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SKYWAY Technology

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The World Safety Journal (WSJ) is a quarterly refereed journal (ISSN: 1015-5589) that includes original full-length papers, review articles and case studies on the most recent outcomes of advanced research in any occupational safety and health fields.

All articles shall be written in concise English and typed with a minimum font size of 12 point. Articles should have an abstract of not more than 300 words. Articles shall be submitted as Times New Roman print and presented in the form the writer wants published. On a separate page, the author should supply the author's name, contact details, professional qualifications, current employment position, a brief bio, and a photo of the author. This should be submitted with the article.

Writers should include all references and acknowledgments. Authors are responsible for ensuring that their works do not infringe on any copyright. Failure to do so can result in the writer being accountable for breach of copyright. The accuracy of the references is the author's responsibility.

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Articles should be referenced according to the Publication Manual of the American Psychological Association ,7th ed.

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A Multi-Industry Analysis of Human-Machine Systems: The Connection to Truck Automation

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KEYWORDS

Automation
Mining
Human factors
Human-machine systems
Driverless trucks

ABSTRACT

This research is a critical review of safety-related themes in human-machine systems across multiple industries. The aim is to explore the lessons of engineering human-machine systems and the residual consequences of introducing driverless trucks on a Western Australian (WA) mine site. The method involved the identifying key words, phrases and contributing factors leading to driverless truck events to-date. An eligibility criterion aided the selection of relevant human factors research in the field of artificial intelligence, automated systems and augmentation. Literature is categorised into 9 publication types, with 11 separate industries associated within 182 pieces of material. Three broad categories were synthesised to include: (i) technology; (ii) processes; and (iii) human factors, with three research questions answering how this research applies to truck automation. Within those categories, 23 research themes were found under the human-machine system domain. The findings highlight the Mining Industry's knowledge gaps and informs the design of driverless technology, formation of work processes and the accommodation of local human adaption. Conclusions provide a way forward for the industry and pass on lessons learnt to avoid automation pitfalls.

1. INTRODUCTION

More than a decade ago, Rio Tinto trialed the first driverless haul truck in Western Australia (WA). Driverless haul trucks do not need a safety driver and operate independently via machine algorithms (Hamada & Saito, 2018). An algorithm is responsible for controlling the actions of the haul truck, with every truck operating within the same operating parameters. The only difference is that Mine Control gives individual truck assignments in order to deliver the daily plan. In addition, system-based roles and ancillary equipment operators are given residual tasks to help the driverless trucks through non-designed situations (Caterpillar, 2013). Therefore, the haul trucks are semi-automated and interact frequently with humans in performing operational tasks.

Driverless haul trucks introduced a new set of hazards and risks, which appeared to be transforming the risk profile of mine sites who were deploying automated technology (Department of Mines and Petroleum, 2014b). The inherent nature of automated system design and architecture introduce properties like complexity, reductionism, literalism, and brittleness (Billings, 2018; Dekker, 2014b; Ito

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& Howe, 2016). An engineered human-machine system can be considered a 'joint' system, where both agents are required to collaborate as a team (Christofferson & Woods, 2002). It is evident that the Aviation Industry has learnt the most on how to cooperate human and machine in one system. This way, beyond isolation, the two agents can work collaboratively to become more resilient in times of disruption. Mining companies invest in driverless technology based on the potential of making their supply chains a lot safer and more productive (Palmer, 2019). However, despite the hype around removing 'driving errors', the technology has simply removed human exposure to driving trucks and transformed what remained (Department of Mines and Petroleum, 2015a).

The number of significant driverless truck incidents illustrates the importance of human factors research, currently six publicly reported since 2014 in WA alone illustrates the importance of human factors research (Department of Mines and Petroleum, 2014b; Jamasmie, 2019; McKinnon, 2019). Such an emergence could hinder the deployment of driverless technology due to the complex nature of unconventional incidents. Moreover, the landscape in mining operations is swiftly evolving as more products and vendors enter the market, with human factors playing a vital role. Human factors in this digital age is argued to be "people in systems, rather than people versus systems" (Dekker, 2019, p. xix). Such a view will allow the Western Australian (WA) Mining Industry to become more human-centered when designing and deploying driverless technology (Giacomin, 2015). Therefore, as a joint human and machine system, despite being two completely different agents, they should complement one another. Thus, within the context of human-machine systems, human factors study the design of technology to suite the attention, memory and perceptions of humans. More specifically, taking the study of human cognition into the 'real world' and understanding the interactions people have in complex systems (Rankin et al., 2016).

As a consequence, cognitive systems engineering has progressively become popular with the expansion of computerised systems (de Vries, 2017; Hew, 2016; Woods & Hollnagel, 2006). Researchers are already aware of the reverberations of automated technology and the human-machine breakdowns that have occurred across various industries. Waves of automation and technological disruption can be identified in: Aviation, which included automated flight capabilities (Sarter, 2008); Manufacturing, comprised of product assembly and machining (Frohm et al., 2006); Healthcare involving ICU devices and monitoring equipment (Dominiczak & Khansa, 2018), Nuclear encompassing plant status and real-time decision making assistance (Schmitt, 2012); Maritime including advances in communication and navigation equipment (de Vries, 2017); Mining equipment that comprises of haul trucks and production drills (Department of Mines and Petroleum, 2015a), and Transportation that deploys driverless cars, trains, trucks and buses (Fridman et al., 2018; Gschwandtner et al., 2010).

Despite there being various perspectives concerning automated mining equipment (Bellamy & Pravica, 2011), it is argued that driverless haul truck safety has not been given enough attention. The full extent of the human factors that apply in driverless haul truck systems are yet to be explored. There are in fact perspectives that concentrate on designing remote operating equipment that is user centered (Horberry, 2012; Horberry et al., 2011), and the benefits of removing human exposure through remote control (Fisher & Schnittger, 2012). Further perspectives argue the need for more human factors research given safety outcomes are unknown (Lynas & Horberry, 2010), while others claim automation reduces 'human error' (Hamada & Saito, 2018) and increases safety through obstacle detection (Brundrett, 2014). Furthermore, there are interviews such as Lynas and Horberry (2010) that concentrate on developers and users of technology, which explore the cognitive capacities required to operate equipment remotely.

Undoubtedly, the literature is yet to understand how human factors research applies to haul truck automation, an opportunity that underpinned the reason for undertaking this research. More

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specifically, the review attempts to address the following questions: (1) How are the theoretical viewpoints of human-machine systems influencing the approach to haul truck automation? (2) What processes are designed to support automation, and do they equip human supervisors to improvise in non-designed situations? (3) Does human adaptive behavior manage unanticipated machine performances and the decisions to intervene or not during beyond design performances? This review draws on human factors research from other industries that have adopted and deployed automated technology, applying the concepts and lessons learnt to fast-forward the WA Mining Industry's thinking to equip them for this digital revolution.

2. METHODOLOGY

2.1 Introduction

To outline the process for identifying and organizing the research on the topic, the steps proposed by Creswell and Creswell (2017) were embraced. The methodological process encompassed the following steps:

1. Identify studies and key words, search databases and websites
2. Collect at least 50 research studies, prioritise them and validate the abstracts, chapters and conclusions
3. Design a literature map to visually represent the groupings
4. Summarise and organize the literature into themes and concepts to identify opportunities

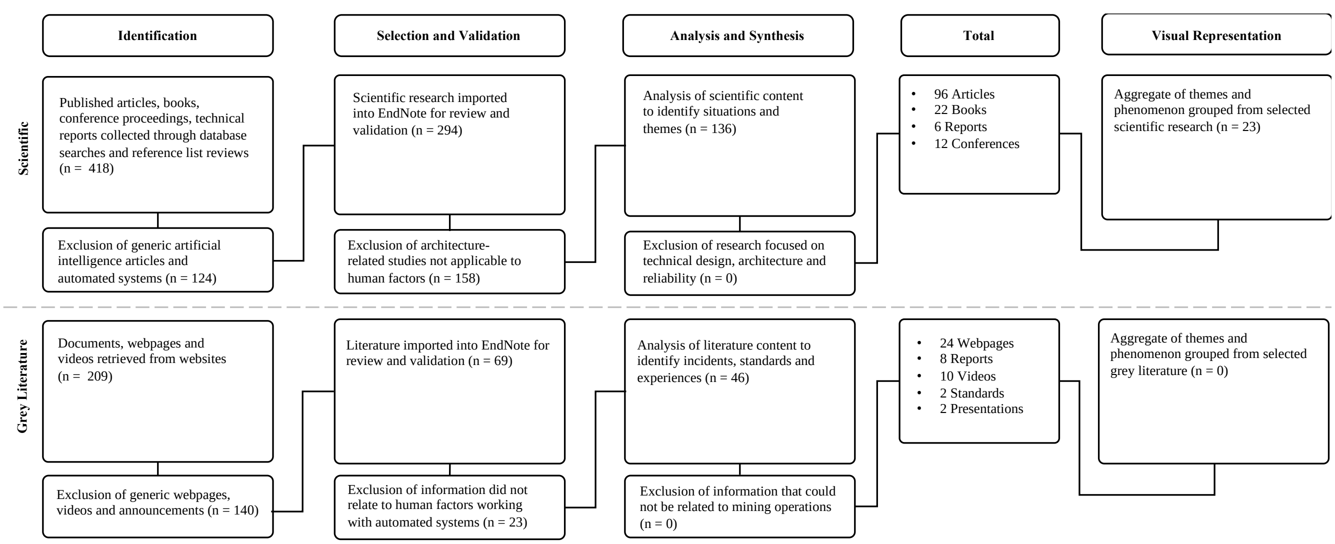

Figure 1. Process flowchart for reviewing the literature

2.2 Study and Literature Identification

The literature review originally began by evaluating the two driverless incidents reports (Department of Mines and Petroleum, 2014b; 2015c). Both reports were analysed to identify key words, phrases and contributing factors that led to the event. The first report (Department of Mines and Petroleum, 2014b, pp. 1-2) provided a summary of the hazards. Through seeking the safe use of mobile autonomous equipment, the safety bulletin identified "detection systems" and "remotely overriding" as a factor of design in driverless haulage. Human factors included responding to "system information and warnings", misinterpreting "system information", "lack of knowledge and understanding" and "not adhering to clearance zones". Secondly, Department of Mines and Petroleum (2015c, pp. 1-2) summarised an incident between a manually watercart and a driverless haul truck. The report noted that

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"assigning roads in the control system were inadequate". In addition, the watercart driver was not aware of the autonomous truck's direction despite an in-cab awareness system to "monitor the autonomous truck's path". These key words and phrases used in this report provided the basis for searching for research studies associated with human-machine systems.

2.3 Selection and Validation

The selection of literature was based on an eligibility criterion. To be selected the literature (scientific or grey) needed to be relevant in the fields of artificial intelligence, automated systems, or augmentation. In addition, the literature needed to be applicable to human factors, which could then allow similarities to be drawn in how people work with artificial agents. More importantly, the situations where humans are successful and sometimes fail, ultimately leading or avoiding undesired situations. Firstly, the abstracts of the research papers and introductions were evaluated based on their intent. For example, if the literature was not designed to understand how humans and machines work together, then it was excluded. The excluded writings were arranged into their reasons for exclusion. Secondly, the content of the literature was evaluated for substance and relevance, excluding those that could not be impactful in a mining context. Thirdly, the writings that were more centered around human adaption, cognition and response were included, while technical architecture of the automated system were removed. Despite this, a majority of scientific papers focused on the human element working with a machine. Lastly, the literature found to be unsuitable for inclusion were used in the introduction for context setting.

Table 1. Criteria for inclusion and exclusion

Selection	Component	Scientific Literature	Grey Literature
		Conference proceedings, peer-reviewed articles, books and chapters, interviews.	*Government reports and standards, publicly released incidents, YouTube videos, announcements, Company tutorials and public engagements*
Inclusion	Title	Key words: automation, driverless, autonomous haul trucks, human factors, augmentation, artificial intelligence	Key words: haul truck automation, driverless, autonomous haulage, haul truck incident.
	Abstract	Articles relating to the human factors in automated systems	
	Content	Human factors research orientated towards understanding situations, experiences and adaptions of humans while working with artificial systems.	Details of reports and situations, code of practices highlighting risks and hazards, issues with application, workplace incidents and anecdotal experiences
Exclusion	Title	Generic artificial intelligence and automated system articles	Generic webpages, videos and announcements with no correlations with driverless/ automated haulage
	Abstract	Design and architecture-related studies that did not explore associated human factors	
	Content	Research focused on technical design, architecture and network reliability	Writings paraphrasing the intent and purpose of driverless haulage, no specific relation to how the technology works practically

2.4 Analysis and Synthesis

The selected literature was categorised into their associated publication type. The purpose of analysing associated publication types helps frame where the research was publicised. This was necessarily given that the technology is relatively new to the WA Mining Industry and academic research is yet to explore. Moreover, it also highlights the magnitude of research that can be drawn from other industries who have already deployed automated systems. As Figure 1 illustrates, a majority of literature included in the research were scientific papers. This can be explained by the volume of research that has been undertaken in the Aviation Industry shown in Figure 2. The significance of grey literature (i.e. web pages, online videos) highlights the methods currently being used to understand the topic. Once innovation tapers and competitive advantages plateau, perhaps more academic research in the field of human-machine systems can be undertaken in the Mining Industry.

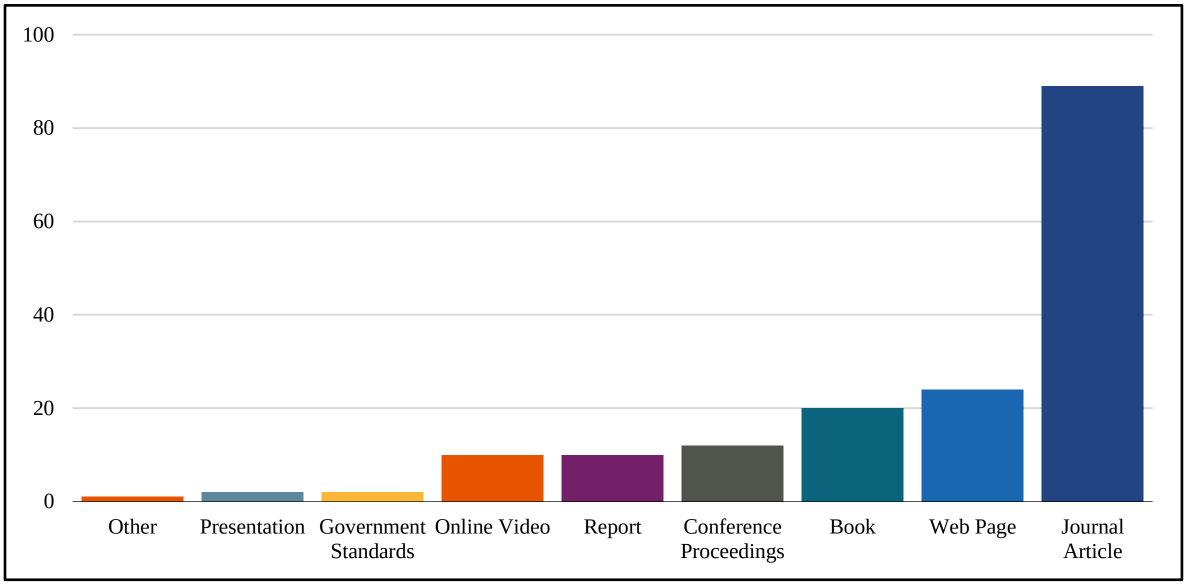

Figure 2. Analysis of literature by type

The timeframe and industry of focus of research were considered in Figure 3. There were 11 industries identified within the 182 pieces of literature included in the research. By including the industry where the research was undertaken, readers are given an indication of where automated systems have been deployed in industry. More specifically, where research has been able to take place and explore the consequences of replacing human work. Figure 2 illustrates how the Aviation Industry was the first industry to explore associated human factors. From there, healthcare, manufacturing, maritime and other associated industries have been able to leverage from those insights. The whole purpose of this literature review is to do exactly that for the WA Mining Industry. Therefore, the industry can avoid the pitfalls of automation, leveraging the lessons learnt from existing research and optimise their current designs and systems of work.

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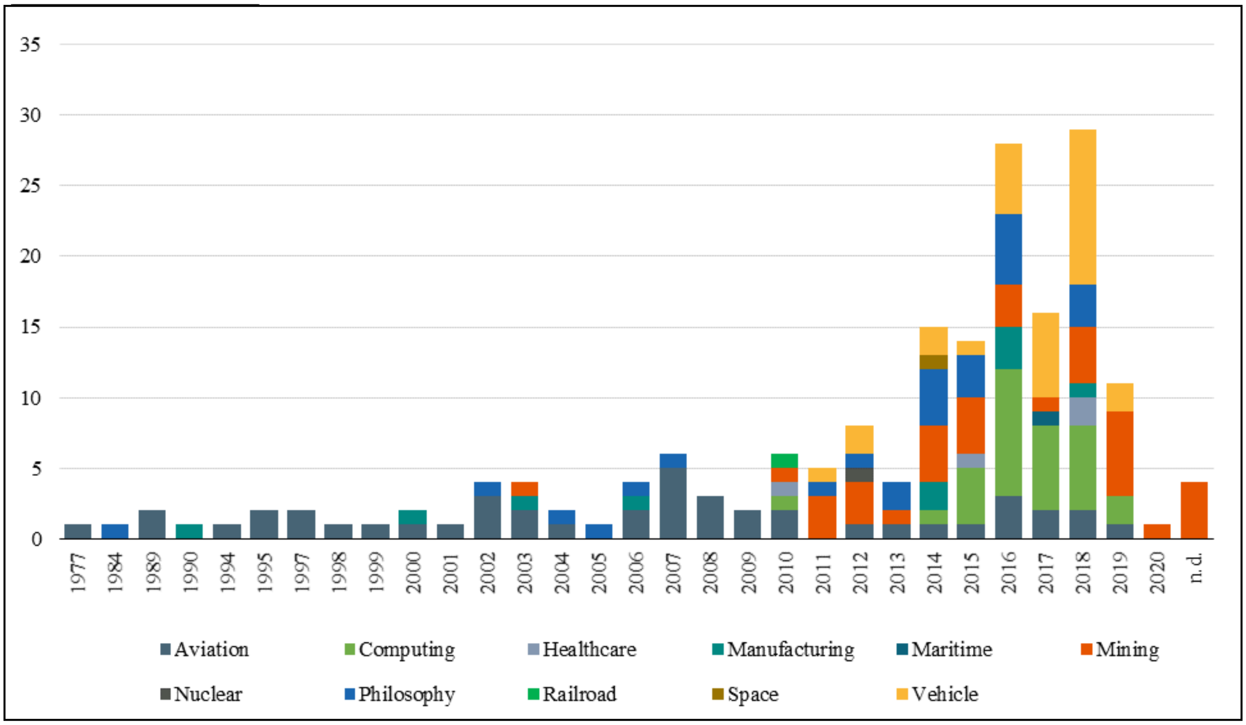

Figure 3. Analysis of publication timeframe by industry type

There were three broad categories that were identified in the literature:

(i) Technology;
(ii) Processes; and
(iii) Human Factors.

These categories also contained sub-themes that provided additional context to the category. For example, machine modes formed a part of technology, which was reinforcing how the technology presented in the workplace. In addition, mode awareness was how well people were being made aware of the machine modes and the complexities behind it.

By providing themes, readers are able to clearly understand the phenomenon that research has identified thus far. Therefore, the illustration of a mind map in Figure 4 provides a visual representation of human-machine system topics. The identified topics and associated findings can then be used for academics, mining operators and regulators to further explore individual topics further.

