LUT University

Industry 5.0 Adoption Among Heavy Machinery Producers: The Potential of Artificial Intelligence in Social Sustainability Facilitation

Valtonen Alena, Saunila Minna, Rantala Tero, Ukko Juhani

This is a Publisher's version version of a publication

published by Palgrave Macmillan, Cham

in Business for Sustainability, Volume II. Palgrave Studies in Cross-disciplinary Business Research

DOI: 10.1007/978-3-031-37365-7_2

Copyright of the original publication:

© 2024 The Author(s), under exclusive license to Springer Nature Switzerland AG

Please cite the publication as follows:

Valtonen, A., Saunila, M., Rantala, T., Ukko, J. (2024). Industry 5.0 Adoption Among Heavy Machinery Producers: The Potential of Artificial Intelligence in Social Sustainability Facilitation. In: Vrontis, D., Thrassou, A., Efthymiou, L., Weber, Y., Shams, S.M.R., Tsoukatos, E. (eds) Business for Sustainability, Volume II. Palgrave Studies in Cross-disciplinary Business Research, In Association with EuroMed Academy of Business. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-031-37365-7_2

This is a parallel published version of an original publication. This version can differ from the original published article.

Industry 5.0 Adoption among Heavy Machinery Producers: The Potential of Artificial Intelligence in Social Sustainability Facilitation

Alena Valtonen, Minna Saunila, Tero Rantala, Juhani Ukko

LUT University, Finland

Abstract

This study investigates the potential of artificial intelligence (AI) in generating social sustainability among operators of heavy machinery in an Industry 5.0 setting. The well-being of industrial workers is an integral part of social sustainability. This study adopted a qualitative multiple-case study strategy. The results reveal the main problems experienced by operators (cognitive and physical strain, safety-related concerns, and a skill gap) and provide examples of AI-powered solutions designed by the case companies that tackle these problems. The findings show that AI can provide several implications for social sustainability, such as improved health, safety, emotional and mental well-being, work efficiency as well as training and education. This research contributes to Industry 5.0 literature by providing evidence from the real industry environment to increase the social sustainability of organisations.

Introduction

Industry 5.0 is merging the digitalisation achievements of Industry 4.0, such as the Internet of Things, robotics, and artificial intelligence (AI), with sustainable development goals that place a greater emphasis on the well-being of industrial workers (Müller, 2020). In particular, human-centric AI-powered solutions have strong potential to support the Industry 5.0 vision by facilitating social sustainability in industrial organisations. Social sustainability refers to the dimension of sustainability that relates to satisfying the needs of human well-being (Rogers et al., 2012). In organisations, social sustainability refers to health and safety management; learning and growth opportunities; and equality, diversity, inclusion, and fair labour practices (Ajmal et al., 2018).

AI-powered solutions are known to assist various aspects of work (e.g., Mahroof, 2019; Cao et al., 2021; Chatterjee and Chaudhuri, 2022; Choi et al., 2022). According to Makarius et al. (2020),

integration of AI into organisational work can result in implications for cognitive, relational, and structural issues. For example, it can enhance decision making (Cao et al., 2021; Choi et al., 2022), lead to quicker operations and reduction of errors (Choi et al., 2022), and assist in the undertaking of more complex tasks (Mahroof, 2019). Organisations should seriously consider the impact of AI on social sustainability and human well-being to maintain resilience, competitiveness, and a good reputation (Wang et al., 2020).

Despite the growing trend towards the implementation of AI and the adoption of social sustainability practices by organisations, little is known about its impact, and particularly, its aspect related to the well-being of industrial workers. Only a small number of studies concerning the social sustainability implications of digital technologies have been reported—possibly because social sustainability research is generally lacking (Brenner and Hartl, 2021). Most AI-related studies focus on technical aspects (Nishant et al., 2020). Apart from the need for more research at the intersection of AI and social sustainability areas, there is a lack of empirical evidence from industry, which adds to the relevance of this study's contribution (Grybauskas et al., 2022).

This study aims to contribute to emerging AI and social sustainability research by examining the potential of AI in generating social sustainability among operators of heavy machinery. The aim is accomplished through case studies of AI utilisation in three Finnish manufacturing companies. The results reveal the central problems experienced by operators (cognitive and physical strain, safety-related concerns, and a skill gap) and give examples of AI-powered solutions designed by the case companies that tackle these problems. Our findings show that AI can provide implications for such aspects of social sustainability as improved health, safety, work efficiency, emotional and mental well-being, and training and education. In this way, the study contributes to existing AI and social sustainability research by showing what factors of social sustainability are impacted by AI adoption. The study also provides managerial implications for practitioners for enhancing social sustainability via AI in their organisations.

The chapter is structured as follows: After the introduction, we present the current understanding of the interplay between artificial intelligence and social sustainability. In the next section, we present the data collection, and analysis, followed by the results of the empirical examination. Finally, we provide the most important conclusions and implications.

