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The Designers' Perspective on Autonomous Mining Systems and Sociotechnology

Erik Lund[1] · Jan Johansson[1] · Joel Lööw[1]

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Abstract
Digitalization and automation technology offer new possibilities to increase productivity and obtain higher levels of autonomy in mining operations. Introducing autonomous systems into mining is not only a technical problem in terms of effectiveness and efficiency, nor a problem of safety in human-automation interactions. The systems also need to be designed and developed so that they foster healthy and attractive working environments. The design and development phase of new mining technology has not been extensively studied previously. To fill this knowledge gap, we investigated technology developers' basic assumptions about humans and their interactions with the technology they develop. We conducted five semi-structured workshops within an EU funded project concerned with developing digitalization and automation solutions for the mining industry. The data suggests that many critical functions will still be under human control in future mining systems. The results also indicate increased complexity in the interaction between autonomous systems and humans as the technology becomes more advanced. As a result, we suggest that a human perspective, based on sociotechnical principles, should not only be considered in implementing the technology at mines but also in the early conceptual phases of developing and designing the technology. This will ensure healthy and attractive work environments in the future mining industry.

Keywords Ergonomics · Mining · Digitalization · Human-automation interactions · Work-environment

1 Introduction

The mining industry is facing a great technological shift that must be managed wisely in order to foster healthy and attractive work environments. This technological shift is described by the concept *Industrie 4.0* [1] and by *Mining 4.0* [2, 3] in the context of mining. Digitalization is at the core of this shift, including technologies such as cyber-physical systems and artificial intelligence that are now being introduced into mining contexts. The essential aspect of this technological shift is that artefacts and systems are now starting to have the power to act on their own; in other words, they are becoming autonomous. The potential impact of these systems on work environments is not well known and has not been widely studied within mining contexts. Overall, digitalization and autonomous technology offer great possibilities for the mining industry in terms of increased efficiency, productivity, and safety, but they also entail daunting challenges in trying to ensure healthy and productive interactions between technology and humans in their often-challenging environment.

This paper uses sociotechnical systems theory to investigate how these new autonomous systems may affect the quality of working life. Sociotechnical design originated in Trist and Bamforth's study of the social and psychological consequences of the longwall method published in 1951 [4]. The approach is closely related to action research, the intention of which is to either change the work situation for the better or change it inadvertently because the research has taken place [5].

A sociotechnical system is *'the synergistic combination of humans, machines, environments, work activities and*

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✉ Erik Lund
erik.lund@ltu.se

Jan Johansson
jan.johansson@ltu.se

Joel Lööw
joel.loow@ltu.se

[1] Department of Social Sciences, Technology and Arts, Luleå University of Technology, Universitetsområdet, Porsön, Luleå 971 87, Norrbotten, Sweden

organizational structures and processes that comprise a given enterprise' [6, p. 550]. The sociotechnical system consists of two inter-related sub-systems. The first is the social system, which includes individuals, teams, coordination, control, and management, and the second is the technological system, including things like equipment, machines, tools, and the work organization [6]. The entire work system is 'created' through the interaction between the social and the technical systems [7]. There are three central tenets to the sociotechnical systems theory. The first is that all systems that have a mix of humans and technology are in fact sociotechnical systems. The second tenet is that these sociotechnical systems can function well or poorly depending on how they are designed. The third tenet is that these sociotechnical systems can be optimized.

Optimization of sociotechnical systems can be illustrated using an example based on Trist and Bamforth's [4] study from 1951, which explored how the longwall method changed many of the social structures for the workers in mines. The preceding 'hand got' method consisted of several small groups located at the mine face, each group with internal leadership in the group, often with strong social bounds between the members of the groups. They also gained experience of the entire cycle of the mining operation. The longwall method that subsequently replaced the hand-got system was built around large teams consisting of 40–50 men working in three shifts. Their work tasks were specific, thus nobody had visibility of the entire mining operation. The workers were spread out over longer distances, and large areas were covered during each shift. Due to this, it was more difficult to maintain contact between colleagues. The longwall method changed the work organization so that it started to resemble industrial, mass-production factory organizations, and productivity consequently decreased. These observations lead to the formation of the sociotechnical theory. There are several sociotechnical principles, see Cherns [8], aimed at optimizing sociotechnical systems.