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Figure 4. Mind map abstraction of research themes associated with human-machine systems

3. RESULTS

3.1 Engineering Human-Machine Systems

Reductionism and Complexity

Reductionism simplifies haulage systems into their most basic parts (Dekker, 2010). The parts are made up of driving to a load source, awaiting to be loaded by an excavator, driving to a destination and then dumping (Caterpillar, 2013). When this process is complete, it is then repeated. Systems are simplified in this way to enable technology to change out human tasks that it can perform (Lake et al., 2016). Often, the replacement is dependent on what technological advancements make it viable (Panetta, 2019). That means that driverless trucks must achieve or exceed human level performance. Although, human level performance is evaluated in isolation, the study is only a constituent part in a complex whole. That constituent part is then reverse engineered into a machine, following a narrow set of instructions (Fridman et al., 2018). On the surface, the restructured haulage system can appear to operate as intended. However, it is the reverberations along the fringes where the consequences take place (Department of Mines and Petroluem, 2015c). A driverless truck, for instance, may be unable to achieve its dump destination due to material being placed in the way. A human is now required to remove that material or redirect the truck to a new dump location. This example highlights the characteristics of the system, complex interactions between components. Therefore, the properties of the system arise after drivers have been replaced, which can be difficult to predict (Department of Mines and Petroluem, 2014b). Complex systems create their own individual structures, which can be defiant of the product designer. In response to the introduction, the environment modifies and restructures the entire system (Dekker, 2014b).

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Complex systems cannot be understood through the analysis of independent tasks. Complexity evolves through the interactions of the systems' components (Cilliers, 2002a). Furthermore, automation creates interdependencies that generate non-linear relationships. Therefore, systems are not linear input-output devices as metaphorically described (McCarthy et al., 2000). Humans will not simply undertake one task, while an automated system uninterruptedly perform another (Mitchell, 2018). A system is a complex web of component dependencies, transformations, trade-offs and influences (Dekker, 2019). Although automation has freed trucks drivers to perform 'more important' tasks, the reality is that the truck fleet becomes silent, awkward and difficult to instruct (Christoffersen & Woods, 2002). What used to be a mine site filled with radio calls, now quietly and independently executes the task. The difficult and clumsy part, however, is that the apparent simplicities turn into actual complexities (Woods, 2018). The automation of sub-driving tasks, which asks Engineers to focus on the components. This is quite appealing when attempting to seek ways to produce and optimise at a lower cost (Caterpillar, n.d.-a). Inefficiencies are targeted, ironing out the variability and increasing the predictability (Hamada & Saito, 2018). However, the simplification can be achieved from what is excluded. Complex systems are ignorant of local control and external influences that leave the system vulnerable beyond engineering predictions (Chandler, 2014). For example, a design engineer who is located internationally, can simply change a filter that can impact the vendors entire fleet across Western Australia. Hence, the reason why haulage systems are now becoming more complex. The connections are becoming wider, closely connected to a socio-technical system that cannot be isolated (Bellamy & Pravica, 2011).

The analysis of what a system contains will not explain what it will do. The components will react differently, depending on the type and number of influential factors (Dekker et al., 2012). The properties will emerge once they interact in the workplace. For example, a truck is unable to identify a wet road, therefore the interaction will require traction controls to avoid losing control (Jamasmie, 2019). Upon realising the trucks' limitations, system supervisors will install speed restrictions on haul routes to avoid truck slides (Department of Mines and Petroluem, 2015a). This is why the reconstruction of systems with machine agents sometimes fail; the non-linearity of the consequences does not represent the entire system. Despite the neat allocation of functions (de Winter & Dodou, 2011), the activities are derived from arbitrary views of human-machine strengths and weaknesses (Dekker & Woods, 2002b). The problem is that they are never fixed, the capabilities and limitations evolve as people learn and technological systems are upgraded (Lake et al., 2016; Woodward & Finn, 2016). Moreover, automation systems can only operate within the confines of the data they were programmed upon (Earley, 2016). This often leaves users waiting for upgrades before new capabilities start to emerge. At best, the system will be upgraded with the designer's imagination on how the system will work (Hamada & Saito, 2018). Therefore, it is the human helping driverless trucks to adapt, while understanding how the technology works. Once it is understood, automation is opportunity to improve how safely and efficiently trucks are driven. It could, however, just make haulage just as high-risk as it is today, or worse (Department of Mines and Petroluem, 2014b).

Data Outputs and Insights

Data produced by a machine has typically outweighed the ability of humans to remain in-the-loop (Wiener, 1989). Being out-of-loop is driven by automated system that combines labels, numbers and colors that contain various levels of meaning (Endsley & Kiris, 1995). Supervisors of automated systems need to adapt to new data languages often cloaked as machine insights (Sarter et al., 1997). People follow recommendations given by a machine, with little insight into how it arrived at its conclusion (Hurley & Adebayo, 2016). Automated systems are marginally transparent, given that their algorithms are considered Intellectual Property of the designer (World Intellectual Property Organization, 2019). Therefore, automated systems operate independently from their users, limiting the decision-making process to enable user's ability to solve their own problems (Brantingham et al., 2018). While the automated systems gather performance data, the information is fed back to the vendor for optimisation (Hurley & Adebayo, 2016). Optimising the system without educating the end-user to truly understand what is happening, limits the overall human-centered improvement cycle (Giacomin, 2015). Transferring driving tasks to a machine, redistributes all the tactical information previously communicated by truck drivers (Caterpillar, 2013). Where a simple discussion could be held with a truck driver, now needs to be carefully extracted from filtered information or collected by observing truck movements (Caterpillar Global Mining, 2019).

Driverless technology appears to have skipped ahead of the research theories that try to explain data ontology. The WA Mining Industry automated trucks whose agency they previously understood and actively controlled (Department of Mines and Petroluem, 2015b). However, as haulage systems were engineered, the interaction and dependencies on others change, yielding a more complex by-product (Department of Mines and Petroluem, 2015a). Vehicle interactions evolved from complex situations (Department of Mines and Petroluem, 2015c); requiring equipment operators to use data to navigate and foresee situations. Understanding system data is unique to that person and cannot be reconstructed by any other person (Sieck et al., 2007). As more driving tasks are automated, the further people are removed from the immediate process (Wessel et al., 2019). Therefore, data outputs can become more mysterious than they were previously (Rankin et al., 2016). Although the developer designs the system, it is the user who is responsible for working out what the data trying to explain (Endsley, 2016). The problem is that interconnections form to quickly distribute data across the system, informing and directing people on what automated equipment will do next (Christoffersen & Woods, 2002).

The lack of transparency in automation has not stopped designers from attempting to 'augment' human work (Araujo, 2018). Augmentation is to enable people to be more creative and thoughtful by computing data insights (Hebbar, 2017). Big data does all the heavy lifting, while a human simply actions the recommendations from the machine (Hurley & Adebayo, 2016). However, a solution-driven approach is argued to deskill the human, rather than increase their knowledge and understanding (Bravo Orellana, 2015; Ito & Howe, 2016). As people are promoted to higher levels of supervisory control, the less they learn about the operation (Sarter & Woods, 1995). Whether data informs people on what to execute, or simply supervise a machine to perform a task, people must identify situations that are beyond the machine's data set (Skeem & Lowenkamp, 2016). This activity is often under-specified and requires people to improvise, reintroducing them into non-designed situations (de Visser et al., 2018). The data presented can appear more confusing than it did before, making it difficult to return the system to a safe state (Stensson & Jansson, 2014). Although display functions may list rules that decided an outcome, the literal representation during peak periods may be cognitively restrictive (Cummings et al., 2016). Nonetheless, providing users with access to computations and partial decision-making are more useful than solutions (Zittrain et al., 2018). Furthermore, if the aim of using data to is to augment human work, then the human must be creative with that data. While the ontology is biased (Bolukbasi et al., 2016), opaque (Buolamwini & Gebrum, 2018), solutionist (Ross & Swetlitz, 2018) and specialised (Skeem & Lowenkamp, 2016), data will continue to reinforce old habits and underpin the optimisation problems that led them to automation.

Literalism and Parameterisation

Driverless haul trucks give the impression they are safer by projecting their haul route. A truck displays its travel pathway via an in-cab display in manually operated equipment (Caterpillar Global Mining, 2019). This level of transparency in travel routes can also increase the level of trust people have for automated systems (Botsman, 2017). Providing travel pathways increase the certainty around what the machine will do next. However, despite this level of transparency, a manually operated machine with an in-cab display collided with a redirected haul truck (Department of Mines and Petroluem, 2015c). This incident questions whether people are even observing intended truck routes. The redirected pathway, following a corresponding truck slide, highlights the operating boundaries of automation (Ockerman & Pritchett, 2002). Automated systems work well under designed conditions, yet they perform poorly when situations are beyond their design parameters (Billings, 2018). These situations can be compounded by machine logic that is able to identify a hazard, however, is unable to provide a safe way forward (Caterpillar, n.d.-c). Operational boundaries are attributed to a set of constrained instructions, which are insensitive to the continuous shift in priorities and objectives (Vul et al., 2014). While attempting to achieve an objective, brittleness upsets the process, with an inability to execute its part of the process (Ockerman & Pritchett, 2002). Therefore, the technology simply 'throws up its hands', effectively stopping the process or immediately handing back control (SlashGear, 2017).

The value of human supervisors is their ability to exercise unconstrained thinking (Lake et al., 2015). A human is capable of drawing information from external sources to improvise during novel situations. Leveraging from previous experiences allows humans to solve localised problems, which machines may be incapable of solving (Reason, 1990). Despite the benefits of a truck performing "exactly as the computer has programmed it do" (ADVI Hub, 2016), the downside is that they perform nothing else. Systems that are predictable, are not overly adaptable (Inagaki, 2003). Therefore, it is the system-based roles that cover the shortfall (Dekker, 2003). This trade-off raises an interesting conundrum of the value of replacing human work. With constant supervision and intervention, the value proposition diminishes (Noy et al., 2018). Despite the direct safety benefits of removing humans from a high-risk task (Palmer, 2019), the consequences are only just coming to fruition (Department of Mines and Petroluem, 2015c). After all, automation is 'stupid' (Domingos, 2015), exacerbating the reliance on humans to provide the context to make informed decisions. However, this can be difficult, with literalism restricting the reconfiguration of instructions (Billings, 2018). Difficulties arise when attempting to redirect an automated system. Not only enabling the machine to understand new instructions, yet to perform those instruction as expected (Woods & Hollnagel, 2006). Without them, the operating parameters simply retain the status quo, hiding the limitations of the logic while everything else adapts (Winfield & Jirotka, 2017).

Automated systems can appear adaptive when compared against the data set it was trained on (Prechelt, 2012). For example, parts of the programming data are held out for testing, so when machines are tested against humans, the performance appears comparable (Walker, 2016). However, the performance is not comparable, particularly when tested on non-training data (Buolamwini & Gebrum, 2018). This logic applies to driverless haul trucks and their ability to recognise objects (Caterpillar, n.d.-c). LiDAR and Radar technology are capable of identify objects, yet they are unable to distinguish between windrows and people (Teichman et al., 2011). Parameterisation problems become apparent when Global Positioning Systems (GPS) on driverless trucks are ineffective, which has reverse obstacle detections fail (McKinnon, 2019). Moreover, self-driving motor vehicles experiences a similar phenomenon, where the oncoming vehicle was unable to identify a pedestrian in time to stop (National Transportation Safety Board, 2018). Despite driverless technology coming along way, it is not there yet. There are more advancements to be made, with various industries that need to be made aware of machines functions and their technical capabilities (Payre et al., 2016).

Protectionism and Resilience

Engineering defence layers to protect a system from failure is widely accepted practice in risk management (Summers, 2003). Defence in-depth is philosophy grounded by intelligence hardware that assumes incidents unfold in a linear chain of events (Murphy, 2016). If this were the case, the more connected a human-machine system became, the more redundancy would be required to counter

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predictable domino-like reactions. The empirical basis for validating the success of controls are the absence of significant events; if the system has not had an incident then the arrangements are safe (ADVI Hub, 2016). Though this assertion can be misleading, Reason (1990) explains how automated systems are not known for their response to isolated hazards. As an example, a virtual intersection that is not demarcated in the physical mine laid dormant until a driverless vehicle needs to use it (Department of Mines and Petroluem, 2015c). Retrospectively, the installation of signs and devices could have assisted the human operated machine to identify potential interactions and avoid the collision. However, the physical demarcation of every intersection simply adds more layers of protection in already complex system, opening more disparities between the physical and virtual environment (Caterpillar, n.d.-b).

To safeguard against incidents, engineers often design extensive levels of protection to create new forms of failure (Caterpillar, 2013). Traditionally, the WA Mining Industry has prioritised layers of protection over resilience, implementing theoretical walls that are incapable of bouncing back (Willey, 2014). The rigorous test structures and fail-safe systems implemented as a means of insulating driverless technology from conventional incidents, seem to have created their own pathways that have mystified the industry (Department of Mines and Petroluem, 2014b). Technology introduced to replace human limitations (i.e. driver attention, concentration, fatigue) with layers of artificial intelligence (i.e. LiDAR, radar, pattern recognition) have now become the industries greatest weakness (Department of Mines and Petroluem, 2014a; 2014b; Teichman et al., 2011, 9-13 May). Perrow (1997) explains how the fallacies of "defence in-depth" can obscure the view on how systems behave when they are stretched and compressed. The result had left investigators puzzled how the driverless system became so opaque to those who use them. The regulator reported a "lack of system knowledge and understanding of how the autonomous equipment system works" (Department of Mines and Petroluem, 2014b, p. 1). What automation taught early adopters of automation, is that the more layers that are in place the more domain experts are removed (Billings, 2018). When users are reintroduced back into the control loop to solve system malfunctions, the processes can appear more peculiar than they did before, making the recovery method process much more difficult (Pritchett et al., 2013).

Assisting people to cope with complexity is at the heart of resilience engineering (Dekker et al., 2008). Technological innovation in the WA Mining Industry has resulted in dramatic improvements in decreasing injury rates since driverless technology was introduced (Caterpillar, n.d.-a). Nevertheless, it takes time for automation to magnify the inefficiencies in a process, even if the industries processes were benchmark in both safety and productivity (Bellamy & Pravica, 2011). The role of the human is radically re-engineered to remain the critical interface between sub-systems of complex whole, particularly if they are dealing with multiple 'expert' systems with various objectives and limitations (Fridman et al., 2018). How well a system withstands variations and disruptions outside of the design envelope is an indication of how resilient it has become (Chandler, 2014). Human flexibility and adaption are yet to be truly understood by cognitive scientists, with various skills sets to be engineered into a machine (Lake et al., 2014). Machine learning may be able to beat the world's best AlphaGo player; however, it still cannot drive to the match (McFarland, 2017). For a system to be agile and successful in this digital revolution, it must mature beyond machine literalism to be pivot and manoeuvre around danger (Srinivasan & Mukherjee, 2018). Ito and Howe (2016) believe that augmentation holds the key, fostering the relationship to create the foresight to anticipate risk and navigate the complexity of ever-changing landscapes.

Manual and Automated Modes

Whether a haul truck is in manual or automated mode depends whether it has been programmed into the machine. Moreover, if system engineers are yet to figure out how to automate the task, then trucks

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must be operated in manual mode. This can also be said for communication losses, where network must be maintained in order to control trucks automatically (McKinnon, 2019). A mode can be identified through the lighting system for ancillary equipment operators and via in-cab display for system-based roles (Caterpillar, 2013; Caterpillar Global Mining, 2019). While some mining operations mix manual and automated haul trucks, others choose to separate the differently operations entirely (Department of Mines and Petroluem, 2015a). This approach can alleviate the confusion behind determining whether the truck is manual or automated mode (Sarter & Woods, 1995). More importantly, the different functions and rules associated either mode (Glover, 2016). Endsley (2016) explains how the consequences emerge when people are surprised by equipment functions, which can ultimately lead to haul truck interactions. Alleviating the issue requires improving the dialogue on the overall objectives, operating envelope, next movements and resolution logic (Salas et al., 2010). Feedback loops are considered to be a starting point to merging the gap (Sklar & Sarter, 1999). Consequently, improving feedback could the minimise short phases of intervention, observed as the frequent cause of people who have lost track of machine assignments (Feldhütter et al., 2019).

Human factors research appears optimistic on the progress towards user comprehension of automated modes and configurations. Norman (2013) argues that the idea is to put knowledge into the world. While some academic papers promote the development of rich ‘mental models’ for automated systems, Sarter (2008) contests that the theory is empirical flawed. Regardless of what product vendors train their users on what to look for (Merritt et al., 2015), Sarter et al. (1997) claim that there will always be mismatches in the way humans supervise machines. Automation surprises are argued to be a normal by-product of a machine that undertakes work independently (de Visser et al., 2018). If a system required ‘safety drivers’ for motor vehicles, for example, the productivity value would soon diminish. However, when a driverless machine confronts a novel situation, it can become quite onerous when attempting to draw from external resources (Endsley, 2016b). Identifying the correct mode is a consequence of the system’s design, not the fact that automation has gone too far (Norman, 2013). A mismatch in mode identification occurs when the machine’s interface does not visibly display the mode, which requires users to remember a mode from hours earlier (Feldhütter et al., 2019). Casner et al. (2016) emphasised that designers should allow for possible intervening situations that can distract humans from remaining in touch with the machine’s mode of operation.

The transition between manual and driverless control has been identified as an unconventional risk for the WA Mining Industry (Department of Mines and Petroluem, 2015a). Automation can generate unanticipated changes in a haul trucks’ direction, leading to a loss of vehicle control. If the loss of control had indeed involved a mode change, then it is likely that this situation was recorded somewhere in the system. Björklund et al. (2006) explain how retrospectively, available data gives rise to engineering confidence that transitions are observed by human users, with the view that higher attention rates can avoid such occurrences. Nevertheless, researchers are left with a puzzling thought when people, who do not communicate with machines, understand what mode a machine is in. Dekker (2014b) suggests comparing the difference between the machine function and user’s intentions, the disparity and similarities offers some indication of the persons’ awareness.

3.2 Research Question 1

How are the theoretical viewpoints of human-machine systems influencing the approach to haul truck automation?

The theoretical viewpoints are underpinned by science and engineering. Both fields study systems by ‘reducing’ them to their most basic parts, analysing what is contained. Engineering attempts to replicate the components by reverse engineering human tasks. Machines are then programmed with the patterns that are recognised in basic human level performances. The technological advancements made

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available are then introduced into the system, reallocating activities to either human or machine. The system is theoretically 'reconstructed' by the designer, specifying tasks to be undertaken by driverless trucks (i.e. drive, load, tip) and residual work by humans (i.e. object clearance, surveys and assignments). When the system is theoretically reconstructed and put back together, existing relationships and connections are transformed to create new situations like the watercart incident (see Department of Mines and Petroleum, 2015c).

