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Predicting Human-System Interaction Risks Associated with Autonomous Systems in Mining

Maureen Hassall[1], Ben Seligmann[1], Danellie Lynas[1], Joel Haight[2], and Robin Burgess-Limerick[1]

[1]The University of Queensland, St Lucia, Brisbane, QLD, 4072 Orlando, Australia
[2]University of Pittsburgh, 3700 O'Hara Street Benedum Hall, Pittsburgh, PA 15261, USA

ABSTRACT

The Australian mining industry is implementing increasing amounts of automation into operations. In most mining environments, humans need to interact with this technology to maintain it and when performing other mining tasks in areas where the automated equipment is operating. Thus, introducing automation into mining environments has the potential to introduce new and significant human-system interaction safety risks. Traditional and contemporary socio-technical approaches can be used to identify and assess these risks. However, no publications could be found that explore the end-users' perspectives on the efficacy of these approaches for assessing human-system interaction risks associated with autonomous systems in mining. In this paper we begin to address this gap by researching mining professionals' perspectives of the useability and usefulness of Preliminary Hazard Analysis (HAZID), Failure Mode and Effects Criticality Analysis (FMECA), Strategies Analysis for Enhancing Resilience (SAfER), and System Theoretic Process Analysis (STPA) in identifying human-system interaction risks associated with autonomous haulage, automated longwall and remote-controlled processing plant operations. Results from the participant feedback suggest that each technique was able to identify potentially hazardous human-system interactions but that each had strengths and weaknesses depending on whether risks were being assessed risks pre or post implementation. A hybrid or combination approach was suggested with further testing of the proposed approach being recommended.

Keywords: Human systems integration, Automation, Risk, Safety

INTRODUCTION

Industry is implementing increasing amounts of automation into operations. The Australian mining industry is no exception as it is introducing autonomous mining vehicles and trains, remote controlled processing plants and the use of drones and robots to do survey and inspection work. Often these technologies are adopted to improve operational efficiencies and to reduce workers' exposure to high-risk situations. However, in most mining environments, the adoption of automated technologies has not completely removed humans from the operation. Humans still need to interact with the technology to clean, service and maintain it. Humans also have to perform other tasks in the automated mining environment such as inspection of ground conditions, mapping mining and dump areas, maintaining roads and infrastructure etc. Thus, introducing automation into mining environments has the potential to introduce new and significant human-system interaction safety risks. The emergence of these new safety risks are evident in recent accidents in the mining industry as well as in other industries that have introduced automation.

Traditionally, risk-based approaches have been used in the Australian mining industry and other industries to identify and treat safety related risks. Such approaches include the use of hazard identification techniques (HAZID), Workplace Risk Assessment and Control (WRAC), Failure Mode and Effects Analysis or Failure Modes and Effects Criticality Analysis (FMEA or FMECA), and Process or Job based Hazard Analysis (PHA or JHA). These traditional techniques have helped reduce fatal and catastrophic incidents in the mining industry but deficiencies in their application has also been highlighted in a number of major accident investigation reports. For example the Pike River Mine Royal Commission found "*that even though the company was operating in a known high-hazard industry . . . and the executive managers did not properly assess the health and safety risks that the workers were facing. . . and exposed the company's workers to unacceptable risks*." (Royal Commission on the Pike River Coal Mine Tragedy, 2012).

In addition, recent research has suggested that traditional risk identification techniques are not very effective for new, software-enabled technologies that are embedded in socio-technical systems with complex or dynamic human-system interactions (Leveson, 2011, Dekker et al., 2011). In response, new socio-technical risk assessment approaches have been developed such as System Theoretic Process Analysis (STPA) (Leveson, 2011) and Strategies Analysis for Enhancing Resilience (SAfER) (Hassall et al., 2014). However, no publications could be found that seek to understand from an end-user perspective the efficacy of the traditional and new techniques in assessing human-system interaction risks associated with the introduction of autonomous and automated technologies in mining environments.

