Computers in Human Behavior Reports 4 (2021) 100115

Contents lists available at ScienceDirect

Computers in Human Behavior Reports

journal homepage: www.journals.elsevier.com/computers-in-human-behavior-reports

Skills development and training of future workers in mining automation control rooms

Peta Chirgwin

University of Southern Queensland, Toowoomba QLD, Australia

ARTICLE INFO

Keywords:
Technology
Automation
Control room
Mining
Training
Work design

ABSTRACT

The benefits and value promised by autonomous mining technologies in mine control will only be delivered when an equal focus is placed on humans and machines alike. This paper explores the obstructions mine controllers face, examining the fundamental reasons why technology adaption does not reach its full potential and why the industry is facing a skills resource shortage in this area.

This is the first of two papers developing our understanding of the job design and task allocations of a mine controller's role. This will assist in addressing the shortcomings of inadequately designed Human Machine Interfaces (HMI) and facilitate improvements in human factors. The goals of this first paper are to present a field study of the mine controller role from a human factors' perspective. Through interviews, in situ observations and analysis of job descriptions of current mine control roles a common skill set, and human factors requirements was developed and analysed against data reviewed from current literature.

The findings reveal issues with technology integration, particularly in job design and training for the mine controller, are resulting in a shortage of available candidates for autonomous control. Therefor there is a need to develop robust workplace training practices, coupled with higher education that is valid, effective, and adaptable to an ever-changing and technology-intensive working environment.

1. Introduction

1.1. Research aim

It is highly likely that regardless of affiliation, the reader has seen or heard something on the news regarding mining companies' expansion into automation. What the current reader may not be aware of, is the role of the mine controller, the person in charge of running an autonomous fleet on a mine site and how that role has developed from running a fleet of manned haul trucks to running a fleet of autonomous haul trucks and training and skills requirements for those roles. This omission in understanding the role of the mine controller can be forgiven as it appears industry itself has all but forgotten this much relied on role (Li et al., 2011). The omission of understanding this role, which is not a new one (autonomy aside) is apparent not just through the lack of articles and data, but also in the lack of curriculum and formal training approaches embedded in the role. A search of the role description for mine controllers or mine dispatchers (as they are also commonly known) illustrates a myriad of tasks and ambiguous requirements that vary from company to company.

In attempting to understand skills development and training requirements for mining automation, this paper focuses on the role of the mine controller (also known as controller or dispatcher) which has been poorly defined in the past with organisations preferring to focus more on technology and systems solutions, 'while its weakness has been at the people end of the business in maximizing and consolidating gains from the technologies'. (Li et al., 2011, p. 895).

Through researching the role including job design, skills, and training requirements with consideration of human systems integration (HSI) and human factors, this paper aims to articulate a practical taxonomy of the knowledge and skills elements required to create a sustainable training package and career pathway for the modern and future mine controller to enter and thrive in an automated mining operation.

Defining the role of the mine controller and with it, the skills requirements is essential in operating in industry 4.0 (I4.0) with a poll by Mining People International (2008) of 80 specialists from a cross-section of mining organisations showing that, as it moves into I4.0, the mining industry would face a skills shortage (Heather, 2018). Of the respondents from this poll, 82% said they were having difficulty recruiting people with management skills, while 75% of respondents agreed that 'the mining industry itself was responsible and not doing enough' to ensure there are relevant skills available among its workforce for the future

E-mail address: U1025821@usq.edu.au.

https://doi.org/10.1016/j.chbr.2021.100115
Received 13 May 2021; Received in revised form 21 June 2021; Accepted 23 June 2021
Available online 24 June 2021

(Heather, 2018, p. 1). The first step in developing these skills will be defining the role of the mine controller and the tasks allocated to them.

1.2. Research methodology

Given the strong reliance of observation and immersion into the role of the mine controller by the researcher, this study lends itself to both a positivism and constructivist paradigm (Creswell 2003).

The is a high degree of qualitative data collection methods used including the afore mentioned observations and informal interviews, and thereafter, using content analysis to derive the suggested findings. Whilst this method of data collection could lend itself to bias given the researchers close association and experience in the role of a controller, triangulation of the evidence was conducted through the use of the interviews to gather other controllers' understanding, literature research to consider other researchers' findings, technology systems audits to understand how organisations were implementing different technologies, and what technologies controllers were required to use compared with other roles associated to mining automation.

1.3. Literature review

The literature review included a search of the literature to reveal the definition of a mine controller, tasks associated to a controller role and explore trends in HF and job design in control room operations. The search was then further refined to contextualise mining automation and mining control rooms. Databases for research included Science Direct, Emerald Insights, Taylor and Francis and Elsevier, which then expanded to include mining journals, industry publications, organisational reports and conference papers.

At the beginning of this study, the author was focused on understanding the HF impacts of introducing automation to the mine control room. Thus, the initial literature search was directed toward that topic. However, it was soon realised that this was a field of research yet to be done and there was very little that the researcher could find specific to the role of the mine controller including definition, tasks and effects of automation to control room operators including, HFs or psychological safety or specific topics of training requirements within mine control for moving into automation.

1.4. In situ observations

The primary aim of the in-situ observations was to understand what tasks the mine controller currently does in a manned operation, how those tasks change moving into automation and how they compare with the generalised 'skills of the future'. The secondary aim of the observations was to reveal HF and behavioural attributes when operating as an autonomous controller. Tertiarily, in understanding the mine controller role further, the observations aimed to reveal how training was currently being conducted in the mine control field, and what gaps could be identified in the delivery of that training.

In situ observations of 4 mining companies within Australia and control rooms across 2 commodities (coal and iron ore) were conducted over a period of 6 years. Control systems utilised across the control rooms were an even mix from 2 major suppliers. Observations were also taken in 7 control room operations, both manned and autonomous, on site and in remote operating centres over the 6-year period with 1 of the control rooms visited twice with a gap of 6 years. The operating centres featured at least 6 operational sites in the 1 centre.

The observations were conducted not just on the internal working of the control room, but also the entire business interaction with the control role to determine the requirements of the controller role, the HF, personal attributes and behaviours of a controller, the skills required for the role, and integration points of the role, both at a systems and sociological level.

A list of tasks from each control room was formulated and assessed against each other as part of the audits conducted to determine the most common tasks expected of a controller, both manned and autonomous. How the controllers managed these tasks, the frequency of tasks and the appearance of stress, discomfort or change in mood or behaviour were observed in each control room. These tasks were then compared with the EY (Ernst and Young, 2019) Skills Movement (Fig. 1) to determine how aligned the controller role is with skills necessary for moving into I4.0, and the Australian Government Department of Industry, Sciences Energy and Resources report on the 'most important skills and attributes' for work (Prinsley & Baranyai 2015, p.2).

