Human Interaction and Emerging Technologies (IHIET 2022), Vol. 68, 2022, 526–534
https://doi.org/10.54941/ahfe1002773

Understanding Challenges of Integrating Automation Solutions for Underground Mining in a Sociotechnical System: A Qualitative Interview Study

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ABSTRACT

In recent years there has been more development of automation solutions for underground mining operations. Various vendors usually provide their proprietary machines and remote operation stations (ROS) to their customers, which makes information for remote supervisory control increasingly distributed and scattered for the operators. Integrating existing automation solutions such as introducing unified ROS could be considered potentially beneficial to ameliorate the problem of information fragmentation, enhance user experience and improve productivity, but it is critical to understand the effect of such future technological solutions in the sociotechnical system where elements of human, technologies and organization interact with each other. Integrating automation solutions is essentially bringing changes to the work system which would potentially pose new demands on the human operators and existing rules. This paper aims to uncover the challenges that may emerge in the sociotechnical system of remote underground mining as well as their design implications. A field study to a modern underground mining site in Sweden was conducted to explore the user perspectives of a diverse range of the workers who are designated different tasks per current organizational structure and goals. During the field study, eight participants including six remote control operators and two management personnel were invited for in-depth individual interviews. Additionally, two of them and another five operators were invited for a focus group interview. The participants were asked about their experiences of remote control operations and their interaction with the existing systems, together with their perceptions and views on how a unified remote operation station can affect their daily practice. The qualitative data were analyzed using thematic analysis. The findings have revealed a range of inter-connected challenges for the realization of the unified ROS, covering cognitive, organizational, physical, technical and interface design aspects. They suggest that whether the operators can continue succeeding in remote supervisory control does not only rely on the capabilities of the futuristic notion of unified ROS, but also on how the human-technology interaction relationship unfolds in the new working context. These insights inform the value of a holistic systems approach when it comes to feasibility studies on new technologies and their impact on human users. To address the concerns of the operators and ensure improved user experience and safety, it is important that the design of the systems is aligned with reorganization endeavors. Besides, collaborative efforts among industrial vendors are considered necessary to ultimately benefit the users.

Keywords: Challenge, Integration automation, Unified, Cognition, Organization, Mining, Sociotechnical systems, Interface design

INTRODUCTION

Underground mining is a complex and sophisticated process where various machines, personal, safety and technical infrastructure coordinately cooperate to extract ore that is refined to valuable and desirable concentrated minerals. During recent years automated solutions have been increasingly used to improve productivity and efficiency. Sophisticated and various semi-automated machines are used for procedures like hole drilling, corridor reinforcement, rock fragmentation and transportation. To stay competitive and have flexibility to use the latest services and products, the mining company use proprietary machines and Remote Operation Stations (ROS) from different vendors. Currently the different remote-control solutions are not integrated which makes information for remote supervisory control increasingly distributed and scattered for the operators. Integrating existing automation solutions such as introducing a concept of unified ROS could be considered potentially beneficial to ameliorate the problem of information fragmentation, enhance user experience and improve productivity. This paper uses the sociotechnical perspective to reveal the multidisciplinary interrelations and implications for unified remote supervisory control, where emerging challenges and demands can be seen on individual, organizational, technical and design level.

RELATED WORK

Integration may sound as a very straightforward solution for distributed automation solutions, but the reverberations of technological change can propagate throughout the entire system and cause other changes, e.g., redefining relationship between actors, transforming practicing and roles, influencing operational requirements (Dekker & Nyce, 2004; Woods & Dekker, 2000). In order to steer design into the direction of supporting safe and efficient supervisory control operations, it is critical to understand the whole system as a socio-technical system where there are complex interactions between humans, technology, context of the work system (e.g., environmental or organizational aspects) (Baxter & Sommerville, 2010), and explore relevant diverse challenges from different dimensions. This would allow a system approach to be used to address the dynamic and complex relationships and processes that emerge in the human-technology-work interaction.