3.3 Processes in Human-Machine Systems

Opacity and Transparency

Augmenting the relationship between driverless trucks and their supervisors depends on the technology's transparency. Opacity is the by-product of a highly protected technology that reduces human capacity to comprehend its function (Billings, 2018). Therefore, the system provides minimal insight into how the algorithm decides an outcome (Dressel & Farid, 2018). For example, driverless trucks may perform U-turn at a loading source without notifying human supervisors on the reasons why. Demystifying the opacity requires the illumination of the decision-making process (Winfield & Jirotka, 2017). According to Wiener (1989, p. 244), pilots of automated aircraft frequently asked: "What is [the machine] doing? Why is doing that? What is it going to do next?" Automated systems can even be deliberately designed to limit their transparency. One of the reasons is to protect the designer's Intellectual Property (World Intellectual Property Organization, 2019), while another is to avoid the technology from being overridden. However, the consequences leave humans unable to track the machine's mode of operation (Sarter et al., 1997). Furthermore, the unanticipated actions of the machine can result in automation surprises (Woods & Sarter, 1998). Automation surprises are anticipation of one action (turn left), yet the machine performs something different (turns right). These surprises where previously alluded to by Norbert Wiener. His study of B-757 pilots found that 69% of participants were surprised by the automated actions, while 35% were unsure of the technology's modes and features (Wiener, 1989). This phenomenon was replicated in the WA Mining Industry, where an investigation found that people involved in a driverless truck incident had a "lack of system knowledge" (Department of Mines and Petroluem, 2015c, p. 1). Despite the protection of a truck's decision-making process, it appears the trade-off is stifling the creativity and understanding of driverless truck functionality.

The processes used to collaborate with machine can become increasingly vague to humans. Particularly as the technology evolves and progressively replaces more human work. The more people are promoted to a higher level of supervisory control, the more they are removed from the immediate process (Stanton et al., 2001). Moreover, the greater number of trucks that are automated, the smaller number of people available to understand suitable driving techniques. The intricate knowledge of a truck's gear range, turning circle, reverse capability and handling will be minimised. Therefore, the transparency of the system's capability will become increasingly important, explaining how the truck performs routine tasks. Contrastingly, in order to compensate, humans learn by observing how the truck behaves. Automation typically filters out direct information that explains the reasons for those actions (Zittrain et al., 2018). Consequently, the user implements more test structures to verify compliance to existing systems, simply adding more complexity and opacity to already multi-faceted piece of technology (Department of Mines and Petroluem, 2014b). Despite comprehensive training programs, Woods (1996b) explains how traditional training approaches may interfere with current monitoring routines and learned interpretations of automation functionality. Providing transparent feedback can be significant challenge, with interfaces required to provide vital pieces of information. The balance is presenting information people need, without overloading them with information they don't need, or know how to interpret (Salas et al., 2010). Warning signs can become hidden among complex web of information, the risk being no response at all (Dekker et al., 2008). The reverberations of opacity are a false sense of security that processes are working as intended (Rasmussen & Vincente, 1989). However, if the transparency is there, human supervisors may be able to provide the improvisations that they are designed to provide.

Tight and Loose Coupling

According to Perrow's Interaction/ Coupling Chart, conventional mining techniques are loosely coupled and highly complex in their interactions (Perrow, 1984). Prior to driverless technology, haulage operations contained conventional buffers with flexible tendencies that the industry came to understand (Department of Mines and Petroluem, 2015b). However, when driving responsibilities were transferred to an automated system, haul truck connections with others had changed (Department of Mines and Petroluem, 2015c). Where positive communication would be utilised to pass a haul truck, now requires the truck to be virtually locked before passing (Hansen, 2020). Moreover, if a driverless truck is assigned to tip at the crusher, the truck will remain stationary until it is cleared to tip, regardless of time (ADVI Hub, 2016). Since the algorithm propagates across the entire system, every truck performs the exact same activity. Such a highly connected system exacerbates the literalist thinking of a machine (Dekker et al., 2012). Therefore, supervisors must think quickly to change functions and instruct the automated system on what to do next (Miller & Parasuraman, 2007). Contrastingly, trucks drivers who notice the crushers' unavailability, simply ask the control room for another dump location (BHP, 2018). The flexible tendencies of a human to adapt and ask questions, enables the haulage system to become free flowing. Similarly, the situation occurs in losses of network communication (McKinnon, 2019). In a manual system, truck drivers could operate if communications were lost. However, for a driverless truck, the technology simply cannot operate unless communications are maintained (Hamada & Saito, 2018). While automated systems are constrained by a narrow set of objectives, the impacts of tighter coupling are experienced more rapidly (Jamasmie, 2019). Therefore, the inefficiencies and failures have a greater impact and are much more difficult to isolate.

Automated systems are historically known for introducing characteristics that produce 'normal accidents' (Perrow, 1984). An incident is considered normal when it involved normal people, completing routine work, under normal circumstances (Wears et al., 2015). The focus is often at the sharp end, arbitrarily reconstructing the sequence of events to evaluate human responses (Dekker, 2014a). The further the investigation moves back from the sharp end, the more coupled and connected interactions become (Weber & Dekker, 2017). Therefore, systematic explanations are often replaced with what was observed (Drury et al., 2012). This is where the notion of direct causes narrows our thinking, the tight connections in a complex system are oversimplified (Department of Mines and Petroluem, 2015c). As a consequence, the reductionist thinking leads to a broken component, while other latent and tightly coupled aspects are underrepresented (Dekker, 2010). For example, a driverless truck may slide out of lane, yet the loss of control could have been created by communications, traction controls, speed zones, wet weather or road material (Department of Mines and Petroluem, 2015a). Since the human response is to go after what did not work as intended, they immediately focus on failure (Hollnagel et al., 2015). However, coupling is about focusing on the interactions themselves, not the components themselves (Wears et al., 2015). In addition, all the components may have behaved successfully. Therefore, safety lies in the interaction in tightly coupled systems, not the perfectly engineered component (Hamada & Saito, 2018). Systems must be flexible, nimble and robust if they are to navigate the complexities of the interactions they face (Cilliers & Presier, 2010).

Explaining the non-linearity of interactions does not prevent vendors attempting to provide solution-driven products. Despite driverless capabilities being developed, the automated vehicle is unable to effectively communicate with the crusher (Hitachi, 2015). Transferring control to a machine can

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exemplify the inefficiencies that are contrary to the technology's original intent. For example, without information being shared between driverless trucks and the crusher, the reverberations of queue time at the crusher can be enormous (Brundrett, 2014). The impact on people is that they are now being required to intervene and reassigned the truck fleet. Although success is celebrated when technology is componentised into a supple chain (Rio Tinto, 2018), automation eventually reaches its peak of innovation (Panetta, 2019; Trudell et al., 2014). Eventually, technology becomes so standardised that supervisors forget that systems' defences can only protect against known causal pathways (Reason, 1990). Perrow (1984) points out that it only takes two or more components in a tightly couple system to interact unexpectedly. As an example, it was unexpected that a driverless truck was unresponsive towards a manual watercart, which was heading for its pre-defined pathway (Department of Mines and Petroluem, 2015c). The non-linear reaction towards the watercart was under-specified relative to its relationship, an oversight that caused a near fatal collision. And yet this problem would never have occurred to the designer who has designed further collision and avoidance systems. As a result, additional control systems can simply tighten the system's coupling, while opening up more possible interactions and pathways to failure.

Centralisation and Democratisation

Standardising residual human tasks is based on the predictive capacity of the designer. A capacity that assumes centralising the most basic steps can guide supervisors to the safest outcome (Dekker, 2014b). However, in a human-machine system, work instructions come with a caveat. A proviso that expects people to follow written instructions, yet improvise when operational practices demand it (Dekker, 2003). Reason (1990) explains how the 'Catch 22' of supervising a machine cannot be escaped: "Human supervisory control was not conceived with humans in mind. It was a by-product of the microchip revolution." (p. 2). As a consequence, the by-product is the result of designers unable to predict and plan for every contingency (Caterpillar Global Mining, 2019). Despite this, Domingos (2015) claims that his Master Algorithm will eventually equip machines with every contingency. Until then, human intuition must inject smooth layers of local adaption, pulling information outside of centralised sources to manage unanticipated situations (Pettersen & Schulman, 2016).

Spending countless hours training people in standardised methods is a common thread in safety. The assumption is that standardising methods will build a cognitive repertoire to combat irregular situations (Dekker et al., 2012). Moreover, designers will argue that their automated system has figured out it all out, and there is no need for human intervention (Dietvorst et al., 2016). However, when the machine malfunctions, supervisors must intervene in situations they may not truly understand (Tech Light, 2016). Reason (1990) made the point that automation denies machine supervisors the opportunity to practice their post-automation skills, which ultimately leads to degeneration of domain expertise. When human supervisors are eventually relied upon, they perform poorly (McKinnon, 2019). For example, driverless trucks may not need human assistance for hours, then suddenly required to clear a reverse object. In order to democratise their automated system, Toyota built their process from the bottom up. The purpose was to increase their effectiveness and quality of workmanship (Trudell et al., 2014). A company cannot "… simply depend on machines that only repeat the same task over and over again." argued Mitsuri Kawai, Toyota Executive Vice President (Mols & Vergunst, 2018, p. 122). Therefore, automated systems may be efficient; but they are not overly skilful. Reverse engineering human mastery in a machine will eventually become redundant (McCarthy et al., 2000). Thus, to compete with low cost companies, industrialised nations are realising that their prosperity resides in user-centred innovation (von Hippel, 2005). Improving a company's supply chain may mean cultivating their inner-Artisan, returning to the days of human craftmanship (Protzman et al., 2016).

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Historical experiences do not account for truly novel events. A procedure detailing every design aspect of the process does not always reflect the limitations of automated systems (Pritchett et al., 2013). For example, the actions of machine supervisors labelled as “not adhering to…” or “failure to respond…” may be an indication of the creativity required to get real work done under technological constraints (Department of Mines and Petroluem, 2015c). In contrast to compliance-based approaches, perhaps the use of procedures as recipes can democratise the system enough for the people to continuously innovate (von Hippel, 2005). As a result, processes can then leverage the problem-solving aspect of human intelligence, therein be more impactful than debating deviations from centralised procedures and contrasting individual experiences (Lake et al., 2016).

Virtual and Real-World Distinctions

Representing the physical world through virtual maps may suggest to human supervisors that the systems’ interface is a true. Supervisors may also believe that physical controls are in place simply because the virtual representation displays it (Caterpillar, n.d.-b). Research surrounding the distinction between physical and virtual worlds however, points to something different: an ideal world that is free from localised constraints (Dahlstrom et al., 2009). For example, virtual displays can be a supreme worldview how the system should look and function from an engineering perspective. Salas et al. (2010, p. 10) argue that real-world problems are “far removed” and are replaced with simplistic representation. It is essential that virtual representations co-evolve, seeking human input as they attempt to solve frontline problems (de Visser et al., 2018). Local constraints consist of many different parts, which can produce surprising and unpredictable situations for the user (Sarter et al., 1997). Thus, when physical changes that are not retrospectively updated, the condition may not visible to the user to warn them of an upcoming intersection (Department of Mines and Petroluem, 2015c).

The regulator governing mobile autonomous mining systems in Western Australia (WA) appears fairly pessimistic about the representation of physical mines. The Department of Mines and Petroluem (2015a) highlight a number of hazards associated with integrating driverless machines into an existing environment, recommending a phased approach to the introduction of advanced technology. The segregation of manually and automated haul trucks is designed to manage the risk of virtually and physically controlled interfaces. Although the designer may have developed tools to redesign the virtual system to meet operational needs, technology cannot remove the problems that technology creates (Baxter et al., 2012). The challenge of pre-programming a machine is that operational problems just keep moving, pushing the innovation curve outside of the automated systems’ pipeline (Trudell et al., 2014). Analysing what a process contains does not explain what it will do, which makes updating virtual displays a never-ending iteration (Woods, 2016). Moreover, representative samples of the physical world can differ from human perception, which are constantly re-framed for meaning and insight when displays are not in real-time (Rankin et al., 2016). Given the complexity of representing the physical world, the on-board computational requirements for automated systems are extensive. Therefore, there is a need for more computer power than what can physically fit on a machine, given the amount of data processing required to operate LiDAR, image recognition and radar technology (Goel, 2016).

Processing data gathered from vehicle sensors is critical to keeping visual representations real. Road network surveys allow a virtual road map to be created (Teichman et al., 2011). The location of each ‘connected’ vehicle can then be tracked against the virtual model to determine the vehicle’s speed and direction (Hamada & Saito, 2018). Automated and manually operated vehicles can then identify the proximity of other vehicles, providing both agents with the means to reduce potential interactions (BHP, 2017). System supervisors are also given the capability of implementing virtual speed, traction zones and clearing obstacles (Caterpillar, 2013). Virtual zones allow users to make the connection

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between surveys and surfaces in line with the physical environment. Supervisors can also control the speed of the vehicle in the event that a machine is unaware of changing weather conditions (Department of Mines and Petroluem, 2015a). However, as previously discussed, the machine will do exactly what it has been programmed to do. Consequently, if a virtual zone has been surveyed beyond the physical boundary, a driverless machine will still attempt to drive to those parameters (Department of Mines and Petroluem, 2014b). Moreover, if a truck loses communication, the virtual mine model can only identify its last known location. In the event of an interaction, the truck is now considered an object and has the potential to cause a collision (McKinnon, 2019).

Active and Passive Workload

Transferring control to a machine may appear like a logical step to reduce human workload. Perform lots of analysis, work out the most effective method and then engineer those actions into a machine (Lake et al., 2016). Although the assumption here, however, is that the underlying conditions that make this method possible will remain unchanged. Eventually, an automated system will face situations beyond its training set (Buolamwini & Gebru, 2018). Ferris et al. (2010) explain how the workload of supervising machines are short intensive moments, backed up by long periods of inactivity. This workload phenomenon was uniquely observed by Perrow (1984) to cause workload 'bunching'. Bunching the demands for human input is an error inducing mode of operation according to Reason (1990). Moreover, humans can be faced with an influx of requests from a machine that may not even be executing a better job (Endsley, 2017). Attempts to evenly spread human workload is often confronted with more engineering (Dekker, 2004). Product vendors will claim that the user will always be in control (Rousseau, 2015). However, a quick transfer of responsibility can result in negative outcomes when humans are not equipped to take over control (National Transportation Safety Board, 2017).

Automating human techniques have been long argued as a performance optimiser than a workload minimiser (Prewett et al., 2010). Nonetheless, efforts are still being made to reduce human input often cloaked as 'augmentation' (Dressel & Farid, 2018). For example, a machine may be assigned to analyse data and offer solutions, however users are not privy to inputted data and how it arrived at a conclusion (Dressel & Farid, 2018). The inaccuracies of data prediction highlighted by Brantingham et al. (2018) and the clumsiness of automation noted by Lee and See (2004), undermines a supervisors' trust. Constantly verifying a machines' decision-making process is a highly cognitive task, meaning that humans will avert using algorithms altogether (Dietvorst et al., 2016). The workload of machine supervisors is argued to be a normal by-product of an automated system that proceeds without user input (Miller & Parasuraman, 2007). Contemporary research in cockpit automation found a misleading conclusion on workload, noting that automation is not 'autonomous' and cannot always be left to its own devices (Edwards, 1977). Despite fewer physical activities being performed, the cognitive demands of monitoring a computer system actually increases (Wickens, 2008). Moreover, it is less likely that the intervention methods needed to recover a machine are not memorised, nor would they unfold as the training proceeds them (Engle, 2016). The main driver for automation is not reducing workload per se, rather making a process safer and more productive (Yeomans, 2014). Therefore, the more reliable automated machines become, the higher the expectation to improve their performance will become.

Cognitive overload has contributed to many incidents in Aviation. Flight deck incidents have occurred in systems where human workload was thought to have been reduced (Wickens et al., 2016). For instance, an automated system failure led to pilots' performing a manual calculation for the aircraft's landing. At the same time, the pilots were unaware of the parallel problems of a single engine malfunction. Although the pilots eventually responded, the wrong engine (the only functioning engine) was subsequently shutdown (Salas et al., 2010). Prior to this event, the Aviation Industry would have celebrated the reallocation of workload to a machine. Allocating work to a machine is argued to relieve humans to focus on more important tasks (de Winter & Dodou, 2011). Yet, human users still find themselves monitoring a machine's activities for non-designed situations (Victor et al., 2018). The residual is a bi-directional bridge between physical and cognitive tasks, manoeuvring among monitoring and taking control over control in order to remain in touch with local constraints (Casner et al., 2016).

3.4 Research Question 2

What processes are designed to support automation to equip human supervisors to improvise during non-designed situations?

The processes of automation are residual tasks that the designer is yet to figure out how to automate. The processes work well when the system is performing as intended. However, when faced with novel situations, the processes are unable to be adapted beyond their design parameters. Since the designer is unable to imagine and prepare for every contingency, human supervisors must use their unconstrained thinking to draw from external information and previous experiences. Therefore, the processes work well in designed situations, yet lack the relevance and adaptability when situations do not unfold along pre-determined lines.

3.5 Human Factors

Mode Awareness

Mode awareness is recognising a machine's state and understanding its operational parameters (Funk et al., 2009). Driverless haul trucks operate in three different modes: autonomous (solid blue); autonomous-ready (flashing blue) or manual (green) (Caterpillar, 2013). Mobile equipment operators, maintainers and system technicians must understand the functions of each mode, particularly when mode changing a truck. Maintainers and system technicians are required to enter the truck's footprint to manually recover, refuel and inspect the machine (Department of Mines and Petroluem, 2015a). Therefore, the truck is required to be switched to manual mode for the duration of the task. A system interface located inside the light vehicle allows technicians to perform mode changes locally (Today Tonight, 2018). Alternatively, Mine Control is contacted via two-way radio to switch the truck's state to manual mode (Glover, 2016).

Driverless haul trucks can operate in the mine in manual or autonomous mode. Manually operated equipment must identify the mode of operation and satisfy the attentional demands. Sarter and Woods (1995) claim that when designers increase automated mode functions without the support of human cognitive requests, mistakes in mode identification is often the consequence. Errors in identifying operating modes have been a factor in human-machine systems for decades (Monk, 1986). The introduction of driverless haul trucks into a mining operation has the potential to replicate similar mode-related incidents (Sarter, 2008). Confusion around what mode a machine is in is at the heart of automation surprises, where a user instructs the system to do one thing, yet the mode allows it to perform something different (Sarter et al., 1997; Wickens et al., 2016). Studies into mode errors in Aviation have found that minimal system feedback, complex functions and mental models reduce mode awareness of pilots (Björklund et al., 2006; Sarter & Woods, 1995). In addition, the testing of partially automated vehicles is finding similar mode awareness problems in safety drivers, which identified a lack of mode awareness being driven by monitoring inattention (Feldhütter et al., 2019).

The importance of mode monitoring of driverless trucks is to anticipate the actions of the machine. Misconceptions can arise in a persons' mental model of automated systems, which underpins the

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expectation of what the system will do next (Salas et al., 2010). Mental models that are vague and incomplete, invite opportunities for automated systems to engage in functions not assigned by users (Rankin et al., 2016). Equipment operators are able to observe a haul truck's assignment; however, they cannot see the details of that assignment, performance restrictions or decision-makings. Instead, they must rely on their mental model of the driverless truck's function to manage the underlying process (Hansen, 2020; Today Tonight, 2018). For example, a technician will be unsuccessful in attempting to activate an emergency stop a truck manually controlled. Unlike automated motor vehicles, technicians are not expected to immediately regain control of a truck (Kyriakidis et al., 2017). As a result, driverless trucks that are unable to operate automatically come to a controlled stop and are driven manually to a safe location for observation.