1.5. Practical observation

Observation included the author participating in a role as an autonomous technician and project controller for a major Original Equipment Manufacturers (OEM) on their first Australian AHS (Autonomous Haulage System) deployment through to site handover and then, 6 years later, revisiting the same site in the remote-control centre, taking on a practical role as a controller (manned and autonomous) over a period of 5 months. Observations, interviews and discussions were conducted on both occasions as per all of the in-situ observations conducted.

1.6. Audits

The audits conducted were the least relied on method of data collection for this current research as data was taken from company specific audits and assessments on topics not directly for the purposes of this current research however, they did reveal organisation structures, processes, preparedness for automation, system use, training availability, and human system integration strategies (or lack thereof). Responsibility matrices (RACI) were also used to determine the number of tasks that a controller was responsible for and compare that with other roles within the control room. Specific details from these audits and assessments is not provided for this current paper.

1.7. Interviews with subject matter experts

Informal interviews were conducted from over 100 employees from different mining organisations, suppliers, educators, and industry experts ranging from HR professionals, business leaders and subject matter experts to provide an insight on the role of the mine controller. Specifically, expert opinion about shifts in thinking moving toward automation, an employee perspective of the role (including job satisfaction) and a perspective on what could be done to ensure maximum benefits and adaptation for mining automation whilst keeping a HF perspective to keep controllers safe was sought.

Due to the nature of the work, the demand and time pressures, the majority of interviews were conducted one-on-one basis, on the job. Questions were semi-structured although generic enough in nature so that they did not lead a candidate and allowed the candidate to speak freely regarding their role. These questions included job satisfaction, workload, career plan, training completed or planned and general feelings about the role.

2. Defining mine control

2.1. Definition of a mine controller

For the purpose of this current paper, the control room operators are noted as mine controllers, although as mentioned in the introduction, are also referred to as dispatchers or controllers. This paper further specifies the role by utilising the terms autonomous mine controller and manned mine controller. It should be noted that these terms refer to the equipment the mine controllers are working with ie. autonomous haulage compared to haul trucks manned with operators, not the control room itself (as yet there are no autonomous control rooms, and they are all

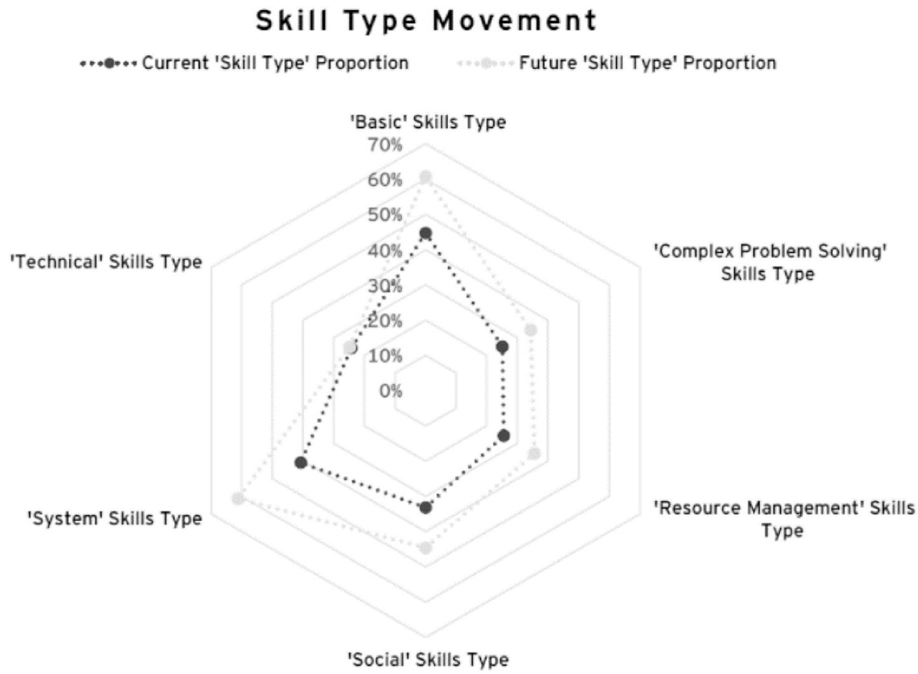

Fig. 1. Skill type Movement (EY 2019).

reliant on mine controllers to run the technologies).

In reviewing literature regarding mine controllers and autonomous mine controllers, the researcher was able to find several articles referencing 'future skills' (presented in chapter 1 of this paper Fig. 1 EY 2019) or the 'future worker' in mining automation, however, literature was space on what exactly what the specific expectations of a controller were, particularly moving into automation, in either task requirements or skills and attributes. Ballantyne (2010) was one author who provided specific reference to the manned mine controller role and the requirements within the role. Ballantyne (p.122, 2010) suggested the following success factors for a control room to operate;

1. High calibre controllers,
2. Controller's relationship with field supervision,
3. Diligent systems administration,
4. Respected 'owner' of the process,
5. Committed management support, and
6. Quality infrastructure – technology must work.

What was only touched on in this 2010 paper by Ballantyne was what were the skills and attributes that made a 'high calibre controller'. The paper suggested that the person must have status and skills equivalent to 'the most senior supervisor' (p.122) and along with fleet management experience, should have field experience.

The researcher of this current paper failed to find other literature that spoke specifically about the skills and attributes that made a good mine controller (manned or autonomous). There was a general indication that key skill requirements for mining automation jobs of the future include extensive technical and system interface skills, alongside tacit and emotionally astute skills.

Fig. 1 (taken from EY, 'Skill type Movement', 2019) displays the skill type movement of the future of work and sums up much of the consensus of all the literature found related to the topic within this current paper and demonstrates the expected shift toward 'basic, social and system skills'. It was noted that the future skills predicted in the reviewed literature and observed and discussed later in this current paper, as consistent to those required in mine control rooms in the process of moving from manned to autonomous, and in fact, a lot of this shift has already occurred, it has merely gone unresearched and there has been no clear training developed to support the growth of these skill sets within mine control.

The literature did not reveal how a mine controller might apply the skills required and interlace them with the HF conditions-imposed on their job role to ensure the best production performance with the lowest safety risk, without also risking the health of the controller. Despite this, Li et al. (2011) theorise that:

Developing effective Human Machine Interfaces (HMI) and alarms, improving operator training, and optimising organisational factors are all recommended as key items to help achieve a better integration of operators and technologies. (p.1).