Artificial intelligence and social sustainability in Industry 5.0

Although manufacturing companies continue to develop their efficiency and productivity around the technology-driven Industry 4.0, the shift towards a value-driven and human-centric Industry 5.0 is underway. Xu et al. (2021) posited that the introduction of Industry 5.0 is based on the observation that Industry 4.0 focuses less on the original principles of social justice and sustainability, and more on digitalisation and AI-based technologies to increase production efficiency and flexibility. They continue that Industry 5.0 focuses on the interconnection between human-centricity, sustainability, and resilience, where the human-centric approach puts core human needs and interests at the heart of the production process, shifting from a technology-driven approach to a thoroughly human-centric social sustainability approach. In the human-centric approach, technology is intended to serve people and societies, meaning that the technology used in manufacturing is adaptive to the needs *and* diversity of industry workers (Lu et al., 2021; Xu et al., 2021). In this study, social sustainability in Industry 5.0 relies on the statement that 'a safe and inclusive work environment is to be created to prioritise physical health, mental health and well-being, and ultimately safeguard worker's fundamental rights, i.e., autonomy, human dignity and privacy' (Xu et al., 2021). The need to keep upskilling and re-skilling is essential for industrial workers to achieve better career opportunities and work–life balance (Breque et al., 2021; Xu et al., 2021).

To achieve social sustainability in the Industry 5.0 context, augmented cognitive capabilities are needed to process, understand, and analyse the massive amount of machine and production data to get valuable information from it (e.g., Longo et al., 2020; Romero et al., 2018). Individualised human–machine interaction technologies that can assist, for example, heavy machinery operators and that interconnect and combine the strengths of humans and machines are needed (Xu et al., 2021). One key technology

in enhancing cognitive capabilities is AI (i.e., cognitive computing, computer vision, knowledge representation, machine learning, recommender systems, and planning, scheduling, and optimisation algorithms; Longo et al., 2020), which can be used to detect, for example, causalities in complex, dynamic systems, leading to actionable intelligence (Xu et al., 2021). Wirtz et al. (2018) asserted that a special feature of AI is the replication of human thinking and learning, as well as problem-solving capabilities intended to enhance performance. Accordingly, they defined AI as 'the capability of a computer system to show humanlike intelligent behaviour characterised by certain core competencies, including perception, understanding, action, and learning'. This is also the definition of AI used in this study.

The contribution of artificial intelligence to social sustainability

Even though the focus on shifting from Industry 4.0 to Industry 5.0 is to pay increased attention to social sustainability at the organisational and individual level, the role AI plays in contributing to social sustainability is considered somewhat controversial in many cases (Connelly et al., 2021; Lee and Lim, 2021). According to Chowdhury et al. (2022), the emergence of AI solutions in operation environments will affect workforce demographics, the nature and meaningfulness of jobs, and technology–human interaction. Wilson and Van Der Velden (2022) contend that the long-term impacts of AI are widely speculated but poorly understood from an empirical point of view. Grybauskas et al. (2022) summarised in their study that, on a positive note, AI-related implications can be connected, for example, to smart working, increased employee safety, and well-being. On the negative side, AI-powered solutions can affect, for example, skill mismatches and employees' privacy (Grybauskas et al., 2022). Even though technological development and Industry 4.0-related technologies have reduced human-related work among several industries (Grybauskas et al., 2022; Neumann et al., 2021), at the societal level, Industry 5.0 and the utilisation of AI will create a significant number of new job opportunities among different industries that are, for example, related to data analysis and decision making based on AI-supported big data analysis.

While AI will have a significant effect on the generation of new jobs, many of the new working possibilities related to human–AI interaction will be capability-intensive. For this reason, the expanding utilisation of AI will require new capabilities from both organisations and individuals (Chowdhury et al., 2022). From the perspective of social sustainability, it may require organisations to educate their employees, which may affect individuals differently. While some might consider the learning of new skills and capabilities meaningful, others may consider it stressful and unnecessarily time-consuming (Grybauskas et al., 2022). While the scale of AI utilisation and human-machine interaction is expanding, there are also concerns related to allocating the responsibility of decision making to algorithm-based AI solutions (Bellamy et al., 2019). Bellamy et al. (2019) highlighted that an AI-powered solution, in the end, is software that can go wrong and thus make mistakes. Therefore, there is always a need for human work to fix these problems. There exists a lack of empirical understanding about the hindering role of the interplay between AI decision making and responsibility issues. In other words, among many industries, there is a need to understand more about the role of responsibility related to the adoption and utilisation of AI (Chowdhury et al., 2022).