One of the central assumptions of sociotechnical systems theory is that the social and the technological systems are symbiotic, such that it is only when both are given equal weight that the entire sociotechnical system performs well [5]. Giving each an equal amount of weight entails both of these sub-systems being optimized [9]. The mining industry has typically been more successful in optimizing the technological sub-system compared to the social sub-system. For instance, the mining industry struggles to attract and retain new generations of miners [10, 11] and women [12], and this is one consequence of failing to optimize the social system. It has also been pointed out that in many cases, the mining industry has (unsuccessfully) tried to solve many of its social issues with the help of technology [9]. While introducing new technology does have an effect on social factors, it is not the optimal way to solve issues such as the low level of attractiveness and not retaining new generations of miners. The physical work environment is not identical to the social work environment.

A single focus on the technological system, in the hope that an optimized technological will system also improve the social system, is similar to what Parasuraman [13] refers to as the default strategy to automation, which is simply to automate as much as possible. This often leads to substandard work environments or an arbitrary set of work tasks that the designer does not know how to automate [14] or tasks which are too expensive or too complicated to automate [13]. An optimized social sub-system consists of good and healthy working conditions in which the personnel are highly motivated [15] to work and keep working [7]. This is consistent with the definition of 'attractive work' as work that people *like having* and *want to have* [16]. An attractive work system consists of healthy and safe work environments that take into account both physical and psycho-social factors.

Attractive work systems should be an objective of ergonomics [7]. By *ergonomics*, we mean an applied science concerned with the understanding and design of the interaction between humans and technology, such that human physical and mental well-being, safety, and overall system performance is optimized. An ergonomics perspective emphasizes that technology should be designed and developed to suit the human, with the aim to improve the health, safety, and well-being of all users as well as to improve the overall work performance, including both the quantity and quality of performance [17]. The task of ergonomics has much in common with the optimization of the sociotechnical system, in particular concerning the social system, but not exclusively. Ergonomics is also concerned with the overall system performance. Human-centred design has been suggested as a viable approach to designing new technological systems in mining operations [18]. Human-centred design includes human-related design requirements for all end users, their tasks, and the environmental context in which the task is performed in the development and throughout the design process.

In recent years, ergonomics has received attention in the debate regarding digitalization of industrial activities in general. Concepts such as *Industry 5.0*, focused on a human-centric approach to technological advancements, have gained traction in such discussions [19]. These debates have highlighted the importance of considering the human perspective when designing and developing technological systems, and mining is no different. A non-optimized social sub-system might lead to bad, unhealthy, and unattractive work environments in mining. According to the sociotechnical systems theory, if the social sub-system is not optimized, the entire work system will function poorly.

The sociotechnical systems theory builds on general systems theory [20]. A review of systems theory is beyond the scope of this paper (interested readers are recommended Mele et al. [21] for a review of general systems theory and Ropohl [20] for a detailed account of sociotechnical systems theory). Nevertheless, some of the key features necessary for clarity are outlined here. A system is an entity that includes a set of elements and their relationships [20]. These relationships transform input into output depending on specific internal states (including goals), known as *functions*, in a hierarchical structure. Each sub-system might also be divided into several sub-subsystems. The work system, including both the technological and the social system, should therefore be viewed as one system, with extensive interactions between its actors. In this paper, we only focus on interactions between the technological system and the social system, yet human-to-human and machine-to-machine interactions are also important for overall optimization.

Few studies have focused on the designers and developers of new technology. Thus, the designers' and developers' views of the interaction between the humans and the technological systems they design and develop are largely unknown. This paper investigates the designers' perspectives and examines how they view the interactions that the systems they design and develop will have on the sociotechnical system once implemented. The designer perspective can also provide insights on how it will be to work with these systems. This paper aims to describe factors that are essential to consider in the process of developing autonomous technology in order to bring about healthy and attractive work environments in mining.

This study uses qualitative data to investigate how the next generation of autonomous technology will change work in future mining operations according to the designers and developers of that technology. The data was gathered through five semi-structured workshops that were conducted with technology designers and developers. The study has a clear focus on the design and development of technology and does not investigate the organizational aspects of the new technology. We argue that the technological shift facing the mining industry has the potential to change the power dynamics between the social and the technical systems. Although autonomy increases as technology matures, the social system will continue to play an essential role in mining. This paper highlights aspects that will be essential to optimize for overall performance. Including ergonomics in the design of future mining systems is also emphasized as a key factor for ensuring overall work system performance. Furthermore, we identify instances when the humans will be responsible for training and instructing the technological sub-system to perform tasks they previously performed themselves. The results also indicate ways in which the technological shift might change the skills and competences required for future mining operations.

