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ORIGINAL ARTICLE

Digitalization and changes to work organization and management in the Norwegian petroleum industry

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Abstract
This article analyses how implementation and use of digital technologies involve changes in work content, organization, and management in the petroleum industry. This is important, given that the industry is in a phase with mature technology and heavy pressure on efficiency and cost-effectiveness, at the same time as older systems and work processes prevail. The article draws on data acquired through interviews in a number of companies, organizations and specialist teams. The results show that far-reaching digitalization will mean radical changes to the way employees and managers work. The level of success in using digital technologies can be related to the ability to alter the content and form of work and expertise requirements, while retaining trust in technology and coping with uncertainty. A key conclusion is that clarifications related to work processes, roles, and responsibilities between the various actors in the supply chain are the most significant obstacles to successful technology adoption.

Keywords Work organization · digitalization · Industry 4.0 · interorganizational complexity · management · petroleum industry

1 Introduction

This article analyzes how the implementation and use of digital technologies relate to changes in work conduct, organization, and management in the petroleum industry. Introducing new technology and digital solutions changes work tasks and processes, and digitalization therefore has consequences for the content, execution, and organization of work (Forman et al. 2014; Tilson et al. 2010). However, studies show that it can be challenging to assess and predict what work process adaptations follow from new technology and systems (Cresswell and Sheikh 2013). These could relate, for example, to changed roles and procedures, which may in turn alter power structures as well as organizational and business models.

Literature on the implementation and use of new technology emphasizes the importance of focusing on human, social, and organizational aspects, in addition to technological factors (e.g., Carlsson et al. 2022; Yusof et al. 2008). For example, studies have shown that management support is important to facilitate the redesign of work processes, to ensure the necessary education and training, and to create shared goals and build bridges between the different actors involved (e.g., Greenhalgh et al. 2004). Furthermore, recent studies show that uncertainty associated with digitalization relates more to employees and their technical expertise than to the actual technology (Trzaska et al. 2021). However, in-depth knowledge is lacking about the way digitalization involves changes in the division of responsibility, allocation of duties between humans and machines, modes of collaboration, and organizational structures. There is hence a lack of empirical studies on the current digitalization trend in different sectors (Thun et al. 2019), including a scarcity of research about digital transformation in the energy sector more specifically (Fernandez-Vidal et al. 2022). This article addresses this gap in research, and seeks to answer the following research question: *how does implementation and use of digital technologies influence and depend on human and organizational factors?*

Digitalization is high on the agenda in the petroleum sector, a highly innovative industry with historically many developments of new technologies and where many

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companies currently have ambitious plans for increased use of digital technology (Thune et al. 2019, DNV GL 2017). Major restructuring processes involving the implementation of digital technology and associated modes of working and organizational models are currently being pursued by petroleum companies. As the petroleum industry in Norway is at the international digital forefront and is becoming increasingly dependent on digital systems (Monteiro 2022; Fernandez-Vidal et al. 2022; Bergh et al. 2021), it represents a highly relevant context for digitalization research. The purpose of this study is on this basis to add to the understanding of the interdependencies between technology, human, and organizational factors (HTO) by investigating how digital tools are implemented and affect the working life of employees and managers in organizations working on digitalization efforts. The article uses data collected through semi-structured interviews and workshops with technical experts, employees, managers, labor union representatives, and safety deputies in operating companies and other organizations in the petroleum industry.

2 Theoretical framework

Various assumptions about changes to work and organization related to technology use and greater access to information have long been discussed in the research literature (Malone 2004; Brynjolfsson and McAfee 2014). Autor (2015) identified why automation and technological progress have not substituted human labor, but that the frontier of automation and advances in artificial intelligence and robotics is rapidly advancing and both substitute for and complement labor, increase productivity, and lead to higher demand for labor. Zuboff (1988, 2019) was among the first to recognize how digital technologies transform work as the reach and scope of digitalization have expanded (Monteiro 2022). While Brynjolfsson and McAfee (2014) and McAfee and Brynjolfsson (2012) distinguish between early or predigital practices and—as a result of radical change—more recent forms of digitalization such as artificial intelligence, blockchain, digital platforms, and the Internet of Things (IoT), Monteiro (2022:2) describes small-step, socially negotiated (with unions and national safety authorities), digitally enabled transformations of work practices, roles, and organization in the petroleum industry. Still, the changes over the last decades are said to significantly have changed existing organizational routines, roles, and division of labor (Monteiro 2022; Rosendahl and Hepsø 2013; Forsythe 1993).