Over the 6 years of the study, it was noted that the discussion around mining automation and to a lesser extent, automation and mine controllers, increased in both academic literature and industry-relevant journals. In a 2017 AusIMM business case (Price, 2017) on the cost-benefit analysis of implementing an autonomous haulage system, noted that a 'team of control room operators' are a 'key component' of the implementation of this technology (Price, 2017, p. 11). The report indicates that the benefits of implementation outweigh the associated costs and 'there is the potential for operational issues during the transition phase,' (Price, 2017, p. 16). These operational issues are due to technical skills to operate the system being different to operator skills, and an increased 'reliance on higher-skilled staff members.' (Price, 2017, p. 16). The planning and installation costs in the report do cover change management and documentation services, but do not mention the cost (or implementation) of initial and ongoing training for mine controllers and other 'higher-skilled staff members.' (Price, 2017, p. 16). This was one of few articles at the time mentioning the mine controller role, and although it did not analyse the broader topic of HF, the mention of training and technical skill of the controller indicates a turning point in the mining industry's awareness of the importance (and benefits) of further understanding the controller role.

Using observations addressed later in this paper in an attempt to address the gaps that the reviewed research has yet to discuss in depth and to provide an understanding of the role we are presenting within this paper, the author theorises that mine control is (or should be) the central hub of any mine. The mine control room is where the plan for the day is executed against the weekly, monthly, and yearly plans which have been determined by professional mine planners. Among the many tasks allocated to the mine controller, is the responsibility for allocating resources to execute the daily plan as optimally, safely, efficiently, and cost-effectively as possible. The business case for introducing increased technological innovation is aligned to the tasks of the mine controller; to increase production, reduce costs, reduce inefficiencies seen in human input, increase accuracy, and increase safety. What is often not considered is the impact of these technological innovations on the mine controller. The increased complexities of the technologies affect the mental workload and HMI of the mine controller. In addition, the skills, training, and qualifications of the existing mine controllers are often not reviewed and updated at the same rate of technological change, which can result in frustration (as noted by observation and professional experience of the author). These frustrations are not necessarily regarding the technological innovations themselves, but in the lack of human factors considerations when these changes are introduced.

In summary the author postulates that a mine controller is an integral function of an efficient autonomous mining process, possessing advanced mining systems and technical skills and attributes that allow them to manage systems and technology whilst displaying high level execution of softer type social and emotional skills.

2.2. Human and organisational factors in the autonomous control room

Mine controllers (autonomous and manned) are usually amongst the first users on a mine site to encounter introduced technologies at work. They monitor multiple systems and obtain information to run and to forward-plan the running of a mining fleet, optimally using multiple control panels, dashboards, communication with site personnel and other sources of data. Most control rooms are run remotely, whether that be on-site in a sound-proof room with a barrier from the operations on-site, or in another location altogether. The afore mentioned topics require a level of understanding of human factors and training in human factors and whilst there were a lot of articles on HF found for the broader literature search, as with the broader topic of HF in controls rooms, very few studies (if any) have been done, particularly on the HF or psychological safety of introducing automation into mine control. Many psychological and health issues that can occur due to stressors brought about from introducing new technologies with little or no consultation and training can lay dormant or undiagnosed in many instances with the controller not realising the issues are apparent until many years after they have finished their employment. Psychological and psychosomatic factors including stress, burnout and depression and physical health issues including diabetes, cardiovascular disease, and obesity (Juster et al., 2011) contribute to safety issues that relate to work and task design. There are many articles, mostly around the medical, aviation and military fields, that discuss long term health effects of fatigue and shift work, sedentary lifestyles and extended screen time, all present in the current mine controller's role. However, the author failed to find a study combining the effects of shift work with the psychological stressors found within a mine control room, and the outcomes of these on employee health.

The search broadened to include industries outside of mining, and over the years, it was noted that the discussion around the mine control space and mining automation increased in both academic literature and industry-relevant journals. While this increase was noted, there is still very limited literature, specifically on HF in mine control.

Human Factors (HF) and human systems integration (HSI)can be described as 'the scientific discipline concerned with the understanding of interactions among humans and other elements of a system in order to optimise human well-being and overall system performance' (Neumann, 2016, p. 924).

Removing people from a mine site through the introduction of autonomous haulage has unrefuted benefits on increasing safety performance and has been proven quickly and quantifiably in safety statistics across the automation and robotics communities. It is also a goal of HF in systems interaction to 'enhance performance, increase safety and increase user satisfaction' (Wickens et al., 2004, p. 2). However, the workplace stressors and HF issues involved with controlling autonomous equipment have been ill-considered, which can result in the goals and benefits of HF in automation failing.

Table 1 from the Victorian Trades Hall Council (2015) lists psychosocial and HF risks that can occur in all organisations and is included in this paper as many of these are seen commonly in mine control rooms (not all have been noted and some were observed to varying degrees through the study dependant on organisation) but are very rarely seen in an autonomous project risk assessment.

To add to workplace stressors, mine controllers are frequently required to learn new systems as technology is introduced or upgraded, yet workplace training and recruitment strategies are falling behind the rate of their introduction into the mine control domain. Replacing tasks previously done by humans can mean that, if automation fails, humans may not understand how to respond appropriately, or how to complete the task manually. The changes to human tasks can also change human behaviour, how they respond, and their skill requirement.

Many psychological and health issues that can occur due to stressors brought about from introducing new technologies with little or no consultation and training can lay dormant or undiagnosed in many instances with the controller not realising the issues are apparent until many years after they have finished their employment. Psychological and psychosomatic factors including stress, burnout and depression and physical health issues including diabetes, cardiovascular disease and obesity (Juster et al., 2011) contribute to safety issues that relate to work and task design. There are many articles, mostly around the medical, aviation and military fields, that discuss long term health effects of fatigue and shift work, sedentary lifestyles and extended screen time, all present in the current mine controller's role. However, the author failed to find a study combining the effects of shift work with the psychological stressors found within a mine control room, and the outcomes of these on employee health.

Understanding the aspects of work that affect a mine controller role, inclusive of work design, work organisation, work management, work relationship and work environment can provide organisations the insight to develop training strategies for the whole of the organisation that plans for and manages human and organisations factors that can be a risk to employee's health and wellbeing. Through the development of a holistic Human Systems Integration (HSI) framework, employers could not only understand an employee's work role, but also potentially design a HR (Human Resources) strategy from recruitment, training, onboarding, support, and career development, improving productivity outcomes and protecting employee's health.