The sociotechnical system model has been increasingly applied within the field of human factors across domains (Cohen, 2012; Costa, 2016; Harris & Stanton, 2010), because human factors essentially study various elements of the system (such as physical, cognitive, organizational, environmental dimensions) and their interactions (Grech, 2008; Hendrick & Kleiner, 2001; Wilson, 2014). However, only a few studies used the sociotechnical perspective in the domain of mining, investigating social factors or technical factors associated with a certain type of technical system (Mallett, Vaught, & Brnich, 1993; Seccatore & de Theije, 2017). There is also a lack of research that explores human factors related challenges introduced by the integration of technological solutions for underground mining and informs design implications.

METHODS AND PROCEDURES

A field study was conducted in a live mine environment. Data was collected through semi-structured interviews which were held with operators during machine operations. The interviews were complemented by observations of the operators during their daily work routine, as well as guided observations of the machines during operations in the mine. Further data was collected through a workshop held with seven employees with varying roles in the mine, including both machine operators as well as business managers.

The interviews were approximately one hour long and consisted of questions aimed at understanding the operator's working environment, their daily tasks and their attitude toward remote operations and automation. Before beginning the interviews, the operators were asked to read and sign a form of consent, where GPDR information and the intended use of data was specified. The interviews were recorded with audio and video. The operators were seated at their stations during the interviews, which allowed them to show different interactions, screens and hardware corresponding to the questions being asked.

The workshop ran for one hour, and it began with a brief introduction of the researchers and the purpose of the project. The participating operators had roles which included operations of long hole drills, rock loaders, rock crushers, scraping and blasting. The loaders, drillers, and crushers all had some experience of remotely operating their machines. One manager, responsible for mine-automation, was also present during the workshop. The workshop was held by two facilitators with a total of 7 participants. Operators were initially asked to provide their understanding and thoughts on the unified ROS concepts. The operators were then asked to write down their opinions on which requirements need to be met for the unified ROS to become a successful solution. To help operators think about different problem areas, a number of categories that could help the operators consider different areas of importance were listed These categories included "business", "organization", "steering of machines", "security", "process", "technology" and "machines". When the operators had written their thoughts on post-its, the facilitators and participants jointly placed them in a pre-prepared matrix aimed at categorizing the ideas from least to most useful, as well as less and more difficult to develop. The purpose of this exercise was to detect ideas and solutions that would contribute much towards a successful implementation of unified ROS, with as low development effort as possible. The placement of these post-its generated some discussion and when all participants had agreed on the categorizations, the workshop was concluded.

All interview data was first transcribed, then thematic analysis (Clarke, 2006) was used to analyze the transcribed data with the help of a qualitative analysis tool MAXQDA (VERBI, 2021). A preliminary code structure that guides the coding process was developed based on the sociotechnical system model developed by Grech (2008). Emerging categories were also added to the code structure during the coding.

RESULTS

The individual and group interview data revealed several categories of challenges that arise in relation to a future implementation of a unified ROS.

Cognitive Challenges

The first challenge is how the operators cope with switching from one station to another when the workstations are unified. Operators may have errant mental models when they believe that the system is in one mode but it is actually in another (Endsley, 2011). An example is that an operator is switching to vendor A's loader but still thinking that he is controlling vendor B's loader. Some participants commented that this could "*somehow mess with your brain*".

There are also challenges regarding perception when an operator excessively focuses on one machine or some particular situation due to attention tunneling. As a participant mentioned, "*you are so focused on everything so you will miss small details*". The chance of failing to notice key information (e.g., an alarm) from the display would likely increase if there are multiple machines under one operator's supervision. A connected and generally concerned issue is workload and stress, which depend on multiple factors, such as how many machines an operator monitors, the conditions in which these machines are running (e.g., loader operators evaluate the workload by looking at self-driving distance while crusher operators focus on the kind of ore), automation level and the corresponding system reliability etc. Additionally, when automation does not behave as expected, operators may have difficulties to get themselves from out-of-the-loop to in-the-loop. This could mean taking longer time to detect an automation failure (Gouraud, Delorme, & Berberian, 2017). Going back and forth between multiple machines involves switch costs that decrease efficiency and accuracy in all involved tasks (Monsell, 2003) as confirmed by some participants saying that "*it might be difficult to switch attention between tasks*".