One aspect given prominence in the scientific discussions has been the significance of information and communications technology (ICT) for opportunities to interact internally and across organizational boundaries, which calls for changes in the geographical distribution of work and can in turn have both human (perception of autonomy, for example) (Mazmanian et al. 2013) and organizational effects (such as security) (Grabowski and Roberts 2016). In the petroleum industry, the availability of real-time sensor data and engineering applications for visualizing the data enables onshore engineers to actively perform the manual and embodied work formerly done offshore. Big data, being large volumes of data that are generated, captured, and processed, are considered to be a breakthrough technological development over the recent years (Günther et al. 2017:191), giving organizations great challenges and opportunities. Monteiro (2022:4) states that the content and context of work practices have profoundly changed in offshore oil and gas. Future research needs to focus on the work involved in producing the data and empirically examine the different actors in organizations' work on big data (Monteiro 2022:73), to empirically validate the societal consequences of organizational actions (Günther et al. 2017:204).

With the rapid sociotechnical innovations in the petroleum industry, the concept of *sensework* has been introduced (Haavik 2014, 2017, 2020) that addresses "the nature of sociotechnical work in safety–critical operations, where groups of professionals try to put together pieces of information to create a coherent picture of to give meaning to familiar and unfamiliar situations." (Haavik 2014:269). Sensework unfolds in multidisciplinary interpretative work in high-tech environments where dependence on digital sensor data and digital representation is high (Haavik 2014; Almklov and Antonsen 2020), and it is analytically associated with work and organization in contexts of increased use of sensor data and new technology, including the use of digital representation to collaborate, communicate and coordinate (Haavik 2017:152). Hence, sensework has the potential to theoretically and empirically cover the characteristics of the distributed and digitalized work environments (Haavik 2010, 2011, 2020), being of relevance for understanding the implementation of new technology in the petroleum industry. Haavik (2020:113) states that as the sensework research agenda is in the making, empirical studies of sociotechnical work processes which inspire and direct the research are welcome.

The petroleum industry is characterized by complex, specialized work processes and geographically distributed teams. Because of its high level of outsourcing and organizational complexity, it is organized into an industrial hierarchy or ecosystem of organizations (Monteiro 2022; Milch and Laumann 2018; Bayerl and Lauche 2010). This ecosystem is assumed to work assumingly "seamlessly" together on long-term contracts. The many different organizations involved in the different but interdependent activities have, however, long created collaboration and communication problems according to Monteiro (2022:57). An activity or a set of linked work processes are, in many cases, not confined to a formal organization, employee or department in a specific company. Rather, work processes often involve people from several companies (Milch and Laumann 2018). For that reason, technology development and implementation projects may have important stakeholders and users in a number of organizations.

In contrast to the Norwegian authority-imposed regulations to facilitate data sharing, companies tend to "black box" measurements and raw data to protect business interests, which undermines the possibilities of digitalization (Monteiro 2022). Also, as specialized rather than integrated digital tools dominate the market, organizational and professional silos are amplified. In sum, this is assumed to limit communication, sharing, and collaboration across companies and disciplines, potentially hindering digitalization. On this background, researchers are advised to focus on the digital transformation of the whole industry rather than the regular case studies of a particular organization or profession (Monteiro 2022:178).

