then of course, as the system grew and as we grew as a mine site, it went more to the supervision of the people and delegating those other roles to the actual people that were doing it.* [P19]

As the system matured, supervisors were performing similar tasks—for example, pre-shift briefings, daily meeting and workplace inspections. Depending on what tasks people performed, some adjustments made in the way the tasks were executed. A grader, for instance, needed to change the way they maintained the road. Participants highlighted how graders no longer take control of their entire route; they must work in smaller sections to work in with the trucks. Similarly, with dozer operators working on the pit floor, operators need to work around the machines, rather than automation working around them. Therefore, for a supervisor, it was more about verifying that these tasks were performed correctly. Furthermore, there was more to confirm in a driverless operation, including load plans, survey lines and speed zones. Supervisors needed to adapt and plan their work through the system:

> *... you now have a lot more visibility. So, you can see a lot more without having to do the k's (kilometres) in the pit... You don't have to be running back and forward all the time. You know you still got to do your physical inspections, but you just don't have to be doing it 24/ 7...* *[P16]*

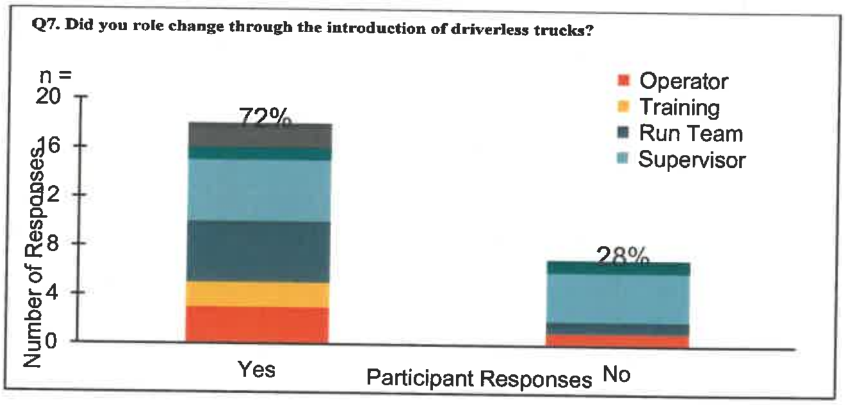

Figure 1. Responses to question whether participants' role change through the introduction of driverless haul trucks. Data collected through one-on-one interviews.

Personnel frequently described their role as being the eyes and ears for the operation. Despite trucks stopping if there was something wrong, the automated system cannot identify potholes or wet roads. Humans must intervene to slow the trucks down by putting speed zones in place. The control room requires in-field personnel to advise them of environmental conditions:

> *So that's the big change. Don't let the truck just do their thing... They might run through potholes. Like for example, now it's raining. The roads are absolutely buggered, but they will just go flat out until something breaks.* *[P23]*

The fact that people are dealing with the technology described to be a significant change. Personnel need to trust a computer, as well as their colleagues. The actions people make also impact on the decisions that are made by the machine. For example, anything that automation is instructed to do, the trucks will perform. In contrast, a human explained to question a lot more of the decision makings. Yet, the machines fitted with additional perception and object detection. Therefore, some people now validate those systems to ensure they are working—the system design tailored for people who like to be in control. The entire mine can be observed, including lanes and speeds within the mine. Most importantly, how to interact with a truck with no driver.

3.1.3 New technology and computer-based skills

Participants explained how the introduction of driverless haul trucks increased their skills. The base level of operational understanding remains, while automation took it to a whole new level:

> *The way I look at it is you know; this is the next level for operators. It's how they can use their current skill level and integrate it with a new technology.* *[P2]*

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Participants reported how people that apply the system are the ones who are more comfortable; they also work-in the system. The ability to interface effectively with automation explained as one of the differences. There was no doubt that some participants created new skills. Personnel now have to observe visual displays to monitor the virtual system. Some operators need to manipulate loading points and where they want the truck to go. The most challenging part is that the physical world may not always represent the virtual model. Therefore, skills developed to observe the screen and visualise where you want to position the truck. Work areas may be tight, yet the operator must be able to get trucks into narrow areas. Driverless systems need more room to maneuver, yet the adaptive skills are difficult to teach:

> *So, you've got to be able to imagine how you're going to get the truck in there and manipulate sometimes your spot points and all that sort of stuff to try and get the truck to come in and do what you need it to do. So it's definitely created another skill because you've got to think outside the square sometimes, you've got to load the truck where you wouldn't usually load a truck, or how you wouldn't usually load a truck, but to get a truck loaded you will just deal with what you've got to get it in there.* *[P4]*

Operators also explain how they must be thinking ahead of the game. The skill is changing boundary lines to give driverless trucks more space to operate. As a result, the excavator operator can avoid getting stuck in a corner and start to plan where they are moving to next. Its forward-thinking developing skills and working with the technology. Participants explained how personnel must want to be good at learning technology. Those who do not wish to excel simply are not interested, nor are they effective. People were reported to need time to understand how to interact with the technology. Participants did note, however, that frontline workers soon became reliant on technology. Reliance claimed to remove some of the abilities to excavate without a screen. In addition, the tolerances for loading a truck narrowed, where operators were more cautious with truck drivers behind the wheel. While dig patterns and wall compliance remained unchanged, it is the interface with the truck fleet where transformations occurred. Described as a learning curve in interfacing with computers and planning further ahead:

> *Yeah... changed dramatically. Like I said before I'm a basic guy, but you know learning these computer things I'm like wow... man, I didn't even lift up a pencil, I didn't even know how to lift up a pencil and write on a piece of paper when I was at school... For me, the autonomous side has sort of taught me you know how to be like a, what do you call those things? Not like a Pac-Man, Technoman...* *[P6]*

Learning how to interact with driverless haul truck increased the confidence of people in the use of the technology. Participants highlighted how they had purchased new technology on the back of learning screen interfaces at work. Learning the system and implementing their adaptions, refining their skills and improving their performance. Technology has opened new pathways and methods of thinking:

> *Well, you know in my mining career I've never worked with screens before, everything has been eyeballing. Use your eyeballs, and those are the screens you use. But you know, getting to know how to use the screens and how to use the system properly. I think that's the main thing, hey, the system.* *[P6]*

Driving haul trucks was described as a monotonous and unchallenging. More importantly, there were little problem-solving aspects in the role. Supervising a driverless fleet in the control room now offers

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controllers the opportunity to develop new methods. Conventional techniques such as refueling a truck may take participants a little longer they did before, however the skill is yet to diminish. For personnel already in the control room, participants explained how the fundamental skills were relatively the same. Automation simply added another layer onto their routine, with an emphasis on positive communication. A truck driver would previously enter a delay if the truck broke down—however, this is managed by a control room operator. The layer of automation introduced new skills in fleet management. The fleet management system taught people how to enhance truck performances through the virtual mine model. In particular, how speed zones and lane designs can impact on a truck's reaction. Computer interfaces inside light vehicles allow the system-based role to learn how to use a computer. The more people used this system, the more they learnt. With the ability to lift computer skills, personnel develop how to reduce and increase truck speed. Moreover, there are simultaneous activities needed to be completed at the same time. More importantly, learning what the trucks can and cannot perform, while understanding the boundaries in a safe environment:

> *One thing about autonomous is that it introduces new skills. It affects everybody in the pit and actually affects everybody as a whole... It affects water cart operators, affects every machine operator in the field; it affects all your mine controllers. Now it introduces new roles, your pit operator competency, you got your field builder, you got you, system builder, you got your autonomous mine controller...* [P13]