Organisational Challenges

Another kind of prominent challenge is from the organizational level where cross-organizational communication and collaboration is essential for unified ROS. The success of the unification concept hinges on how different vendors and customers form their partnership to build a generic workstation together. However, the interview data suggested that the cooperative synergy was not clear at this stage, as vendors are not keen on communication. This is probably mainly due to economic causes, suggested by a management interviewee, that "[the vendors see it as] there's no money in it".

There are other significant challenges in terms of reorganization and its surrounding work effort. The management of the mining company admitted that that right now they have a few silos but with unified ROS, they "*would have a bigger group…a mixed department*". The challenge here is more than just structural change such as merging divisions, but there should be some considerations including, but not limited to, changes on roles, rules, teamwork, communication, responsibilities and training. In the context of unified

ROS, the operators would no longer work as drilling/loader/crusher operators but as a sort of universal operator. To accommodate the role change, rules and safety regulations need to be established to clearly specify new roles, task requirements, communication protocols, work procedures, and so on. A critical part of the rule change shall deal with how the operators are going to communicate and collaborate with each other and other workers in the mine in the unified ROS context and what their boundaries of responsibility are. This part was emphasized much during the focus group. The operators mentioned a lot about teamwork and potential risks to operational efficiency. The operators expressed that they would often go to the mines to fix various things. When they are away from the remote workstations, other operators could help to monitor the machines for them. It works rather well in today's context, but this "covering-each-other-up" type of teamwork might not fit for the unified ROS context in which each operator is required to have full attention on multiple machines. An operator's opinion is quite representative - *"someone may ask you to drive another machine and you may end up getting many… I am supposed to do five different things and if I have to go for one of them, of course everything else is at risk. That's the main issue."*. New ways of reallocating resources need to be developed.

In addition to the concerns regarding operational efficiency, the interviews have also identified operators' slightly negative sentiment on training and job security, e.g., some mentioned that learning to drive new machines could be an issue for older operators. There is also a challenge to adapt the exiting training programs because new ways of working and Human Machine Interfaces (HMIs) would likely be introduced to unified ROS. A few others suggested that they were concerned with losing their jobs, which may pose further challenges on internal support.

Physical Challenges

A relevant challenge related to forementioned responsibility and operational efficiency is the distributed work nature in the underground mining operations, which has been observed and mentioned much during the interviews and focus group. Moving between the mines and control room becomes the daily routine for all operators. They have to inspect the machines onsite before or after use and fix certain things. The nature of having distributed workplaces (mine and control room) would likely have a negative impact on the productivity of unified ROS, suggested by some comments from the operators - *"the whole idea falls apart if you need to go around the whole time"*. In addition, there is also feedback regarding physical fatigue and tiredness when it comes to control devices. Some operators said that a certain vendor's joystick causes fatigue in the wrists because they have to hold the joystick with their palms all day.

Technical and Human-Machine-Interface (HMI) Challenges

The data have identified several technical challenges that would emerge if integration of multiple automation solutions from different vendors is desired, e.g., interoperability and maintenance. Standardization provides a common set of expectations that enable interoperability between systems and/or devices, but how the vendors and customer achieve such standards, what their roles and responsibilities are, how the maintenance work should be done – these aspects are highly related to organizational challenges, and they remained to be discussed.

Additionally, technological readiness is a key success factor for unified ROS, e.g., automation level, system robustness and reliability. The levels of automation in each part of the tasks could directly affect how operators perform the tasks and how stressed they could become. The operators perceived that the more reliable and robust the technical systems are, the more efficient remote operations would become.

The success of unified ROS also depends on well-functioning unified HMIs that can help the operators to efficiently get into the loop and confirm that the machine is doing what it is supposed to do. Many operators expressed the importance of having an overview of the status of different types of machines under supervision and a detailed view when controlling a specific machine. It is a great challenge to structure, organize and balance the elements of views, given that there will be a mixture of the processes and multiple types of machines to be supervised. HMIs should also consider how to support the task reallocation in a more organized and trackable manner for safe and efficient operations. Last but not the least, having the operators use different controls for different types of machines is unlikely the ideal solution for unified ROS. It is not clear how much of the existing interfaces (joysticks, buttons, etc.) from the current workstations should remain in an integrated solution of unified ROS. Each vendor has their own logic and language of design, corresponding to different functionalities and intended use cases. "Cherry-picking" control functions from different workstations may bring most benefit to the operators, but it is certainly a design challenge on the representational layer.