Despite the pressing need to digitalize operations and the rapid development of new technologies available (Fernandez-Vidal et al. 2022), developing and introducing new technology in such complex organizational systems as the petroleum industry is associated with uncertainty and experimentation. Information systems researchers acknowledge that realizing value from technological advancements is complex and emergent and that dynamic processes that involve many social dimensions reach beyond organizational boundaries (Marabelli and Galliers 2017; Günther et al. 2017:205). Hence, organizations need to realign work processes and organizational models in order to strategically benefit from digitalization, automatization, and the use of big data. Information systems literature emphasizes in this regard the importance of devoting attention to social and organizational aspects (Cresswell and Sheikh 2013). Major challenges relate to defining and handling new work processes after adopting technology and in tackling the dynamic and cyclical (rather than linear) phases, since the technological, social, and organizational dimensions gradually adapt to each other (Salazar and Sawyer 2007). This calls for interdisciplinary research drawing on theories such as psychology, ethics, and sociology, and incorporating knowledge from computer science and artificial intelligence according to Günther et al. (2017), creating emerging scientific fields like *computational social sciences* and *digital humanities* (Kitchin 2014). Taking this into account, research on technology implementation emphasizes the importance of looking at *HTO* (human, technology, organization) aspects and their mutual adaptation (Cresswell and Sheikh 2013; Barrett 2007).

Regarding the relation between *technology* and *human aspects*, Johnson and Real (2007) indicate that end users are generally not negative to new technology as such but are liable to oppose the use of systems that they regard as inadequate or in conflict with their own values, goals, and roles. A key feature of the technology should therefore be that it is perceived as beneficial and as providing relative benefits compared with existing practice (Marres 2017). This includes both paying attention to speed, user-friendliness, and cost, ensuring that the new system is compatible with existing technology and associated work processes. Research also refers to a number of social aspects related to technological innovation which improve the chances of successful implementation (Marres 2017). These include a sufficient understanding of ICT and general user competence, successfully building the right attitudes to innovation, taking account of financial considerations, and ensuring that the technology supports and is suited to employee roles and tasks. In contrast, technologies which unintentionally undermine the social status and/or professional autonomy of employees are unlikely to be accepted or adopted by users. However, active and adequate involvement of important stakeholders, testing of early prototypes, and open communication channels can help to ensure that new technology and systems are trusted, valued, and utilized.

As digital technology matures and becomes routinized, a larger proportion of normal operations offshore in the petroleum industry are likely to experience larger differences in work content, processes, and requirements when unexpected incidents occur. That could become even more relevant with a growing degree of specialization and the threat of "black boxing", where communication, openness, and information flow will be important (Latour 1986, 1999; Haavik 2014: 270). Black boxing refers to "the way scientific and technological work is made invisible by its own success. When a machine runs efficiently, when a matter of fact is settled, one needs to focus only on inputs and outputs and not on its internal complexity" (Latour 1999:304). Waardenburg et al. (2022) illustrate this by the example of humans having difficulty to discerning how and which connections between data points are made, making it challenging to understand how algorithmic predictions are generated. This presents a challenging new phenomenon as artificial intelligence and machine learning become increasingly difficult for humans to understand, increasing the risk of creating a "black box" problem (Waardenburg et al. 2022).

Regarding *organizational aspects*, research emphasizes the importance of senior management and professional support from specialist personnel to secure both ownership of and necessary attention to technology implementation such as machine learning (Kreutzer et al. 2018). Studies also highlight the importance of collegial and organizational support for building a positive experience with new technologies (Konttila et al. 2019). Industry-level studies show a strong connection between the development of high-technology equipment and the demand for skilled, educated workers, being consistent with the idea that increased use of ICT is associated with a demand for human capital (Brynjolfsson and Hitt 2000). Leading specialists can in this regard take on the role of bridgebuilders to reduce the gap often found between IT staff, management, and users. Professionals can also facilitate redesign and workflow improvements, provide adequate training and support for users, and direct attention to key challenges.

Research also emphasizes that new forms of digitally mediated employment contracts and hiring create opportunities for greater use of temporary and short-term relationships between employer and employee at the expense of traditional long-term employment (Nesheim et al. 2007). This can moreover be significant for such factors as job design, work and resource planning, recruitment, education and training, and compensation systems (Aguinis and Laval 2013). Changes in standards for various occupational groups and management levels are also under discussion in relation to technological advances (Brynjolfsson and McAfee 2014; Autor et al. 2003), as is the extent to which different jobs and work tasks can be performed by machines (Frey and Osborne 2017). Another aspect of this development is increased specialization (Malone et al. 2011), and thereby greater differences in expertise between employees involved in the same work process and who must coordinate their work tasks. Kreutzer et al. (2018) also emphasize that management clarity is necessary in providing strategic consistency with the aim of ensuring that personnel in the organization work towards a common goal. In addition, studies show that a pragmatic assessment of likely benefits and trade-offs—with regard to time consumed, for example—must be communicated to employees (Nöhammer and Stichlberger 2019). Further considerations involve avoiding scope creep in digitalization projects, taking into account interoperability, and choosing an implementation method adapted to the technology and organization in question (Schallmo and Tidd 2021). Through this process, management must also plan for potential extreme cases – such as a failure of the technology.