Those roles learn how to mode change a truck and interact with them safely in the pit—learning how to survey and verify high walls. They are creating virtual environments that are important to the operation. Physically mapping the mine site digitally and mapped to coordinates. If the virtual environment does not match the actual mine, then risks can emerge. Therefore, system-based roles were described as the cog in the wheel for the operation:

> *So, here you've got one person who is the driver of 30 trucks. And I think that takes a skill, because not only are you monitoring those trucks and you're assigning them... you gotta monitor their health as well too, because if a truck stops, you don't have a trucky calling up...* [P13]

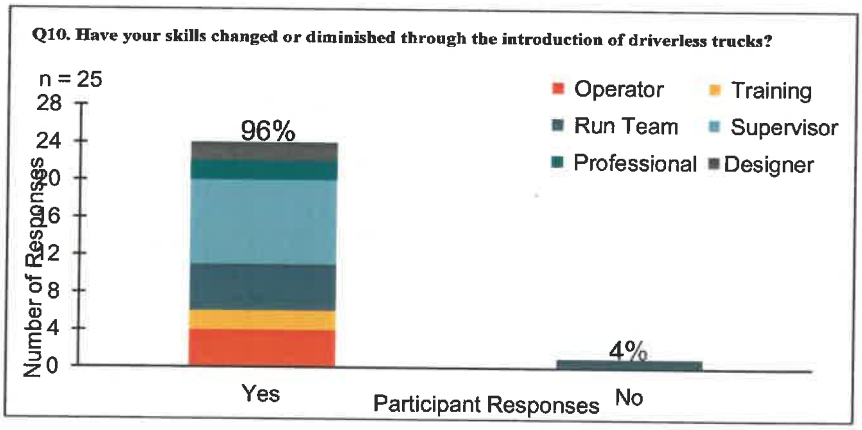

Figure 2. Responses to question whether participants' skills had changed or diminished through the introduction of driverless haul trucks.

Computer interfaces alert system-based roles of what trucks are performing. Those interfaces did not exist in a manual truck operation. Every role has been touched by automation, whether it is multiple

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screens in the control room or small interfaces in cabs. Supervisors taught how to mode change and recover trucks when they lose communications. Furthermore, how to build a virtual dump model, a lane network and implement hazard zones. The system was described as a large computer game that participants needed to understand. Instead of driving around and physically observing things, the system allows people to look at the area through a device. They are learning how to use a tool that enabled personnel to be more efficient and plan what they wanted to do next.

3.2 Residual workload

3.2.1 Bunching workload

The workload of residual tasks can be short and intensive, followed by long period of inactivity. If a driverless truck breaks down or identifies an object, people must respond immediately. The workload compounds with machines queuing when a broken-down truck is not cleared. Balance comes with keeping on top of clearing objects, validating and surveying dumps. Core operational activities are part of routine tasks, planning work based on what is happening. For system-based roles, this means driving around the site, following trucks and improving their cycle times. Changing lanes angles to increase truck speed and monitoring the way truck turns a corner. At times, the workload is described as high stress, with constant interruptions and breakdowns. From a users' perspective, since there is much going on at one point, system-based roles need to be across it:

> *Previously for a manned operation you wouldn't, you have 40 trucks drivers that can think about it and do it yourself. You've got one controller, on average, looking after 25 trucks, with one builder. Planning all the work for those 25 trucks, as well. So, it's constant just churn; it doesn't stop; it's relentless...* [P2]

When a driverless truck loses communications, it immediately stops. There is a lot of interaction and intervention to keep the operation moving. Controllers, for example, have to intervene when something happens. Whether it is an obstacle detection or a close interaction with a light vehicle. Moreover, a driverless truck may also lose its assignment, which can also compound issues. Particularly when production pressure is placed on top of everything as well. Delivering outcomes for the business with high expectations on Key Performance Indicators (KPIs). Participants explained how it is not a job that people can do for a very long time. On average personnel fulfil such a role for two to three years. People are moved around every couple of days, which reduces their internal stress levels. Some people described to be able to handle such workload, while others have lower tolerances:

> *Some people can handle it better than others, but you got to try and keep that balance right for them as well.*
>
> *Otherwise, people just get frustrated and get burn out, make mistakes. There's this whole other piece that we have to consider now, which we never did before.* [P2]

Participants highlighted how the control room no longer has people in the cab to witness activities unfold. Therefore, local adaptions by truck drivers to avoid situations are no longer there. The workload in responding to those needs now reside with system-based roles. For example, if a machine broke down on a section of road, a manual machine would use an alternative route. However, with automation, the driverless fleet would continue to use that same pathway and wait behind the broken-down truck. Manually operated equipment could also navigate around the truck; automation is unable to perform this function. With set planned routes in the system assignment, driverless trucks are unable to react to emerging situations.

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What can tend to happen there... if a scenario like that is unfolding and it's not identified soon enough, suddenly is potentially a simple solution or recovery, suddenly compounds and becomes bigger and bigger and bigger. [P3]

The intensity to resolve driverless truck issues can be quite high. In particular, when the physical environment is not overly stable with rough roads and low network coverage. When the situation is unstable system-based roles can always be recovering trucks. Furthermore, dump spaces need to be allocated to the fleet evenly across the mine. The workload can increase to rebuild dumps, surveying and modifying the dump plans. The high workload follows extended periods of inactivity:

Short intensive moments. Like so you'll have a lot of not a lot. Then you will have a whole lot of outages... there will be bloody trucks falling off the thing (network) everywhere that you gotta go fix... get trucks and put them back into manual mode and move them out of areas and stuff like that. It's very sporadic. [P4]

The workload on the excavator operator described as one of the most straightforward tasks on site. The role explained as dull in comparison to system-based roles and functions. Particularly when the excavator is benching, and there are a limited number of trucks presenting. When operating the dozer, participants found it challenging to avoid machines while trying to perform their work. In preventing driverless truck interactions, a grading task can take three or four times longer when maintaining the road where driverless trucks travel. Participants explained how the control room should always be busy. There is data retention or tasks to follow up on with maintenance when the system is running smoothly. Despite this, there are only two people designated for the entire haulage fleet:

So, it is a busy thing, and I think a lot of people forget you've taken away the thirty truck drivers and left one person in charge now. [P8]

A higher workload noted to take away their attention from what personnel need to focus on. Participants described how merely looking at the virtual mine model; participants can determine how their day is likely to unfold. When the excavators are in tight areas or drop cuts, the system-based workload is going to be high. Close areas do not flow as the automated system needs space to reverse trucks under the loading unit. Setting the goals in a group of excavators and haul trucks can be difficult, taking approximately an hour to complete.