DISCUSSION

The identified challenges concern operator cognition, organization, physical challenges, technical challenges, and specific challenges regarding HMI design. The analysis of our data indicated that these challenges are interconnected to varying degrees, meaning that solving them in isolation would not provide an optimal outcome. To better understand these challenges, several hypothetical scenarios were created to describe possible situations in the context of unified ROS as each scenario embodies a distinct set of challenges. This would not only strengthen the discussion but also help to inform some design implications.

Scenario one describes a situation where an operator needs to supervise several different machines at the same time. This will create a need to navigate quickly between different views, while staying in-the-loop for several different machine processes at once. The HMI must be designed to facilitate quick switching of attention, while displaying relevant information without cognitively overloading the operator. Scenario two describes a situation where the operator needs to manually take control of a vehicle that has previously been operated by automation. This change of control can be initiated by either the system, or by another operator, where the interface needs to indicate where the request came from and what the context of the request is. Technical challenges in the scenario include mapping of the machine controls, where controls differ a lot between machines. Creating universal controls, or alternatively being able to dynamically remap the controls for the various machines being controlled, would help improve efficiency while simultaneously making for a better user experience. Scenario three describes a situation where responsibility for machines needs to be divided dynamically between operators. Given that situations arise where operators need to solve issues on site (and therefore leave their control station), there needs to be a way for quick and dynamic switching of responsibility for machines. This creates a need for new ways of communicating, along with changed team compositions and responsibilities.

While each scenario identifies a specific set of challenges, they are interconnected, meaning that solving one of these challenges is likely to affect the requirements needed to solve the other challenges. As an example, we may try to increase automation in order reduce the workload of the operator, thereby making manual intervention less frequent and reducing the frequency of task switches. However, increasing automation will mean that monitoring behavior increases, potentially causing issues such as complacency and skill degradation (Bainbridge, 1983). It also requires that digital infrastructure becomes stronger, given that communication between machines and operators becomes increasingly important when operations are automated and supervised remotely. The competence of the operator will also need to shift, where being able to drive several types of machines means that new training procedures must be created. Interpersonal communication will also play a different role in this new context, where the system will need to afford close collaboration between operators to facilitate efficient handling of machines.

The traditional response to these situations usually entails the introduction of new systems and technology to the workplace, to help support new requirements and organizational changes. As an example, more screens can be added to help the operator get a better overview of the current machines and views. New cameras can be installed on the machine, to allow the operator to better see the current context and environment. New software can be installed to help operators communicate efficiently. These solutions are most likely effective and well thought-through as isolated solutions. They may also have been developed together with customers and had rigorous usability testing. However, the constant introduction of isolated technical solutions may cause the whole sociotechnical system "drift into failure" (Dekker & Nyce, 2004), where the system slowly deteriorates due to consequent patching of problems that arise, rather than addressing the connected issues with a holistic systems approach.

In order to create human-centric solutions, the technological solutions need to be designed with the context in which technological subsystems, personnel subsystems and relevant external environments are taken into account (Hendrick & Kleiner, 2001). The holistic approach to the implementation of novel technology would allow contributing towards the goal of creating sustainable and user-friendly socio-technical ecosystems in organizations. It is also one step towards improving ecosystems across organizations, such as facilitating the development of a collaborative synergy among various vendors. While cooperation between competing vendors may not yield direct profitable economic results, it is likely to increase customer satisfaction, safety and efficiency in the long run.

CONCLUSIONS AND FUTURE RESEARCH

This paper has provided an in-depth understanding of the potential challenges to integrating automation solutions for underground mining in a sociotechnical system. Integrating technological solutions is essentially bringing changes to the work system which would potentially pose new demands on the human operators, operational context and organizations. The findings suggest that whether the operators can continue succeeding in remote supervisory control does not only rely on the capabilities of the futuristic notion of unified ROS, but also on how the human-technology interaction relationship unfolds in its new working context. These insights inform the value of a holistic systems approach when it comes to feasibility studies on new technologies and their impact on human users. To address the concerns of the operators and to ensure improved user experience and safety, it is important that the design of the systems is aligned with reorganization endeavors. Besides, collaborative efforts among industrial vendors are considered necessary to ultimately benefit the users.