To begin to address this gap, research was conducted that sought to answer the question - **What combination of risk assessment techniques do end-users perceive as being most effective for identifying risks associated with human-system interactions in automated and autonomous mining operations?**

METHOD

The research method involved mining industry professionals trialing four techniques across three different workshops. The four techniques were Preliminary Hazard Analysis (HAZID) which followed the process set out in Figure 1; Failure Mode and Effects Criticality Analysis (FMECA) which followed the process described in IEC60812:2018 (International Electrotechnical Commission, 2018); Strategies Analysis for Enhancing Resilience (SAfER) approach as outlined in Figure 2 and described in detail in Hassall (2013), and System Theoretic Process Analysis (STPA) using guidance provided by Leveson and Thomas (2018). In using these techniques, the work

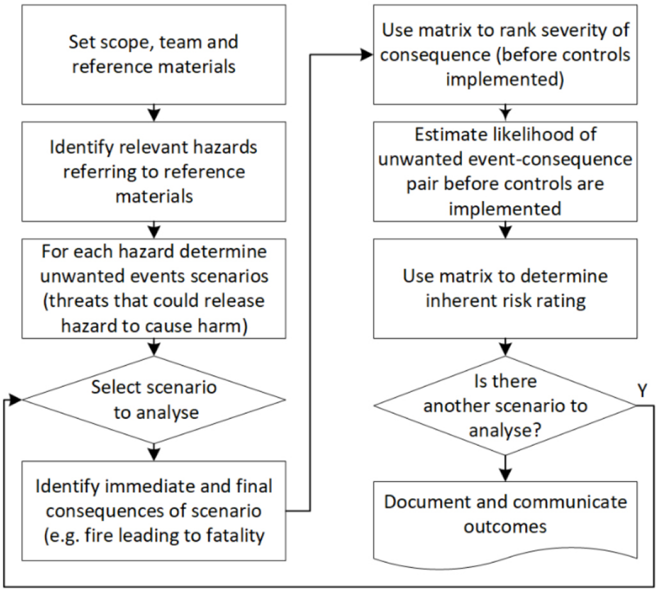

Figure 1: The HAZID process used in workshops.

focused on identifying risk scenarios and not on determining appropriate risk treatments.

Three workshops were conducted, each focused on a different automated technology. The first workshop focused on identifying human-system interaction safety risks in surface mine autonomous haulage operations. The second focused on identifying human-system interaction safety risks associated with underground mine automated longwall mining operations. The third focused on human-system interaction safety risks associated with remote controlled operation of ore processing plants.

Before and after each technique was trialed, the participants were surveyed to collect their experience with each technique (in survey given before the technique was trialed) and their perceptions of the ease of use and effectiveness of each technique (in survey given after the technique was trialed). Responses from Likert survey questions were then analysed using Shannon Entropy Ratio to produce measures of "overall effectiveness" and "ease of learning". Free text responses were also examined. Results are described next.

RESULTS

The surface mine autonomous haulage workshop was held May 25, 2021 and was attended by 9 industry personnel. The underground mine automated longwall mining workshop was held August 2, 2021 and by 8 industry personnel. The remote controlled ore processing plant workshop was held August 23, 2021 and attended by 9 industry personnel. All workshops were attended by four researchers.

During each workshop all four techniques were able to be tested. The researchers' made a number of observations during the workshop and when reviewing the documented risk assessment information. These observations