2 Methods

2.1 The Project

The data for this study was collected as part of a Horizon 2020 mining project. The project is a world-leading mining consortium whose objective is to develop and demonstrate an autonomous mining solution for more efficient and sustainable mining systems. The main emphasis is on autonomous material handling, although the project also includes other aspects of mining. The consortium includes universities, mining companies, equipment manufacturers, and system developers for the mining technology, mostly located in Europe, and there is extensive interaction and collaboration between the partners. The project is divided into smaller focus areas (see Table 1). Each focus area is concerned with different technological solutions making up the autonomous mining solution.

The first focus area entails the development of a 5G network solution for connectivity and positioning in underground mining operations. Connectivity is a key enabler for the other focus areas. The second focus area concerns an artificially intelligent (AI) fleet optimization system for communication between machines, navigational support, traffic awareness, situational awareness, and fleet management for coordination of the entire fleet. The third focus area aims to develop an autonomous robotized inspection before and after blasting. These inspections will be carried out by drones, which will collect data for a visual 3D representation of the muck pile as well as data on air quality and explosive gas. The system will also be used for shaft inspections for loose rocks and cracks in the ceiling. The fourth focus area concerns a fully autonomous material handling cycle (driverless), including bucket filling and dumping into the truck. Finally, the fifth focus area looks at a system for mixed traffic between manually operated and autonomous machines. The project is an initiative aimed at connecting parts of the mining operation into one autonomous system.

2.2 Data Collection

We used a qualitative approach in this study and conducted five semi-structured workshops with technology developers

Table 1 Project focus areas

1	Connectivity and positioning
2	AI powered fleet optimization
3	Robotized inspections
4	Autonomous material handling
5	Autonomous vehicles in mixed traffic

in line with the focus areas in Table 1. Each workshop lasted about 2 h with a 15-min break and had an average of six participants, apart from one workshop which only had two participants and lasted about 1 h. All workshops were performed in a digital setting.

The informants were technology developers from the different focus areas of the project, working av mining companies, universities and companies specialized in the research, design and development of technology used in mining. We consider all informants as contributors to the design and development of the autonomous mining solution, and they are regarded as experts, according to Flick [22]. Data collection can therefore be considered as group-expert interviews, in which the main interest is the interviewee's expert knowledge within a certain field, rather than their own personal experiences.

Two of the authors were involved in the data collection. The corresponding author asked the questions, follow up questions and probes, and the other author took extensive notes of everything that was said. The questions asked centred on what the technology will do and what humans will have to do and know to handle the technology. The questions also revolved around the designers' views on the interaction between humans and the technology they are designing and developing, in terms of aspects such as safety and trust. A summary of what was said during the workshop was written and sent to the participants for review and comments. Overall, all participants agreed with our interpretation of what was said during the workshop after minor clarifications. These summaries were the basis for the analysis described below. Two of the workshops were conducted in Swedish. All participants in these workshops were native Swedish speakers. These workshops were summarized and coded in Swedish and translated into English during the process of writing the results.

2.3 Data Analysis

Data analysis was performed on the summaries approved by the informants. Analysis followed Braun and Clarke's six-step approach to the thematic analysis of qualitative data [23]. The first step is to familiarize oneself with the data. Step two is to generate initial codes. Step three is to search for themes. Step four is to review and refine the themes. Step five is to define and name the themes, and step six is to write up the results. The aim of the type of analysis performed was to obtain a rich description of the data set (as opposed to a detailed account of one aspect of the data set), and an inductive approach was used to identify pattern within the data. Themes were identified and coded without trying to fit them into a pre-existing coding frame. Analysis was therefore data-driven. Themes were identified and analyzed at the semantic level.

The results described in this paper are not to be considered a prediction of specific cases of future mining operations. Instead, the findings should be considered as what Yin refers to as analytical generalizations, which are insights that are analytically relevant in wider contexts [24]. The informants in this study consisted of developers and designers of state-of-the-art systems for mining solutions. It is therefore likely that their views about the future are directly relevant to the mining systems of tomorrow.