Viewed overall, extant research shows that technology implementation is affected by a number of technological, human, and organizational factors, which may vary in significance between different implementation stages (Ustundag and Cevikcan 2018). Digitalization requires organizational routines and processes to be adapted to the opportunities and limitations represented by the technology and the industrial context. That becomes even more important when combined with a challenging operational setting and high-risk activities, as in the petroleum industry.

3 Methods, data collection and analysis

The article analyzes interviews with technical experts, managers, and employees from various organizations in the Norwegian petroleum industry. Interviews were conducted in 2018 with a total of 34 participants. Recruitment for participation in this study was performed by the researchers contacting different companies in the industry which had a track record within digitalization, being at different stages of technological development, having innovative solutions, and/or strategic ambitions. Further, technical experts were contacted on the basis of their professional track record, as well as persons in public organizations who had a public and/formal role of relevance. Public records, the researchers' network, and advice/tips from participants and stakeholders (so-called "snowball effect") were used to get contact information. All participants were given information about the project and their rights according to the General Data Protection Regulation (GDPR) and ethical aspects and signed a declaration of consent. See the table below for the number and types of interviews. Due both to practical reasons and to be as methodologically targeted as possible, informants were interviewed individually when personal responses and experiences, company or professional experiences were the topic, and in groups when a group dynamic, discussions, and reflections were needed (Table 1).

About a third of the participants were technical experts from Norwegian research teams involved with offshore and petroleum technology, risk management, ICT, and data security. Another third were key individuals at various companies in the petroleum industry. These were located in Norway but often had international ownership and operated in a global market. Both operators and suppliers in the petroleum industry were included in the sample, and interviews were

Table 1 Participants, number of interviewees and data collection

Type participant	Number of interviewees	Data collection
Technical experts	10 persons	Individual interviews (1) Group interviews (3)
Employees and managers in operating companies and suppliers/subcontractors	12 persons	Individual interviews (3) Group interviews (3)
Labor union representatives and safety deputies	12 persons	Group interviews (4)

conducted with two–three people in each company who had to vary strategic and operational responsibilities and experience with digitalization. The final group of participants represents employer organizations and unions (elected officials in the latter case) as well as chief safety delegates. Semi-structured qualitative interviews—either individual or group—were conducted.

An interview guide tailored to the type of participants was used. The interview guide represented a general script and functioned as the main thematic structure of the interviews (Kvale and Brinkman 2009). The guide was based on the HTO framework and hence aimed at covering human, technological, and organizational factors. The topics covered included knowledge of and experience with digitalization efforts, as well as health, safety, and environmental (HSE) consequences, views on work processes, management, collaboration between employers and employees, supervision, and regulations related to digitalization. The topics that were discussed varied according to organizational affiliations, roles, experiences, and competences of the participants. The interviewees rarely brought up themes outside the interview guide.

In the data analysis process, the individual interviews were recorded and read, and transcripts were written focusing on digitalization processes, the consequences, and how this was experienced personally, in teams and organizations, and reflections considering future digitalization. Similarly, the group interviews were performed focusing on the same subject. Transcripts were written, based on both the individual interviews and the collective reflections from group interviews, focusing on the different stages of and experiences with digitalization. The transcribed text was coded according to topics. The analytical phase of the study involved mutual construction of meaning among the researchers (Rismark and Sølvberg 2007), where the first-stage analysis was performed by one researcher, and the second stage involved a collective discussion of results among all researchers. In this stage, the research team had open discussions about the coding and analytical practice. In total, the analytical process was exploratory and inductive, characterized by alternation between individual analysis and joint discussions based on empirical data and broad theoretical understanding.