If nothing happens in an hour, all your processes, all your dumps are fine, all your dig units just miraculously go. It would be really good, but it never happens in a drop cut, it never happens in a reverse drop cut, there's a lot of cleanups, there's not a lot of room there, so you are mucking around with builders. The trucks are stuck, and you can't get cusps. So yeah there's a lot of workload in situations like that. [P9]

The driverless system described as being designed for opened spaces, with big dumps and short runs. In those situations, it is more effective than manual operation. Although communication with field-based roles is crucial, calling people by phone and using messaging applications. The control room is not only managing in-field interfaces, but they also communicate with plant control. The roles become the voice for the system in and advise others where the material is heading:

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Yeah, you can have hours where you don't stop... Being on the radio, talking on communicator, talking to maintenance, talking to supervisors and all that. Then you might have four hours flat out and then nothing. Ha-ha. So, it really does fluctuate a lot [for a controller]. *[P9]*

Participants noted that it depends on the conditions. There might be perfect conditions with a limited number of detected obstacles. Whether there is a full crew, or the team is short of people for the shift. Therefore, with the balance of potential obstacles and road conditions, the workload can differ:

One shift you could be recovering trucks, clearing obstacles none stop, and you are just getting calls for two-ways both of them don't stop all night. Then other nights when the system is running well, and the roads are maintained well; spillage is low. You could be cruising around, waiting for something to happen. *[P11]*

The workload described as moving from one extreme to the other. System-based roles can also fulfil simultaneous activities, including hot seating, calling trucks into maintenance bays or covering breaks. While it was described to be balanced a majority of the time, it is the intense moments that can increase the cognitive workload. Those moments appear to all come at once:

Like yesterday, at one stage we had the scraper broken down and 100 metres, couple hundred metres up the ramp we had a dump truck broken down. Then another 150 metres we had another dump truck broken down. We are trying to build bunds behind the dump trucks that are broken down on the ramps and get the Mine 5s and 6s, with the maintenance guys to come and fix them. *[P12]*

The main activities include verifying dumps, travel lanes and speed zones. More importantly, following the trucks around the mine and ensure they are optimising the cycle. When the cycle is efficient, there are limited abnormal reactions to situations. Participants reported how this is rarely the case, despite the workload balance improving. The problem is that if one of the variables is taken out of the equation humans must intervene. For example, if a dump is full, the truck cannot think for itself in terms of where it needs to go. Therefore, the workload increases for system-based roles to provide a new location. If a truck stops for an obstacle and is not cleared, the oncoming machines will sit behind the truck and wait. When the system is running smoothly, the workforce is calm. However, when workloads increase from disruption, the situation becomes tense. The health events, truck stoppages, network loses, and truck recoveries all come at once.

3.2.2 *Executing tasks that driverless trucks cannot perform*

There are several roles performed by humans that are the by-product of automation. Personnel must take surveys of the real mine site and upload them into the mine model. The task drives the physical parameter of the area with a mobile machine. Despite the development of LiDAR technology to gather this data, it is not there yet. The trucks also need to be recovered after losing communications or breaking down, manually driven out of the haul road.

Road obstacles detected within the lane visually inspected before clearing. Moreover, since the trucks do not retain that information, the human can be back to the same location moments later. Since the driverless system has improved, the residual work overtime argued to have improved. However, with the operation expanding, the driverless fleet was moving into areas designed for a manual truck operation. The spaces were tighter and developed on smaller fleet classes. Therefore, the participants needed to assist driverless trucks more through those areas.

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A lot of the newer areas we're going into were designed for told me whereas a lot of the areas we originally moved into were designed for manned fleets and they're even designed for manned fleets of a smaller truck class. So that was constantly causing issues. *[P3]*

There also several tasks that personnel would like to perform, yet they are restricted. They are undertaking maintenance on roads reduced due to surveys, interactions and obstacles it can create. When it comes to loading a truck, a virtual spot must be placed by the excavator with the bucket. The system accepts that spot if it is within the survey boundary. Excavator operators need to press a button on the joystick to authorise the truck to enter the mining area. The location commonly used twice before the operator needs to reset the spot as they move along the bench. When leaving the excavator, there are settings and adaptions put in place:

I have to slow them down because of the floor conditions. It can't recognised that there are big bumps in the floor and it just goes charging through. Generally, I use the system on office selection. I will use preferences when I am in tight areas. *[P5]*

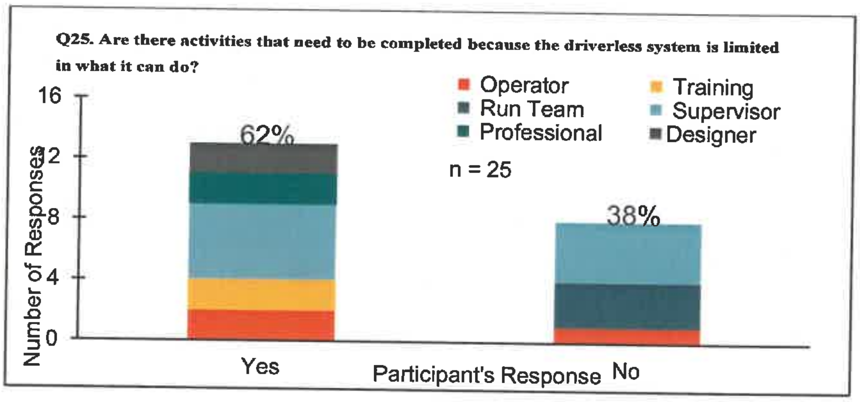

Figure 3. Responses to question whether participants had observed a driverless truck perform something that they did not anticipate. Data collected through one-on-one interviews.

It is not only individual tasks that the trucks cannot perform, but it is also coordinating their movements. At times the fleet needs to be locked to a particular area. Otherwise, the logic would direct trucks to the excavator moving the most tons. It was described as a very manual task to assist the system. Therefore, goals were introduced into the system to determine where trucks are allocated. The dumps will also go full, whereas, in the manual operation, this would not be the case. Therefore, people do not have to re-plan and area and shut the dumps off to resurvey the model. The trucks are then moved around to accommodate the work, which requires personnel to think more ahead.

We do a lot of surveying and verifying of the real world. The autonomous truck, they could do a lot of the surveying as well, I sort of like having the human intervention and ownership of the area.

We have to go and physically or virtually clear a non-obstacle. *[P11]*

The participants believe that there is a suitable level of human-machine interaction. However, participants noted that there is a lot of remedial work. For example, a truck may fail to tip on a waste a dump truck multiple times, which requires the dozer to push more material. The practice can result in weak spots, yet the dozer operator needs to keep pushing. Participants describe how they need to think outside of the box for the trucks:

> *I guess we are the eyes for them, and the brains for them. Because they just do what we tell them to. You gotta be pretty onto it… Monitoring where they are going, make sure the trucks with high grade are going high-grade dumps or crushers. And the trucks with waste are obviously going to waste dumps.* [P12]

The system was noted not to be perfect from the beginning. Participants explained it would be nice to identify objects and classify them appropriately, instead of waiting for a person to clear the object. Moreover, the trucks are yet to identify potholes; therefore, personnel must put in speed zones in hazardous areas. Automation could be more intelligent, rather than merely travelling quickly back to the digger only to queue. Therefore, the system could be a lot smarter and limit the workload on humans. There other examples, such as trucks being unable to lower their tray, with the truck's tray getting stuck on the windrow. Despite this limitation, the focus can soon turn to the people supervising, whether they are planning and enabling the trucks to perform. Since the system requires more room to maneuver, the system is limited in tight spaces. When comparing them to manual operations, there was no need for human intervention.