According to Nishant et al. (2020), AI is widely considered from a technical perspective, and there is a need to understand more about the social and ethical issues related to its utilisation. From the perspective of social sustainability, according to Grybauskas et al. (2022), the smartification of the work environment can also have controversial effects on the feelings and well-being of employees. For example, the authors mention that the utilisation of AI-powered solutions, such as wearable sensor technologies, can support the health monitoring, information access, and decision-making of employees. According to Nishant et al. (2020), AI provides opportunities for operating in high-risk environments without risking human health. On the other hand, according to Grybauskas et al. (2022), modern AI-powered solutions can be used to monitor and evaluate employees' performances and behaviours, which may cause unintended stress. For that reason, there are many open questions, including ethical ones, related to the utilisation of AI among individual employees.

Even though there are concerns related to the utilisation of AI in industrial settings (Stock et al., 2018), AI can simplify working environments. For example, it can break challenging tasks into smaller ones that require less skill, or even take care of the most stressful tasks and thus reduce the cognitive stress of employees (Stock et al., 2018). While AI operates monotonous, stress-inducing tasks, employees get an opportunity to do work that is cognitively less stressful (cf. Pinzone et al., 2020). According to Pinzone et al. (2020), AI also provides a better understanding of the evaluation of psychological parameters that affect the social sustainability of employees, such as stress and fatigue.

In summary, AI adoption is increasing rapidly, and it affects the social sustainability of both organisations and individuals. While the effects can be controversial and diverse, and the literature on AI and social sustainability can be considered rather novel, there is a need for more empirical understanding of how AI affects social sustainability (cf. Grybauskas et al., 2022).

Research design

A qualitative approach with multiple case studies was adopted to examine the topic in its actual environment (Eisenhardt, 1989; Yin, 2018). The sampling included companies in the heavy manufacturing industry. These companies were selected because of their active approach and concrete initiatives towards AI implementation in their operations. This strategy enabled a comprehensive overview of the potential of AI in heavy manufacturing.

The data used in the case studies is described in Table 1. The primary data was gathered via group interviews, as the aim was to collect rich, empirical evidence about the studied phenomenon (Eisenhardt and Graebner, 2007). Several researchers participated in the data collection, the aims of which were to (1) ensure that any important areas were not omitted, and (2) ensure wide experience from the studied topic from technology and business perspectives. The interviewees were selected based on their knowledge and responsibilities regarding the research topic. Most of them were in managerial positions, such as product manager or project lead. The study included several interviewees per company who each provided different perspectives on the topic. The interviews were conducted between June 2022

and September 2022 and followed a semi-structured protocol. The interview protocol included: (1) the usage of analytics, AI, and simulation technologies; (2) the development of target-related demands and barriers; (3) data exchange and representation; and (4) operator-specific factors. The interviews were recorded to facilitate data analysis. The anonymity and confidentiality of the interviews we ensured for all study participants, and permission for recording asked prior to interview.

The interview data analysis followed an approach in which new constructs were inductively searched (Kovács and Spens, 2005). Content analyses were employed to systematically analyse the qualitative data transcribed from the interview recordings. First, the collected data was organised into written form. Second, the evidence was extracted when the gathered material indicated an issue pertaining to social sustainability. Third, the coded content was classified into groups, leading to the interpretation of the findings. Secondary data was also collected to triangulate the interview data and increase the validity of the findings (Voss et al., 2002). Company presentations and webpage content were used to profile the cases and find backup for the interview findings.

<TABLE 1. DESCRIPTION OF THE DATA ABOUT HERE>.

Results

The interviews revealed several problems affecting social sustainability, particularly in the dimension related to the well-being of operators. These problems were later inductively coded into four distinct categories: cognitive strain, physical strain, safety, and varying proficiency of operators (Table 2). This section discusses what constitutes each category based on the content analysis of the interviews and what AI-powered solutions were used by the case companies to tackle these problems.

The implications of AI in facilitating cognitive strain

One persistent problem mentioned by the respondents was the need for fast and complex decision making by operators. This complexity was primarily induced by the environment in which operators had to work and the tasks they performed. Environmental factors contributing to the complexity include

working in various weather conditions (Cases A and B) and in areas with difficult access, such as remote forest plots and stone mines (Cases A and C, respectively). The tasks ranged from very complex operations, such as rock drilling and bolting (Case C), to more routine ones, such as cargo loading (Case B). However, even with basic tasks, operators must remain vigilant of many changing variables in the environment, such as type of load (e.g., tree trunks of different sizes [Case A] or container cargo or bulk cargo [Case B]), target place for loading (e.g., floating vessel as opposed to stationary train wagon), or presence of other people or machinery on the lot. Another problem induced by environmental factors is the loneliness of operators (Case A). According to the respondents, remote work locations and long hours alone in the cabin are substantial factors affecting the well-being of operators and reducing job attractiveness. Although it is recognised in the extant literature that the feeling of loneliness weakens work engagement (Jung et al., 2021) and aggravates depressive symptoms (Cacioppo et al., 2010), the problem of loneliness is rarely mentioned in relation to the work of heavy machinery operators.