A potential weakness of the data material is that it represents a limited sample which can hardly cover the diversity of digitalization in the petroleum industry. We were nevertheless able to speak with a broad range of participants and achieved a satisfactory information density in the interviews. Viewed overall, the data sources provide a good basis for analyzing the industry's views of and experience with digitalization.

4 Results

The data have been analyzed based on two related perspectives—how do technology implementation and usage in the petroleum industry relate to *human* and *organizational* aspects respectively? Quotes from participants are used to illustrate key points.

4.1 Human aspects

A number of factors related to the connection between people and the development, implementation, and use of digital technology can affect how far enterprises succeed in their digitalization work. They include changes to work content and form, trust in technology, alienation, competence requirements, and insecurity and resistance to change. These factors are discussed below.

4.1.1 Work content and form

Where work content and form are concerned, the interviews show that digitalization can encourage change in several ways. First, development processes and measures are pursued in order to provide physical support for demanding manual operations. One example is developing digital robots for the drill floor to reduce the physical workload, as described by this participant:

> *We're going to select a drill floor robot to replace many of the manual activities done on the drill floor today. We've identified a large number of lifting and handling operations done there by personnel today which we see could be carried out in future by a flexible robot ... Tools will be developed which allow it to replace all the individual manual operations.*

Second, the industry is devoting great attention to developing systems which will provide better decision support. These could involve applying real-time data during drilling operations to obtain early warning of challenges and reduce the risk of making mistakes, while also enhancing operational efficiency. As one participant explained:

> *We have software and controlled physical engineering models which assist the person sitting out on the rig, so that he gets the early warning ... so that safety in the well improves. And when safety improves and this becomes a controlled work process, efficiency will also increase and the risk of errors will be reduced. That's what the software will gradually take over.*

Furthermore, new technologies often involve communication changes in terms of both form and content. Increasing the proportion of ICT-based decision support and automation means more ICT-based interactions between employees over geographical and organizational boundaries. A related issue given emphasis is that developing and implementing new decision-support systems call for adapting/changing work processes. For various reasons, however, this is often overlooked or left out. However, a lack of alignment between technology and work processes and organization may increase the risk of undesirable incidents and is therefore an issue which requires attention.

4.1.2 Trust in technology

Trust in technology is central when work becomes more technology intensive. A number of participants stressed the need to balance trust in decision-support systems with a critical approach because relying too much on the information they provide involves a risk. This must be viewed in relation to the technological maturity of system users, as well as their expertise and experience. Where expertise is concerned, particular emphasis is placed on the need to be on the alert in the transition from an active to a passive role in work execution because of more automation and the use of decision-support systems:

> *The system can cause people to become inattentive. [For example] ... if you become so confident that your adaptive cruise control will brake when the car in front does, you can get a little relaxed behind the wheel. That's also a risk, right? So keeping on your toes and actually starting to monitor a process involves more than just driving along, and that's obviously a change for people. ... One of the big risks, which applies generically for digitalization, is that you rely on what you're given.*

Lack of trust in the technology can also be a barrier to digitalization. Our participants describe circumstances where relatively mature technology fails to function satisfactorily and creates skepticism about allowing technology to take over key roles in more safety–critical operations. Building up the necessary trust calls for more testing and involvement of employees and users, particularly since many operations involve the risk of major accidents.

4.1.3 Alienation

A potential negative effect of digitalization is work alienation. When connecting systems and processes in new ways, people often forget the underlying preconditions identified and assumptions made. On other occasions, assumptions which no longer apply are retained. People required to take critical decisions risk being alienated, and no longer have a full overview of vulnerabilities. This will be a relevant issue in automating work on offshore installations. Another aspect highlighted in the interviews is that, although automation creates a more limited area of responsibility and a shift in concentration and attention by the personnel involved, it does not eliminate human responsibility and risk:

> *You still face a personal risk. Because you're much more closely tied to the job being done, you're directly responsible, the only thing is that it's digital, if you do anything wrong it remains with you the rest of your life.*