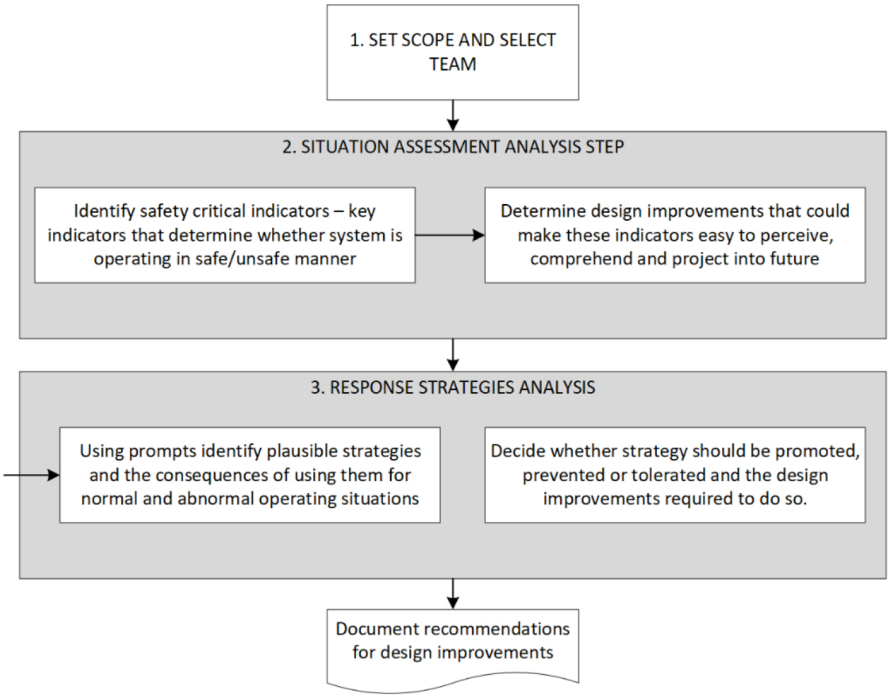

Figure 2: Outline of the SAfER process.

including the following: (1) The HAZID process seemed to be familiar to the attendees, perhaps because similar risk assessment techniques are used in mining (although they may be called different things like WRAC, BBRA etc); (2) The FMECA process was slightly more challenging to focus it on human-system interactions rather than on the equipment automation. Better understanding of the component function (e.g. the function of the human-system interaction) should help improve the efficacy of the technique; (3) The SAfER technique provided new insights around situation awareness requirements and strategy options. The approach was new to participants so it took more effort and time to elicit information and a complete analysis was not produced from any of the workshops; (4) The control diagram produced by the STPA also seemed to be a new process for participants it took some time to develop but it helped identify and clarify interactions. The resultant diagram made the analysis of deviations in human-system interactions reasonably straight forward.

The participants' responses to ease of use and effectiveness for each technique are illustrated in Figure 3 for the traditional approaches of HAZID and FMECA and Figure 4 for the socio-technical techniques of SAfER and STPA. The summary from the Shannon Entropy Ratio analysis is shown in Figure 5.

DISCUSSION AND CONCLUSION

This study had a number of limitations. Due to COVID-19 restrictions and the availability of industry personnel during the pandemic the workshops were restricted to one-day timeslots which were run either partly for