Apart from the need for excellent visual estimation ability and spatial thinking, operators should master machine operation and be able to perform multiple manipulations at the same time. According to the respondents, the complexity of the dashboard and the machine parts manipulation processes are the main contributors to operators' distress in the machine cabin. The machines used in forestry, such as forwarders and loaders, are reportedly the most complex and difficult to operate (Case A) in comparison with the rock drilling machines (Case B) and the materials handling machines (Case C). However, in each case, the cost of a mistake is high, because one wrong move on the operator's part can lead to damage to the load, the machine, or the surroundings (e.g., the forest or other machinery), subsequent fines, and increased maintenance costs. To avoid mistakes, the operators have to maintain focus for an extended time (at times up to 13 hours, Case B), react quickly to many changing variables in the environment, make fast decisions, and perform accurate manipulations under stressful conditions, which cumulatively leads to increased cognitive strain in the operators.

All respondents highlighted the detrimental effect of cognitive strain on the well-being of operators and the efficiency of their work. In all three cases, the main goal behind the introduction of novel AI-

powered solutions was to facilitate decision-making processes for operators and to reduce the possibility of human error related to machine operation. Among the proposed solutions were the automation of work sequences (Case A), an operator assistance control system (Case B), and the automation of rock support drills (Case C). All respondents believed that the introduction of automated systems to assist operators' work makes the work of operators easier, which, apart from improving their efficiency, contributes to maintaining their emotional and mental well-being.

The implications of AI in facilitating physical strain

Long hours of sitting in one position can cause various health problems. In the case of operators of heavy machinery, it can be aggravated by excessive fatigue and continuous stress induced by cognitive strain. Respondents mentioned musculoskeletal disorders as a factor determining the career duration of operators. Some of the respondents admitted that back problems cause significant distress and make operators retire earlier due to health reasons (Case A).

Additionally, the necessity of performing complex manual manipulations in the machine operation process takes its toll on operators in the first years of their work. According to the respondents, the effect is particularly strong when operators are required to engage both their hands and feet at the same time, which is necessary, for example, in forestry machines that are operated in parallel and overlapping sequences (Case A). To address this problem, Case Company A designed a simplified dashboard. This simplification was brought about by the automation of work sequences, which resulted in a reduced number of manual manipulations necessary for machine operation. In addition to lessening physical strain, the introduction of a simplified dashboard can potentially reduce cognitive strain, improving operators' physical, emotional, and mental well-being.

Admittedly, multiple manual manipulations with the machine have a more pronounced effect on the physical well-being of operators than the fixed sitting position. According to the respondents, operators of more standard machinery, such as materials handling and rock drilling machines (Cases B and C), while also sitting long hours, do not report significant health problems related to machine operation.

The implications of AI in facilitating safety

Operating heavy machinery in a challenging environment can be dangerous, which is particularly true in the forestry and mining industries. That is why safety was a recurrent topic throughout the interviews. The respondents were concerned with the safety of the operators, loads/cargo, machines, and environment. While operators are protected by the cabin, they can still be injured. Respondents from Case Company A mentioned a situation in which, due to incorrect manipulations with the boom, a tree trunk reversed in the air and hit the cabin. In this situation, apart from damaging the machine itself and threatening the safety of the operator, the load (in this case, a tree trunk) was destroyed, which incurred fines from load owners, increased maintenance costs, and caused reputational damage. The safety of the work environment was another concern. Respondents mentioned the necessity to handle falling trees carefully so surrounding trees were not damaged (Case A), and the necessity to observe people and other machinery working nearby so they are not hit by the boom or driven over (Case B). The respondents also mentioned safety standards imposed by the government, such as emission legislation and land use, and reputational considerations, such as being a preferred partner for responsible forestry (Case A), as drivers of safety improvement.

The respondents stated that AI-powered automation of machine operations allows for achieving the required levels of accuracy, predictability, and energy efficiency that translate into improved safety in the work of operators. For example, an automated system for controlling the boom movement prevents the boom from hitting surrounding trees and damaging the forest (Case A), a semi-automatic system in the material handling machine allows effective navigation even through narrow spaces without scratching the machine (Case B), and an automated system in rock support drills minimises human error that ensures safe and efficient work, even for less experienced operators (Case C). By improving the safety of work, AI-powered automation can positively influence physical, mental, and emotional well-being, and increase work efficiency.

The implications of AI in facilitating the varying proficiency of operators

All respondents noted that it is important and at the same time difficult to find good operators. All heavy machines require some level of experience on the operator's part, from basic in the case of materials handling machinery (Case B) to advanced in the case of forestry machinery (Case A). Respondents from Case Company B mentioned that the experience of driving excavators is enough for a new operator to get going, although additional training is also available. Training takes from two hours to several weeks, depending on the difficulty of the task for which the operator is trained. Accordingly, respondents from Case Company A stated that no licence or school was necessary to drive forestry machinery. However, due to the complexity of forestry machine operation, operators need training to achieve the required level of efficiency. The respondents reported that inexperienced operators mostly make losses for a company because they are less productive and cause more damage to the machine or load than their more experienced colleagues (Case A).