3 Results

The findings from the workshops are presented under three themes and sections. The first, Section 3.1, is concerned with the technological system, that is to say what the technology will do. Section 3.2 focuses on the conditions that are necessary for successful interactions between technology and humans in mining operations. Finally, Section 3.3 describes the social system, in other words, what humans will do when working with the autonomous mining systems of the future. Each of these sections consists of sub-sections corresponding to the sub-themes. See Table 2 for an overview of themes and sub-themes.

The results presented in this section constitute a condensed version of the summaries that were approved by the informants. They do not therefore contain any analysis by the authors of this paper. The authors' analysis of the results is presented in the subsequent discussion section.

3.1 The Technological System

The study investigated what the technology will do once in place. The key factors identified are that the system will increase efficiency, provide information, and give instructions to humans. Additionally, the results indicate that the

Table 2 Overview of themes and sub-themes identified

Theme	Sub-theme
The technological system	Efficiency
	Information and instructions
	Executive functions
Mediating processes	Competence
	Trust
	Safety
	Usability
The social system	Maintenance
	Instructions and improvements
	Monitoring and intervention
	Strategic decisions

system is starting to become autonomous in that it can make certain decisions on its own. This section discusses what the technology will do in future mining operations according to the informants.

3.1.1 Efficiency

In terms of material handling, some informants hope that the autonomous mining solution will increase efficiency by about 10–15% by cutting the non-value-adding time between shifts and after blasting.[1] This is because the autonomous system can remain in production between shifts and it can enter blasting areas almost immediately after blasting.

In some cases, the usefulness of this system will be directly apparent to the user as it will function as a tool for increased efficiency. In other cases, when the data provided by the system simply 'disappears into the cloud', the user does not have control of the data and the usefulness of the system is therefore not as apparent. In these cases, it might be important to justify the system by showing that it does in fact increase efficiency. It should be clear to the humans that it is beneficial for them to use the system to work more efficiently (cf. Section 3.2.2).

3.1.2 Information and Instructions

Another key aspect identified is that the system will provide information and instructions to humans. As a first step, the system will produce a more detailed description of the entire mining activity through better connected solutions. Other aspects of the system, such as autonomous drone inspections, could become the eyes and ears of the workers. These inspections are expected to provide input into the broader context when shared with many different actors in the system. In this sense, functionality is added beyond the immediate context through what can be described as *shared eyes* between many actors in the mining operation.

As a next step, the system will give instructions to humans. Artificial intelligence-based monitoring and planning of the entire mining operation can inform humans what to do in certain situations. Another example is autonomous drone inspections that will use data on air flow rates and limit values for gas concentration to give a 'thumbs up' or a 'thumbs down' to humans to enter certain areas. A further example is traffic awareness systems that will provide information on how to navigate through the mine without disturbing production.

[1] This percentage will depend on the mining method, the technology used, and the deposit and rock characteristics, as pointed out by one of the reviewers for an earlier version of this paper.

3.1.3 Executive Functions

In some cases, the autonomous system makes decisions on its own. For instance, decisions concerning which draw point to load from are more or less already automated today. For certain scenarios, the system must be able to make decisions to be useful in the first place.

As it stands today, the autonomous system supports humans, i.e., humans are helped by the system. However, with the fully autonomous systems of future mining operations, one can expect a transition towards mining operations where humans will have to support the autonomous system instead. Humans should nevertheless always have the final say, although it is a kind of journey, where technology will eventually have a greater influence in future mining operations. Along the way, it is also likely that more humans will be removed from the mines to work remotely from the site. This could increase risk-taking in manual handling of the system. The system may also underperform if connectivity drops, which could increase human stress and frustration if it happens often.

3.2 Mediating Processes

The study also identified four mediators between humans and the technology: competence, trust, safety, and usability. This section expands on the mediators, which, according to the informants, are necessary for successful interactions between humans and the autonomous technology in future mining operations.

3.2.1 Competence

Many parts of the autonomous technology are envisioned to have an intuitive and well-designed interface. Nowadays, the standard expectation is that mobile-phone apps should work directly, and users should immediately understand how to use them. Mining technology should adhere to these expectations as a principle (although mining systems are more complex). Data should be presented such that it can be easily understood, and the ordinary operator should not need any specific education to use the autonomous system in everyday production. All that should be required is an introduction to the system and to understand its basic functioning. General computer skills should be sufficient. If this expectation is not met, trust in technology might be damaged (cf. Section 3.2.2). Ease of use may also determine the extent to which the autonomous technology can help the human (cf. Section 3.1.1), increase safety (cf. Section 3.2.3), and provide the right kind of data to achieve adequate ease of use.