3.2.3 Interpretation of system information

Humans may misinterpret the information outputs from the driverless system. Operators may interpret some warnings and codes in a particular way. More detailed analysis is usually said to be provided by engineering, mainly when they are the designers of the codes. The design in practice can create situations that are not reflective of the intended design. As a result, video footage and snapshots are taken by people to compare the outputs with actions. There is diagnostic information presented to display fault codes, which must be interpreted by the people supervising the system. Without the background information, the users can be left confused about what the truck is trying to tell them. Depending on the person's role, they may have access to diagnostic information. Therefore, they rely upon in-cab interfaces or system-based personnel. Some of the indications are even more passive, with a change in lane colour or truck function:

> *So, you get an obstacle; the lanes go green. You may not read that this is happening or take notice. You may misinterpret it or be prompted by control. You might also be in the body boundary and be in its lane. Sometimes people don't know they're in the lane, and the truck won't come back.* [P4]

There are other examples where trucks do not reverse into position because it is already in a loading sequence. The excavator operator presses the send button and truck backs under the excavator. Operators must also learn what the lanes colours represent. For example, if a truck does not reverse into position and the lane colour is blue, it means that the digger bucket is blocking the lane. The in-cab display may also indicate that a truck is 10 minutes away. However, the truck does not arrive when the system stated it would on the screen. There may be specific errors or messages that operations do not understand; therefore, personnel are required to read maintenance manuals to understand the data:

> *There is some information there that doesn't make sense. You are troubleshooting, you might troubleshoot it three or four times, and all of sudden it works. I've had instances where I can't figure out why the trucks are doing what they are meant to be doing, and all of a sudden worked. And I can't even explain it.* [P9]

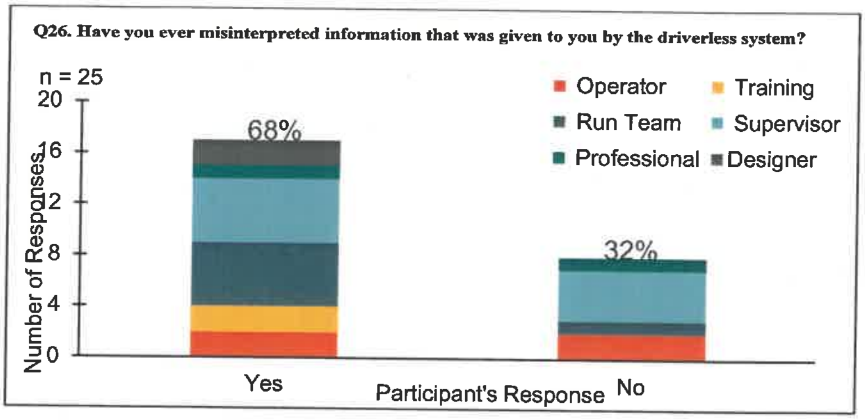

Figure 4. Responses to question whether people had misinterpreted the information given to participants by the driverless system. Data collected through one-on-one interviews.

Participants explained how, at times, driverless trucks do not know where to go. A truck that is stationary with a green tile, and there is no information to highlight the issue. People described those situations as errors in the details outputted that do not make any sense. Therefore, personnel troubleshoot it by pressing stop/ play and the truck drives away. There were also instances where the system highlighted that a truck in operation, yet it was reversing back to the loading bay. Deadlocks can occur in the loading area, despite no additional instructions given by the digger operator:

> *So, I suppose like when you are looking at what you are seeing, like the information you are receiving, you can't explain why it is doing it... Sometimes in a dig unit and all that you can have a truck on your screen but it's not actually there.* *[P9]*

Despite some of the information or glitches that are unable to be interpreted, participants believed the information is always accurate. Everything that is presented on screens to operators and is available in real-time. The labels, acronyms and the types of data were noted by participants to be understood once they understood them. However, the language is new, which highlights terms with little meaning:

> *Like the new people that come over, you'll hear: 'Can you power cycle that truck?' Which is basically can you turn that truck on and off again. They like to use stuff like that.*

There are help pages available to personnel to interpret system information. Moreover, the predicted pathways of the trucks were argued by participants to be accurate. For example, if the blue lanes indicate that the truck is going straight through the interaction, the truck always travels straight. However, it was noted by participants that misinformation can be provided, such as updated survey files or the system is not transmitting the positions of equipment. Road lanes can be observed on the right-hand side of the screen, yet the paths are actually on the left-hand side. Therefore, not necessarily misinterpretation of information, more the fact that the correct information needed to be displayed to operators. Designers label the codes used with terms that personnel do not always understand:

> *Not in autonomous run mode. What does that mean?... Unload assignment request. So, no one knows what that means, and it (the driverless truck) just sits there in red (red tile). [P14]*

Participants in system-based roles explain how it takes time to learn the systems' information outputs. Once those terms are understood, personnel can start to determine what the system is attempting to

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explain. The understanding of the information was argued by participants to be underpinned by experience, attaching the reference or warning to a specific meaning from previous interactions.

3.3 Local adaptions

3.3.1 Situations emerge outside of processes and procedures

In the initial stages of driverless truck development, there we situations the technology had never faced before. In particular, when the operation first attempted drop cuts, participants described them as a 'nightmare'. Since the space was so tight, the trucks could not turn around and reverse back to the excavator. Without the trucks being able to reverse to the loading point, the trucks were unable to be correctly loaded. This phenomenon forced excavator operators to adapt and change their techniques. Also, the system functionality was adjusted to accommodate the mining environment. Design criterion created by operations for engineers to design the system to match the environment and work more effectively. Upgrades allowed the trucks to perform in tighter spaces and allow trucks to reverse back to the excavator:

> *Early on, it was a lot of manual intervention to do that before. You know, you'd have a builder focused on that the whole time. Just sitting there, tweaking the lanes or moving the spot point or just doing a whole pile of manual click work to make that happen. And that gets pretty onerous when you are doing that for 12 hours, consistently.* [P2]

The practical experiences faced since the implementation have enabled the technology to evolve. Participants reported that this is where a lot of the improvements came from; working through the pain points. Participants explained how operators consistently confront with novel situations. Since the structured processes were designed for operators to broadly cover scenarios, embracing the dynamic and fluid environment of mining. The scenarios faced may not be the same every single time:

> *You get variations of that scenario. That's the situations when I say constantly. It is how to match the scenario and slightly modify your response but following the process in principle. Depending on what is happening and where the truck has stopped. They may have to get a little bit creative within the area to resolve the issue.* [P3]

Participants noted that mining procedures were re-written in the early stages every day of the week. What was executed by people, in the beginning, would not be sensible in the future. The operation was said to be continuously improving upon safety and productivity. Moreover, participated reported thinking outside the box when troubleshooting trucks. A truck may remain stationary, and system-based roles are unable to move the truck. They are figuring out why the truck was not and working through a process of elimination. There was no manual or instruction for unique situations that arise. Therefore, the participants are adapting their experiences in those situations:

> *Or you have to do silly things like override it to sit on the correct lane, or you know. Or it could be as in-depth as... getting a power cycle for the truck to reset. Kind of what was, system-wise was happening on that truck... Outside the box like it happens all the time. I can't really say one thing.* [P7]

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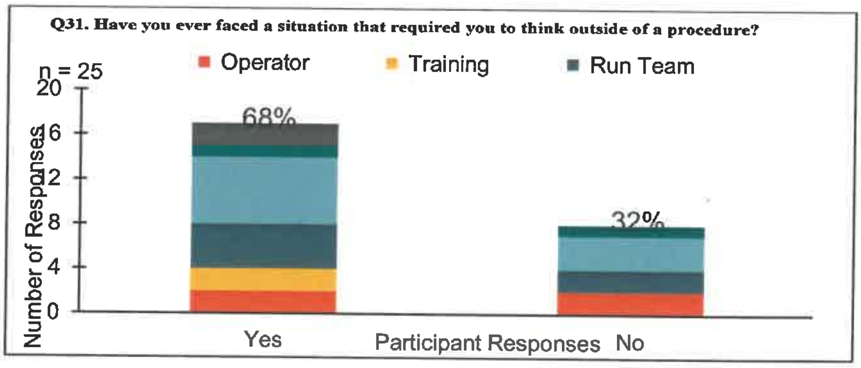

Figure 5. Responses to question whether participants had ever faced a situation that required them to think outside of a procedure. Data collected through one-on-one interviews.