4.1.4 Competence requirements

Changes in the content and conduct of work entail the need and demand to update knowledge and expertise. That applies at both operational and management levels. In the first case, it involves learning about the safe and correct use of new systems and technology for executing the work. Generally speaking, more ICT expertise will be needed—including people with advanced technical education who can provide support in the form of land-based expert and decision support. One participant explained how this could change for the driller role on installations:

> *When automation increases, you need a much better understanding of the mechanics—in a way, after all, that's not the driller's focus now. So the profile of a driller in a more digital world with more automation is not necessarily the same as today. Particularly if he's away from the rig altogether.*

Furthermore, it is assumed that differences in the way onshore and offshore personnel develop their expertise will widen. While the former group will be characterized by increasing specialization, employees on installations will be generalists and have an operational role. That leads to a wider competence gap between personnel who must interact, which can create HSE challenges and demand attention. An important consideration in this respect is that a development in roles which creates a bigger expertise gap between sea and shore makes big demands on communication and a "sensework" capability (Haavik 2014, 2017, 2010), at the same time as this trend limits the ways communication can be conducted. This is also related to the relevance and risk of black boxing of work. More complex and specialized components in a work process and increased use of digital technologies that potentially subsume key work practices (Anthony 2021), combined with longer intervals between "opening" and understanding components and the connections between them, will represent challenges. That will require attention and purposeful training. One participant described this:

How you move from automated to manual mode, and are ready to handle these situations, become important. And particularly if we hope that automation reduces the number of incidents. If you're less exposed to these incidents, you're less trained in dealing with them. So these are fairly important elements in maintaining safety. You increase safety but can also decrease it through a lack of competence.

Participants also noted that the current phase of substantial technological development in the industry could mean particularly heavy burdens and expertise requirements. Changes related to implementing new technology will be a burden since it is initially necessary to handle both old and new ways of doing things. That calls for clear leadership:

Because, of course, you don't take anything away to begin with, you simple pile on something new. And if you're sitting there as a drilling engineer and must maintain all the old systems ... this will come on top and then becomes a burden.

This concerns the need for a strategic perspective on technology and decisions related to implementation and management. A number of participants noted that developing the digital expertise of managers will be important and that this is one of several factors which will be significant for the industry's ability to achieve a mutual evolution of technology as well as work processes and organization. That applies not only to internal technology development in the companies but also to the knowledge required to handle issues related to interaction, coordination, and integration of processes across organizational boundaries.

One concern related to expertise requirements and development mentioned in the interviews is inadequate recruitment of younger, digitally competent employees. Recruitment of digital expertise has been limited at a time of high demand for such skills, combined with downsizing in the industry. That has created a big gap between demand and reality with regard to digital expertise.

4.1.5 Insecurity and resistance to change

Much of the industry's digitalization attention is directed towards moving jobs from sea to shore. One consequence of this is greater job insecurity because of changes to work tasks and processes as well as associated expertise requirements. Participants report that it can be challenging to convince employees that they will be doing other tasks while simultaneously creating a sense of security. That applies at both operative and management levels and may be factors which pose challenges for adopting technology and changing work processes. Opposition to change because people feel that their position is threatened, combined with a system for technology adoption where managers on the installations largely decide what to accept, will complicate such introduction and the necessary changes to work processes.

4.2 Organizational aspects

The interviews show that technology development in the petroleum industry is influenced by and has a number of consequences for organizational conditions.

4.2.1 Distributed work

A key aspect associated with digitalization is transferring people from sea to shore. Several operating companies demand substantial reductions in offshore personnel, first and foremost for reasons of efficiency. This also has safety implications. Positive consequences are fewer employees in exposed locations, and thereby a lower risk of physical injuries. Furthermore, participants emphasize that experience transfer and opportunities for learning across installations are improved if personnel at onshore centers are involved in several parallel operations on different facilities. Waiting time is also reduced at such centers compared with offshore workplaces. For the same reason, opportunities to build up expertise are better, and it is easier to introduce new tasks and processes on land.