Humans should not be overwhelmed with information (cf. Section 3.2.4).

Mining-specific knowledge specific will be required for humans to validate the data provided by the system (cf. Section 3.3.3). For instance, in the case of autonomous shaft inspections, humans will need to have shaft inspection know-how to validate the data provided by the system. It is important to know what a muck pile looks like in real life and how it behaves when loading to create an accurate representation of that muck. Experience of manually controlling the system is key for managing instances when the autonomous system fails. Future generations of miners might not have this practical knowledge and might only have acquired it through theory, which is not the same.

The workshops discussions also raised the issue of transfer of skills from manually performing mining related-activities, such as loading, to having knowledge on when to initiate certain operations or when to perform maintenance. Humans also need to be knowledgeable about the technology itself to be able to make judgements about it. Specific knowledge about the technology and how it functions is also important to evaluate the results provided by the technology (cf. Section 3.3.3). An understanding of how the system functions and how it makes its decisions is important to generate trust that it has produced reliable and accurate results (cf. Section 3.2.2). Visual thinking might be important in this regard.

Understanding contextual factors is also important, particularly when the system fails (cf. Section 3.3.3). If there is a problem, those involved need to understand the nature and the scope of the problem to allocate the right resources to solve it. Local or global problems (affecting the entire fleet) are handled differently. An understanding of why problems occur is also important to prevent them from recurring. The informants also highlighted that it is important to know that no systems are infallible (cf. Section 3.2.2).

Mining companies will also need dedicated roles to manage the more advanced aspects of the autonomous systems, such as setting up the system, adapting it to the evolving mine, and improving its functioning. There is currently a lack of technicians in mining who can take care of these systems, and at the same time, substantial amounts of new technology are being implemented. Furthermore, domain knowledge must be integrated into the new systems. One question that also needs to be considered is where these competences should be situated. Locally, at the mine sites, there might be enough expertise to handle simpler problems, whereas higher-level experts might have to be called in for more complex issues. One solution is to manage these cases remotely using VR and AR technology. Software issues can also be handled remotely.

3.2.2 Trust

Two different aspects of trust were discussed in the workshops. First, in the interaction between humans and the technology, there must be trust in the results produced by the system and trust in its performance. For instance, if the system gives a 'thumbs up' on a safety inspection, humans will still have to decide whether to trust it or not. This form of trust is largely garnered by validating the results, which leads to confidence and increased trust in the performance. One way to build this kind of trust is to let humans replicate the results. In this regard, it is essential that the system is in fact reliable, that it performs as expected, and that it produces the right outcomes. It is not only a question of trust in the output, but there must also be trust in the system's ability to execute the task consistently, that it can get the right data in a safe manner. In relation to this, there is also a question of validation of the data produced by the autonomous system. If there is enough trust in the process, then the data could be validated autonomously.

Secondly, trust was discussed in terms of how the technology is used. Overuse or underuse of automation can be problematic, and data can be trusted too little or too much. One way to generate the right level of trust could be to test what happens in different scenarios, such as during misuse. One example of misuse is when cruise control to prevent accident is disabled in mine trucks. Operators have then enabled these cruise control functions themselves, leading to accidents.

3.2.3 Safety

The new autonomous system will improve safety in mining operations by removing the humans from areas where there is a risk of falling rocks and cave-ins. While new technological systems generally make mines safer, it is unclear how we should handle the fact that there is no guarantee that autonomous technology will always successfully detect humans. It is nevertheless important that new technology is built in layers of safety, such that if one layer fails, the second is not likely to do so. Redundancy might be another way to increase safety, for instance using several positioning tags for each machine or human. It is also important to identify the right level of safety, however, which is done through trial and error. Too much sensitivity is likely to impede production so one solution might be to work with safety bubbles in the form of spatial predictions regarding the physical location of objects, machines, or humans. In terms of general mine safety, there should be a stand-alone system for emergencies.

3.2.4 Usability

The system must be practical for its users; otherwise, it will not be used. Depending on the task at hand, the operator might be required to take over in critical situations, so it is therefore important that the system is flexible (cf. Section 3.3.3). The ability to be taken over is not automatically built into the system, and creating autonomous systems that have this ability can sometimes be challenging. Changing the structure of ongoing autonomous operations could introduce many uncertainties, according to the informants.