The training of operators is a key factor in determining work efficiency and performance. According to the respondents, the operator is the main driver of the work process, as the operator makes all decisions and is responsible for work progress and outcomes (Cases B and C). The role of the machine is to be a tool for the operator necessary to perform the work (Case B). As all operators come with different skillsets, levels of experience, and cultural backgrounds, the training can be problematic (Cases A and B). At the same time, individualised training is not an option, as machines produced by the case companies are sold to different companies located in different countries. To address this challenge, Case Company A designed a training simulator that provided an immersive learning experience. In this way, operators can improve their machine-driving skills in various simulated conditions at locations of different levels of complexity but in a safe and controlled environment. Reportedly, this kind of training allows for upskilling operators without accidental damage to the machines, which reduces maintenance costs and increases the operational life of the machine (Case A). In the same vein, Case Company B has considered using an operator assistance control system to assist new operators during their induction.

According to the respondents, AI-powered training systems have the potential to improve social sustainability. First, using these training systems ensures the smooth and safe induction of new operators. New operators get the necessary experience without compromising work quality and their emotional and mental health. Second, training simulators allow existing operators to be trained for new tasks and working conditions without causing additional stress. Lastly, a training simulation is a safe way to test new technical solutions before introducing them to operators. It saves operators from the trouble of struggling with a novel solution while trying to perform their work duties. Admittedly, respondents noted that AI-powered training systems are mostly utilised by either new operators for training purposes or highly experienced operators who provide their skill and expertise to train the system further, and in this way to transfer their skill to less experienced operators. Some skilled operators, however, perceive this training system, as well as other incremental innovations provided by the company, as unnecessary, deeming that these novelties only take time to get used to without making their work easier (Case A).

<TABLE 2. THE POTENTIAL IMPLICATIONS OF ARTIFICIAL INTELLIGENCE>.

Discussion and conclusions

Although the separate bodies of academic literature on AI and social sustainability are growing, their intersection is relatively unexplored, which calls for further research. Advancing this research area is essential for promoting the Industry 5.0 vision, enhancing social sustainability in organisations, and improving the well-being of industrial workers. The aim of this study was to investigate *what implications AI-powered technological solutions can have on social sustainability in organisations*, with a specific focus on the well-being of industrial workers. The study's findings suggest that AI can provide solutions to improve social sustainability, particularly its aspects of emotional, mental, and physical well-being, safety, work efficiency, education, and training (Figure 1).

<FIGURE 1. ASPECTS OF SOCIAL SUSTAINABILITY IMPROVED BY AI-POWERED SOLUTIONS IN CASE OF OPERATORS OF HEAVY MACHINERY ABOUT HERE>.

Theoretical implications

First, the findings provide industry-specific empirical evidence for factors that influence the well-being of operators of heavy machinery. Such problems as cognitive strain, physical strain, safety concerns, and the varying proficiency of operators adversely affect organisational-level social sustainability and operators' well-being at work. Specifically, these problems have been proven to influence not only operators' everyday work efficiency but also their career duration and turnover intentions. A better understanding of working conditions and routines brings more clarity as to what factors impact social sustainability in organisations on the individual level. Thus, this study contributes to the stream of research investigating the potential of AI-powered solutions to support the health, information access, performance, behaviour, and decision-making of employees (Nishant et al., 2020; Pinzone et al., 2020; Grybauskas et al., 2022).

Second, the study's findings shed light on the many applications of AI-powered solutions for improving the well-being of operators of heavy machinery. In the case companies, these solutions are implemented primarily as the assistance, support, and training environment for the operators. Remarkably, human judgment and discernment still prove to be superior to AI. The ability of operators to assess the situation, consider all the variables in volatile environments, and make decisions supersedes the current capabilities of AI-powered solutions employed by the case companies. The decision-making ability of operators was highlighted as a key contributing factor to efficient machine operation, whereas the machine and AI are only supportive tools in operators' hands. As prior research states, AI can break the challenging tasks into smaller ones that require less skill, or even take care of the most stressful tasks and thus make the work cognitively less stressful (Stock et al., 2018; Pinzone et al., 2020). Another takeaway concerns AI-powered training systems. The findings show that the more skill and expertise an operator has, the less potential the AI provides for the operator's upskilling. This supports previous research stating that implementing AI-powered solutions to the work environment can have controversial effects on the feelings and well-being of employees (cf. Pinzone et al., 2020; Grybauskas et al., 2022). The study also shows that the relationship between skill level and level of engagement

with AI-powered training systems resembles the u-curve: AI-powered training systems are the most useful either for training new and unexperienced operators or for getting trained by highly experienced operators who can provide their expertise for the improvement of the training system. Those operators who fall in between these two extremes reportedly do not benefit from AI-powered training and assistance, as they consider their skill level to be good enough to do their work without AI support.