Responding to Information and Warnings

Supervisors of driverless technology must be capable of responding to information and warnings. Information and warnings in driverless systems include obstacle detections, health events, proximity detections and truck performances (CAT, 2020; Glover, 2016). Therefore, observing and acting upon this information is critical to supervising automated systems. The modality of the information is presented in various forms, including visual and auditory cues (Caterpillar Global Mining, 2019). Investigations may find that supervisors of automated systems failed to respond to system warning. A critical point in time when someone should have intervened (Department of Mines and Petroluem, 2015c). However, the information that was available, is not necessarily the information that was observed (Dekker, 2014). For information to be observed, cognitive is work required to determine what the system is trying to tell them (Woods, 2018). Woods and Hollnagel (2006) explain that observability not only depends on visual displays, but on personal interests, workload, objects and attentional demands.

Humans are not passive receivers of information; they are actively acquiring, sensemaking and acting upon data. The basic ideology of information processing is surveying the surrounding environment and comparing it to stored memory (Dekker, 2019). For the processing of that memory, Engle (2016) considers Baddeley and Hitch's (1974) working memory system as a temporary storage of information that regulates attentional demands. When determining the relevance of that information, the process of sensemaking fills the gaps between in what was anticipated (remembered) and what was observed (stimulus) (Rankin et al., 2016). When a sudden mismatch occurs between the two, automation surprises start to emerge (De Boer & Dekker, 2017). Information processing has historically been modelled on computer functionality (Eysenck, 1993). Visual information was theorised to be a visual scratchpad that is situated in a working memory. For example, Parasuraman (2000) proposed that information was acquired, analysed, selected and responded to, through these four broad functions of human processing. The functions could then also be used as a basis for automation (de Winter & Dodou, 2011). This notion, however, has been argued as an arbitrary view on information sharing among human-machine systems (Dekker, 2019). Researchers also argue whether input-output devices should resemble human properties, as computer metaphors are artefacts that represent an over-simplification of human thought (Stensson & Jansson, 2014). Processing information is not the only problem, there are other collaborative issues such as transparency (Winfield & Jirotka, 2017), explainability (Gunning, 2016), feedback (Sklar & Sarter, 1999) and literalism (Billings, 2018).

Computers are rarely transparent in what they are doing and how they got there (Skeem & Lowenkamp, 2016). Technology often withholds the data sets that were used to decide an outcome. This is a normal by-product of automated systems. When working with a strong and silent character, the cognitive demands of interpreting its outputs are high (Christoffersen & Woods, 2002). The purpose of data, however, is not just providing information per se, its assisting the supervisor to

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understand what the machine is performing (Miller & Parasuraman, 2007). The critical test is when the device helps humans notice more than what they were specifically looking for or expecting (Sarter and Woods, 1997). The failure of this test is restricted to humans: not identifying information, observing information correctly, forgetting data and negatively reacting (Dekker, 2014a). However, it is a much more complex relationship between human and machine, not the sole processing capability of the human to observe, analyse and respond to information (Woods & Hollnagel, 2006). If humans are going to fulfil their role as machine supervisors, information needs to flow freely between human and machine. The impact of responding to information on supervisory roles are significant, given that the position direct trucks based on the system's information (Caterpillar Global Mining, 2019). Consequently, the available information has become an instrument to inform supervisors on what driverless trucks are likely to do next.

Craftsmanship and Skill Degeneration

While machines are replacing humans in repetitive tasks, a level of Artisan craftsmanship must still be retained (The Wheel Network, 2016). Domain expertise comes to fruition when a machine is unable to resolve a non-designed situation (Endsley, 2018). While automated systems are not known for improvising, the process they are repeating must eventually be improved upon (Trudell et al., 2014). As a machine becomes more reliable, supervisors are denied the opportunity to practice their marginalised existence (Berdicchia & Masino, 2018). The degeneration of skills forms a vicious cycle, where the domain expert begins realising their own incompetence and dependency on machines (Bravo Orellana, 2015). Even though manual skills are mastered through practical application, recalling those craft-like skills in an emergency are reduced (Li et al., 2014). Particular cases in automated driving point towards an over-reliance on automation (Körber et al., 2018). Salas et al. (2010) noted that pilots became heavily dependent on FMS-generated displays, which were reducing their ability to identify the proximity of travel way points. More immediate information is supposedly available in conventional methods such as flight charts. However, there is no real purpose of introducing advantageous technology if the value of the product is not being realised.

Taking advantage of automation means fully understanding the tool humans are using. The uptake is an indication of the trust people have in the machine's ability to operate independently (Hoff & Bashir, 2015). Although Lee and See (2004) observed a high level of trust, the consequence was a much higher dependency on automation. In contrast, a heavily manually operated system was a symbol of distrust, resulting in lower levels of utilisation (Payre et al., 2016). When users manually control a system to "help the robot through some situations…" (MIT Sloan CIO Symposium Videos, 2017), the local adaptions can be confusing when solving beyond the control loop (Dekker, 2003). What procedure to apply and when is the talent, especially when the recovery mission is novel, complex and the procedure is arbitrary (Goteman & Dekker, 2007). Users discovering their own competence in the application of a procedure can be misled, confronted by overlaps in the physical and virtual world that obscures the 'truth' (Reason, 1990). Furthermore, reflexivity is underpinned by the limitations of explaining failure and how their bias impacts on relevance (Holroyd, 2015). The cognitive skills that are vital to solving frontline problems are now on the peripheral, only 'flicking the switch' when needed.

The main reasons why humans are retained in automated processes is to help the machine through 'blind spots' (Noy et al., 2018). Aiding the machine meant that humans must also develop an adequate 'mental model' of how the system works (Strand et al., 2018). Product designers cannot imagine every scenario that is likely to be encountered, even if machine learning can help robots learn various scenarios from big data (Fridman et al., 2018). Therefore, users are often left to work out what the machine is capable of and what it is not (Lynas & Horberry, 2011). Suddenly re-introducing humans back into the control loop can leave them feeling disorientated (SlashGear, 2017). A quick transfer of

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control in aviation is considered by Endsley (2016) to be risky, as pilots are not necessarily aware of the situation that is arising. Recent evidence suggests that driverless processes are becoming so novel and complex, that humans are performing negatively (McKinnon, 2019). Reinforcing supervisors in residual recovery methods to combat non-designed situations may not even be relevant (Payre et al., 2016). Task simulation can mirror the process through virtual reality, however there is no guarantee that the situation will proceed in such a manner (Frimpong et al., 2003). Perhaps, it is not through big data that machines will learn how to perform human work, rather through the coaching and mentoring from the finest experts in the domain.

Intervention and Omission

People will always consider their 'tinkering' as a master stroke. Whether a supervisor is installing a speed zone, managing the fleet's saturation or pursing more tonnes for the day. Intervention is an extension of demonstrating that they know more about the situation than the machine. Conversely, designers view human intervention as an unnecessary step in the process (Caterpillar, n.d.-a). This is due to the fact that functions are already allocated on human and machine strengths (de Winter & Dodou, 2011). However, Dekker and Woods (2002a) rendered the MABA-MABA (Men-Are-Better-At/ Machines-Are-Better-At) approach irrelevant for human-machine systems. This rationale is that human-machine capabilities co-evolve over time. Not only do humans continuously learn how driverless trucks perform, the technology itself is subjected to software upgrades (Today Tonight, 2018). Since the both capabilities are continuously evolving, the evolution could explain the types of acts and omissions of observed on driverless mine sites (Department of Mines and Petroluem, 2014b). For example, a software upgrade may no longer require supervisors to upload a survey, however the automatic upload may not be suitable for use. Therefore, the human needs to intervene in order receive accurate information. This type of localised intervention, however, is often seen as non-routine and contradictory to standardised methods (Dekker et al., 2008).

Designers retain people in automated systems to monitor truck performances. A paradox emerges when deciding whether to intervene in the situation or not (Dekker, 2003). When pre-empting failure, driverless truck supervisors have the option to step-in and control the situation or allow the machine to manage itself. For example, emergency stop devices can bring the fleet to a controlled stop, yet an immediate stop can also generate its own set of risks (Department of Mines and Petroluem, 2015a). For instance, driverless trucks can slide out of lane as they attempt to suddenly stop. Moreover, the situation could be compounded if trucks were descending a ramp into an Active Mining Area (AMA). Conversely, if human intervention avoids failure, then the act is seen as a mark of expertise (Reason, 1990). Then again, if the action is not in accordance with a procedure, it can be considered a non-compliance towards the safety system (Dixon et al., 2007). When it comes to omissions, supervisors can simply be following the procedure, despite foreseeing the potential dangers. This is where human supervisors are held responsible for not intervening when they should have (National Transportation Safety Board, 2018). However, people can be heavily influenced by increases in false alarms and warnings (Wickens et al., 2009). This explains why safety drivers have turned off automated control systems in the past (Coppola, 2018). Nevertheless, closing the performance gap of automated systems is what intervention is striving to do, while omissions can be a sign that people are out-of-the-loop (Endsley & Kiris, 1995).

On the inside, informal work processes are powered people connecting the dots. As previously explained, procedures and RACI's (Responsibilities, Accountabilities, Consulted and Informed) are no more than the designer's imagination of the system (Glover, 2016). Real work is performed along the fringes through information systems and experimental invention (Protzman et al., 2016). Despite the designers' best intentions, there will always be instances where human supervision needs to help

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machines through sight, touch and sound (The Wheel Network, 2016). Therefore, formal processes can be scarcely inadequate to handle goal conflicts among the design and the application (Xu et al., 2007). While standardised work collides with conflicting goal conflicts, the tension between the person omitting just do their part, versus the intervention to ensure work quality, is heightened on the frontline.

Role Transformation

Driverless haul trucks have not only replaced truck drivers, automation creates residual roles and transforms tasks on the peripheral (Caterpillar, 2013). Haul truck drivers now fulfil system support roles, equipment maintainers or ancillary operators on transitioned mine sites (Palmer, 2019). Truck drivers who were once active participants, now passively monitor driverless haul trucks through a computer screen interface (Glover, 2016; Today Tonight, 2018). Monitoring automated systems is a higher level of supervisory control, which expects humans to intervene intermittently during non-designed situations (Banks & Stanton, 2016). People who may never have operated a computer before, are now virtually adjusting lanes, installing speed zones and clearing obstacles (BHP, 2017, July 6). Supervisory roles are not specially taught how to program a truck, they learn automated functions by observing truck movements (Caterpillar Global Mining, 2019, Dec 17). The irony of learning functions through observation is following the strict functional allocation, yet embody the improvised skills to recover from system malfunctions (Baxter et al., 2012).

Truck drivers also have the option to become ancillary operators. Although the activities remain manual, there are additional technological layers operators must learn (Caterpillar, 2013). Technology demands that operators build a mental model of the system (Sarter & Woods, 1994), particularly when operators are not involved in the programming. For example, grader operators may interact closely with the truck to witness how the system responds. Learning by doing helps operators build their knowledge base on automated systems. In addition, the introduction of mode lights requires ancillary operators to understand the meaning of each mode (Today Tonight, 2018). There is also a screen located inside the cab, which provides a predicted path for each driverless truck. Although the predictive capacity increases transparency, it is another capability of observation and information processing (Parasuraman et al., 2000). Traditionally, radio communication would be made in the event an ancillary machine wanted to communicate with a truck (BHP, 2018). However, the control room is now contacted, requiring trucks to be locked from moving before passing (Hansen, 2020).

The inclusion of system roles in automated systems is to aid robots through beyond design situations. Endsley (2017a) points out, however, that humans are not overly skilful in responding to system information. The reason is that supervisory roles are passive monitors of the system, suddenly handed back control of a situation (Reason, 1990). Even with the unique ability to recall domain expertise, supervisory roles are far removed from the immediate process (Miller & Parasuraman, 2007). In addition, the information they receive is filtered by a computer interface (Fridman et al., 2018). For example, intersections designed into the virtual mine model may not actually exist in the physical mine, which can leave mine controllers none-the wiser (Department of Mines and Petroluem, 2015c). There is a skill in locating information that is needed, when it is needed, while filtering through non-essential information to determine what is happening (Endsley, 2016b). When re-introduced back into the control loop, the recovery can become so complex and peculiar, that cognitive gaps in recovering the system safely can emerge (Endsley & Kiris, 1995).

One apparent means of solving the problem is repetitively training people in system recovery and diagnostics. Training humans to manage complex, opaque and tightly coupled systems can be difficult (Billings, 2018). If it were possible to simulate and gameplay an extensive suite of emergency situations, there is no guarantee that they would ever occur (Frimpong et al., 2003). Extensive use of automated systems can lead to deskilling and over-dependence, reducing the cognitive and

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psychomotor skills that required for manual control (Parasuraman & Riley, 1997). Moreover, as automated systems become more reliability, the less domain expertise is actually needed (Wickens et al., 2016). Toyota expressed concerns over automation creating too many laymen and not enough masters of the craft (Tech Light, 2016). By being so far removed, Bleicher (August 2017) explains how the human craft reduces overtime. Despite technology endeavouring to augment human work, it can also degenerate conventional skills and dependency on machines (Bravo Orellana, 2015). The replacement of drivers undoubtedly transforms mine site work, with unconventional situations confronting humans in their new formed roles (Department of Mines and Petroluem, 2014b)

Supervisory Control

Supervisory control was never conceived with humans in mind. Supervisors of automated systems involve a residual set of tasks that engineers are yet to figure out how to automate (Caterpillar Global Mining, 2019). More specifically, the role is in place to respond to non-designed situations to help driverless trucks navigate around them (Hansen, 2020). For example, a driverless truck is capable of identifying an object (Caterpillar, n.d.-c), however it is unable to clear or override the object (Caterpillar Global Mining, 2019). The unrestrained ability of humans to solve problems underpins their residual existence. Examining, monitoring and modifying processes that are otherwise executed by automated systems (Miller & Parasuraman, 2007). While carrying out online problems, supervisors are expected to monitor and tweak the system within the operating limits (Today Tonight, 2018). The difficult component of this, is whether to intervene or not in signs of weakness (Dekker, 2003). Supervisors can find themselves on a pathway to failure (Department of Mines and Petroluem, 2015c). The catch is whether the intervention will be successful in avoiding the situation. It is also can be their responsibility when they failed to intervene before an incident happened (National Transportation Safety Board, 2018). In contrast, if their intervention is unsuccessful, the supervisor is often the one who is accountable (McKinnon, 2019). Therefore, while ever automated systems are only responsible for a narrow set of parameters, the role of the supervisory controller is expected to cover the latter.

Supervisors are not taught how driverless trucks are programmed; they learn by observing them. In addition, supervisors are trained in how to work automation (i.e. press a button), not necessarily how it works (i.e. algorithms, logic) (MIT Sloan CIO Symposium Videos, 2017). Therefore, if a driverless truck performs something unintended, supervisors are not necessarily equipped with the knowledge of the underlying logic (Hebbar, 2017). Although the role is specified, from a design perspective, the re-introductions to control loops during novel situations are not (Endsley, 2016b). Non-designed situations require human improvisations to perform outside the box (Reason, 1990). Enabling people to work well under these circumstances, requires a collection of system knowledge, feedback loops (Sklar & Sarter, 1999) and greater transparency (Zittrain et al., 2018). However, automation is not always easy to work with, often described as an opponent rather than a team player (Christoffersen & Woods, 2002). Since the logic is fixated on achieving its goal, it will literally hold the ball until a human is needed. Multiply this by thirty to fifty times, and this gives some indication of the monitoring demands of a driverless fleet (Today Tonight, 2018). Automation is designed to operate independently, resulting in the human monitoring needs falling to the wayside (Sarter et al., 2007). Consequently, the focus becomes centred around the technology, other than user who is expected to assist the machine through difficult situations.

Assisting automated systems has been described as being bunched (Billings, 2018). Workload that is bunched is long periods of inactivity, followed by short intensive moments (Li et al., 2014). Human workload can appear in these situations as the bottleneck, with the inability of supervisors to respond and recover promptly (Prewett et al., 2010). Quite often, however, the machine has instantly reintroduced them back into a novel situation. Suddenly, the supervisor is confronted with multiple

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failures and is attempting to prioritise what should be done first (Miller & Parasuraman, 2007). Unlike self-driving cars, where the safety driver is expected to take the wheel in any situation and at any speed (Payre et al., 2016). Driverless trucks simply come to a stop wherever control is lost (International Organization for Standardization, 2019). The difficulty, however, for supervisors of driverless trucks is the recovery after a stoppage (Department of Mines and Petroluem, 2014b). For example, the task is likely to be conducted remotely by Mine Control. In addition, field technicians and ancillary operators become the eyes and ears to physically verify the situation. A combination of these roles enables the driverless fleet to execute their daily tasks (Caterpillar Global Mining, 2019). Although certain tasks are specified, situations emerge that require objects to be cleared (rock on road), surveys to be taken (updating mine model) and instructions to be given (send truck away) at various times (Caterpillar, 2013). Therefore, there is a unique relationship that forms among humans and machines, and it is not just those directly supervising the trucks either. The reverberations of supervisory control are as far reaching as drilling, blasting, ancillary equipment, equipment maintenance and the control room (Bellamy & Pravica, 2011).

3.6 Research Question 3

How does human adaptive behavior manage unanticipated machine performances and decide to intervene or not during beyond design performances?

Humans adapt to unanticipated situations by drawing from external information and previous experiences. Deciding whether to intervene or not is based on whether the supervisor believes that the automated system will recover from the situation. External information such as radio calls, weather forecasts and network systems provide external intelligence, while previous experiences of driverless trucks navigating downpours, pit interaction and potential network losses indicate whether intervention should occur. Interventions include speed restrictions, traction controls and setting changes. On the surface, the adaptability of the human can appear unnecessarily tinkering to upset the automated decision-making process. However, it is human who is held accountable if the outcome was negative and the system supervisor was deemed to have the opportunity to intervene and avoid the outcome.

4. DISCUSSION

The literature has highlighted the fascination with creating and designing new products. Especially when those products have the potential to advance the human race and provide a platform for improving the way humans live their lives. However, the immediate approach to designing a new product is to reduce the system into its most basic parts, separating the system into theoretical components to determine how things work (Dekker, 2010). The problem with a reductionist approach to understanding a system, is that a system is defined by what it does, not what it has. Designers are instantly on the back foot, engineering a vehicle to travel from A to B with little knowledge on how the mind made it possible (Victor et al., 2018). Moreover, the various paces of individual technologies have limited the full deployment capability of some AI products. For example, a vehicle may be capable of detecting an object, however it is yet to classify those objects for relevance (Held et al., 2012). Such limitations in the real world has already led to car manufactures turning off automated functionalities to accrue more travel time (Wakabayashi, 2018). Although researchers are attempting to design technology that correctly classify objects in a vehicle's travel path, the technology has a long lead time for being deployed into a real-world environment. Moreover, testing similar technology in the public sector has already highlighted the biases that exist in current engineering practices (Brantingham et al., 2018; Buolamwini & Gebrum, 2018). The impact on driving could see vehicles classifying objects incorrectly and applying the wrong functionality. For instance, the classification of a person for a tree would ignore the fact that the person may cross the road. Furthermore, attempts to navigate a road networks' signs and signals with implied road rules is a significant task for a machine, given that it may not have been confronted with those variables through previous interactions (i.e. green light and an emergency vehicle approaching) (Endsley, 2018).