A change is occurring in the distribution of competence between sea and shore, with a move towards leading-edge expertise on land and "operators" out on the installations. According to one participant, a general pressure exists for offshore personnel to be cross trained (in other words, become more generalist). That calls for training and updating of expertise. Sending specialists offshore for a day or two to solve a specific problem is being replaced by ICT and land-based expert and decision support. Participants also note that this development means information must be shared to a greater extent with people in their free time so that they have the necessary overall understanding. Moving employees from sea to shore and a greater diversity of tasks for those offshore can also result in more frequent call-outs for employees, and in sleep problems and challenges with swing shifts.

"It's very sensible that you create a team which provides a more even "utilization" of the resources which are out there. But that, of course, requires masses of training to be put in place with regard to the tasks to be done. And circumstances can also arise where you might end up having to wake up people who're sleeping, which could cause the accident

> *frequency to rise because personnel fail to get the sleep they need. There are many factors.*

Moreover, participants emphasize that work schedules represent a challenge when moving personnel from sea to shore. People working offshore on the two-week on, four-week off schedule do not necessarily live close to their employer's office premises/onshore operations center, and different work schedules on land could pose challenges in retaining expertise.

4.2.2 Interaction

Distributed work presupposes interaction, communication, and data-sharing. A number of participants emphasize that the biggest challenge they experience in relation to distributed working is communication. This relates to problems in establishing a shared understanding between personnel involved in a work process when communication is technologically mediated and thereby provides limited input on body language and so forth. Participants also note that much learning and experience transfer occurs through informal channels and meetings, which are limited in distributed working. However, this may to a certain extent be a matter of habit and calls for adaptation.

Many initiatives are being pursued with regard to interaction and data-sharing, both internally in companies and across organizational boundaries. A number of companies, for example, are working to develop/implement sharing and applying data for drilling operations. One consequence is a necessary shift from a planning to a communication culture in the industry. This is demanding for both technological and organizational reasons, and big differences are perceived between realities and visions. Furthermore, major challenges are described with regard to IT security and access to systems and data for different personnel. Having to strike difficult balances between data security measures and the need for sharing, updating, and using information is also reported by participants. In addition, legal and ethical issues raised by more data-sharing and transparency are emphasized, such as the type of data to be included:

> *… this came up when we talked about automating error reporting in the software. Do you send it then, because somebody has observed it, [and] do you then send their name?*

Organizational factors include different attitudes to inter-organizational collaboration and data-sharing. All such conditions have significance, a relationship with a perceived democratic approach to developing and implementing technology.

4.2.3 Complexity and absorbability

Numerous initiatives and development processes have been initiated in the companies. The level of complexity is high in technology, work processes, and organizational conditions, both within the companies and in the industry overall. This means that adapting to different demands and wishes from partners can be challenging. Participants report potential challenges in enabling personnel to use technology/systems developed externally. This is related to the need to be able to adapt to different operating models and requirements between various partners and clients, and the increased workload which follows from implementing new technology and associated work processes must often be combined with traditional modes of working.

Many participants emphasize that horizontal collaboration (between operating companies) is important in making it simpler for the suppliers to handle the complexity which increased digitalization and organizational changes involved. In this context, attention is also called to the difficulty of striking a balance between technological progress in small steps and an overarching, integrated, and strategic approach to modernization through the use of digital technology. The latter is important for seeking key connections and dependencies across areas and processes (achieve appropriate integration, data flow, management commitment, and so forth), while the former may be necessary to create a good maturation process and help users feel secure with new technology and systems.

> *You're solving a digital jigsaw puzzle about the way future work process and technology will look. But if you think you know today what the solution will look like, you don't know it. You have to start with the pieces you intend to develop and arrive at optimally, then build around these, and then you've got to expand. And I feel a bit that you see the big companies, which are kind of going to design the whole puzzle and then start putting it into practice. But you must start with the pieces ... you must accustom the organization to use this type of tool, then of course you're under way with digitalization.*

This could be one reason for the perception that starting to adopt new technology is not always followed up by an appropriate change in work processes, as a participant from one company describes:

> *But they're kind of, you could say that you start with the technology, but don't do anything with the work process.*

4.2.4 Barriers to technology adoption and organizational change

The petroleum industry has a significant potential for efficiency gains and improvements through new technology, but nevertheless there exists an adoption reluctance among actors. One view shared by a number of participants is that the sector has failed to utilize available technology and thereby missed out on major opportunities for innovation. In that context, the participants described several (related) barriers to technology adoption. This is relevant from an HSE perspective, since conformity between technology, work processes, and organization is needed for safe implementation.