Managerial implications

From the perspective of managerial implications, this study highlights the challenges to which AI solutions will be able to find responses in the future among heavy machinery producers. By offering current and relevant information on the interplay between AI-powered solutions and social sustainability, the study provides an interesting additional understanding of what motivates companies in the heavy machinery industry to develop AI-powered solutions to improve drivers' well-being at work, extend their working careers, or increase work safety. All case companies recognised the importance of operator well-being not only for staff acquisition and retention but also for work efficiency.

The results are relevant not only for heavy machinery producers, but on a larger scale, these implications also provide interesting insights for other industries into how AI can be used to support the social sustainability of employees. Further, the results of the study demonstrate that among heavy machinery industry drivers, the working environment is demanding, and constant decision making causes cognitive and psychological load for drivers, the implications of which are both interesting and relevant for the developers of AI-powered solutions. The results of the study further demonstrate in more detail the factors causing the psychological load and the reasons behind the identified challenges. These include, for example, the long working hours of drivers and the pressure to constantly make a large number of decisions in a short time in a work environment where even one mistake can be fatal.

As another managerial implication, this research brings out solutions that are currently seen as potential alternatives for utilising AI in the heavy machinery industry. Although AI provides attractive

opportunities to increase social sustainability among employees, it is not without challenges. As such, the utilisation of these solutions currently involves a number of open questions, which are brought to the fore in research—including, for example, questions related to responsibility and, from the point of view of social sustainability, questions related to the learning of extensive new subject areas. The questions and concerns raised can guide the further practical development of AI.

Limitations and further research directions

One limitation of this study is the context of Finland. Although the studied organisations operate internationally, the generalisability of the results to other regions requires further research. For example, the safety implications of AI-powered solutions were not emphasised in the results, which can be due to advanced safety procedures that are already utilised in Finnish companies. It would be interesting to study whether safety implications are more important in other parts of the world. This study also focuses on the managerial perspective in utilising AI-powered solutions; thus, an in-depth analysis of the operator perspective is another fruitful direction for future research. Furthermore, the research on the factors influencing operator well-being is rather fragmented and incomplete. For example, some of the identified factors, such as loneliness, have recently emerged in the context of the well-being of operators of heavy machinery and require more scholarly attention. Further research could also focus on specific industries or interorganisational relationships to gain deeper insights into how AI-powered solutions contribute to social sustainability.

References

Bellamy, R. K., Dey, K., Hind, M., Hoffman, S. C., Houde, S., Kannan, K., ... & Zhang, Y. (2019). Think your artificial intelligence software is fair? Think again. *IEEE Software*, *36*(4), 76-80.

Breque, M., De Nul, L., & Petridis, A. (2021). *Industry 5.0: Towards a Sustainable, Human-Centric and Resilient European Industry*. Luxembourg, LU: European Commission, Directorate-General for Research and Innovation.

Brenner, B., & Hartl, B. (2021). The perceived relationship between digitalization and ecological, economic, and social sustainability. *Journal of Cleaner Production*, *315*, 128128.

Cacioppo, J. T., Hawkley, L. C., & Thisted, R. A. (2010). Perceived social isolation makes me sad: 5-year cross-lagged analyses of loneliness and depressive symptomatology in the Chicago Health, Aging, and Social Relations Study. *Psychology and aging*, *25*(2), 453.

Cao, G., Duan, Y., Edwards, J. S., & Dwivedi, Y. K. (2021). Understanding managers' attitudes and behavioral intentions towards using artificial intelligence for organizational decision-making. Technovation, 106, 102312.

Chatterjee, S., & Chaudhuri, R. (2022). Adoption of Artificial Intelligence Integrated Customer Relationship Management in Organizations for Sustainability. In Business Under Crisis, Volume III (pp. 137-156). Palgrave Macmillan, Cham.

Choi, T. M., Kumar, S., Yue, X., & Chan, H. L. (2022). Disruptive technologies and operations management in the Industry 4.0 era and beyond. Production and Operations Management, 31(1), 9-31.

Chowdhury, S., Dey, P., Joel-Edgar, S., Bhattacharya, S., Rodriguez-Espindola, O., Abadie, A., & Truong, L. (2022). Unlocking the value of artificial intelligence in human resource management through AI capability framework. *Human Resource Management Review*, 100899

Connelly, C. E., Fieseler, C., Černe, M., Giessner, S. R., & Wong, S. I. (2021). Working in the digitized economy: HRM theory & practice. *Human Resource Management Review*, *31*(1), 100762.

Jung, H. S., Song, M. K., & Yoon, H. H. (2021). The effects of workplace loneliness on work engagement and organizational commitment: moderating roles of leader-member exchange and coworker exchange. *Sustainability*, *13*(2), 948.

Lee, C., & Lim, C. (2021). From technological development to social advance: A review of Industry 4.0 through machine learning. *Technological Forecasting and Social Change*, *167*, 120653.