The WA Mining Industry appears to be currently avoiding the complexities of object classification. Driverless haul trucks do not attempt to distinguish between objects, rather stopping when the object meets a size criterion (Caterpillar, 2013). This is a similar function to what Adaptiv claims to have been turned off by Uber (Coppola, 2018). Since the technology struggles to distinguish between objects, the vehicle would be constantly reacting to adversarial conditions on the side of the road (Eykholt et al., 2018). By turning off the object recognition function, the vehicle could then travel uninterruptedly and seek guidance from the supervisor only when required (National Transportation Safety Board, 2018). The circumstances are, however, marginally different, with haul trucks unlikely to be carrying passengers and therefore lowering the likelihood. Mining companies also have a team of well-trained professionals who are taught how the processes support the technology (ADVI Hub, 2016). Although, those processes are usually a set of residual tasks that were unable to be engineered into a machine. Standardised processes are only as effective as the designers' imagination, leaving the non-designed situations up to human intuition (Noy et al., 2018). Sharing the control between human and machine appears more realistic in the short term, becoming more transparent in the decision-making process to allow humans to navigate the vehicles through complex situations. Despite this, Intellectual Property and data protection concerns are stifling the pursuit of shared management (World Intellectual Property Organization, 2019), the algorithms are at the heart of any business product (Mitchell, 2018). On the other hand, for the technology to become truly 'self-managed', researchers and engineers must figure out how the technology can be more adaptive like a human. Until then, designers will have to do more to make shared technology more user-centered, allowing people to be more supportive in aiding driverless systems through complex situations (Fridman, 2018).

The literature has highlighted, however, that technology has not always been developed with humans in mind. The focus has always been to replicate and replace human labour, not partially succeed and allow humans to take control of the system. Through the deployment of automation in industry though, researchers have revealed that there is more to making a system work than allocating 25ecognize25ed functions to various roles (Strand et al., 2014). Disruptions may arise that requires the function owner to think outside the box. For example, if a weather system moves in, driverless machines and automated aircrafts are currently ill-equipped to 25ecognize the changing conditions (Jamasmie, 2019). The modes of communication between agents are not simple enough to explain that a weather system is approaching either, requiring the automated system to change speed or direction. Obviously, if the human supervisor was to argue 'that the task was not their job', the machine would likely put passengers at-risk by functioning as if the weather conditions were not present. The interface between human and machine is where this research investigation begins, not where it ends. Driverless technology has changed the connections that manual driving had originally formed. There have been numerous incidents on WA mine sites since the driverless technology was introduced, leaving researchers wondering why. The lack of knowledge in this field provides focus and reasoning, illustrating what research is yet to be fully understood and how objective findings can be drawn.

5. KNOWLEDGE GAPS

The reasons for incidents involving driverless haul trucks across the WA Mining Industry remains relatively unknown. Although individual investigations may point out errors from either human or machine, research is yet to explain the systemic influences of engineering a haulage system. For example, there is more to a truck–on–truck collision than an inability of humans to respond quick enough to a down pour of rain (Jamasmie, 2019). Certainly, having a process around the situation may have coordinated the response to reduce truck speed. However, this observation is after the fact, neatly

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joining the dots between the driverless machines' limitations and the expectation of human supervisors to manage the rest. It is often assumed that human supervisors will apply a smooth layer of local adaption to fill in the shortfalls of automation; becoming the 'eyes and ears of the operation'. Whether a human should adapt a localised practice is not always clear, facing various situations that rarely unfold in a predictable manner. Even though the assumption is that driverless machines are a like-for-like replacement for truck drivers, this view could not be further from the truth. Not only do mining companies transfer agency to the vendor when they automate the fleet, they appear to be left in the dark on the decision-making process of their haul trucks (Mitchell, 2018).

This is where the gap becomes apparent. What was once a haul truck system that was under local control is now transferred to a vendor's central algorithm. The interactions change and require other variables to adapt to the new relationships that are co-evolving on the mine. For instance, a truck no longer makes a call over the radio to pass a working ancillary machine. Instead, a screen interface is used to provide the intended route and alerts operators if they are too close. The different modes of communication between mining equipment on a haul road demonstrates one element of the adaption's humans are making. The full capability of a driverless machine is not necessarily explained to the user either, learning the strengths and weaknesses by observing its functionality over time. Therefore, a driverless machine's full capability is rarely understood upfront, leaning on local users to press the buttons along the fringes to 'feel out' the machine's parameters (i.e. what can this truck actually do?). Although there are processes designed to support the system's application, the processes are based on how to work the system (e.g. press the button), not how the system actually works (e.g. how does it function?). As the decision-making is not programmed by the user, the system has performed some surprising functions. Those functions are not necessarily aligned to the users' objectives either, driven by the designers' imagination and ability to reverse engineer best practices in mining. The impact of the outcomes arising from automating machinery sketches a landscape where unique incidents start to unfold, for which safety research must help the WA Mining Industry to understand.

With a backdrop of the arrangements that enable humans to be technically substituted for a machine, the emergence of uncontrolled situations gives rise to the potential negative consequences. There is no research exploring why truck slides out of lane and the potential those situations can cause. Perhaps the sensitivity around new technology and the competitive advantage of being first, hinders the WA Mining Industry's ability to share lessons that are being learnt. Moreover, if the new risk profile of driverless haul trucks is unknown, the risks can never be controlled. For instance, the LiDAR and Radar systems on trucks are not capable of predicting slippery road conditions, what other mitigating controls must be put in place? The explanation of the sequence of events and the contributing factors that led to the incident are paramount when improving the safety system. Research must go beyond the investigation findings that evaluates the trucks actions against its capability, which often reinforces the common statement that the machine 'did exactly what it was supposed to do'. If this approach to understanding incidents was to continue, the WA Mining Industry's knowledge will be forever constrained by the world imagined by the product designer. The limitations of the technology and local user adaptions that are taking place are forming new methods of work. The industry's assumption is that truck drivers are being replaced, and that technology removes the safety risks associated with haul trucks. However, the entire process is far from being substituted, leaving a set of residual processes that were technically difficult to automate. The interaction with driverless machines in operation still poses risks to those who remain. Moreover, the uncontrolled nature of reversing a driverless vehicle over a waste dump brings to mind other situations in which those circumstances could arise. Besides reporting the cause as the humans' inability to adapt, research must offer more constructive explanations to manage risk, enabling the industry to develop effective systems of work when deploying driverless haul trucks.

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6. CONCLUSIONS

Exploring the experiences of other benchmark industries in their application of computerised control systems is fruitful. The context in which negative events occur is important to examine, given the transferrable similarities in the way the systems are designed and how professionals are using them. Although there are many studies that consider the consequences of automation in various high-risk industries, research is yet to comprehensively analyse what impact artificial intelligent machines are having on WA mine sites. Furthermore, in light of recent events (McKinnon, 2019), understanding why incidents involving driverless haul trucks are occurring in particular instances (Department of Mines and Petroluem, 2014b). Thus, understanding the interactions between human and machine will explain how the relationship is evolving in WA. Coinciding with theoretical models of the human-machine relationship (Hancock et al., 2013), an examination of the contributing factors leading to incidents are needed. This research endeavors to extend this knowledge through real-world examples, demonstrating the causal pathways that have generated on a mine site.

The knowledge expressed throughout this study can inform the design of driverless technology, support the formation of work processes and accommodate the local adaptions of human users. Previous studies indicate that a human-centered design is central to positive performances in both safety and productivity (de Visser et al., 2018). Researching the context behind a range of incidents involving driverless vehicles has greater implications for the WA Mining Industry. The study highlights a range of systematic trends that are not present in any one investigation. Furthermore, the analysis provides an in-depth understanding of the phenomenon, which are often omitted and filtered when publishing the investigation findings publicly. The underlying hypothesis of this research is that incidents involving driverless vehicles are being shaped by WA Mining Industry's assumptions, which has inflated the expectation that the technology is a like-for-like replacement for haul truck drivers (Ernst and Young, 2019). However, as this study will explain, the technology is far from human-like. Despite its recent advancements, local domain expertise continues to sooth the novelties along the fringes, while the boundaries of its capability are continuously learn.

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Analysis of Australian Coronial Inquest and Non-Inquest findings of heavy vehicle fatal crashes reveals shortcomings in investigations

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KEYWORDS

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ABSTRACT

Heavy vehicle crashes occur daily where drivers, occupants and other road users are either killed or seriously injured. Investigations are conducted by regulatory authorities of these crashes and reports are submitted to the Coroner to determine the cause of death, make findings regarding the cause of the crash and then make recommendations to improve safety and mitigate the risk of a crash occurring. The Coroner plays a critical role in examining the cause of these crashes; however, this research has identified there are a number of substandard investigative practices where the investigations have not obtained the level of detail that would assist the Coroner in making appropriate findings. This study has also identified that this sub-optimal practice has been ongoing for a considerable period of time with a number of Coroners expressing their concerns. This study has reviewed a total of 34 publicly available Coronial Inquest and Non-Inquest findings. The review has identified there are inconsistencies in the quality of the investigations. A fatal crash investigation properly conducted can be a valuable tool in identify why a crash has occurred and greatly assist the Coroner the opportunity to make recommendations from the findings to improve heavy vehicle transport safety.

1. INTRODUCTION

Coroners plays a critical role in examining the underlying causes of the deaths and have the opportunity to make recommendations from findings to improve safety (Brodie et al., 2010). Coroners however rely on the information presented to them from the fatal crash investigation report or from the information presented during an Inquest if one is held. The quality of that investigation or the Inquest is dependent on the experiences, competencies and knowledge of the investigator and the type of investigative methodology being used, if any (Cikara et al., 2020).

A fatal crash investigation, properly conducted, can be a valuable tool in identifying the underlying causes and contributory factors of a crash, why a crash has occurred and suggesting recommendations for future prevention (Brodie et al., 2010; Klockner & Toft, 2014; Dell, 2015; Dell, 2019). In most instances the heavy vehicle fatal crash investigation is conducted on behalf of Coroners by the police.

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As stated by various Coroners, police may not have the knowledge, skills, competencies and resources to understand and navigate the complexities of the heavy vehicle transport industry socio-technical system and in some instances do not know what is needed to investigate a heavy vehicle crash to identify the underlying causes (Productivity Commission, 2020).

The role of police is diverse, as well as complex, with competing priorities. In most instances police investigate matters for prosecution purposes or for identifying liability (Selk & Benner, 2019; Doecke et al., 2020; Productivity Commission, 2020) and their investigative training is not specific to the heavy vehicle transport industry (Productivity Commission, 2020), with most investigators either learning their skills on the job or bringing those skills acquired elsewhere with them which may not be conducive to the regulatory setting they are working within.

2. CORONERS

A Coroner's primary role is to establish the cause and circumstances of a sudden or unexplained death. The role of a Coroner is fact finding, inquisitorial rather than fault finding, adversarial (Burns, 2014). Deputy Coroner Loch of the Office of the State Coroner Queensland (2014) in a Finding of Inquest (File 2012/334) stated 'An Inquest is not a trial between opposing parties but an inquiry into the death. The focus is on discovering what happened, not on ascribing guilt, attributing blame or apportioning liability' (p. 2). Chief Justice Neal Maclean described New Zealand's coronial process as speaking 'truth to power' and the New Zealand Coroners website explains that a 'Coroner speaks for the dead to protect the living (Burns, 2014). The Western Australian State Coroner has stated that: 'It is said that the role of the Coroner's Court is to speak for the dead and to protect the living. This two-fold role is a vital component of a civil society' (Fogliani, 2017, p. 5).

Information drawn from a Coronial Inquest is vital to facilitate risk identification and strengthen countermeasures (Brodie et al., 2009). The significance of Coroners' recommendations and comments is their ability to advocate for change and potential wide-ranging impact (Brodie et al., 2010). In a study to quantify Coroners' recommendations and examine the nature of those recommendations according to public health principles of injury causation and prevention, Bugeja et al. (2012) stated that 'exploring the characteristics of recommendations generated from medicolegal death investigations is an important step towards improving their contribution to injury prevention' (p. 326).

Throughout Australia, Coroners' courts are state based jurisdictions where it is a legislated requirement that all deaths, including heavy vehicle fatal crashes must be reported to the Coroner in the State or Territory in which that fatal crash occurs. Generally speaking, any unexpected, unnatural or violent death must be reported. Internationally, within the Commonwealth, the requirement is not too dissimilar. In fact, throughout the United Kingdom and countries of the British Commonwealth there is much in common (Studdert & Cordner, 2010).

Coroners undertake Inquests based on the information gathered by police during the investigative process. Studdert and Cordner (2010) identified that a Coroner's role in establishing cause of deaths is especially valuable for fatalities in which the fundamental cause is obscure, or first impressions are misleading, which can be the case in heavy vehicle crashes. However, it was found that Coroners have limited resources where accurately identifying causes of deaths requires prudent efforts and directions towards investigations (Studdert & Cordner, 2010). Studdert and Cordner (2010) identified that coronial investigations in Australia changed basic presumptions about how deaths occur only in a small number of cases. This is concerning considering the findings of previous research that expressed concerns at the lack of quality of investigations of heavy vehicle crash fatalities (Victorian Parliament Law Reform Committee Review, 2006; Brodie et al., 2009; Brodie et al., 2010). This is made even more complicated where there has been a continuous effort to apportion blame for crashes on those directly involved such as the driver of a vehicle and then taking legal action against them (Dell, 2015).

3. AIM

The aim of this research project was to analyse the findings of Coronial Inquests and Non-Inquests to identify whether investigations of heavy vehicle fatal crashes by police provided sufficient evidence of crash causation for Coroners to make informed decisions and recommendations to improve safety in the heavy vehicle transport industry.

4. METHOD

A search was conducted of each Australian State and Territory-based Coroner's office website. Publicly available coronial reports were searched to identify those reports that included a crash involving a heavy vehicle. The search was conducted for the years between 2005 and 2020. The reports were either those arising from an Inquest as well as findings from a Non-Inquest. In total 34 reports were selected. Each report was downloaded and read to ensure the report fell within the date range and included a crash involving a heavy vehicle. The reports selected came from the Coroners Courts in the states of New South Wales, Tasmanian, Victorian, South Australian, Queensland and Western Australian.

The analysis identified the type of crash, i.e., truck vs car, the type of report, i.e., Inquest or Non-Inquest, the findings and recommendations, the number of recommendations and types of recommendations. The reports were further analysed to identify:

- If the crash was considered a workplace crash or not;
- The type of investigative methodology used by investigators;
- If comments were made by the Coroner with regards to the quality of the investigation and information provided;
- Who was involved in the investigation process i.e., Police, Worksafe, National Heavy Vehicle Regulator, Office of Transport Safety Investigations, Office National Rail Safety Regulator or others?

5. CRASH TYPE

The search results identified 34 Coroners reports comprising of 13 x truck vs. car, 11 x truck rollover; 2 x truck vs. cyclist, 1 x lost load from truck vs. car, 1 x truck trailer vs. car, 1 x truck vs. tree, 1 x truck vs. building, 1 x truck vs. motorcycle, 1 x truck vs. pedestrian, 1 x bus vs. pedestrian; and 1 x truck vs. train.

6. CRASH TYPE AND WITH RECOMMENDATIONS

Recommendations arising from the coronial Inquests and Non-Inquest findings included:

1. **Truck vs. train:**

   This was a workplace incident. The heavy vehicle driver was charged with criminal offences however was found not guilty at trial. Two recommendations arose from the Non-Inquest. Both recommendations related to the locomotive crashworthiness and structural integrity of

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the locomotive driver's cabin. The Office of Transport Safety Regulator was involved in a parallel investigation providing information to the Coroner. WorkSafe was not involved in the investigation process.

2. **A heavy articulated vehicle collided with a car:**

Eight recommendations were submitted by the Coroner. These recommendations included imposing speed restrictions for the articulated vehicle, instal internal speed limiters to be set at 60kph or at 80 kph if electronic stability control was fitted, driver must undertake practical and theoretical assessments, amend the articulated code of practice to include guidance on handling characteristics.

3. **Truck vs. car:**

The heavy vehicle rolled over rounding a bend, toppling over onto a car. Recommendations included government to investigate stability control systems for heavy vehicles and for the Queensland Department of Transport to appoint a coronial officer as well as mandate the attendance of a transport inspector to the scene of fatal crashes involving heavy vehicles.

4. **Truck vs. pedestrian:**

This Inquest took into account five separate fatalities and recommended the Vehicle Standards Australian Design Rules 42/04- General Safety Requirements 2005 be amended to require front warning sensors be installed during manufacture of all cab over heavy vehicles.

5. **Oversized escorts Inquests:**

There were two Inquests that analysed three fatal crashes. In total 12 recommendations were made. These included only granting permits for loads that are indivisible, not granting permits for loads if they can me made smaller, night-time escorts to be limited to dual carriageways and metropolitan areas, Police review the use of motorcycles as escort vehicles, oversized load activity must be well managed, the National Heavy Vehicle Regulator regard the evidence of the Inquest to develop regulations and guidelines for arrangements of oversized loads, ensuring the wording for oversized loads are more effectively communicated, public awareness campaigns ensuring public are aware of their obligations, traffic management plans must be developed and distributed to all escort parties for the escort, procedures and permit conditions to be more explicit when describing risks of transporting a wide load, using more information signs for very wide loads, more attention be given to the spacing of the escorts and the oversized load, must include this in the training for the Police officers escorting oversized loads, lighting of oversized loads to be review.

6. **Unstable trailer towed by truck colliding with a vehicle:**

Recommendations included Government request training providers review content of training and assessment for license holders, whether competence for loading and towing trailers should be included in the training, government consider whether medium rigid licence holders ought to be permitted to tow trailers behind medium rigid trucks, government to raise this issue with other government agencies for consideration.

7. **Car struck by heavy log falling from a truck:**

Coroner recommended that WorkSafe review its industry standards and guidelines to address aspects of the standards that were shown and conceded to be deficient during the Inquest.

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8. **Truck colliding with a push cycle:**

   It was recommended that Government immediately prohibit cyclists from using the highway, government engage with stakeholders to deal with safety concerns and provide an alternative route, signage should be erected on onramps to warn cyclists that the roadway was dangerous.

9. **Truck vs. car, double fatality:**

   It was recommended that government and Police maintain their awareness campaigns of the risks of using mobile phones whilst driving and ongoing attention be given to detecting those who breach the rules and consideration be given to the level of penalty applicable to such offences.

10. **Truck vs. tree:**

    It was recommended the shire conduct a risk assessment of the road with a view to placing signage at the beginning of the road to forewarn road users of the road's curves and undulations and the dangers within.

11. **Truck colliding with a push cyclist:**

    Seven recommendations were made. Some included the routine and mandatory electronic recording of witness statements, government to regulate that vehicle stop one vehicle behind the bike box which enables drivers to see the bike. Targeted and education program to alert motorists of the risk of placing themselves immediately in front of a heavy vehicle, make such actions an offence, conventional shaped heavy vehicle should be fitted with technologies to warn drivers of obstacles and other road users in the driver's blind spot, educate all motorists about blind spots in front of a conventional heavy vehicle.

12. **Bus hitting a pedestrian:**

    It was recommended that government urgently review the operations of the traffic and pedestrian crossings at intersections.

13. **Truck vs. car:**

    The Coroner recommended that Government proceed with the design and construction of a channelised right turn at the intersection with priority.

14. **Truck vs. tree:**

    It was recommended that the government consider enhanced education and awareness to ensure employees performing inspection of heavy vehicle are of the risks involved in not having clean components to inspect, and that government review the current memorandum of understanding between Police and Worksafe that includes a process for the notification of a heavy vehicle incident to the national heavy vehicle regulator.

15. **i) Truck vs. car & ii) truck vs. pedestrian:**

    One Inquest was held for two separate fatalities occurring at the same location. 17 recommendations were made (South Australian Government 2015) these included:

    Increase penalties, including imprisonment, be enforced on drivers who do not use a safety ramp when their truck is out of control, a truck driver automatically be charged with dangerous driving should they exceed the speed limit of 60kph on the down stretch of the freeway, owners or companies employing drivers compensate victims and their families for crashes involving heavy vehicles, truck drivers get compulsory training about driving downhill and using arrester beds.