Table 1
Psychosocial and human factors risks.

Aspects of Work	Examples of Risk
Work Design	• High or low job demand • Low job control • High cognitive demands • High emotional demands • Exposure to occupational violence
Work Organisation	• Poor organisational change management • High-risk work arrangements such as shift work • Job insecurity
Work Management	• Lack of role clarity • Low organisational justice • Low recognition and reward
Work Relationships	• Lack of supervisor or co-worker support • Inequitable or disrespectful workplace culture • Exposure to violence and harassment • Bullying
Work Environment	• Traumatic events • Vicarious trauma • Isolated or remote work

Source: Victorian Trades Hall Council, 2015

3. Results

3.1. Mine control observation results

In situ observations and interviews were the main source of data for the current research, given the lack of focus in the mine control space. The common 'skills of the future' and HF implications for automation revealed from the literature research were utilised to guide the focus of the observations.

Observations of the control rooms showed varying tasks and skillsets from the controllers, as well as different organisational factors across different mines and different companies. An easily identifiable difference from the manned control rooms to autonomous control rooms was an increase in the number of staff. The autonomous control rooms appeared to have more support staff, including technical support and a new controller role, commonly referred to as a builder. This role supports the controller to manage the mine model and take some of the radio calls.

The common tasks assessed for a Mine Controller manned (MCm) to Mine Controller autonomous (MCa) were reviewed concurrently and many of the tasks remained the same for both roles. What was very evident was the Higher Frequency of Tasks (HfoT) (Fig. 2) that were carried in MCa compared with MCm, as well as a heavy reliance on technology to complete tasks. In an autonomous mining pit, the controller is also effectively the operator, using the system to be the eyes and ears of the operation. Some organisations are also using their mine controllers to control both manned and autonomous operations together, adding additional cognitive pressure.

The in-situ observations revealed that the tasks and behaviours most commonly noted from the mine control role and Fig. 2 below was created from these findings and highlights the HF considerations noted in the control room that were relevant to these skills.

This figure highlights the 'most important skills and attributes' employers seek (Prinsley & Baranyai 2015, p.2) and each segment shows the how prevalent each skill or attribute is as used by a controller in their daily tasks. Those skills that have the highest demand are all being used in the control room today, with just over half of the positions surveyed requiring a higher aptitude to change moving into automation due to the higher frequency of certain tasks. You can see 'Programming' is the least used skill or attribute in the controller role, and it was observed that it had little change moving into automation, as this skill was rarely noted in the controller role, whether manned or autonomous. Those skills and attributes used more frequently by the controller had much higher reliance on HF, lending to the hypothesis that this is where the focus should be in reviewing the controller role and improving and closing the skills gap for the future control room worker.

3.2. Practical observation results

Initial findings of the control room observations showed that they seemed to be a place of order and well-defined parameters. It was not until the researcher was placed in the controller role itself that true observation could begin. One such observation was that many controllers (particularly longer-term controllers) seemed to be over-achievers. Throughout the average 12-h shift, many controllers sustained a high-performance output and level of concentration not observed by the author in many other roles in the mining organisations for such a sustained period. Many controllers were so focused on achieving optimum results that they took limited breaks. They rarely talked openly to their colleagues about how they felt or acted in this regard, or the consequences this could be having on them both physically and mentally. In fact, they rarely had time for any personal talk, and it was noted that many employees do not speak up regarding fatigue or other psychological issues. As a result, the controllers are inadvertently absolving their company of any responsibility to change the way the control room functions, and the tasks allocated to them. The interviews conducted explored this observation further.

At on-site control rooms, controllers were often observed being on-shift before mining production employees, and were often the last to leave, going beyond their allocated 12hr shift. It was not uncommon to see a controller not take a break (including a toilet break) for up to 6 h, and sometimes that extended to the entire shift. Several controllers were observed falling asleep at their desks despite being provided with sleep pods. Controllers were not observed leaving for fatigue breaks outside of their lunch/dinner break, even if it was suggested by a colleague. Many controllers ate at their desks and did not receive a break at all. This seemed to improve for those controllers who were employed at one of the

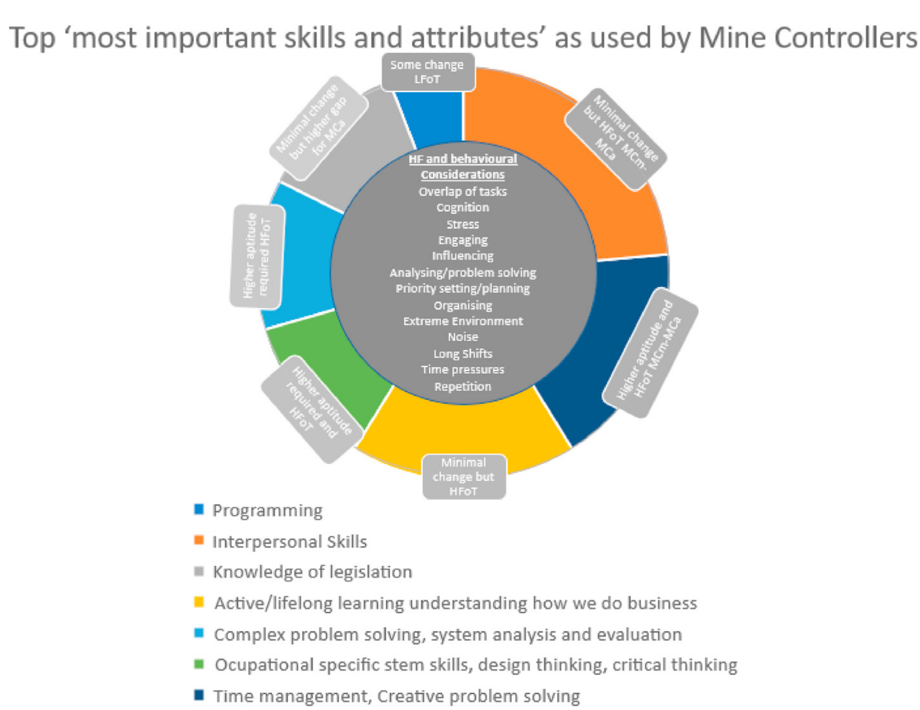

Fig. 2. Controller skills analysis and human factors consideration framework.

country's city-based remote operating centres. Often there was no-one to replace the controller for their break, so they would either not have one, or the other controllers or their supervisor would take on the additional workload for that break period. If the latter occurred, it was noted that, generally, the controller would not take the full break time allowed.