Since personnel are adapting in novel situations, there were reports of inconsistencies across the shift. The participants argued that every shift should be performing the same tasks. The differences were explained by participants to be as simple as handing back control of a truck. A chain of command that informs personnel controlling the fleet that the mine is safe for driverless equipment. Participants noted that for an operator, there was not a lot of adaption outside of the available functions. Although some operators have the flexibility to play within the parameters, for example, selecting what side the trucks should reverse to the excavator. Therefore, operators usually lean on system-based roles for technology support. More importantly, when attempting to recover the truck from a situation, utilising learned functions to influence truck performances:

> *... there's definitely a few tricks you can do here and there to get trucks out of situations that wouldn't be like textbook... you might not have lanes to get a truck out, but you can still... plan-exit-forward or reverse a truck. So, you can actually deal with an issue with the truck and get rid of it without the input of anyone else.* [P9]

The participants explained how vital thinking outside the box could be. Particularly given that if automation is to be successful, the trucks need to keep moving. Therefore, if a truck faces a situation that it cannot overcome, it is the human who is troubleshooting the case. Participants describe that it is something they get better out, and it is challenging to teach. In the early stages, participants described how there were many situations where standards were still being developed. Some minimal people understood driverless technology. As time has evolved, more processes and systems were developed by professionals for people. The gaps were covered, and personnel began to know how to perform those tasks. Over time, as situations have emerged, the systems for working with machines to prevent incidents from occurring:

> *That's the thing with autonomous the processes have been developed because of things. To prevent that happening against we have developed those processes. Activities outside of the processes eventually become the structured process.* [P23]

Participants explained how the processes also attempt to cater to the masses. Therefore, participants argued that methods would never cover for all situations. As a result, there will be times where personnel need to provide a level of adaption to suit the scenario.

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3.3.2 *Remaining in-the-loop with the system*

There remained opportunities to assist people in understanding what the trucks are performing. Different roles also have separate displays. Where a system-based position may have an in-depth assignment engine display, an operator of a machine has far less. Therefore, operators are not necessarily informed by the system of what function the truck is performing. Operators simply have the lanes displayed and identify the mode light function. For example, If a truck performs a U-turn, the operator will not receive information on why the truck performs the task. Additionally, if a truck stops, a machine operator will not be informed of why. There could be various reasons why it stopped, including obstacle detections or loss of communication.

> *They don't have any feedback point currently to understand some of those things. I think that's where our next generation of software for in-cab displays will start to change. We want to be able to give the operators a level of detail and understanding so they can see some of the stuff. And potentially engage at a certain level.* [P2]

Remaining in the loop appeared to depend on the level of visibility in the system. Without a computer-screen interface, it can be challenging to determine what the truck will do next. That is, of course, is unless personnel understand the pattern of the truck cycle. For example, a person may intuitively know what the next step is in the sequence maybe. However, the surprising component of this is when the truck performs something different. A driverless truck, for instance, may turn around while waiting in queue to be loaded. Participants explain how it comes down to visual displays in the field and understanding the basics of mining:

> *The truck's travelling it's either full, or it's empty, it's queuing or its spotting, loading or tipping. I think if you were new to mining and didn't really understand the basic cycle of a truck. Even if you didn't know what each element was called, then you may think it is unpredictable behaviour.* [P3]

Participants describe how driverless trucks can only perform tasks within the cycle sequence. Actions are not completed without the correct instructions from the system, indicating that the information is available somewhere in the system. A truck cannot physically move without a valid lane to drive on. Therefore, rather than being informed, the truck's actions are observed to determine what cycle the truck is performing. This experience, however, depends on the persons' experience and role. There, participants who grapple with the interfaces to know what is happening:

> *I struggle with those pages that tell you where the truck has been and where it is coming from the loading unit and process. What dump it's going and how it is going and where it's going. I think those pages are fairly technical. For a digger operator (their type of interface) it's fine, it's basic.* [P4]

For simpler interfaces in manually operated equipment, the screen is described by participants as straightforward. Operators can observe the lanes coming towards them and the colour changes as it gets closer. Operators without technical displays seek guidance from system-based roles to inform them of truck performances. Those roles relay messages to enable operators to remain in the loop. For example, a request may be made over the radio to determine why a truck is not reversing. A controller may advise operators to move their bucket out of the way when it was detected as an object. Experiences of control room operators can be much different, particularly given that they now supervise up to 25 trucks.

Yes, you may be looking at one truck on this side but then like 20 seconds later you're back at the side... like it's constantly flicking between the two, because of your screens... I literally have two screens, and then I'm looking at both at the same time (to remain in-the-loop). *[P5]*

The participants explained how they do not disconnect from the situation; instead, they direct their attention to where they are needed. For example, if the flow of the daily plan changes and the excavator is moving locations. Monitoring the screens and scanning the situations to stay in touch. Despite actively involved in an activity, participants in the control room utilise their peripheral to observe any abnormalities. Furthermore, the radio calls enable personnel to hear what is happening and get an indication of what is coming next:

I listen to my two-way. That's a big indication... like with the trucks you can watch and observe, so that's how you stay in the loop thereby watching that. But if you're not told what's going on, you can only do what you can do then. *[P8]*

Radio communications were noted by participants to provide essential information. The difficulty, however, is predicting what the system will do next. After truck tips, for example, the system generates its assignment based on the goals provided. If the truck is heading in the wrong direction, it gives system-based roles minimal time to redirect the fleet. A controller may also decide to lower the production of an excavator to avoid trucks favouring one machine over another. Despite the indication of the current function and listening to the radio, the system was reported not to indicate what it is going to do next. However, in terms of what a truck is currently performing, it was argued to be reasonably straightforward:

The trucks are doing what they are supposed to do—the lane colours and what not you know where's its going. You know where it is turning. I think it generates itself. You can tell by the lane colours. It's just being familiar with the truck. *[P3]*

There are other queues outside of the system that participants use to remain in-the-loop, including identifying the material type they are carrying and through pre-shift briefings. The material type indicates whether the truck is going to a waste dump or crusher. The system also can send messages between personnel or inform them of a site-wide stop. If there is an emergency, an alert is presented on the screen to indicate that operation is to cease. Participants described how detailed information is provided to system-based roles through in-cab displays, yet remain limited for operators:

I'd say you are not really informed unless you have a client (technical screen) in the car at all. You'll have dump spots close on you for no apparent reason. Dumps close, dump reopen and that. I'd say there's no feedback in that sense. *[P12]*

The technical displays provide more information on what is happening, which is different from the predicted pathways provided to operators on every in-cab display. There are several pages to enable personnel to monitor the performance of the trucks. Travel progress monitoring pages tell people where the truck is going and where it has been. The status page provides haul routes for all trucks and is monitored by operators to determine where it was loaded. A yellow route path indicates the truck's destination. Furthermore, the viewing options provide travel pathways and continuously monitored for performance issues:

Let's say if I'm driving around, I see a truck stop. I'll bring up the autonomy status page. Boom I'll click on the truck. Why is that truck stopped? What is it doing? That information is fed to me immediately. So, I know what's going on with it. It's having a comms loss; it'll turn green and go in a minute. It's crapped out it's not going to move, so I know we have to recover it. So constantly using all that data on the monitor to tell me what's going on in any one point. [P5]

The in-cab displays are used by personnel to determine what is happening. The status page highlights whether the trucks are in operation or on delay. Radio communication is used by people to provide additional context to the status of the machines. Therefore, participants emphasise using various means to remain in the loop.