Trainee drivers should undergo specific tuition in relation to the required manner of driving on the descent of the South Eastern Freeway, a truck driver must be supervised when driving down the South Eastern Freeway for the first time and the accompanying driver must have demonstrated experience and competence on that down-track, no heavy vehicle licence of any kind should be issued to any person in Australia unless they have demonstrated competence in the safe negotiation of the decent on the South Eastern Freeway.

Speed limit for heavy vehicles be reduced to 40km/h on the down track, improved signage, including informing drivers that heavy penalties apply if trucks and buses do not use low gear, promote arrester bed use, roadworthiness and maintenance be brought within the chain of responsibility regime with the Heavy Vehicle National Law (South Australia) Act 2013 and be undertaken nationally, all heavy vehicles be subjected to a periodic and frequent inspection regime, investigating the capability of technology to detect the speed of a heavy vehicle and tell a driver that their speed is excessive and they needed to use a safety ramp.

Consideration given to the creation of an area situated between the Heysen Tunnels and the second arrester bed to be used for consideration be given to the creation of an area situated between the Heysen Tunnels and the second arrester bed to be used for the mandatory stopping of all heavy vehicles with a further requirement that if the vehicle is incapable of stopping at that area, the driver must use the second safety ramp (Marcus, 2015).

However, in this Inquest the Government of the day stated it would only support 13 of the 17 recommendations (MacLennan, 2015).

16. Truck rollover:

No recommendations were made however a number of points were raised. Company did not do any act or omission to contribute to the crash. Driver not wearing seatbelt. Delays in completing investigation, investigation not completed to a required standard. Workplace incident, WorkSafe not involved.

7. FINDINGS

Over the 15-year period this study identified a total of 34 publicly available Coronial Inquest and Non-Inquest reports. In those 34 reports a total of 60 recommendations were made with five Inquests providing 43 recommendations and the remaining 29 Inquest and Non-Inquest findings providing 17 recommendations. This study supports the findings of a previous study conducted by Brodie et al. (2010) in which it was identified that Coroners recommendations from fatal crashes were infrequent. The Inquests where multiple recommendations were made came about where Coronial Inquests were combined and heard as one because the fatalities occurred at the same location or were similar types. i.e., fatal crash occurring during the escort of an oversized load.

There was one Inquest that investigated two incidents because the fatalities that occurred were the result of the same type of incident, this being a collision occurring as a result of escorting oversized loads. From these two fatalities there were seven recommendations. There was a second Inquest that also involved an oversized escort from which there were five recommendations.

There was one Inquest that had a total of eight recommendations, one Inquest had six recommendations. Twenty of the Coroners' reports focused on the heavy vehicle driver behaviours. In seven of the reports, it was noted the driver was criminally charged however the driver was found not guilty in four of the crashes. In another crash the driver pleaded guilty, despite there being evidence to suggest other contributing factors. In another crash the driver was convicted of the offences and in another crash the charges were downgraded to lessor charges to which the driver pleaded guilty.

Thirty-three of the crashes involved a workplace incident as the heavy vehicle driver was working at that time. Only one of the 33 crashes that were workplace incidents was investigated by WorkSafe.

The types and focus of recommendations made were varied. Most were directed towards the management of driver behaviour such as imposing speed restrictions, driver training, installing speed limiters in heavy vehicles, better risk management of oversized escorts, employees performing inspection of vehicles and increased penalties for drivers who do not travel at restricted speeds. There were recommendations that included increased penalties for breaching the laws, installing in-vehicle technologies such as stability control and front warning sensors and other recommendations were aimed at improving the manner in which investigations are conducted. For example, in one Inquest it was recommended that there be routine and mandatory electronic recording of interviews, another recommended the mandatory attendance of a transport inspector at the scene of a fatal crash and in another that government review its current memorandum of understanding between police and WorkSafe. Support, by way of applying a consistent investigative methodology as well as providing training to investigators on the heavy vehicle transport system, is needed. This will enable the collection of evidence and information to identify and analyse the underlying causes for targeted prevention. As stated by Brodie et al. (2009) 'Increased recognition of heavy vehicle safety beyond individual driver responsibility is needed' (p.563). In support Newnam et al. (2017) identified that a comprehensive investigative process is likely to identify interventions that have contributed to a crash all the way up to the level of regulatory bodies and Government agencies

More importantly, in 22 of the Coronial reports, it was identified that the heavy vehicle driver behaviour, actions or omissions had in some part contributed to the crash. For example, in one Inquest it was identified the driver had no experience driving a heavy vehicle and, in another Inquest, it was found the driver was significantly fatigued as a result of being under too much pressure to meet a deadline to deliver their load. However, the Inquest did not delve more deeply into the safety management system to identify 1. If the driver's employer had checked the drivers were competent and experienced to drive a heavy vehicle 2. whether the scheduling and risk management processes permitted a driver to drive a heavy vehicle to meet unrealistic deadlines causing them to become fatigued.

In addition, the role and importance of systemic investigations was recognised. In an Inquest where separate investigations had been conducted by police and the Queensland Office of Transport Safety Investigations, the Coroner noted that police were statutorily prohibited from relying on the investigation reports from another agency for prosecution purposes and that police had to independently gather and analyse the evidence using their own expertise and resources. The Coroner went on to further state that the other agency involved in the investigation was focused on identifying contributory factors for the purpose of identifying opportunities to improve safety and health (Queensland Coroners Court 2008/392 & 2008/393, p. 4).

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8. DISCUSSION

8.1 Quality of crash investigations

A review of the Inquest and Non-Inquest findings suggests that systemic investigations are not being undertake. This is supported by comments made by Coroners. This study found there were a number of comments made by Coroners regarding the quality of crash investigations. This has been consistent since 2001 where Coroners around Australia have made similar findings and expressed their concerns. For example, in a Victorian Coronial Inquest (1114/2001), the Coroner recommended that police consider developing a basic investigation standard for fatal and serious crashes. This recommendation came about due to a number of serious deficiencies identified by the Coroner of an investigation conducted by the police of a fatal crash. Additionally, the Victorian Parliament Law Reform Committee Review (2006) conducted a review of the Victorian Coroners Act 1985 and reported that the limitations of Coroner's investigations related to transport collision had been raised in a number of forums over the previous past five years. The review identified that:

- Coroners did not have legal control over the death investigation process nor any power to direct the investigation, and
- There was an absence of comprehensive guidelines for Coroners conducting death investigations as well as widespread discrepancy between the standard of Coroners' investigations in Melbourne and those in rural areas.

In a Coronial Inquest regarding a vehicle colliding with an escorted oversized load, killing the car driver (Queensland Coroners Court 2199/05(0)), the family of the deceased were dissatisfied with the evidence submitted to the Coroner by the police. The family of the deceased had taken it upon themselves to assemble a substantial body of material regarding the conditions and events prior to the collision and provided that information to the Coroner. That material was subsequently forwarded by the Coroner to the police for further investigation who were then able to obtain further evidence for the Coroner. Although not criticising the investigation, the Coroner found (Queensland Coroners Court, 2199/05(0), p. 28) that a Coronial Inquest is better informed when evidence is available from all perspectives.

In another Findings of Inquest, (Queensland 2011/1631 & 2010/4091) a police officer riding a motorcycle and escorting an oversized load was struck and killed by a heavy vehicle travelling in the opposite direction. The heavy vehicle driver was charged with driving without due care and attention, however, after a three-day trial, the heavy vehicle driver was found not guilty (p. 11). In the subsequent Inquest, the deceased's wife made a submission to the Coroner to consider flaws in the way the investigation was undertaken and managed (p. 12). During the Coronial Inquest the Coroner identified a number of 'sub-optimal practices' (p.12) that included:

- Conversations with witness at the crash scene were not tape recorded.
- Detailed accounts were not taken from any witnesses on the morning of the crash.
- Police did not have witnesses adopt any notes taken of the conversations.
- Key witnesses were allowed to confer at the scene and then leave on the understanding they could attend to a Police Station at a time and place convenient to them to provide a statement.
- The defendant was spoken to by four officers on the day of the crash, but none took detailed statement or questioned the defendant closely as should have been in such circumstances.

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- One officer was notionally put in charge, but other officers gave directions about aspects of the investigation without consulting with the person in charge and did not ensure the person in charge was advised of the outcomes.
- Other officers who were tasked with various inquiries or to obtain statements were inadequately briefed regarding the issues under investigation as well as the versions provided by other witnesses meaning they could contribute little to the investigation.
- The expert investigators from the Fatal Crash Unit did not arrive until two days after the crash.
- Significant delays occurred during the investigation as the supervisors allowed significant delays to occur.

The Coroner noted that 'Whilst these criticisms have some force, as a result of reviewing the investigations of numerous traffic fatalities I am aware that similar practices are common' (p. 13).

The Coroner went on to further identify a number of key points in relation to the quality of the investigation. These included the investigating police officer worked in a very busy station, the officer had very limited crash investigation training and experience, there was no specialist support, experts undertook discreet parallel investigations or reviews, there was limited coordination of the number of investigations being conducted at the same time. The Coroner noted that:

> *'(name redacted) was the officer in charge of a very busy division with limited crash investigation training and experience. Nonetheless, in the normal course he would investigate fatal road crashes in that division, there being at the time no specialist FCU in central region. However, in this case he was left to undertake a criminal and coronial investigation of a particularly sensitive matter, while other experts undertook discreet investigations or reviews of aspects of the incident. There was limited coordination of the four inquiries and less supervision of (name redacted).*

In conclusion, the Coroner stated that '[t]he outcome was less than perfect, but probably no worse than many investigations regularly undertaken throughout the state' (p.13).

These comments raise a number of concerns at the lack of quality of investigations that are conducted of fatal crashes. The Coroner's comments suggest that sub-optimal practices in investigations are common place and the quality of heavy vehicle fatal crash investigations are not to a suitable standard.

The Coroner's comments were consistent with the findings from research conducted by the authors of this paper where a number of participants were interviewed to identify why heavy vehicle drivers were blamed for crashes. The participants in the interviews, many being either police officers or former police officers, stated that police officers, themselves included, were required to conduct heavy vehicle fatal crash investigations whilst working under strenuous circumstances, without support, in busy police stations with limited or no training or crash investigation experiences. This may, to some extent, explain the sub-standard quality of investigations being conducted resulting in deficient investigation reports being submitted to Coroners.

Research by Brodie et al. (2010) found there was no systematic approach to Coroners' investigations of heavy vehicle fatalities. The research identified that police crash expert investigators are not involved in the investigation of all fatal heavy vehicle crashes, especially those that are single heavy vehicle crashes. Generally, these investigations are conducted by general duties police often with less experience and expertise that those within the specialised crash investigation squads.

In another Non-Inquest of a single heavy vehicle rollover fatal crash killing the driver (Magistrates Court of Tasmania 2020), the Coroner found the police officer allocated to the investigation was not a qualified investigator and was attached to a police station with a very heavy workload. The Coroner concluded that it was understandable the police officer was unable to complete the investigation to a required standard and in a timely manner (Magistrates Court of Tasmania 2020, p. 7). These comments are consistent with the research findings by the authors of this paper who conducted a number of semi-structured interviews with a participant who had investigation experiences. The participants stated that when working in busy police stations, particularly those police stations in country areas, they did not have the support or resources to properly complete a heavy vehicle fatal crash investigation, nor did they have the training, competencies or experiences to conduct those investigations.

In an Inquest finding of a fatality caused by an incorrectly loaded trailer causing it to lose balance leading to a crash, the Coroner became aware of a number of systemic failings identified during the investigation. The Coroner suggested that 'where systemic flaws in the system are disclosed, they should be addressed with urgency and careful attention' (Coroner's report 2013/298913, p. 11). Later in the report, the Coroner stated in relation to the circumstance surrounding the death that:

> *Coroners have no professional expertise in relation to these questions. I have therefore framed the recommendations not in rigidly prescriptive terms but putting the serious issues (name redacted) death raises before the experts in the field for them to consider and resolve (p. 13).*

However, the substandard quality of investigations is not just specific to police. In another example of an Inquest, the Coroner expressed concerns regarding an improperly conducted investigation by another government agency. The Coroner commented on the substandard quality of a tape-recorded interview, noting that:

> *The tape recording of the interview reveals a rather shambolic, rambling and unstructured interchange. The panel chair stated at the Inquest he had taken some comfort from knowing that a coronial investigation was to follow. However, subsequent events have revealed this to be illusory. While there is no doubt the panel members had high level content knowledge, it might be desirable in future to include a person with forensic expertise (Queensland Coroners Court 2009, p. 3).*

The research suggests there are sub-standard and sub-optimal investigation practices that have been evident for a considerable period of time. Driscoll (2003) identified that limited investigative resources and a lack of standard investigation approaches were likely to impede the information and investigative process. Bohensky et al. (2005) identified that if the process for investigating deaths were standardised, these deaths would be more easily and efficiently investigated. Bugeja et al. (2007) concluded there were recognised limitations associated with the coronial investigations of heavy vehicle crashes and the lack of an existing systematic approach affecting investigation outcomes.

A review conducted by the Government of Western Australia Department of Treasury (2018) to improve the efficacy of coronial investigations recommended a number of efficiency and effectiveness reforms, three of which focused the lens on the quality and output of investigations. These recommendations included enhancing the powers of Coroners to obtain information outside of an Inquest, improving consistency of regional investigations and updating guidelines to police and modifying performance measures reflecting the integrated components of coronial investigations. The recommendations highlight the need for police to conduct consistent investigations.

This is not new as previous studies by Brodie et al. (2009) posited that opportunities remain through learnings from fatal crash investigations and the systematic analysis of contributing factors. In that study it was concluded that a standardised approach to heavy vehicle fatal crash investigations will support Coroners and research efforts to increase knowledge. In a subsequent study by Brodie et al. (2010) into recommendations following fatal heavy vehicle crash investigations, it was identified that

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investigation standards were lacking. This included a need for a minimum crash investigation standard, improved investigative practices and increased resources for data collection to enable proactive measures by investigative authorities (p. 140).

9. CONCLUSION

The analysis of the coronial Inquests and Non-Inquest findings identified that crash investigations differed in quality and complexity. This study identified there have been historical concerns raised by Coroners over the substandard quality of investigations arising from reviews and Coroners' findings. This study has revealed a number of comments from Coroners who have continued to voice their concerns of the quality of investigations and that it suggested that sub optimal practices are commonplace. The investigations were all conducted by the Police for the Coroner from differing states. The thematic analysis identified there were differing quality of investigation, some of which were criticised by the Coroner.

A review of the coronial Inquests and Non-Inquest findings revealed that there did not appear to be a standardised approach to the investigations. There were varying degrees of quality and detail as evidenced by Coroners' remarks and the investigations did not identify contributory factors across the levels of the socio-technical system. Most factors identified in the coronial Inquests would more than likely be limited in scope because the investigations did not appear to adopt a systematic approach. It is also highly likely that other systems factors at the upper levels of the socio-technical system were present however not identified nor investigated due to the investigator's lack of understanding and knowledge of effective investigation practices.

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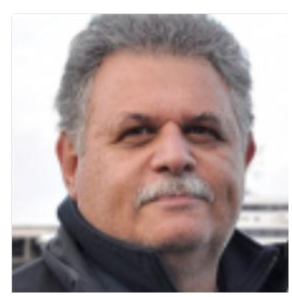

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Fast-track Industry Safety Culture and Reduction of Incidents/Losses

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KEYWORDS

Behaviour
Risk
Safety
Culture
Qualitative

ABSTRACT

The term "safe culture" refers to people's safe habits. Safety culture is on the rise in today's industry. A safety culture must be developed to prevent workplace mistakes and accidents. Safety culture philosophies vary by industry in terms of practices. The goal of this article is to identify key issues in establishing a behavioral safety-friendly culture in business, as well as potential solutions. Ten themes that address critical issues, such as fundamental questions about long-term safety cultures, reactive safety cultures, collective voice and leadership for at-risk behaviors, religion, spirituality, and festivities for site safety, and safety implementation with empathy for others, are presented.

1. INTRODUCTION

In a favorable safety culture, workers choose safety in everything they do, even if it goes beyond industry rules. In a bad safety culture, safety is an afterthought, or a delayed step (ISHN, 2021). A supportive safety culture helps to ensure everyone's safety.

In recent years, the concept of cultivating a positive safety culture has gained much attention (Williams, 2021). The safety culture of an organization is attributed to it in a number of ways. A sequence of small acts of kindness and adjustments in safety habits can have a big influence in the long run (Pettinger, 2020).

Safety cultures can persist for a long time when they are integrated into a strong company culture (Paoletta, 2020). The safety culture improves dramatically when companies involve all employees in the process of risk control through observation and spot-correction. In terms of long-term safety culture management, the employer's aphorism is a high-risk proposition for long-term economic survival (Kaila, 2021). The company's safety culture both supports and propels it forward.

The organizational behavior culture is to blame for thousands of deaths and injuries. To remove at-risk behaviors, plant employees must appreciate safe behaviors, which they develop on a daily basis as observers of the safety culture. Every plant requires immediate changes to its safety culture, which can only be carried out by people. The majority of safety professionals are trained in safety systems rather than safety culture development, which is a critical issue. This article offers recommendations in this

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respect (Kaila, 2021). The goal of safety culture is to serve humanity without causing mishaps or accidents; that is the essence of safety culture!

Zero-risk management necessitates a variety of behavioral patterns from top to bottom, as well as among colleagues. The road to get there, on the other hand, is both entertaining and enlightening, as well as heartbreaking. In this regard, there are numerous organizational antecedents that must be considered. Employees perceive change within an organizational safety culture as a result of involvement through processes of observations and spot-corrections. Kaila (2021): When this intervention is done on a regular basis and employees like it, the business's values become part of the way they do business.

2. BEHAVIORAL RISK MANAGEMENT IN THE CONTEXT OF SAFETY CULTURE

The fundamental fault is that there are no safety regulations in place. Systematized, common sense practice has become a standard in the industry. There are still a lot of questions about behavioral risk management for safety culture adoption that need to be addressed, as one goes through the safety steps (defining, systems, culture, and management). Below are some alternative answers.

Theme 1: Fundamental questions about creating a long-term supportive safety culture

In India, the size of the safety net for employees is determined by the size of the employer's pocket. The amount of profit made by the organization determines whether employees need a safety system or not. Care is a distant second; money comes first. Consequently, at-risk employees' lives are at risk, and employers' businesses are at risk too, as a result of at-risk behavior on the job. To ensure the long-term viability of businesses, a culture that prioritizes employee safety must be adopted. Due to various variables at sites, it can be difficult for even leaders to persuade some employees that HSE infractions are not acceptable. It must be recognized that high-risk behaviors in the workplace are regarded as dangerous to citizens in civilized societies and can be debilitating, harmful, or even lethal. To develop a safety culture, spot-correction is a function for everyone. Businesses appear to have a grim future if they do not build a long-term, supportive safety culture at their sites.

By all means, a safety culture is "a set of common practices and behaviors that are used by everyone in an organization to try to control the most important risks associated with its work" (Velas, 2021).