Usability in this sense is largely a matter of requirements from the mining companies. If they require systems that are flexible during tasks where the operator can make changes in the task, then systems can be *made to have* this ability. In terms of drone inspections, it is crucial that there is great flexibility before the task starts, but it is less important that the system is flexible during the task. Long-life mines change all the time, and the technological system must be able to cope with this constant change, which means system should be designed to be flexible at a macro level too.

3.3 The Social System

The findings of this study indicate that humans will continue to play an important role in the autonomous mining systems of the future. Humans will be responsible for many tasks such as maintenance, setting up the systems, giving instructions, and initiating tasks. Humans will also have an important role in strategic decisions related to production, based on tasks such as monitoring, interpreting, and evaluating the data produced by these systems, as well as intervening if something deviates from the expected functioning. This section elaborates on the informants' views of what humans will do in future mining operations.

3.3.1 Maintenance

The underground mining environment is tough. Humans will have an active role in the maintenance of the autonomous technology in future mining operations. Maintenance is key for system performance and includes tasks such as repairing and replacing cables, modules, sensors, and nodes. Mines grow constantly, and their topography changes, which calls for continuous installations and replacements of hardware. In the future, as technology becomes more advanced, maintenance is likely to be handled by IT departments and similar functions.

3.3.2 Instructions and Improvements

Humans will have an active role in installations and initiating operations. Generally, the system does not simply perform activities on its own. In the case of autonomous drone inspections, humans will still be responsible for getting the drone to the right location, setting it up, checking that everything functions properly before giving the instructions, and initiating the inspection. The route must be dictated by the human.

At the next stage, humans will have an active role in teaching the autonomous technology. In the case of autonomous loading, the system sometimes partly fails or does not perform satisfactorily. Since the system is intelligent, it can be taught by humans to classify success rates. Over time, the system will improve, and in the long run, it is expected to outperform the most experienced humans. Teaching the technology is more important at the beginning of implementation. Humans will also be responsible for other aspects of improvements such as providing better network solutions and revising algorithms.

3.3.3 Monitoring and Intervention

Once the autonomous system has been implemented, one of the central functions ascribed to humans will be monitoring system performance. Monitoring includes interpretation and evaluation of what the system does and how well it performs. For instance, one task might be to keep track of and correct machine activity as well as keeping track of energy consumption. Humans will have to evaluate whether the autonomous operations are successful or not.

Humans will also have to respond to alarms and check that key performance indicators are not breached. If the autonomous system does not perform as expected, or if it encounters a problem which it cannot solve, humans will have to intervene. There are in principle two sorts of deviations, smaller and larger, both of which require humans. The smaller deviations can easily be handled tele-remotely. Larger deviations, for example when a machine loses connectivity or that an entire fleet goes down, will need human intervention locally. Intervention as well as the possibility to intervene when needed is important in fostering trust in the system (cf. Section 3.2.2).

3.3.4 Strategic Decisions

Humans will have an active role in planning and re-planning mining operations. Strategic decisions are hard to automate and will therefore most likely be left to humans. Humans will also have an active role in the design and planning of system requirements from different stakeholders within the mining system. This task includes translations, handling the information flow between stakeholders and making decisions about where to allocate resources.

Humans might also have to take an active part in making decisions on-site about exceptional maintenance. The basis for these decisions might be intuition or gut feelings, for instance if they suspect that something is not quite working as it should or is about to break down. Mining is an environment where unexpected events are likely to occur.

4 Discussion

This paper investigates the designers' perspective and examines how they view the interactions that the systems they design and develop will eventually have on the sociotechnical system once implemented. The designers' perspectives can provide insights into the future of work in mining. Such insights are valuable in fostering healthy work environments in the future mining industry.

The paper contributes with insights on the designers' perspectives of sociotechnical considerations linked to the systems they design and develop. The designers' perspectives of the development process have not been studied previously in mining contexts. Using these insights, the paper identifies four key work tasks that are essential to the success of future autonomous mining systems.

The paper also provides a refinement of the sociotechnical model by proposing a conceptualization of the sociotechnical system based on three systems: the technical system, the social system, and between these, what we refer to as the mediating processes. A conceptual framework based on this characterization could provide better tools for optimizing the performance of the sociotechnical system.