3.3.3 Human intervention

There are various diagnostic tools that driverless trucks use to self-analyse functional issues. The self-analysis assists people to understand the health of the machine. Despite the sensors located on driverless trucks, humans are still required to intervene when the trucks face novel situations. From a diagnostic point, if a truck appears to be performing not as intended, personnel monitor the system in the back and dial into the truck live. Observing the actions and evaluate the responses to the desired design, attempting to understand what is influencing the actions. For more immediate effects, participants describe not trying to intervene unless someone is at risk. Participants explained that humans do not have to intervene unless the truck does something beyond what it is programmed to do. Therefore, in the event of an emergency, personnel are provided with an emergency stop device. The device enables people to stop the fleet when activating the device.

The AHT, for whatever reason, hadn't identified as a potential risk at the time. Maybe it is a situation where the AHT had and based on what the individual piece of equipment was doing it didn't believe it would interact with it or it may have already performing he necessary steps to avoid the situation. However, as a reactionary measure, I would have hit the emergency stop. [P3]

The driverless truck has been observed stationary with their tray in the air. When observation like this is by personnel, intervention is required to put the truck back into the operation. Despite the control room attempting to send a script to recover the truck, the truck was unresponsive. The truck was mode changed to manual and driven to a safe location. When it comes to deciding whether to intervene, participants describe that it comes down to chronic unease. If a situation does not look right, the participants explained the feeling they got to intervene. When asked what indications participants look for, people pointed to their experiences that reinforce their confidence in taking control.

I've made some stupid calls; I've called up and asked what that truck doing is. It's alright it's just doing this. It's about being proactive; if something is not right, you react to it. Whether you call control or press the emergency stop and have a discussion with control. [P4]

From an excavator point of view, if I don't see anything, I don't like I'm up against them straight away to get it fixed or ask them why—some a driven by data, while others explain using their instincts when deciding whether to intervene. For example, if a truck is bouncing over a rough floor, participants revealed that truck speed is reduced by operators to avoid truck damage and false overloads. Personnel intervene by placing speed zones across the loading floor. Participants argued that people must take ownership when working with driverless trucks:

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> *We are the eyes and ears for it, like I tell everybody. So, don't be afraid to question it if it's not right. Fix it. Chronic unease. If it doesn't feel right, then it's probably not right.* [P4]

There were reports of choosing to intervene when identifying incorrect lane colours or trucks not moving. The control room is called by operators to analyse the diagnostic page and determine what has occurred. Participants highlight making calls when they believe is not safe enough to operate. Trucks may be shut down by the control room to reboot the system. Additionally, driverless trucks observed travelling over the rough ground are stopped by personnel until the road surface has improved. Participants explained how system-roles monitor the actions of the trucks when determining to intervene, particularly in comparing settings to the conditions:

> *I was at the top of a waste dump putting in a centre island. That's when I saw the truck; it got sent away because all the dump spots were full and I saw that it was about to go down the ramp. I checked my screen, saw that there was a zone on it, zone had 42 k's (kilometers an hour), so I tried getting a hold of mine control. Couldn't in time so I [emergency stopped] it. Called control and told them the situation. And yeah got the speed limit on the way down.* [P12]

The participant explained how the settings did not accommodate a loaded truck descending the ramp. Although speed zones would be in place heading away from a loading unit, it is usually not in place heading away from a dumping area. When safety is the primary issue, people intervene. However, when it comes to the assignment engine, personnel avoid intervening and re-assigning trucks where possible. The reason is that the cycles can be interrupted and lead to more trucks bunching. There are instances where there is no choice to intervene when excavators go down:

> *Sometimes, that's not feasible... sometimes this digger will have four trucks and the trucks are still wanting to go back there, and I don't want any more trucks to go back there so I'll hard assign them away.* [P7]

When the assignment engine chooses to send a bunch of trucks to one excavator and not another, there will be people who intervene. Participants describe also wanting to avoid incidents and prevent harmful situations from occurring. Moreover, if participants observe a potential interaction with a person in the field, people will intervene.

> *I'll just stop that truck. "can you please move out of the lane." and then we'll be able to proceed with you know... preventing something before it happens. That's the duty of care I guess your operators... like you want to look after them they look after you, they help you out, they clear obstacles, they do everything that we need them to do so do the same for them.* [P8]

If a truck is broken down in the middle of the road, it was explained how personnel intervene to send them manually to another load unit. Since the trucks cannot drive around one another, a person needs to intervene to build a virtual lane to allow trucks to overtake. Participants noted that is can be challenging to intervene since there is so much going on. Unless a truck is observed getting into an awkward situation, it is unlikely that people will have the opportunity to intervene:

If I had of been watching a truck go over the edge, I could have intervened with my [emergency stop]. When I saw it just go over the windrow, we could have [emergency stopped] it. That would have intervened with that truck, and we would have stopped the truck, and it wouldn't have gone over the edge. *[P23]*

Participants also explained how witnessing a truck reversing into a paddock dump and the wheels spinning. In those clear cases, participants highlighted that people would intervene. They are adding that there is no real science behind the intervention, other than intervening when there are flames, or there is smoke coming from the truck. It is, however, a different scenario than in a manual operation. Rather than contacting the driver, the truck is emergency stopped, or system-based roles stop the truck:

Other incidents where a truck was trying to back through a windrow, and you could see it trying to get through the windrow. A water cart spotted it and was like copy mine control this truck is trying to get through the windrow. He should have just [emergency stopped] it. So, it's fairly obvious if there's something going on, hit you're [emergency stop] and call mine control. *[P11]*

The participants reported that there are people who are afraid to intervene and activate the emergency stop device. With experience and time comes the confidence to take over control. There are instances where rocks can fall behind the wheel. The truck would not identify that large rock caught under the tire; therefore, participants highlight that they would intervene. Limitations also include pedestrians on the pit floor and trucks entering the loading area. The fact that someone is at risk triggers personnel to intervene.

Same goes if there was someone on the floor for whatever reason. A person, I wouldn't hesitate to use my [emergency stop] straight away to stop a truck. Anything like that. Anywhere where you think it is going to hurt somebody I just wouldn't even hesitate. *[P15]*

The in-cab displays also allow people to foresee potential interactions of safety incidents. Also, if a person identifies a truck going to an area where it should not be, a person will intervene. As soon as trucks stop or perform a task that is inconsistent with scripts, a human intervenes. There have been instances where trucks are cleared by personnel to proceed, yet it does not drive away. A human must intervene to send the truck another instruction as to where it must travel to. Whether a truck is backing up to a tip head and a person is unsure whether it is going too far unless the person had a full display they would not know.. A technical display provides people with an in-depth understanding of the where it is going to stop, how much further and what speed it is doing. It was explained by participants how experience in observing truck performances underpins whether people will intervene:

I think with experience watching everything constantly; you know that you don't have to intervene. I've never intervened other than an a-stop, wet road or escort. I think its experience, being showed and taught what to do. And wanting to know the system. If you don't want to know the system, you are not going to know what to look for. *[P14]*

Participants revealed how personnel need to be more proactive. Currently, it was noted by participants how people are reactive and what for something to happen. For example, rather than intervene in a situation, wait until the driverless truck needs assistance. Field participants ring system-based roles to ask them for me details behind a truck's performance, increasing their understanding. There were contrasting views on whether people should intervene or not, only intervening when trucks step out of their parameters. A truck may have lost communications or breach its travel lane and stopped.