Theme 2: A reactive safety culture

A reactive culture indicates that safety mechanisms are patched together and developed in response to negative incidents and legal obligations (Halligan et al., 2013). Why are industry professionals so adamant about maintaining a reactive safety culture? "It is their comfort zone, and they don't want to feel discomfort," says Pavan Rao of Sembcorp Nellore. According to KK Sharma of DCM Shriram, those who are reactive at sites are those that are self-centered and need to demonstrate their strength, while others require attention, guidance, or instructions for important tasks to be completed, owing to their upbringing or culture. Safety is an afterthought in a weak or reactive safety culture, whereas in a positive safety culture, safety is pushed beyond industry requirements (ISHN, 2021). At the NTPC Safety Academy, A. K. Dang says that behavior-based safety plays a big part in accident prevention and intervening behavioral science. This is when site management, including contractors, requires people to be proactive rather than reactive in identifying at-risk behaviors in order to meet the zero-accident goal.

Theme 3: At-risk behaviors, the collective voice of observers and leadership

The power of a group's collective voice outweighs the threat of any type of punishment. At-risk behaviors serve as a warning signal, right before an incident occurs. The most crucial aspect of observer training is to comprehend the daily observations in terms of the company's safety culture. Building a safety culture requires both personal and organizational safety practices. Urbach and Fay (2020) found that the quality of the leader-member exchange was a key predictor of whether leaders would back employees' ideas for positive change.

Leaders rarely conduct observation rounds on their own; instead, they present observations made by their observers to the lower levels. Incidents are also triggered by hotspots of at-risk behaviors, and while spot-correction of at-risk behaviors is done, behavior must be altered through regular risk-based dialogues (RBC). This is critical feedback that must be addressed in order to maintain a safe work environment. As a result, long-term safety culture management requires a strong leader who can guide and direct everyone from the top down.

Theme 4: Religion, spirituality, and festivities are important forms of multicultural diversity for site safety

People who feel spiritually protected are more likely to care for others at work, thus reducing workplace dangers. When people respect one another's spiritual principles, they form strong bonds that help to foster a sense of fraternal safety (Keenan, 2017). Spiritual beliefs and HSE beliefs are intertwined because they are based on human experience (Kaila, 2021). Allowing for variances in religious views and spirituality in the workplace promotes the creation of a psychologically healthy working environment (SHRM, 2020).

Safety culture is a journey, not a goal. By all means, a strong safety culture within a business has been found to cut down on the number of workplace injuries and accidents.

Theme 5: The execution of safety with consideration for others

HSE systems are maintained by management. They must ensure that the behaviors associated with these systems are triggered. For the HSE's cultural transformation to succeed, industry-wide action is needed. Implementing behavioral safety is an extension of care to culture from the workplace to every place (Kaila, 2021). Spot-appreciation of safe actions and spot-correction of risky behaviors are both important to improving safety culture.

For corporations, safety is a priority; for contractors, safety is a must. The consequences of safety implementation differ dramatically and are challenging to achieve. By all means, excellence in safety culture leads to business sustainability. To have a truly comprehensive safety program, managers need to include psychological safety (Barnes, 2021).

Theme 6: Companies that do not enable their employees to carry out safety implementation

Building a safety culture can help businesses succeed in their safety processes (Vos, 2021). If one is truly interested in creating a strong safety culture, then s(he) must listen to every observer who instills in each employee a desire to behave safely when they are behaving unsafely (Kaila, 2021).

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By all means, a low budget for safety is equivalent to a large budget for mishaps. Mentors who are talking about safety culture engagement should think about real-world examples of safety culture changes that have been shown to work (ISHN, 2021).

In order to effectively implement behavioral safety at workplaces, leaders must incorporate a safety culture into their personal lives.

Theme 7: The safety professionals' competencies gap

Competency development is a process that lasts a lifetime. There are numerous aspects that influence an individual's ability to achieve competency: age, gender, education, geography, local influences, family background, and environment are just a few examples. When establishing competency, these criteria are never taken into account as a whole. Because of the lack of consistency in judging competency, there is always a gap that is never filled.

By all means, the world is shifting away from industrial safety toward a new perspective on safety. Human Factors, Human Performance, Psychological Safety, and so forth, are all new concepts. These HSE viewpoints are not taught to safety experts. The job description of HSE experts seems to be changing around the world, which means that they need new skills (Burdick, 2019).

Theme 8: Major obstacles to taking health and safety decisions

When firms abuse safety, safety specialists become frustrated; but they should not be made scapegoats (MySafetySign, 2021). By all means, maintaining the highest level of long-term safety culture is a never-ending journey for management and workers on the job. A positive outcome in terms of safety necessitates honest practice by all parties involved. It will be incredibly difficult for business executives to save their companies and their employees if they do not prioritize safety over commercial operations (Kaila, 2021).

Some so-called BBS (Big Brother/Big Sister) specialists are attempting to teach behavioral safety culture in a muddled manner due to a lack of understanding of the BBS approach to behavioral science. This sends the wrong impression to businesses about what BBS is and is not, as well as how to scientifically adopt it. The BBS journey is beneficial to the company's financial security since it allows management to say goodbye to incident costs, compensation, and litigation. A safe workplace is one where everyone gets home without being hurt. (Kaila, 2021).

Theme 9: Top leaders' spot-implementation of the BBS approach

The crucial question is how quickly a safety culture can be instilled in order to save everyone at work. To reinforce spot-implementation of the BBS strategy for quick results and a long-term safety culture at sites, it requires highly brave, fast-track leadership.

By all means, if the safety culture is accurate and faultless, the company will save a lot of time. Safety procedures will be driven from the top down in the perfect safety culture. Practices for safety will filter down to the grassroot level. When a new employee joins the company, the first thing s(he) learns is how to follow Standard Operating Procedures (SOPs). If SOPs are in place, they will streamline operations and save the business a significant amount of time. Because time is money in today's world, this is an excellent tool for saving money.

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Theme 10: How should we speed up the process of establishing a supportive safety culture at work?

Implementation entails building empathy for each other's safety on site, which necessitates sensitizing the workforce to at-risk behaviors and constant spot-corrections. The most effective method is to increase the number of qualified observers and make on-the-spot corrections during every shift. We need to set up a way for employees to be able to say what they think. Without their help, the safety culture movement won't move forward.

Regular management intervention, as well as sensitizing the workforce during daily toolbox talks and meetings with a friendly approach, as well as observing safety behaviors on site, has accelerated the safety culture of companies. Organizations should integrate HSE as a planned intervention into their programs to make a safety culture a way of life. The trained behavioral safety observer is not limited to the site; instead, he or she should make one observation daily, both on and off site, to make society safer.

3. CONCLUSIONS AND RECOMMENDATIONS

To set the foundation for continuous improvement, a systematic process of assessment, identification of strengths and weaknesses, deployment of focused interventions, and learning from the results is required to change the safety culture (Ravi et al., 2021). The applications of psychology have significantly improved site safety culture, as has the rigorous monitoring of behavioral risk patterns, which is backed up by HSE systems and a strong commitment from management. Although there are HSE standards in place, there is still a need to prevent fatalities on construction sites, for example.

Occupational safety and health practitioners must continue to learn in order to meet current regulations. Multiple training approaches, particularly for junior safety practitioners, may stimulate competency growth (Ishimaru et al. 2020). Because safety experts don't get enough basic training at college, there have always been gaps in their skills, making it hard for them to learn more on the job, gain more experience, and improve their performance.

When leadership commits to safety, every employee leads the firm to a culture of no hurt, no harm. Even though underreporting is a dark reality and has always bothered people in the field of OHS, strong monitoring (inspections) and a comprehensive database to figure out what to do and how to do it are needed.

For industry and social science professionals, looking at reality through behavioral criteria is critical. For long-term changes in safety culture, everyone involved must correct at-risk behaviors and apply behavioral safety concepts and applications. These include psychological safety perspectives that go beyond work content to include broad aspects of employees' personal circumstances and experiences (Edmondson and Mortensen, 2021), as well as psychosocial risks that affect psychological health (ISO 45003, 2021).

Firms trying to change a safety culture focus too much on tools and processes, but they don't pay attention to how employees think about their own safety and how that affects their behavior and interactions (Hortense de la Boutetière, 2019). Business excellence is impossible to achieve without a strong safety culture, and safety-time appears to be the best indicator of how much of a safety culture has been developed in the organization by its employees through daily contributions to an observation round. The active safety time of observations and spot-corrections can be correspondingly equated to the probability of injuries and mishaps on site (Kaila, 2020). The absence of a supportive safety culture at work places could hurt the company; thus, it is important to get it quickly.

Individuals, companies, and the economy all suffer when job dangers are overlooked. As a result, initiatives to promote a safety culture would save all of these in the long term, benefiting society as a whole. When safety culture becomes a value system, and everyone values and speaks up for one another's safety, it is deemed successful (Choueiri (2021).

In conclusion, we need to build and form safety culture implementation strategy groups at the national or state level that can be taught to extend the training and implementation throughout industry and society. This will benefit income tax, insurance, and contractors, as well as any other government or commercial groups. All profits lost as a result of events, fires, fatalities, and accidents will be conserved and distributed to the general public in some way.

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Public Transportation Infrastructure Projects and Financial Risks

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KEYWORDS

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Public Transport
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ABSTRACT

When implementing a public transport infrastructure project, there are always a number of financing risks that need to be addressed before any such project is embarked upon. One of these risks concerns traffic demand/revenue risk – the envisaged public transport system needs to attract patronage; this requires private car users to make the switch to the alternative mode of transport. This would also be the case for the various public transport infrastructure projects that are being investigated to alleviate road traffic congestion in the Greater Beirut Area (GBA), Lebanon, as alluded to in this article.

1. INTRODUCTION

Successful private-sector funded public transport infrastructure projects are those projects that are able to meet financial commitments and provide private participants their required rates-of-return. The ability to meet financial commitments is a direct result of the establishment of proper financial and project structures. Establishing the proper structures results from identifying key project risks, then creating structures and policies that mitigate those risks.

2. PRINCIPAL RISKS IN FINANCING PUBLIC TRANSPORT INFRASTRUCTURE PROJECTS

The principal risks involved in financing public transport infrastructure projects can be categorized into (Estache & Strong, 2000; Schwartz et al., 2006):

- construction-phase dangers; and
- start-up and operating phase risks.

2.1 Construction-related dangers

During the construction phase, the major risks are:

- *Delays in project completion and the commencement of project cash flows* can result in an increase in total costs through higher capitalized interest charges. It may also affect the scheduled flow of project revenues necessary for debt servicing costs and operating and maintenance expenditures.

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- *cost overruns with an increase in the capital needed to complete construction.* For a variety of reasons, including incorrect engineering and design, increased material and labor costs, and project start-up delays;
- *Contractor insolvency or lack of experience: The main contractors and key subcontractors should have the experience and reputation, as well as the financial, technical, and human resources, to complete the project on time and within budget.*

Further, the risk of non-availability of materials or equipment for construction or operation exists, especially in many developing countries. This is especially true with respect to specialized equipment. Also, environmental and land risks may cause delays. Public transport infrastructure projects can have a substantial environmental impact. Such projects frequently attract strong opposition from community and environmental groups over issues of pollution, congestion, and visual impact. Similarly, land acquisition can be a protracted process with the potential for extensive legal delays, particularly in developing countries. Furthermore, the cost of land acquisition can become a major factor where land values have risen rapidly or are subject to speculative activity over which the project developer has no control. In these cases, agreement on some form of cost ceiling may be necessary in the concession contract.

2.2 Start-up and operating phase risks

The major risks for public transport infrastructure projects during the start-up and operating phase are:

- *Technology risks:* project financing participants cannot ignore new technologies since they can significantly improve the profitability of a project. The use of obsolete technology may adversely affect a project.
- *Financial risks (interest rate and foreign exchange rate fluctuations):* since the advent of financial crises in emerging markets, few projects are able to generate returns-on-investment sufficient to attract private capital. This suggests that until macro-economic risk premiums decline and traffic demand is more established, only a limited set of projects will be undertaken without substantial government support. The financial crisis may force many programs to slow down and force debt restructuring of many of the existing concessions. Since the risk of bailouts is high, there is a need for more secure financing structures.

Another financial risk is driven by the impact of fluctuations in foreign exchange rates on the value of the business. This is a major issue for some projects, where revenues are commonly in local currency and adjustments for inflation and foreign exchange rates may lag or encounter political opposition.

- *Force majeure risks:* force majeure refers to risks beyond the control of either the public or the private sector, such as flooding or earthquakes, which impair the ability of the project to earn revenues. The rule is that if there is a risk of force majeure, the contract should say what happens if that happens.
- *Regulatory and legal risks:* regulatory risks stem from the weak implementation of regulatory commitments built into concession contracts but also in laws or other legal instruments relevant to the value of the transaction. The question to be asked is whether the regulator will exercise its authority and responsibilities over prices, public obligations, and competition rules, as well as other rules that are specified in the contracts and influence the value of the business. Because, even if regulatory rules are clear enough, they are only as effective as the regulators can be.

Legal risks entail the fact that, typically, project financing structures cover periods of ten years or more. However, over that time period, the relevant legal and regulatory environment is likely to change substantially. The rules governing the financial consequences of these changes between the government, users, and operators are critical, but they are frequently overlooked. The rules must allow for changes to the contract terms during the time that the project is being funded.

- *Governments* generally agree to compensate investors for political risks, although in practice, justifications for government actions may be cited to delay or prevent such payments. Thus, private investors generally assume the risks associated with dispute resolution and the ability to obtain compensation should the government violate the concession agreement. The issue of meeting financial obligations while disputes are resolved may be achieved through a requirement for debt servicing reserves, contingency funds, or standby financing.

Political risks concern government actions that affect the ability to generate earnings, such as actions that terminate the concession, the imposition of taxes or regulations that significantly reduce the value of the business for investors; placing restrictions on the ability to collect or increase tariffs; precluding contract disputes from being resolved in reasonable ways;

2.3 Traffic demand/revenue risks

Unlike project financing in other sectors, take-or-pay or fixed-price contracts are typically not available in public transport infrastructure projects, so traffic demand risk is a major issue in virtually all of these projects. Even when there is a reasonable level of confidence in forecasts, traffic demand can be dramatically affected by competition from other modes or facilities, changing usage patterns, and macro-economic conditions. These inter-related issues, over which the project sponsor often has little or no control, are very difficult to predict and represent a major risk to financing. In particular, traffic demand forecasting during the early years can be quite subjective. To the extent that these risks are driven by economic conditions, there is a potential role for the government to play in risk sharing, either through traffic demand, revenue guarantees, or other forms of support.

3. ATTRACTING PRIVATE-CAR USERS TO BECOME A PUBLIC TRANSPORT PATRON

For any newly implemented public transport system, it is of great importance to attract patronage. This would also be the case for those that are under study to solve the dire road traffic congestion situation in the Greater Beirut Area (GBA) in Lebanon, where currently no efficient and reliable public transport system is in place. Most commuters use their private cars to get to/from their places of work or education. In this respect, it is worth noting that over 24% of employment opportunities in Lebanon are located along the Beirut-Jounieh (Tabarja) corridor, and that the majority (78%) of commuters travelling on this route use their private cars; the remaining 22% use taxi (van) services, and (mainly private sector) minibus/bus services that do not really provide scheduled services. All this road traffic on the Northern Corridor, in addition to that on the Eastern and Southern Corridors, lies at the source of the dire road traffic congestion situation in Beirut, which is such that up to 70% of commuter travel time is lost in delays due to the sa(i)d road traffic congestion situation. The average reported inter-modal road traffic speed is 11 km/h (calculated as the weighted average speed across all modes), with an average speed of 9.4-13.5 km/h for private cars, 6.5-9.3 km/h for buses, 7.5-10.8 km/h for minibuses, and 8.6-12.3 km/h for taxis. As a result, every day, commuters are forced to spend hours stuck in traffic jams and in their cars, struggling to somehow reach their respective destinations.

As noted in previous articles (e.g. Choueiri, 2014, 2018, 2020, 2021a), studies to implement an efficient and modern public transport system to alleviate road traffic congestion in the Greater Beirut Area (GBA) have been underway for several years now, but are struggling to make much progress due to the various political, economic, financial, and other crises Lebanon is currently plagued with.

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Among these studies, railways are also being looked at, such as revitalizing (using the already existing rights-of-way) railway services on the routes (see Map):

- Beirut-Jounieh-Tabarja-Maameltein (Tripoli); and
- Tripoli-Abboudiyeh.

3.1 The SkyWay option

Another option being considered is to build an elevated SkyWay system between Beirut Rafic Hariri International Airport and Casino du Liban (Jounieh), with intermediate stations at strategic locations (Aoun et al., 2019; Choueiri, 2021b), which could achieve significantly shorter travel times than a private car (*see Figures 1 and 2*). Travelling by private car from Beirut-Rafic Hariri International Airport to Casino du Liban in Jounieh, a distance of 49.7 km, takes about 1 hour and 50 minutes. However, as can be observed from the table below, when travelling by the SkyWay system (average travel speed of 100 km/h), which would have a shorter route of 40 km (10 km shorter than the road alternative), the travel time would be just 30 minutes (this figure takes into account a travel speed of approximately 5 km/h when passing through the intermediate stations, as people would embark and disembark, which would take about 1 minute per station), *see Table 1*.