Also observed in all the control rooms was a tendency to overload controllers with tasks not necessarily related to running the fleet and increasing production. The same was noted with the introduction of new technologies, including autonomous haulage, and other less publicised technologies such as decision automation, data collection tools, wearable technologies in the field, tyre monitoring, fuel monitoring, creek level monitoring, weather monitoring and geotechnical monitoring to name a few. It was observed, and again reiterated in the one-on-one informal interviews with the controllers, that they became frustrated with the lack of consultation from engineers and project managers when conducting feasibility studies through to execution of technologies which would ultimately fall to the controllers to be responsible for.

The controllers were observed to receive multiple radio calls per hour, many of which they had to action whilst also monitoring several systems, meeting KPIs (Key performance indicators), responding to alarms and alerts, updating and interpreting data, and corresponding by phone and email regarding production-specific information.

Training observed within the control rooms for the controller role was most prevalent for skills required to operate a specific technology, and that training usually came directly from the system's manufacturer. Other training for the role came from observation and on-the-job training from other employees. Consequently, much of the training was based on the previous employees' knowledge of the tools and the functionalities they had used or understood. Very few of the control rooms observed in the early years of the study had any clear training plan or career progression for the controller role, although it was noted that many companies were starting to create training plans for the role as the company increased its autonomous footprint. Unfortunately, many of these training plans still relied heavily on the system manufacturer for training and was quite limited in teaching other job-ready or behavioural skills.

It was perhaps the observation that the researcher was able to do by first being a part of the system developer team at that system's first autonomous site in Australia, to then coming back 6 years later and being embedded into the same organisation, this time as an autonomous controller, that provided the most insight into the changing role of a controller from manned to autonomous. Initially, the organisation had (for the most part) a well-considered training role for a manned controller compared to other organisations observed, the autonomous role had little material developed and it was unclear how to best separate out some of the tasks traditionally placed on a controller, as the work allocated to the autonomous role was a clear imbalance to that of other roles. The task overload on the autonomous controller role became clearer as more autonomous trucks were introduced into the fleet. Some of those tasks were then distributed to a newly introduced role, known as a builder role. Six years later, although the training on the specific system had changed, little else had changed. The control room had moved from on-site to a remote operating centre in the city which appeared to have removed some of the decision rights and authorisation from the controller. Whilst a city-based role may have meant a lifestyle improvement for many of these controllers, it was noted that many controllers were now commuting over 30 min to and from work for each shift, rather than the few minutes it took to get to the control room from their camp whilst on-site. Access to public transport was difficult for most due to conflicting shift times, forcing most controllers to drive after their 12 h (plus travel time) shift. Access to additional controllers did not appear to be a benefit of the shift to a city-based location, as most shift crews appeared to be understaffed.

The expansion of the autonomous fleet and the combining of the site's manned and autonomous operations meant that the controllers had an increased workload than was observed at the beginning of the research period. The manned fleet required different outputs from the controller than the autonomous fleet, but despite this, the controller was required to manage them simultaneously.

The following was observed for all 4 organisations and all 7 control rooms:

- There were not consistently enough skilled controllers to provide adequate breaks for training or otherwise.
- There was a general lack of understanding across the value chain of the mine controller role, and its importance to automation.
- The controller's role descriptions and task responsibilities were unclear.
- System-specific FMS training for the controllers is not made available to all employees before they begin their role as a controller.
- Companies would often not allow controllers to attend training due to not wanting to lose production time by taking the controller out of their role for extended periods.
- If done at all, training was done at the time of the initial install or system upgrade, and limited to systems knowledge in using the technology itself, and rarely included the other intricacies of the mining controller role as it changed over time.
- Controllers appeared to be frustrated by a lack of training, career development and general lack of engagement regarding decisions that would directly impact their role.
- Psychological safety was ill-considered in the control room.
- Moving to a central city-based control room appeared to have little benefit for the controller role and may have adversely impacted their health due to longer commute times.
- Combining autonomous and manned fleets adds an additional task load on a controller.
- Because of the nature of many of the safety issues in the control room (psychological, sociological and physical) it was observed that issues went unreported, with many employees taking leave days to tackle the issues or simply left the company or position altogether.

3.3. Audit results

Audits of the control rooms were conducted to reveal organisation structures, processes, preparedness for automation, system use, training availability, specific HF health support and human system integration strategies. The audits on the control rooms provided slightly variable results depending on the organisation, size of the operation and the age of the control room operation. The controller role in the longer standing control rooms, particularly those on-site in a manned environment, had quite an ad hoc development. Many tasks given to these controllers were not directly related to running the fleet. Those additional tasks were removed from the Responsibility matrix that was developed to better provide an average across the role. The findings below are from the general tasks seen across all 7 control rooms with some control rooms showing a much higher assignment of tasks to the controller. Additionally, in the manned operation, many of the tasks assigned to the builder in Table 2 were the responsibility of the controller. The other change most predominantly noted from manned to autonomous was workload and task frequency with actions taking place every few minutes, often simultaneously with other tasks.

The tasks required to run a mining fleet system across all operations visited were averaged out to a total of 232 tasks. This table does not include mining equipment operator tasks or in-filed builder tasks.

The table demonstrates that of 232 tasks reviewed relating to control room functions, the controller is responsible, accountable, consulted or informed on just under half at 122 tasks (this does not include tasks specific to the 'coal face' such as operator tasks). The tasks that a controller is responsible for is over double (52) that of the next role's most number of tasks responsible for (17) in a shift.

N.B some of the roles' titles vary from site to site as do tasks and frequency depending on fleet size and number of manned pieces of equipment and autonomous equipment. This RACI was put together from

Table 2
Control task RACI (R) responsible (A)Accountable (C) consulted (I) informed.

	MineController	Builder	MineControlSupervisor	MineControlSuperintendent	MiningProductionSupervisor	MineEngineer	ProductionSchedulingSuperintendent	SchedulingEngineer	MiningProductionSupervisor	MiningProductionSuperintendent	MiningServicesSupervisor
RACI	122	73	23	19	73	17	8	41	73	95	30
RAC	72	45	6	14	57	11	6	26	57	91	20
R	52	13	4	1	17	5	1	10	17	1	11

	MiningServicesSuperintendent	MineProductionAnalyst	BusinessImprovementforControl	MineControlSystemSpecialist	ProcessControlSuperintendent	Geology	Survey	Maintenance	ProductionReporting	IT/OT
RACI	24	12	8	31	26	11	19	26	6	13
RAC	19	8	6	25	26	8	15	16	2	4
R	1	3	2	13	1	2	9	6	2	0

a combination of RACIs from all 7 control rooms.