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Personnel will dial into the truck and change the mode to manual. Participants explained that people learn by making mistakes, developing the skills to intervene with the technology. If something does not look right, people are encouraged to stop a truck.

> *Having the trust of the operators as well if they see something that's not right, they say it. And this is another big one, and I guess this is all to do with training and confidence. What each role does, knowing when the time is right to make a change.* *[P25]*

Participants explain how people in the field at the eyes to identify situations. Despite a central control room that monitors truck performances through the screen, they cannot see everything. The more eyes that are looking for novel situations, the less likely personnel will miss safety issues. Positive communication is key to contacting a person to check on circumstances and devise whether to intervene. Participants explain how it is easy to get distracted with operational duties. Since everyone has different priorities, personnel can overlook driverless truck activities. Unless there is a pothole in the road and there is nothing to slow it down, people will intervene. They were stopping trucks, placing speed zones over the area and letting them go again. The intervention has occurred previously during escorts, with the vehicle being escorted not visible in the system. If a breach in the escort vehicles occurs, it was explained by participants how people intervene to stop the truck from interacting with a vehicle with fewer safety layers in place.

4. DISCUSSION

The roles described by the participants highlight the residual positions introduced through the replacement of truck drivers. Conventional roles were upskilled by trainers to learn how to interface with a machine. The transformation of functions highlights the activities that are yet to be automated. Also, it underpins the capability of humans to examine, monitor and modify processes that cannot be executed by automation (Miller & Parasuraman, 2007). The new roles are included in the run team and consist of builders and technicians. The builders design and maintain the virtual mine model, while the technicians monitor trucks cycles, mode change trucks and recover them from non-designed situations. While there were new roles introduced, conventional roles were transformed by technology to accommodate the introduction of automation. Excavator operators explained now owning the load plan, which required them to identify a loading point, set reverse location preferences and instruct the truck on when it is suitably loaded. An in-cab display highlighted travel lanes, arrival times and system messages to interface with while continuing routine tasks. Therefore, there were additional tasks and activities to monitor introduced through automation, which reflects the cognitive demands of monitoring computer systems (Wickens, 2008).

The most significant transformation was found in participants who previously drove trucks and transitioned to system-based roles. Where driving a truck was described as being quite monotonous, the new position is actively involved in operational tasks. A system-based role promotes to a higher level of supervisory control, which passively received information and intervenes when required (Stanton et al., 2001). Humans are not known to be effective passive information receivers; they need to acquire, interpret and respond to data. Researchers have pointed out that people are not overly skillful in responding to this data (Endsley, 2017). Despite this, every role in the operation now interfaces with a computer screen and engages with the automated system. Participants had to learn how to interact safely with driverless trucks and determine their operating parameters. More importantly, routines previously undertaken by manual equipment were forced by automation to change, graders reduced their road maintenance footprint and excavator needed to manage trucks in the loading area. Equipment practices also shifted, which required dozers to be mindful of their boundary to avoid interacting with

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oncoming trucks. Although there are studies of skills degenerating due to automation, participants described gaining new skills in addition to conventional capabilities (Bravo Orellana, 2015).

The new skills developed included computer-related techniques interfacing with driverless trucks. Techniques that involved interpreting system information, instructing automated trucks and nimble handling of buttons and levers. Participants also increased their understanding of the computerised system's functionality. They discovered how a driverless system performs within its system limitations. The system influenced the participants to think further ahead than they would previously, otherwise personnel could find themselves unable to respond quick enough to novel situations. Automation increased participant problem-solving skills, enabling them to utilise technology to overcome conventional limitations. There was an added benefit in being able to control the truck fleet, with automation introducing the capability to reduce speed and increase traction controls. Also, the introduction of modes increased the ability of participants to change truck modes and functionality. Personnel were learning how to build and maintain virtual mine model, which was described by participants to have significant implications on operations. These skills enabled people to plan and become more efficient.

Participants described supervising driverless trucks as creating work that was short and intensive. This experience reflected similar experiences observed by researchers across various industries, where the workload becomes more bunched (Billings, 2018). Following short and intense moments that can be cognitively demanding for humans, there can be long periods of inactivity (Li et al., 2014). Long periods of inactivity can strain the attention of people supervising the system. The sudden reintroduction into the control loop can be challenging to navigate, particularly when participants shared managing multiple trucks in various pits. Despite the confidence of participants in monitoring an entire truck fleet, the passive roles appear to be far removed from pit operations. Therefore, it was reported by the participants how vital field personnel are in being the 'eyes and the ears' for the driverless trucks. Those roles play a crucial role in soothing disruptions with local adaptions to avoid sharp increases in workload. Residual tasks can be routine, as well as reactive in helping automated trucks navigate complex situations.

Novel situations were faced by the participants that required them to think outside the box. Processes and procedures were reported by participants to evolve as the operation learnt more about the technology. Local adaptions included situations where a truck does not respond to requests, or the truck needs to be recovered by personnel from a location. Participants described the systems of work as a general guideline for interacting with the fleet, with instructions on how automation works by design. However, it is up to the human supervising the system in how that process is adapted. Therefore, participants describe intervening in driverless truck activities when situations did not appear to be correct. There were no real signs other than drawing from previous experiences. It was necessary, however, that participants remained in the loop with what was happening. Participants highlighted how this was dependent on the person's screen interface. Personnel with less technical displays were less informed of truck assignments and underlying zones influencing truck function. The participants shared how they would rather more information than less on what the truck is performing. However, this can be difficult to achieve, particularly when designers are trying to provide people with the information relevant for their role (Salas et al., 2010). Moreover, achieving this objective without inundating them with non-essential details that do not know how to interpret (Endsley, 2016).

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5. CONCLUSIONS

The study results highlight the role transformations that have occurred through truck automation on a mine site. Mineworkers transitioned into new roles or had new technology-based interfaces included. The role descriptions were to support the driverless operation by giving the system direction on where to haul and assisting them through non-designed situations. Conventional roles were fitted with computer screen interfaces and learnt how to interact with automated systems. There were additional tasks learnt, including how to perform surveys and interpret system information. Automated tasks boosted the repertoire of skills and capabilities in computerised systems. Everyday activities such as driving trucks remain; however, it is only in slight instances when trucks need to be recovered manually by personnel. Therefore, the automation of driverless trucks enhances capabilities rather than diminish traditional techniques. Leftover workloads supervising driverless systems were reported to be short-intensive, which left periods of inactivity. Despite other activities being able to be completed, supporting roles can suddenly introduce people to situations that are novel and complex. The human role remains to apply unconstrained thinking to recover from non-designed situations. This exposure has evolved the problem-solving aspects of humans and influencing frontline personnel to think further ahead. The transformation of roles from the participants' experiences appears positive, with the ability to operate a computer and learning more about how automated systems operate.

REFERENCES

Banks, V. A., & Stanton, N. A. (2016). Driver-centred vehicle automation: using network analysis for agent-based modelling of the driver in highly automated driving systems. *Ergonomics, 59*(11), 1442-1452. http://10.1080/00140139.2016.1146344 https://www.ncbi.nlm.nih.gov/pubmed/26912405

Billings, C. E. (2018). *Aviation Automation: The Search for a Human-Centered Approach.* https://play.google.com/store/books/details/Charles_E_Billings_Aviation_Automation?id=wS9KDwAAQBAJ

Bravo Orellana, E. R. (2015). *Deskilling, Up-skilling or Reskilling? Effects of Automation in Information Systems Context.* Twenty-first Americas Conference on Information Systems, Puerto Rico.