4.1 The Future of Mining Systems

The findings from this study are consistent with previous research emphasizing that technological developments in mining increase the level of automation without removing the human from the system [14, 25, 26]. This study indicates that humans will be responsible for a range of different tasks in relation to the autonomous system. Previous research has stressed the importance of considering ergonomics in the design and development of systems with substantial human-automation interactions [18, 27]. In considering ergonomics, the design and development process takes a user-centric design approach which includes the performance and well-being of all users [7].

Previous research into human-automation interactions has underlined that failure to consider ergonomics in the design and development of autonomous systems can result in what is known as *poorly designed automation* [28]. Poorly designed automation has a combination of the following characteristics: it is *strong* in that it can act autonomously; it is *silent* in that it provides little feedback to humans; it is *clumsy* in that it interrupts humans during high workload; it is *difficult to direct* when it is costly, in terms of mental and/or physical resources, for the human to control [28]. Autonomous systems that are poorly designed can cause what is known as *automation bias*, that system is used to the exclusion of other systems and sources; and *automation complacency*, when the user relies too heavily on faulty or unreliable autonomous systems [29] (cf. Section 3.2.2). The risk of introducing automation biases should be taken seriously in the design and development of new autonomous systems for the mining industry. Factors such as these can affect the outlook for recruiting skilled employees.

From a sociotechnical perspective, there are two factors that we can improve to foster overall system performance. The first is the technological system itself. We can build safer, more efficient, more sustainable, and better technological systems based on ergonomics. The second factor is the mediators. We can educate people on the technology and how to work with it in ways that are appropriate; we can improve trust, both in the technology and how it is used within the organizations in which these systems are implemented; we can increase safety through these systems, both actual safety and the perception of safety; and we can improve usability by creating technological systems that are practical for their users. For instance, the results of this study indicate that there is an aggregation of the social and the technological systems taking place. As technology becomes more advanced, it also moves closer to the social system. The technological system provides information, suggestions, and instructions, as well as making decisions on its own in certain aspects. Although this aggregation is desired by the users, resources will still have to be devoted to integrating these systems in the current social settings. Trust will be one key factor in this. Humans will have to trust that the instructions and suggestions provided by the system are in fact reliable.

There is disagreement in the literature about how to build and foster trust in AI. On the one hand, there are those that argue for increasing the level of transparency to promote trust [30]. Factors such as what the system looks like, how it behaves, what others think about it, and how transparent and easily understandable the system is greatly affect trust. Once trust is established, it must be maintained continuously through ensuring the system's usability and reliability, developing collaboration and communication with other systems, and making sure the system is intelligible to its users, in that the system can explain its conclusions or actions [30]. On the other hand, there are those that argue that transparency, i.e., providing explanations of how the AI system makes its decisions, can have a detrimental impact on trust in AI, which can lead to sub-optimal usage [31]. Others have noted several limitations in the evidence base regarding the cognitive and emotional trust in AI, such as over-reliance in short-term and experimental studies and the diversity of trust measures and operationalizations, suggesting that there is no one solution that fits all [32]. In conclusion, if the social and the technical system become aggregated in future mining scenarios, efforts need to be taken to establish productive interactions between these systems so as to generate trust. Future research will have to come to terms with how trust should be fostered in the interaction with AI systems. These efforts will have to be anchored in the social culture, values, and norms where the system is to be used.

The findings of this study also indicate that humans will sometimes be responsible for teaching and training the system so that it produces satisfactory results. According to the informants, once the system is trained, it will outperform the humans, particularly in repetitive tasks such as loading. This insight is not new; it has been known and discussed for decades that automation will eventually outperform humans (in certain tasks) in the future. We now see that this future approaching quickly. However, the results do not only suggest an aggregation of the social and technical systems, they also underline the current demarcation line between humans and technology. Features such as the validation of what the system does (classifications), evaluation of performance as well as the more strategic decisions remain in the responsibility of humans. Some informants discussed the possibility of technology becoming self-evaluating, yet this was not common through all the workshops. Most informants expressed that these functions needed to be handled by humans, in contrast to discussions regarding full automation as the next step in future mining systems. This contradiction is dependent on what is meant by the term *full automation* and similar concepts such as *light-out* or *zero-entry mining*, for instance whether maintenance is included in these concepts or not.