Longo, F., Padovano, A., & Umbrello, S. (2020). Value-oriented and ethical technology engineering in industry 5.0: A human-centric perspective for the design of the factory of the future. *Applied Sciences*, 10(12), 4182.

Lu, Y., Adrados, J. S., Chand, S. S., & Wang, L. (2021). Humans Are Not Machines-Anthropocentric Human-Machine Symbiosis for Ultra-Flexible Smart Manufacturing. *Engineering*, 7(6), 734-737.

Mahroof, K. (2019). A human-centric perspective exploring the readiness towards smart warehousing: The case of a large retail distribution warehouse. International Journal of Information Management, 45, 176-190.

Makarius, E. E., Mukherjee, D., Fox, J. D., & Fox, A. K. (2020). Rising with the machines: A sociotechnical framework for bringing artificial intelligence into the organization. Journal of Business Research, 120, 262-273.

Müller, J. (2020). Enabling Technologies for Industry 5.0—Results of a Workshop with Europe's Technology Leaders. *Directorate-General for Research and Innovation*.

Neumann, W. P., Winkelhaus, S., Grosse, E. H., & Glock, C. H. (2021). Industry 4.0 and the human factor–A systems framework and analysis methodology for successful development. International journal of production economics, 233, 107992.

Nishant, R., Kennedy, M., & Corbett, J. (2020). Artificial intelligence for sustainability: Challenges, opportunities, and a research agenda. *International Journal of Information Management*, *53*, 102104.

Pinzone, M., Albè, F., Orlandelli, D., Barletta, I., Berlin, C., Johansson, B., & Taisch, M. (2020). A framework for operative and social sustainability functionalities in Human-Centric Cyber-Physical Production Systems. *Computers & industrial engineering*, *139*, 105132.

Rogers, D. S., Duraiappah, A. K., Antons, D. C., Munoz, P., Bai, X., Fragkias, M., & Gutscher, H. (2012). A vision for human well-being: transition to social sustainability. *Current Opinion in Environmental Sustainability*, *4*(1), 61-73.

Romero, D., Mattsson, S., Fast-Berglund, Å., Wuest, T., Gorecky, D., & Stahre, J. (2018, August). Digitalizing occupational health, safety and productivity for the operator 4.0. In *IFIP international conference on advances in production management systems* (pp. 473-481). Springer, Cham.

Stock, T., Obenaus, M., Kunz, S., & Kohl, H. (2018). Industry 4.0 as enabler for a sustainable development: A qualitative assessment of its ecological and social potential. *Process Safety and Environmental Protection*, *118*, 254-26

Wang, Y., Xiong, M., & Olya, H. (2020, January). Toward an understanding of responsible artificial intelligence practices. In *Proceedings of the 53rd Hawaii international conference on system sciences* (pp. 4962-4971). Hawaii International Conference on System Sciences (HICSS).

Wilson, C., & Van Der Velden, M. (2022). Sustainable AI: An integrated model to guide public sector decision-making. *Technology in Society*, *68*, 101926.

Wirtz, B. W., Weyerer, J. C., & Geyer, C. (2019). Artificial intelligence and the public sector—applications and challenges. *International Journal of Public Administration*, 42(7), 596-615.

Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0—Inception, conception and perception. *Journal of Manufacturing Systems*, 61, 530-535.