3.4. Informal interview results

Perhaps the most concerning was a shared sentiment across many of the interviewees was that there is a ‘special mental ward for retired controllers, where you will find them rocking back and forward’. Although meant as a joke, the frequency of such a phrase or sentiment amongst control room operators provides an insight into the psychological effects the role can have on individuals. Another concerning result from the interviews was the physical health concerns reported by many control room operators leaning to surmise that there is much more organisations can do to better integrate their systems with the humans operating them. Examples of health issues revealed from 38 out of 50 controllers interviewed included irritable bowel syndrome, urinary tract infections, migraines, headaches, sleep deprivation, weight gain, tumours and diabetes. Whilst this current study does not provide evidence for a direct link to any of these illnesses to the workplace, it could be presumed that at least in some of the cases delaying bathroom breaks (or not having them), skipping meals or snacking through the day, shift work, multiple screens and work overload could all be contributing factors to a number of these issues.

When questioned on their workload, both manned and autonomous controllers said it was high, but most finished the response remarking that ‘it is just the way it is’ in the control room. Almost all of the controllers agreed that most people in the business do not understand what the controller role is, or the tasks assigned to them, and several commented that it is not until something goes wrong that people want to start talking to the controller. Several controllers that had experience in manned and autonomous operations had assumed that automation would make their work life easier, but the experience was the opposite and their workload, cognitive load and communication responsibilities had increased because of automation and the only training given to the controllers or their supervisors in managing human factors issues was general fatigue management training provided to all employees across each of the organisations. Whilst there were two new roles introduced to directly support a mine controller in automation, (builder and in-field builder), across all control rooms, controllers reported that despite many truck drivers being placed in alternative jobs or leaving their organisation, there was only a significant increase in the resourcing in the control room. Experienced manned controllers often had to wait 2–3 months before receiving any systems training from the OEMs and no controllers interviewed, manned or autonomous received any training on skills or attributes specifically required for the role outside of the fleet management system and autonomous haul system training.

Interviews revealed that many organisations continued to hold on to outdated ways of working, and many of them continued to add tasks to the controller role. An example of this is the insistence of manual reporting. Despite the fleet systems having the ability to capture multitudes of data, all of the controllers interviewed reported that they were required to manually report on what was occurring during their shift and justifications for their actions. This task was largely seen as a task given to the controller with the aim of saving someone else time but increased the workload of the controller. Training on the autonomous systems and controller tasks was not provided to roles outside of the mine control domain and many planners provided mine plans inconsistent to what was required to manage the fleet system effectively.

Many controllers felt that there was a lack of career progression options for them once they had spent some time in the control room, with many controllers commenting that they were upskilling themselves outside of the role to get a new job or promotion in another area. In general, despite the difficulties of the job, the majority of controllers said that they liked their job, but that there were several areas that could be improved.

In summary, there are many human factors considerations required when designing work in the control room and consideration must be given to how HSI is carried out. Results revealed that a general lack of training across the broader business in how to integrate technology systems and the mine controller role as well as a lack of formal training for each of the specific tasks and skills required for the mine control role was apparent across the mining industry irrespective of organisation size or age. Developing a new training approach could provide controllers with recognition from across the value chain equal to the requirements and responsibilities of the role. Having a clear and appropriate work design for the controller role would allow HR practitioners to be trained on the correct selection process for the role with controllers being chosen for existing skills and attributes and/or upskilled to meet further requirements of the role. The broader business would also benefit from some level of training on automation and on how to work with control in a new way. New ways of work could consider a different organisational structure and processes including shift lengths, accountability and decision rights, and consideration and consultation of the role before implementation stage of any technology project.

4. Discussion and outcomes

This research was initially begun to review the HF issues in an autonomous mine control room, however, industry interest presented to the author whilst developing the research led the researcher to focus on how to close the perceived skills gap in mining automation, specifically in the control room. What was found in the research was that the controllers were already closing or gaining the skills required to move toward autonomous mining through a combination of existing skills or attributes, systems manufacturer training and on-the job peer training. The literature review, observations, interviews and audits revealed that the perceived skills gaps stemmed from the broader business not being intune with the skills requirements in the control room or how they are currently being applied. To this effect, the mine controllers have received little attention when organisations are planning for technologies, including automation. Scarcely any formal training past that of a technical nature was made available to controllers and it was not until the end of this current research has there been nationally recognised training for control room operations that meets the Australian Quality Framework (AQF) standards.

4.1. Organisational issues

There were major gaps in the understanding of the mine controller role as well as the organisational factors related to that role. Many of the reported skills required for the future of the role were already being applied by controllers, but the development of these skills was haphazard and unstructured. Whilst many controllers appeared to have the behavioural traits required for the role prior to employment, it could benefit the industry to understand what those traits are and if they could be teachable.

It can be presumed by the results demonstrating that none of the organisations seemed to have enough controllers to provide adequate breaks or relief for sick leave or holiday leave that there were turnover issues in the control room and finding adequately available skilled controllers may have been an issue also lending industry to announce a skills gap leading into automation. Some of these gaps could be closed through a change in organisational factors and a new training approach, focused on the integration of systems and HF within the control room. With this approach, organisations may truly be able to optimise the integration between human and machine.

Whilst automation does not necessarily replace human intervention, it changes the activity surrounding it and how we interact with it. This change in human actions can cause results not anticipated in the engineering phase of a project (Parasuraman & Manzey, 2010). Also rarely considered when implementing new autonomous systems is how those systems could be integrated differently. For example, many mine control rooms for larger organisations have been moved to remote operating centres in cities. The control rooms are set up similarly to the way they are set up on-site. Roles, functions, procedures, and hours of work have not changed much considering the increase in technological change across the past decade. Mine sites are also generally adapted or changed to suit the technology rather than included in the planning stage. With automation, the entire way we mine, including the roles and procedures around that, could be done differently. Automation provides us with an opportunity to benefit the organisation as well as the personnel it employs. Air traffic control, space and defence are examples of industries that are changing their control rooms and process with the help of automation and other technologies.