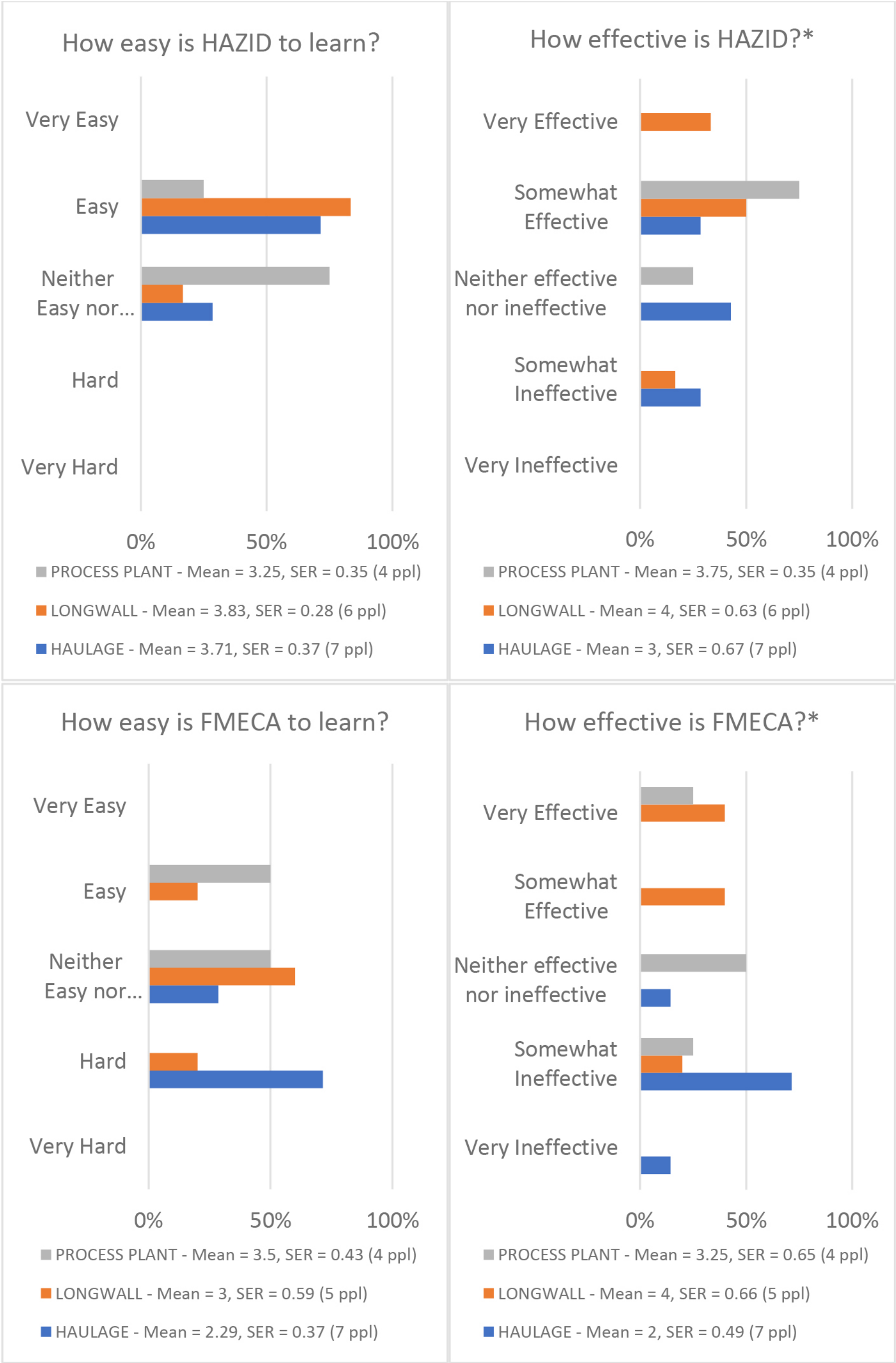

Figure 3: Results from traditional risk assessment processes.

fully online. Participation was also voluntary. Despite these constraints, all risk assessment processes were able to the trialed with industry practitioners across the three case study scenarios. These risk assessments were able to identify insightful human-system interactions that could be potentially hazardous and therefore warrant further analysis to determine how best to