The conducted research indicates a strong need for closer collaboration between involved machine vendors and customers to open technical infrastructures and thereby enable automation solutions to be integrated. Further research is needed to understand additional perspectives, opinions, challenges, or incentives the vendors may encounter if they choose to pursue the customer's expressed desires of creating a unified ROS. This will provide a broader and deeper understanding regarding the additional socio-technical systems existing on the vendor's side.

Several described socio-technical aspects and their inter-connections became apparent in our research, but an assessment of the necessity or urgency for resolving any of the aspects and their inter-interconnections has not been performed. It would be beneficial to further research and identify the outcomes and potential benefits of these aspects in order to assist the involved stakeholders in understanding what must be resolved initially, and which aspects should be down prioritized and looked at further in time.

To strengthen the ecological validity additional mines should be researched to cover the variety between organizational, technical, and operational setups across the different underground mines. It is also wise to research in various locations since the environmental, technical, and cultural differences might reveal yet undiscovered insights.

REFERENCES

Bainbridge, L. (1983). Ironies of automation. Automatica, 19(6), 775–779. doi: 10.1016/0005-1098(83)90046-8

Baxter, G., & Sommerville, I. (2010). Socio-technical systems: From design methods to systems engineering. Interacting with Computers, 23(1), 4–17. doi: 10.1016/j.intcom.2010.07.003

Clarke, V. (2006). Using thematic analysis in psychology AU - Braun, Virginia. Qualitative Research in Psychology, 3(2), 77–101. doi: 10.1191/1478088706qp063oa

Cohen, M. J. (2012). The future of automobile society: a socio-technical transitions perspective. Technology Analysis & Strategic Management, 24(4), 377–390. doi: 10.1080/09537325.2012.663962

Costa, N. (2016). Human Centred Design for Maritime Safety: A User Perspective on the Benefits and Success Factors of User Participation in the Design of Ships and Ship Systems. (Licentiate). Chalmers University of Technology, Gothenburg. (16:162)

Dekker, S., & Nyce, J. (2004). How can ergonomics influence design? Moving from research findings to future systems. Ergonomics, 47(15), 1624–1639. doi: 10.1080/00140130412331290853

Endsley, M. R. (2011). Designing for Situation Awareness: An Approach to User-Centered Design, Second Edition: CRC Press, Inc.

Gouraud, J., Delorme, A., & Berberian, B. (2017). Autopilot, Mind Wandering, and the Out of the Loop Performance Problem. Frontiers in neuro science, 11, 541–541. doi: 10.3389/fnins.2017.00541

Grech, M. R. (2008). Human factors in the maritime domain/Michelle Rita Grech, Tim John Horberry, Thomas Koester. Boca Raton, Fla: CRC Press.

Harris, D., & Stanton, N. A. (2010). Aviation as a system of systems: Preface to the special issue of human factors in aviation. Ergonomics, 53(2), 145–148. doi: 10.1080/00140130903521587

Hendrick, H. W., & Kleiner, B. M. (2001). Macroergonomics: An introduction to work system design: Human Factors and Ergonomics Society.

Mallett, L., Vaught, C., & Brnich, M. J. (1993). Sociotechnical communication in an underground mine fire: a study of warning messages during an emergency evacuation. Safety Science, 16(5), 709–728. doi: https://doi.org/10.1016/0925-7535(93)90032-9

Monsell, S. (2003). Task switching. Trends in cognitive sciences, 7(3), 134–140.

Seccatore, J., & de Theije, M. (2017). Socio-technical study of small-scale gold mining in Suriname. Journal of Cleaner Production, 144, 107–119. doi: https://doi.org/10.1016/j.jclepro.2016.12.119

VERBI. (2021). MAXQDA 2022. Berlin, Germany: VERBI Software. Retrieved from maxqda.com

Wilson, J. R. (2014). Fundamentals of systems ergonomics/human factors. Applied Ergonomics, 45(1), 5–13. doi: http://dx.doi.org/10.1016/j.apergo.2013.03.021

Woods, D., & Dekker, S. (2000). Anticipating the effects of technological change: A new era of dynamics for human factors. Theoretical Issues in Ergonomics Science, 1(3), 272–282. doi: 10.1080/14639220110037452