By focusing on the mine controller role, a mining company can recognise and enhance the fully integrated view of their value chain to optimise performance. The mine controller, forming part of a remote operations centre staff was described by Roy Hill's general manager Mike Lomman as a role which is ‘encouraged’ to ‘take a system view’ of the organisation when making decisions, ‘taking into account interdependencies … between people, process, technology, data and equipment and all of those sorts of things,’ (Crozier, 2018, p1). This systems view can often highlight where inefficiencies may be hidden across the value chain, and where possible, optimisation possibilities may occur. Inefficiencies that emerge often come from a lack of training or poor job fit and are frequently hidden by humans overriding poor decisions made by poor data or incorrect system set-up and use. The oversight of focusing on developing systems and skills shortages in engineering and specialist technicians, and not on controllers who monitor the control room on a 24-h basis with a high task demand load could be costing businesses more than they understand. The difference between high calibre and low calibre controllers can underpin the success or failure of a FMS and remote operations centres or site control rooms. The challenge in finding employees with the skills needed to develop and run automated sites highlights why it is important to conduct a job task analysis to break down what truly makes a “good” controller and the skills required for that role. This should then be couple with robust procedures and processes, the mine controller can truly optimise both the system and the output.

4.2. Human factors

Implementing new systems successfully into a business requires consideration of the interactions that humans have with these systems. The HMI has been a requirement of the mine controllers' role since the introduction of FMS (if not before) and is particularly important in receiving the benefits of automation. However, it is important those benefits are not lost through the degradation of a controller's efficiency due to the results of poor integration of HF/HSI.

Further research also needs to identify not just what the risks are to people who remain on-site, but also to the controller(s) themselves. HF in mine control was observed to include the health effects of shift work, fatigue, stress, HMI and trust in the system, cognitive tasks, vigilance and task load, teamwork, and communication, multitasking and alarm management. Operating, monitoring, and/or maintaining multiple automated and semi-automated technical systems potentially exposes the controller to long term health concerns (Sauer Nickel & Wastell 2012) and anecdotal evidence through the observations and interviews supports this finding.

As such, centralising the operator of the autonomous systems is integral, and Fig. 3 below demonstrates the systems development lifecycle model and suggests a common continuous improvement approach concentrating on the human element within the control room.

4.3. Implications for industry

What was surprising through this research was that despite a 2018 poll of 80 specialists from a cross-section of mining organisations showing that, moving into I4.0, the mining industry would be facing a

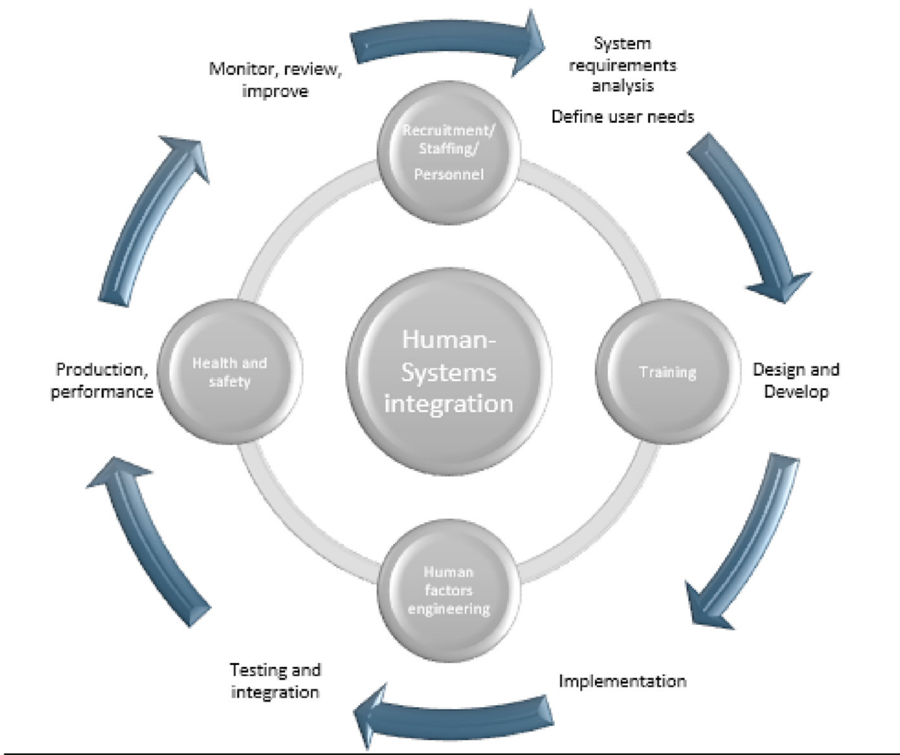

Fig. 3. Human-systems Integrated Lifecycle approach.

skills shortage (Heather, 2018), there is still a lack of focus on the mine controller role. A role, it has been revealed, that is central to the operations and production outcome of autonomous mining.

Findings indicate that controllers now, and in the future, will require a mixture of hard and soft skills. It is the range of core skills and attributes of the controller role, and the reliance on the role for productivity and safety outcomes, that call for a stronger focus on the controller role. The changes to the role and the availability of trained resources will call for an upgraded selection process and a well-designed training program to close any gaps in performance and understanding.

4.4. Training approach

It is suggested by this current paper that a mine controller should be one of the top-performing employees with many production reliant responsibilities, however, recruiters may have difficulty finding skilled workers who have the technical and cognitive skills as well as previous mining experience, or at least an understanding of the mining environment as the industry moves away from the mine site and into remote operating centres. From interviews for this current research with current senior mine controllers and mine control supervisors, it is apparent that previous mining experience, or an understanding of the processes, helps to familiarise a mine controller with the role. This mining familiarity or 'how we do business' (Prinsley & Baranyai 2015, p.2) was noted as the 6th most important skill in the 2015 report for the Australian Government Department of Industry, Sciences Energy and Resources, and supports the training approach of on-the-job learning. Most of the training for tasks, aside from system-specific training, which is predominantly provided by OEMs, is shown to come from peer-to-peer, on-the-job training, or from lifelong learning. It is revealed that even for system-specific skills, there is a heavy reliance in most control rooms for systems training to come from peers.

The lack of adequately trained controllers, other behavioural attributes and skills learnt through life or on the job, the fast pace of changes in technological evolution and the controller role itself, require the immediate application of skills that can't be provided through a traditional four-year engineering degree, despite such a degree being deemed as robust enough to provide the conceptual and practical knowledge. Whilst continuous on-the-job learning will remain an effective way to pass on organisation-specific knowledge, a shorter Vocational education training curriculum could provide learners with a method to update specific skills required to meet the demand in I4.0 jobs while still allowing the controllers to benefit from the experience that comes with on-the-job learning and tacit practical skills that could be lost if the industry focuses only on technical skills.