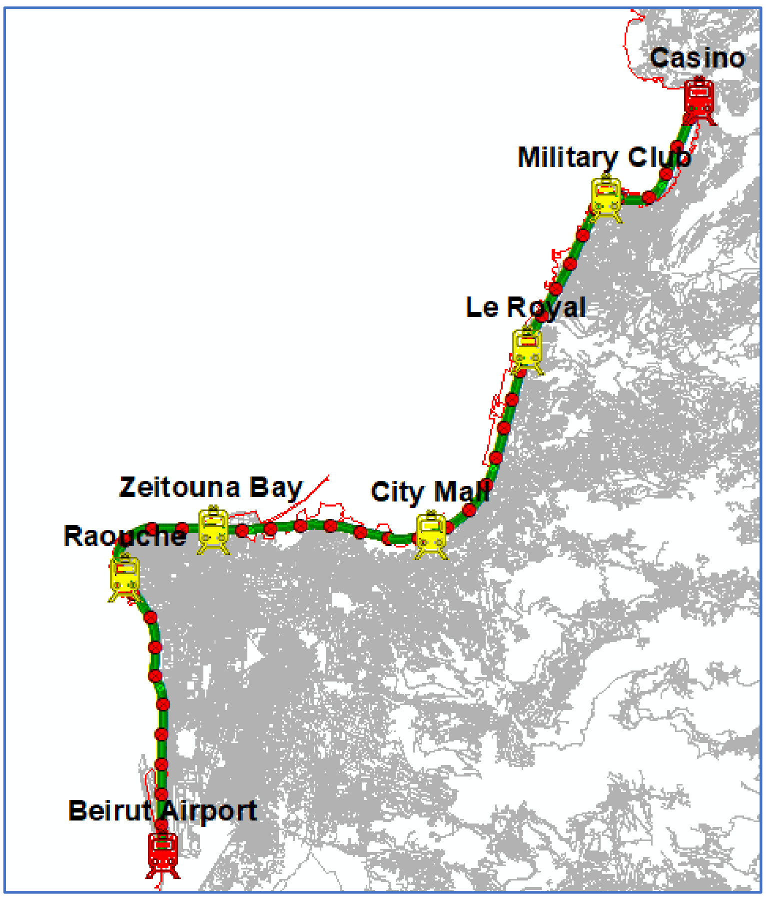

Figure 1. Beirut-Jounieh SkyWay Investigated Alignment and Station Locations on Google Earth Basemap

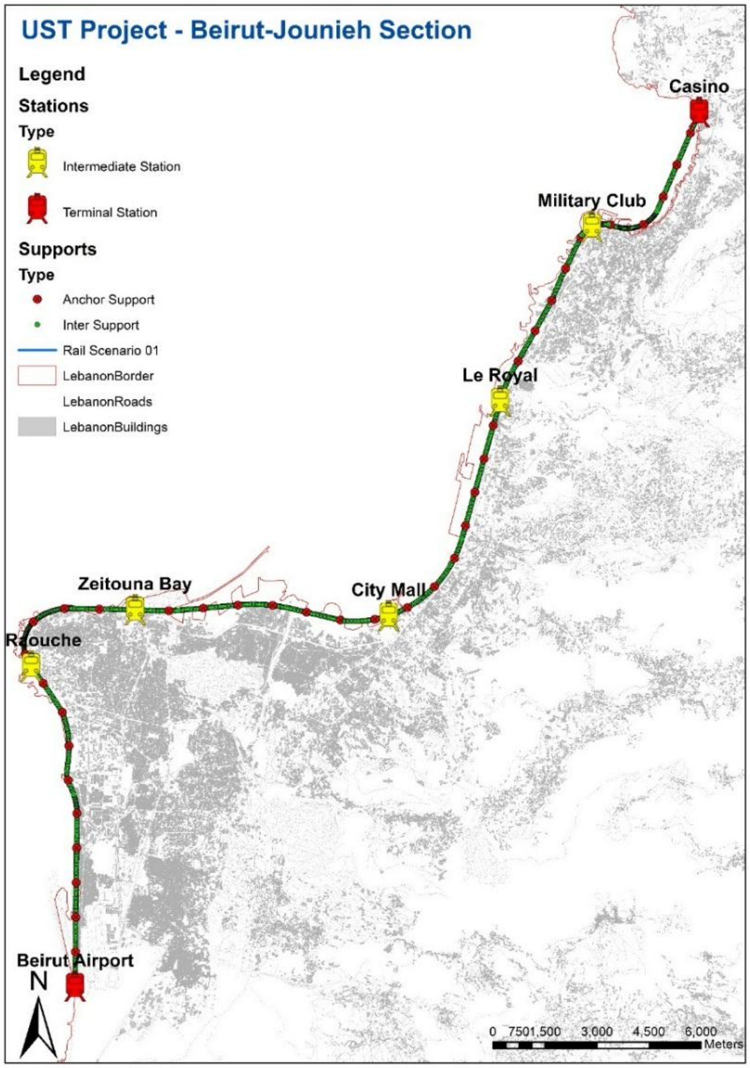

Figure 2. GIS Simulation of the SkyWay Investigated Alignment and Station Locations

In order to meet Ynitskiy's (or Unitsky's) standards, a minimum radius of 1,000 meters was considered for the entire project, resulting in an acceptable speed of 100 km/h along the entire alignment on straight and curved sections (Aoun et al., 2019). In the Unitsky String Technologies (UST) system architecture, a distinction was drawn between two types of support. Every one kilometer, an anchor or tensioning support is employed; the second type is an intermediate support, which was employed to alleviate the sag effect/vertical deflections on the structure. Based on the clearance required from the bottom of the unibus and the travel path below, the typical height of each support erected on the ground is 10 meters above the roadway level and 18 to 25 meters above sea level. There are 43 anchor supports and 1,285 intermediate supports in total on the planned route.

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Table 1. Travel Time Comparisons between Personal Vehicle trips and the SkyWay Technology

Origin-Destination	Length - Personal Vehicle (km)	Time - Personal Vehicle (mins)	Length - UST (km)	Time - UST (mins)
Beirut Airport - Raouche	10.6	27	10.037	6
Raouche - Zeitouna Bay	5.5	23	4.441	3
Zeitouna Bay – City Mall	10.2	23	7.363	4
CityMall - Le Royal	9.2	11	7.310	4
Le Royal - Military Club	6.2	10	5.736	3
Military Club - Casino	8.0	17	5.183	3
Total	**49.700**	**111 (1 hr 51 mins)**	**40.070**	**30 mins**

3.1.1 Cost Estimation

Table 2 shows a summary of the project's costs.

Table 2. UST Construction Cost

Item	Unit Price (USD)	Number of Units	Total Cost (Million USD)
610UB152 Beam	1,555.50	1328 pieces	2.07
502CHS12.1 Column	1,656	1328 pieces	2.20
1000x7000 Pile	1,705	1328 pieces	2.26
35 mm Cable	37	480840 m	17.79
Concrete	75.50	2172.89 m^3	0.16
Materials (Extra)	750	1328 pieces	1.00
Construction Labor	2,996,540	40.07 km	120.07
Terminal Stations	4,167,251	2 pieces	8.33
Intermediate Stations	100,014	5 pieces	0.50
Traffic/Site Management	1,048,789	40.07 km	42.02
Design and Commissioning	111,279,093.36	9%	10.02
Land Acquisition	-	-	5.28
Total	-	-	**211.70**

3.1.2 UST Feasibility Study Results

When public transportation is well-established, driving a private automobile during rush hour becomes a luxury rather than a necessity. As a result, people who choose this level of luxury will pay a higher price in tolls, parking fees, and congestion costs. The following are the key findings from the feasibility study for the UST Project:

3.1.2.1 Ridership Potential

This system may create an average yearly revenue of $3 million if ridership is between 3,000 and 4,000 per day, which is comparable to an average of 1,280,000 people per year, depending on fare price.

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3.1.2.2 Implementation Costs

A UST project system costs $211.7 million in total (*see Table 2*), or $5.3 million per kilometer. As a result, when compared to the expenses of other forms of transportation, this system is extremely cost-effective.

3.1.2.3 Energy Consumption

The UST cableway has a low energy demand of 1.8 million kilowatts per year. Users who shift away from automobile trips result in lower GHG (Greenhouse Gas) and carbon emissions. The more the system expands, the higher the commuter trips that result in lower additional emissions.

3.1.2.4 Comparative Analysis with Other Modes of Transport

High speed, high efficiency, and low rollout cost are the fundamental characteristics of a UST system. Figure 3 highlights comparisons with various modes of transportation in terms of capital costs, pollution, operational costs, and traffic accident rates.

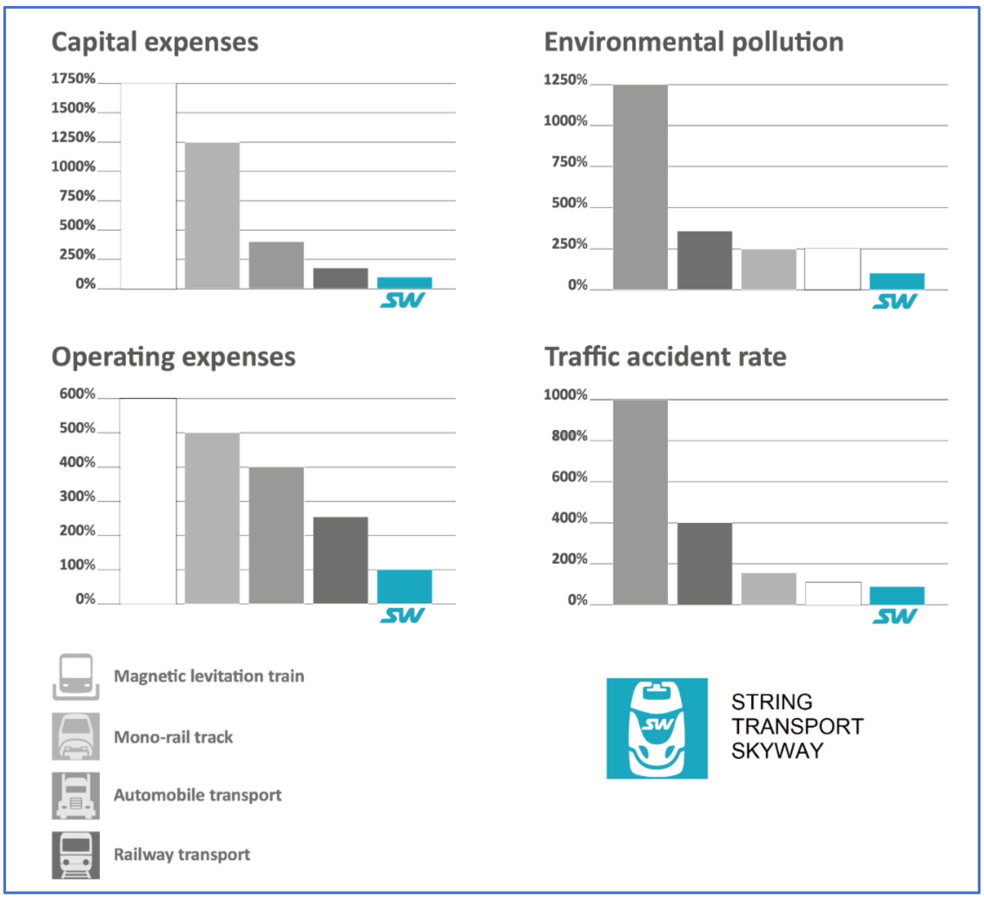

Figure 3. Comparison between Transport Modes Regarding:
a) Capital Expenses, b) Environmental Pollution,
c) Operating Expenses, and d) Traffic Accident Rate

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SkyWay vs. Cableway (Dunayeva & Vinakurava, 2019)

The principle of the cableway is the movement of the cable, on which the cars are fixed, between two points. In SkyWay, the vehicle (electric rail vehicle) is not moving along a cable that requires regular replacement every 6–8 years, but on a steel profile. When moving at the same speed, energy consumption in the string railroad will be 5–6 times lower compared to the cableway.

SkyWay surpasses the cableway in a range of parameters – operating costs, service life, safety, speed, performance. It is worth noting that SkyWay, in contrast to the cableway, has various types of tracks, making it possible to combine them, and a wide range of vehicles.

Table 3. SkyWay vs. Cableway

Characteristics	**Cableway**	**SkyWay**
Speed	21.6 km/h (6 m/s)	Up to 150 km/h (in city)
Track length	Up to 10 km	Unlimited
Principle of movement	Outboard motor moves both cable and cars	Autonomous steel-wheeled
Turning capability	No	Yes
Service life	Complete replacement of cables each 6–8 years	Track structure: 50–100 years; Rolling stock: 25 years
Safety	Low	High
Comfort	No climate control	Climate control
Cost effectiveness	Low	High

SkyWay vs. LRT (Dunayeva & Vinakurava, 2019)

Compared to LRT, SkyWay vehicles' capacity is much more attractive than that of the Light Rail Transit (LRT).

Table 4: SkyWay vs. LRT

Characteristics	**LRT**	**SkyWay**
Rolling stock capacity	Train: from 4–5 cars from up to 100 passengers each. Platform length: minimum 150 m	Coupled unibuses: up to 240 people on the upper track and up to 175 people on the lower track. Platform length: up to 50 m
Headway	From 1–2 minutes	From 20–25 seconds
Safety	Medium	High

SkyWay vs. Monorail (Dunayeva & Vinakurava, 2019)

Compared to monorail, SkyWay wins primarily in terms of speed. In addition, monorail requires a very massive overpass, with high material capacity.

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Table 5: SkyWay vs. Monorail

Characteristics	Monorail	SkyWay
Track length	Up to 50 km	Unlimited
Rolling stock capacity	Train: from 4 cars for up to 80 passengers and more each. Platform length: minimum 100 m	Coupled unibuses: up to 240 people on the upper track and up to 175 people on the lower track. Platform length: up to 50 m
Maximum speed	70 km/h	150 km/h
Principle of movement	Elevated pneumatic-tired transport	Autonomous steel-wheeled vehicles
Headway	5–20 minutes	From 20–25 seconds
Service life	Track structure: 50 years; Rolling stock: 10–15 years	Track structure: 50–100 years; SkyWay rolling stock: 25 years

3.1.2.5 Funding Opportunities

Because the UST system is both creative and cost-effective, it is an excellent contender for funding. Local improvement districts, public and private partnerships, as well as state, federal, and local transit enhancement programs, could all be feasible funding sources.

3.1.2.6 Traffic Assessment Impacts

By 2050, the urban population in Lebanon is expected to have grown to 87 percent of the overall population (Khoury, 2017). Such rapid expansion would result in increased traffic congestion, increased traffic accident risks, and unreliable public transportation systems. Furthermore, the domination of private passenger automobiles would result in overcrowding on current roadways, higher GHG emissions and pollution levels, and higher total mobility costs. Without UST, all existing public transportation modes in Lebanon would result in just unorganized traffic, which would have a negative impact on global warming, mobility, cost safety, and social productivity.

By all accounts, the UST System has the potential to attract a large number of travellers, as 29% of people now use public transportation (Khoury, 2017). Traffic volumes would be reduced by 3,680 vehicles per hour during AM times (4417 passengers) and 2,925 vehicles per hour (3,510 passengers) during PM periods, based on a carrying capacity of 12,200 per day and an occupancy of 1.2 individuals per car. The number of cars would be reduced by 8,362 (10,034 passengers) during AM periods and 6,644 (7,973 passengers) during PM periods if 65.88 percent of residents considered using the UST system.

3.1.3 Project Impact Assessment

Adopting some form of public transportation is, without a doubt, the most consistent, safe, and convenient choice. However, because Lebanon's road space and land area are limited, allocating a bus lane would almost surely worsen traffic congestion. In this regard, the UST elevated railway transportation system avoids issues like road space and uses only 1.8 kilowatts per year, demonstrating its excellent environmental friendliness (Yunitskiy, 2015). The O-D (Origin-Destination) speeds clearly

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illustrate that this technology is far faster than a car and easily avoids all traffic bottlenecks. In terms of cost, the UST is a viable option when compared to other modes of transportation, costing roughly $8 million per 1 km of construction with a 50% contingency. Furthermore, UST's zero-tolerance policy is highly effective.

3.1.4 Project Disadvantages and Limitations

Every public transportation system offers a set of advantages. However, some disadvantages may arise as a result of the UST system's implementation; these are listed below:

- The most challenging issue in any public transportation system is funding and regulatory policies.
- Pile foundations necessitate a high level of precision, which could drive up building costs.
- Relevant stations necessitate site space and regulatory approvals for land acquisition.

As a result, more comprehensive soil research and geotechnical studies would be required to reduce the aforesaid disadvantages, and regulatory requirements would need to be examined to avoid any on-site operational risks.

3.2 SkyWay – a commuter survey

With respect to the SkyWay option, a survey was held among 306 current commuters in Beirut aimed at gathering their viewpoint on their current use or non-use of public transport and to acquire an insight into whether they would be inclined to use the SkyWay system should it become available. Amongst other things, the results of this survey yielded the following (Aoun et al., 2019):

- 238 (78%) of the respondents regularly used the private car as their primary mode of transport, 148 (62.18%) of them would consider shifting from travelling by private car to travelling by SkyWay system should it become available;
- 61 (20%) of the respondents used some form of public transport (taxi (van) services, and (mainly private sector) minibus/bus services), and a negligible proportion used other modes of transport (bike and motorcycle);
- 203 of the respondents earned less than $1,500 per month, 116 of them spent $100-$300 (7%-20% of their monthly income) on transport each month. From these 116 respondents, 96 (82.76%) used the private car as their prime mode of transport. Further, 56 of the respondents travelled by bus. Of those travelling by bus, 52 (92.8%) had an income of less than $1,500 per month (39 (75%) of them spent less than $100 on transport each month). These figures seem to suggest that, despite their low incomes, the respondents prefer to use their private cars;
- 41.07% of the 56 respondents who travelled by bus spent about 30-60 minutes from home to their respective places of work/education. Of the 238 respondents who travelled by car, 108 (45.38%) also spent 30-60 minutes to travel from home to their places of work/education. Both modes of transport get stuck in the same traffic jams;
- 111 (33%) of the respondents ranked travel time to reach one's destination as their first priority for choosing a mode of transport. For this reason, 81 (73%) of them would consider using the SkyWay system which, as noted earlier, would offer very favorable travel times, as an alternative option. Thus, travel time would be a major criterion for using public transport.

It has been estimated that the SkyWay system which, as noted earlier, could offer more favorable travel times than the private car on the route Beirut-Jounieh (as it passes over all traffic congestion obstacles), could attract some 3,000-4,000 passengers per day, which would be equivalent to an average of 1,280,000 passengers per year (Aoun et al., 2019). In view of the low car occupancy rate of 1.2

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persons/car in the Greater Beirut Area (GBA) (Kadi, 2016), this could lead to a significant reduction in the number of cars circulating on the roads.

3.3 Attracting private car users to become public transport patrons

For any public transport system to be conceptualized to accommodate a reasonable level of ridership on a given corridor, it is essential that the system specifically understands, targets, and adapts itself to the current private car users. Once an objective has been established, it can then be carried out through respective levels of subsidy as well as fare and price discrimination mechanisms.

To attract current private car users, the majority of whom would be middle-class professionals, to patronize the public transport system, it should be recognized that one of the key variables, besides the price of tickets, would be the location of stations. Also, in suburban areas, the stations would need to have adequate parking facilities as the majority of commuters would need to park their cars at the station and then use the public transport system to commute into the city. As for stations in Beirut, it would be very important to address the issue of transport mode transfer, as well as to consider the walking distance from the station to the Central Business District or other destinations in the city. For instance, requiring a commuter to use three modes of transport to get to his/her place of work would likely diminish ridership. Noteworthy in this respect are the two following comments that were made by respondents to the SkyWay survey (Aoun et al., 2019):

- If SkyWay coincides with my time and destination, it will be my choice; otherwise, I will use my car.
- There is also the comfort criterion! If it is a hassle to use SkyWay, then I would still consider using my car.

4. FINAL REMARKS

In the various articles that have been published in this journal over the years, it has become quite clear that Lebanon, and especially the Greater Beirut Area (GBA), is in dire need of a modern, reliable, and efficient public transport system that can take commuters to their places of work and education, as well as others to their respective destinations, in a more comfortable and environmentally-friendly manner than when travelling by private car, which is so often characterized by being stuck in polluting traffic jams. A well-established public transport system would greatly enhance the mobility and quality of life of the people, as well as bring other societal and economic benefits. Once in place, people would become more and more familiar and appreciative of its many benefits, thus turning many of them into patrons of such a system.

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POST SCRIPTUM

Please note that the survey addressed in this article was conducted in 2017/2018, i.e. prior to the financial and economic collapse of Lebanon that started in October 2019, and is still continuing this very day, exacerbated even more by the current afflictions taking place in Ukraine. "Up to 90% of Lebanon's wheat and cooking oil imports come from Ukraine and Russia, as well as a large proportion of grain imports" (citation from news item 'Lebanese fearful as fuel and wheat shortage deepens: The war in Ukraine has left cash-strapped Lebanon scrambling for alternative sources of fuel and wheat', Al Jazeera Live, 8 March 2022). Also, the Lebanese Pound has lost some 90% of its value against the US Dollar, which also puts the income figures noted in the article in a different light. Furthermore, as the price of gasoline has gone completely out of control, also exacerbated by what is presently going on in Ukraine and the various restrictions that are in place, only a very small proportion of people can afford to travel to their places of work/education (these days, the price for 20 liters of gasoline stands at $300-00, i.e. $15-00 per liter, to put it into perspective).

Remaining hopeful that, one day, things will get back to normal, solving the issue of the dire road traffic congestion situation in Beirut, either by implementing a ground-based railway system or an over-ground SkyWay system, should remain high on the agenda. It is assumed that, once in place, commuters will soon see the advantage of a modern, reliable and efficient public transport system that can take them to their places of work/education in a passenger-friendly, relaxed and comfortable manner – quite the opposite from the stressful daily battle to get to one's destination.

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