Creswell, J. W. (2014a). *A concise introduction to mixed methods research*. Thousand Oaks, CA.: SAGE Publications.

Creswell, J. W. (2014b). *Research design: Qualitative, quantitative, and mixed methods approach* (4th ed.). Thousand Oaks, CA: SAGE Publications.

Creswell, J. W., & Clark, V. L. P. (2011). *Designing and Conducting Mixed Methods Research*. Thousan Oak, CA: SAGE Publications.

Creswell, J. W., Klassen, A., Plano Clark, V. L., & Smith, C. C. (2011). *Best practices for mixed methods research in the health sciences.* https://obssr.od.nih.gov/wp-content/uploads/2016/02/Best_Practices_for_Mixed_Methods_Research.pdf

Creswell, J. W., & Poth, C. N. (2017). *Qualitative inquiry and research design: Choosing among five approaches*. California: SAGE publications.

de Visser, E. J., Pak, R., & Shaw, T. H. (2018). From 'automation' to 'autonomy': the importance of trust repair in human-machine interaction. *Ergonomics*, 1-19. http://10.1080/00140139.2018.1457725

Dekker, S. W. A. (2003). Failure to adapt or adaptations that fail: contrasting models on procedures and safety. *Applied Ergonomics, 34*(3), 233-238. http://10.1016/s0003-6870(03)00031-0

Dekker, S. W. A., & Woods, D. D. (2002). MABA-MABA or abracadabra? Progress on human–automation co-ordination. *Cognition, Technology & Work, 4*(4), 240-244. http://doi.org/10.1007/s101110200022

Department of Mines and Petroluem. (2014). *Mines Safety Bulletin: Seeking safe mobile autonomous equipment systems (No. 110).* https://www.dmp.wa.gov.au/Documents/Safety/SRS-Publications-Mining_and_Explorations-Safety_Bulletin_114.pdf

Department of Mines and Petroluem. (2015). *Code of Practice: Safe mobile autonomous mining in Western Australia.* http://www.dmp.wa.gov.au/Documents/Safety/MSH_COP_SafeMobileAutonomousMiningWA.pdf

Endsley, M. R. (2016). *Designing for Situation Awareness: An Approach to User-Centered Design (2nd ed.).* Retrieved from https://www-taylorfrancis-com.dbgw.lis.curtin.edu.au/books/9781420063585 https://www-taylorfrancis-com.dbgw.lis.curtin.edu.au/books/9781420063585

Endsley, M. R. (2017). Level of Automation Forms a Key Aspect of Autonomy Design. *Journal of Cognitive Engineering and Decision Making, 12*(1), 29-34. http://10.1177/1555343417723432

Endsley, M. R. (2019). *Situation Awareness in Future Autonomous Vehicles: Beware of the Unexpected.* Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018), http://10.1007/978-3-319-96071-5_32

Ferris, T., Sarter, N. B., & Wickens, C. D. (2010). Cockpit Automation. In E., S. & Maurino, D. (Eds.), *Human Factors in Aviation* (pp. 479-503).

Fridman, L. (2018). Human-Centered Autonomous Vehicle Systems: Principles of Effective Shared Autonomy. Cornell University. https://doi.org/10.48550/arXiv.1810.01835

Fridman, L. (2018, 3 Oct). *Human-Centered Autonomous Vehicle Systems: Principles of Eff€ ective Shared Autonomy*. https://arxiv.org/pdf/1810.01835.pdf

Giacomin, J. (2015). What Is Human Centred Design? *The Design Journal, 17*(4), 606-623. http://10.2752/175630614x14056185480186

Glover, M. (2016). *Caterpillar's Autonomous Journey - The Argument for Autonomy*. Paper presented at the SAE Technical Paper Series.

Lewis, M., Sycara, K., & Walker, P. (2018). The Role of Trust in Human-Robot Interaction. In *Foundations of Trusted Autonomy Studies in Systems, Decision and Control* (pp. 135-159).

Li, H., Wickens, C. D., Sarter, N. B., & Sebok, A. (2014). Stages and levels of automation in support of space teleoperations. *Human Factors, 56*(6), 1050-1061. http://10.1177/0018720814522830 https://www.ncbi.nlm.nih.gov/pubmed/25277016

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: A methods sourcebook* (Vol. 4). California, United States: SAGE publications.

Miller, C. A., & Parasuraman, R. (2007). Designing for flexible interaction between humans and automation: delegation interfaces for supervisory control. *Hum Factors, 49*(1), 57-75. http://10.1518/001872007779598037 https://www.ncbi.nlm.nih.gov/pubmed/17315844

Miller, W. L., & Crabtree, B. F. (2005). Clinical research. In Denzin, N. & Lincoln, Y. (Eds.), *The SAGE handbook of qualitative research* (Vol. 3rd ed., pp. 605-639). California: SAGE publications.

Onwuegbuzie, A. J., & Combs, J. P. (2010). Emergent data analysis techniques in mixed methods research: A synthesis. In Tashakkori, A. & Teddlie, C. (Eds.), *SAGE handbook of mixed methods in social and behavioural research* (Vol. 2, pp. 387-430). California, United States: SAGE publications.

Reason, J. (1990). Latent errors and systems disasters. In *Human Error* (pp. 173-216). Retrieved from https://ebookcentral.proquest.com/lib/curtin/detail.action?docID=691788

Salas, E., Jentsch, F., & Maurino, D. (2010). *Human Factors in Aviation (2nd ed.).* Retrieved from http://www.sciencedirect.com.dbgw.lis.curtin.edu.au/science/book/9780123745187 http://www.sciencedirect.com.dbgw.lis.curtin.edu.au/science/book/9780123745187

Sarter, N. B., Mumaw, R. J., & Wickens, C. D. (2007). Pilots' monitoring strategies and performance on automated flight decks: an empirical study combining behavioral and eye-tracking data. *Human Factors, 49*(3), 347-357. http://10.1518/001872007X196685 https://www.ncbi.nlm.nih.gov/pubmed/17552302

Stanton, N. A., Chambers, P. R. G., & Piggott, J. (2001). Situational awareness and safety. *Safety Science, 39*(3), 189-204. http://https://doi.org/10.1016/S0925-7535(01)00010-8

Tashakkori, A., & Teddlie, C. (2010). *Handbook of mixed methods in social & behavioral research*. Thousand Oaks, CA: SAGE Publications.

Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioural sciences*. California, USA: SAGE publications.

https://doi.org/10.5281/zenodo.7770031

Wainer, H. (2005). *Graphic discovery: A trout in the milk and other visual adventures*. Oxfordshire, United Kingdom: Princeton University Press.

Wessel, G., Altendorf, E., Schreck, C., Canpolat, Y., & Flemisch, F. (2019). Cooperation and the Role of Autonomy in Automated Driving. In *Control Strategies for Advanced Driver Assistance Systems and Autonomous Driving Functions* (pp. 1-27).

Wickens, C. D. (2008). Multiple resources and mental workload. *Human Factors, 50*(3), 449-455. http://10.1518/001872008X288394 https://www.ncbi.nlm.nih.gov/pubmed/18689052

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