Autonomous systems are often discussed as one of the mega-trends in mining contexts [33]. As technology becomes more sophisticated, it also changes the dynamics in relation to humans. Next generation autonomous technology is going to have an even greater potential to make decisions of its own. In this study, the informants discussed a transition of support, from technology being a support to humans to the opposite: that in the future humans will become the support for the technology. This will certainly have a significant impact on work. From an ergonomics perspective, it is often emphasized that work should be attractive to generate healthy work systems [7]. There are many potential benefits of the next generation of autonomous technology related to aspects of good, healthy, and attractive work environments that people want to work and keep working in. These include increased safety, cleaner work environments in control rooms, and a more relaxed work situation (provided that the system works as it should). Many of the monotonous and repetitive work tasks of today will be handled by the technology in the future.

Another key challenge, that is often overlooked, is that although the vision of how things will be in future scenarios does take ergonomics into consideration, the path to realizing this vision might not. The technological shift that the mining industry now faces is perhaps unavoidable because digitalization and new technology cannot, nor should they, be stopped. However, the technological shift is not as rapid in implementation as in theory. Instead, the shift will be incremental rather than stepped, with smaller implementations here and there, extending over decades when autonomy slowly increases as technology matures. It is therefore essential that the path towards realizing the future autonomous system does not leave any workers in bad and unhealthy work situations or work environments. Moreover, the shift will also be *asymmetrical*; some parts of mining operations will naturally use higher levels of automation than others [34], which is particularly challenging to manage because it can cause some parts of the mining operations to fall behind, leaving a set of arbitrary tasks for humans to handle [14].

A philosophical challenge of designing and developing autonomous systems that also have an ergonomics perspective is that humans are not really included in the concept of autonomous systems. If the system were fully autonomous, no human would be required in it (cf. *Ironies of Automation* [14]. The human is conceptually superfluous in autonomous systems, which naturally makes it awkward to bring ergonomics into the equation in the design and development phases. If everything works as it should, humans should have nothing to do in autonomous systems (notwithstanding maintenance). However, when the system does not function as it should, humans will have a great deal to do. The problem is how to include these tasks in the design and development phases of the technology to reduce the risk of building unhealthy work tasks into the system. This challenge is not only limited to the work system, it will also be relevant in the distant future when we develop autonomous maintenance systems for autonomous mining systems.

Further challenges in the design and development of autonomous systems based on ergonomics include the great distance between the designers and the users and how to design and develop for a diverse workforce. Another related challenge is how to demarcate between design and development on the one hand and implementation on the other. Where do we draw the line between issues related to development and issues related to implementation? (cf. Section 3.2.4). On the one hand, those that develop the technology have little power over how it is used by the mining companies in the end. On the other hand, they do have a responsibility to design and develop systems that adhere to ergonomics.

4.2 Conclusions

Previous research has indicated that the less skilled and monotonous work tasks will be handled by autonomous systems in the future [12, 35], which means that the miners of tomorrow that are responsible for 'moving the mountain' will be the autonomous systems designed and developed today. However, these autonomous systems will not succeed in moving any mountains without the support of humans. It is easy to jump to conclusions about the possibilities of autonomous systems in mining operations. There is also fear in the workplace of being replaced by these autonomous systems. This fear needs to be taken seriously and managed properly to avoid technological resistance.

Although there will be a reduction in the amount of labour involved in production in future mining operations due to these autonomous systems, the notion of being replaced, as it is sometimes described (cf. Brynjolfsson and McAfee [36]), is highly exaggerated for the mining industry. A fully autonomous system without human involvement would require a system which is highly reliable in terms of error handling capabilities and that has the ability and the technical capability to effectively handle large amounts of potential anomalous situations, including the ability to handle unforeseen events [37]. Although a mining system that has these characteristics could be designed and developed some day, it is not the sort of system that we see being designed and developed today.

The largest impact we see on the work in future mining operations is the change in the required skills and competences for future mining operations. Working with autonomous technology requires education on how the system functions, as well as safety education, i.e., how to behave safely around these systems and how they should and should not be used.

Further research could focus on user-centric design of autonomous mining systems. Another important aspect for future research concerns the implementation of these autonomous systems on mining sites. It is important to better understand how the autonomous technology changes the work in mining once implemented and how it affects organizational structures within the mining industry.

In summary, the path towards autonomy in mining operations is long and greatly dependent on humans. If human needs, conditions, and limitations are not included in the design and development of these autonomous systems today, then there is a substantial risk that human-technology interactions will have a negative effect on work in mining operations in the future.

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Declarations

Conflict of Interest The authors declare no competing interests.

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