In summary, a new approach is required to provide the experienced personnel a platform to pass on their existing knowledge and provide a formalised on-the-job training method blended with theoretical and conceptual knowledge that shorter AQF training courses can provide.

5. Conclusion

Through reviewing the literature, interviews, audits and in-situ observations, key skill requirements for mining automation jobs of the future must include extensive technical and system interface skills alongside tacit and emotionally astute skills. It has also been revealed that despite the rising use of technology and automation, there is an extensive HF element to the role of the controller. Understanding how a controller applies the skills required with the HF conditions imposed in their job role is paramount to ensuring the best production performance with the lowest safety risk, without also risking the health of the controller. Developing effective HMI and alarms, improving operator training, and optimising organisational factors are all recommended as key items to help achieve better integration of operators and technologies.

This paper has shown that the role of the mine controller has been overlooked in the past and organisations have come across several barriers to implementing effective training packages, which can include:

- Limited external training opportunities with OEMs offering training on their system.
- OEM training is specific to their system and is costly.

- No current external wholistic training package whereby a controller can train on the system whilst getting taught other necessary skills.
- On the-job-training is limited to general company induction training and peer-to-peer, limiting the trainee to being trained by someone else who has also been through an inadequate training process.
- Production pressures and time constraints usually limit the quality of on-the-job training being delivered, and a reluctance to release the controller to send them away from the position to receive training in a non-production critical environment.
- Current on-the-job training teaches process, not soft skills.

In understanding through the research that mining companies are forging ahead with automation and increasing their innovation interest, it is evident that a workforce skilled in operating and managing the new technologies will be required. If the research is correct, then as an industry, we need to start focusing on controllers (Jamasmie 2016, p.1), and in doing so, to recognise the importance of mine controllers, the effects that the introduction of innovation has on controllers, and how that effect can be pre-empted and capitalised on through training, education, and recruitment.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due to the confidential nature of the businesses and expression from participants to remain anonymous Data contains information that could compromise research participant privacy/consent but derived data supporting the findings of this study is available from the corresponding author upon reasonable request.

Ernst & Young, Australia, (EY) 2019 'The Future of Work: The Changing Skills Landscape for Miners', A report for the Minerals Council of Australia, Data Set Fig. 2. <https://minerals.org.au/sites/default/files/190214%20The%20Future%20of%20Work%20the%20Changing%20Skills%20Landscape%20for%20Miners.pdf>.

Declaration of competing interest

The author declares that they have no competing interests however, at the time of writing, the author was employed at the control rooms observed.

Funding

"Not applicable".

Authors' contributions

PC was the sole author and researcher for this manuscript.

Acknowledgements

I would like to thank my study supervisors, Erich Fein, USQ and Steven Goh, USQ for their support whilst researching and writing this paper.

Additionally, I would like to thank copy editor, Rosemary Mulray for her advice and expertise in editing and structuring my paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chbr.2021.100115.

List of abbreviations

AHS	Autonomous Haulage System
AQF	Australian Quality Framework
FMS	Fleet management system
HF	Human Factors
HFoT	Higher Frequency of Tasks
HMI	Human Machine Interface
HR	Human Resources
HSI	Human Systems Integration
I4.0	Industry 4.0
KPI	Key Performance Indicator
LFoT	Lower Frequency of Tasks
MCa	Mine Control autonomous
MCm	Mine Control manned
OEM	Original Equipment Manufacturer
RACI	Responsible, Accountable, Consulted, Informed

References

Ballantyne, R. (2010). *'Mine Control: Why do we do it, and how do we achieve sustainable success?', 7th large open pit mining conference*. Perth WA, 27 – 28th July.
Crozier, R. (2018). *Roy Hill shows interior of its remote ops centre*. IT News, Feb 9 2018, viewed 7 September 2020 https://www.itnews.com.au/news/roy-hill-shows-interior-of-its-remote-ops-centre-484841.
Ernst & Young (EY), Australia. (2019). *'The future of work: The changing skills Landscape for Miners', A report for the Minerals Council of Australia*. https://minerals.org.au/sites/default/files/190214%20The%20Future%20of%20Work%20the%20Changing%20Skills%20Landscape%20for%20Miners.pdf.
Heather, S.31A. (2018). *'Data shows mining's skills shortage is biting and industry is to blame', mining people international*. https://www.miningpeople.com.au/news/Data-shows-minings-skills-shortage-is-biting-and-industry-is-to-blame.
Juster, R. P., Sindi, S., Marin, M. F., Perna, A., Hashemi, A., Pruessner, J., & Lupien, S. (2011). A clinical allostatic load index associated with burnout symptoms and hypocortisolemic profiles in healthy workers. *Psychoneuroendocrinology, 36*, pp797–805. viewed online at www.elsevier.com/loacte/psyneuen www.science.direct.com.
Li, X., McKee, D. J., Horberry, T., & Powell, M. S. (2011). *'The control room operator: The forgotten element in mineral process control', Minerals engineering* (Vol. 23, pp. 894–902). April 2011 www.elsevier.com/locate/mineng.
Neumann, W. (2016). Human factors: Spanning the gap between OM and HRM. *International Journal of Operations & Production Management, 30*(9), 923–950. https://doi.org/10.1108/01443571011075056. viewed online January 2016.
Parasuraman, R., & Manzey, D. (2010). 'Complacency and bias in human use of automation: An attentional integration', *human factors. June, 52*, pp381–410.
Price, R. (2017). *"Autonomous haulage systems – the business case"*. AUSIMM. www.ausimmbulliten> viewed 20/05/2020. (Accessed 5 April 2017).
Prinsley, R., & Baranyan, K. (2015). *'Stem skills in the workforce: What do employers want?' issue 9*. Occasional Paper Series https://bio.mq.edu.au/wp-content/uploads/2015/06/OPS09_02Mar2015_Web.pdf.
Sauer, J., Nickel, P., & Wastell, D. (2012). Designing automation for complex work environments under different levels of stress. *Applied Ergonomics, 44*, 119–127. www.elsevier.com.
Victorian Trades Hall Council. (2015). *Authorised by luke hilakari 'psychosocial hazards' viewed online*. https://www.ohsrep.org.au/psychosocial_hazards.
Wickens, J. L., Liu, Y., & Becker, S. G. (2004). *An introduction to human factors engineering* (2nd ed.). New Jersey: Pearson.