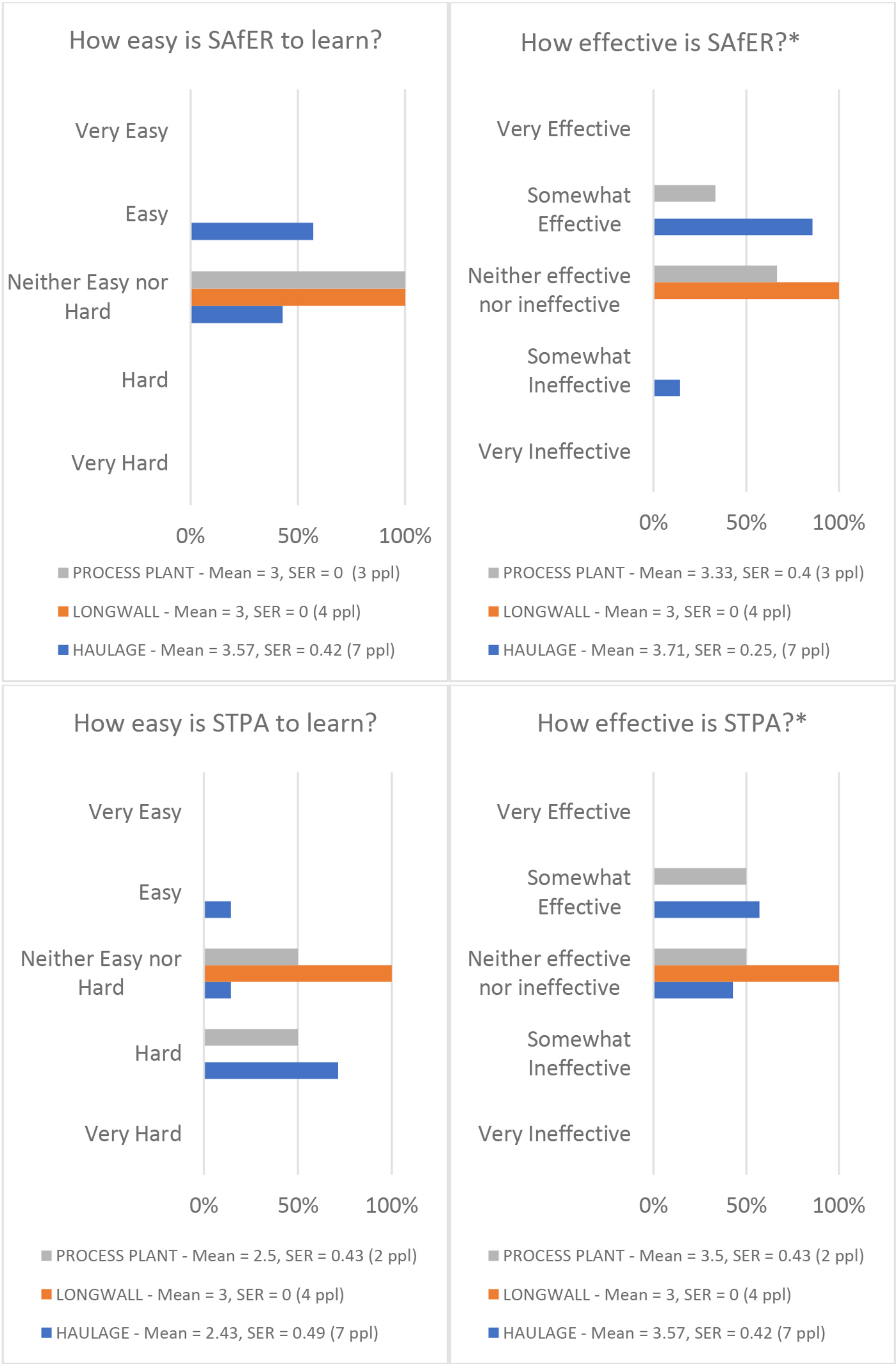

Figure 4: Results from socio-technical risk assessment processes.

manage them. Feedback from the participants and analysis of workshop information suggest that no single approach is significantly more effective than any other for any of the case studies nor across the range of automation case studies trialed. Therefore, it is suggested that further work be done to

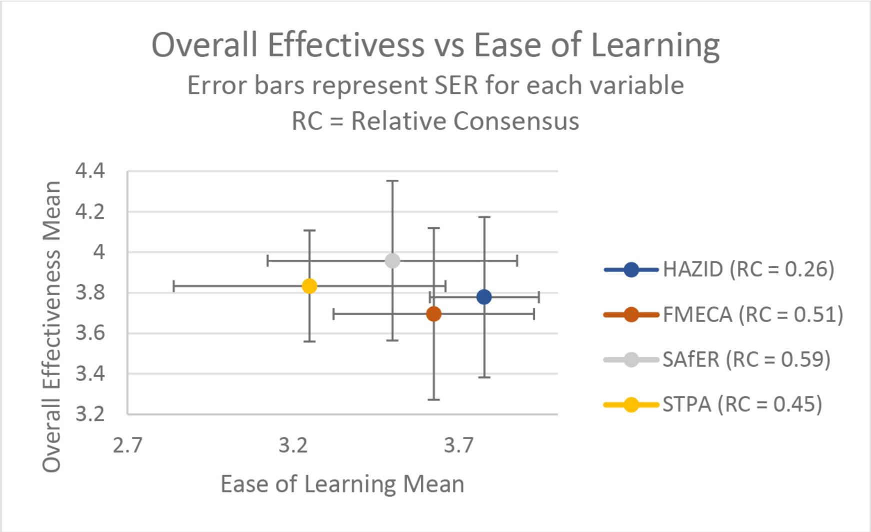

Figure 5: Summary of results from Shannon Entropy Ratio analysis.

leverage off the feedback provided and investigate whether a hybrid or combination of approaches might be best the analysis of human-system interactions in mines. Such an approach might consist of the following steps: (1) Setting the scope and this should include a human-system interaction diagram (as was produced in STPA); (2) For existing systems, performing a HAZID or and refined version of SAfER; (3) For new systems, performing a STPA based FMECA and refined version of SAfER. The refined version of SAfER should involve referencing the human-system interaction diagram, performing the situation assessment analysis with the addition of a risk ranking if indicator was absent/overlooked and/or incorrect/misleading. The identification of causes and consequences of strategies along with a risk ranking of them should also be added. The efficacy of these suggestions should be assessed with further research.

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