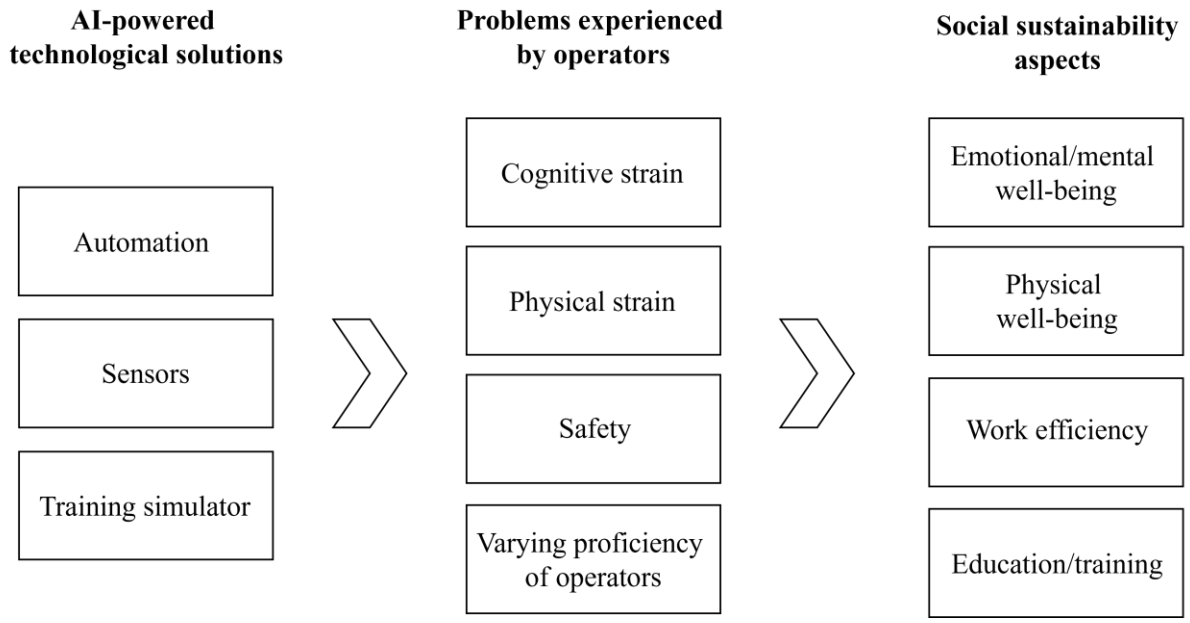

Figure 1. Aspects of social sustainability improved by AI-powered solutions in case of operators of heavy machinery

Table 1. Description of the data

Case company	Main offering	Size	Main data source and participants	Interviewees	Secondary data sources
A	Forest machinery	Large	Group interview	2	Webpages, Company presentation
B	Material handling machinery and logistic services	Mid Cap	Group interview	4	Webpages, Company presentation
C	Mining and rock excavation equipment	Large	Group interview	7	Webpages, Company presentation

Table 2. The potential implications of artificial intelligence

Case	Problem	Reason	Driver	Solution	Goal	Implications
A	Cognitive strain	Complexity of machine operation Need for fast and complex decision making Need for multiple simultaneous manipulations with the machine High costs of mistakes Loneliness—operator is along for long hours, remote work locations	The need to facilitate the decision-making process for the operator The need to reduce the number of manipulations	Automation (machine can take care of some sequences automatically)	Decision-making supported by technology	Emotional/mental well-being Work efficiency
	Physical strain	Multiple often simultaneous movements Back problems (muscle tension, static position) Fatigue and stress	The need to increase the duration and quality of operator's professional life	Automation (dashboard is simplified)	Reduced physical demand	Physical well-being
	Safety	One wrong move can damage a machine, a tree/shipment and sometimes even an operator's cabin	Safety of operator, machine, and environment The need to reduce losses associated with damage (e.g., fines from forest owners)	Automation (easier operation of the machine and prevention of collision reduces the cases of damage) Sensors (operator has more awareness of the situation around the machine)	Safer and better controlled work environment Increased profit (reduced maintenance costs, reduced fines)	Work efficiency Physical well-being Emotional/mental well-being
	Varying proficiency of operators	Training of operators is unequal in different countries Operators with less experience are less productive and less efficient Overconfident operators tend to be more careless	The need to facilitate the induction of new operators	Training simulator (training in the simulated environment that is close to real life but safe at the same time)	Well-trained operators Better productivity Less damage to machines and the forest Less stress for new operators Enabled peer learning	Education/training Work efficiency Emotional/mental well-being

		Experienced operators think they are good enough				
B	Cognitive strain	Many variables in the environment require a lot of focus and brain from operators The need to stay focused all the time (8-13 hours working per day)	The need to facilitate the decision-making process for operator	Automation (operator assisting control system)	Machine does some decision making and operations for the operator (‘machine works the way operators do’)	Emotional/mental well-being Work efficiency
	Physical strain	Vision problem—some people just do not realise the distances, do not see properly in the dark or kind of in different environment	The need to make the operation of machine easier for operators with vision problems		Extended pool of suitable candidates to operator position	Work efficiency
	Safety	One wrong move can damage a machine and/or a shipment People moving around machines are not always visible	Safety of operator, machine, shipment, and people around the machine Safety standards imposed by the government The need to reduce losses associated with damage	Automation (operator assisting control system) Customers may reduce the number of people in the working sites	Safe work environment Increased profit (reduced maintenance costs and reduced fines)	Work efficiency Physical well-being Emotional/mental well-being
	Varying proficiency of operators	In some countries training can be problematic: literacy, training is quite visual-based, teaching methods, skill difference	Training in a safe environment	Operator assisting control system	Well-trained operators Better productivity Less damage Less stress for new operators or operators who prepare for new tasks	Education/training Work efficiency Emotional/mental well-being

C	Cognitive strain	Complex operation because of a lot of cycles and task Operators have to make many choices	The need to improve operator's work (operators play a key role in machine operation)	More automation with the rock support drills Second version of software that could actually beat the manual operator	Decision-making for operators is supported by technology Reduced cognitive stress	Work efficiency Emotional/mental well-being
	Varying proficiency of operators	The way operators work impacts the machine and the whole process	Customers really would like to help the operators to learn to use the machine better way	More automation with the rock support drills, then not much education for operators is needed	Better results Better productivity Better efficiency through process automation	Work efficiency