Structural factors in the industry, power structures, and business models, represent key barriers to developing and/or adopting available technology which enhance efficiency (viewed overall) and reduce the risk of undesirable incidents. Today's technology and ways of organizing and executing work are closely tied to the industry's structure and the business models of the actors involved. Acquiring and implementing technology/systems which means changes to these interactions are therefore difficult to achieve. For the same reason, radical innovation – in other words, developing technology that breaks with established business models and culture – may also be left to small companies with little influence on adoption decisions:

> *If you succeed, you take away business, and then they're not so very interested ... they aren't so very interested in promoting the big innovative changes ... once you've proven the technology, once you've passed, I'd wish they made a bigger effort to accelerate it out into the market ... the difficult part, which I believe will become harder and harder, isn't always the technology bit, but the commercial bit. Contracts and how you allocate the profit.*

Participants point out that many actors in the industry have done too well out of old technology and are unwilling to cannibalize their own business models. Nor was there much pressure from the operators until the most recent oil crisis began. Related to this is the description of the sector in general and its management culture in particular as conservative, which affects both knowledge about and attitudes to technology development and application in the companies and the industry. Developing digital competence among managers is therefore regarded as central to securing technology adoption and organizational adjustments:

> *It's clear that people, ... if you haven't had much education, it's not certain that you understand what research is about. And even if you've got the education, you must kind of think a little before you grasp that this is research, it must be repeatable, provable, it is in a way a universal result. And I believe it's not sort of the case that you bang the table and say, 'OK, here's the research report', ah ha, then it's obviously the truth. No, we must be able to doubt, there's a milieu here.*

The petroleum industry is also characterized by differences in power structures and culture between both companies and different disciplines. That is significant for decisions on adopting technology, particularly because work tasks and processes involve a risk of major accidents. A participant from a supplier company describes this as follows:

> *It's a huge challenge in an industry where the one making the most 'noise' and sounding very assured gets their way, and perhaps not the one sitting in a corner with the answer ... and I think that's part of the drilling sector's dilemma, and I think it's still allowed to continue to behave in this way.*

That trend could reflect the big risk associated with drilling wells, for example, and that these actors have thereby acquired major influence and self-determination. However, this corporate (or industry) culture can in itself represent a risk factor.

This is also related to the perception of a large degree of self-government on the installations. When combined with relatively little rotation/mobility (people have been on the same installation for a long time), it means that distinctive cultures and working methods have been developed. People view their position (installation) as unique and are therefore skeptical about adopting standardized technology and working methods ("they don't suit us"). One result of a high level of self-determination is that technology adoption becomes more people-dependent:

> *If you convince the one who's to deliver results, if he believes in it and wants to do it, and has a little backing from his boss, a lot can happen. But if his boss is negative to this, it means there's not much vigor in the system. And then they can sit at head office and push as much as they want but forget this.*

This leads thereby to great diversity in technology and work processes between different fields, installations, and organizations. That can pose a challenge when employees move to shore, where they are then intended to contribute to operations on different installations (where things are done differently):

> *In one way, of course, you get operations done identically. Today, everything's all over the place, depending on who's shift it is right there and then.*

Another factor which can be significant for technology adoption is the oil crisis which the industry has been through. Although also highlighted as a factor which encourages paying attention to digitalization, this crisis is also claimed to have imposed investment constraints and a “a gamble that things will go well without the best equipment”. Both good and bad times thereby have the same consequence for technology investment. When conditions are good, investment in new technology which could change business models is not under pressure, while bad times impose restrictions on such spending to save money. A final factor mentioned is challenges related to the size and expense of much equipment, and the fact that it takes a long time and requires heavy investment to build/develop (system inertia). This can make digitalization difficult, since big differences in development pace and models will exist between physical and digital components meant to work together (internet of things).

4.2.5 Changes in roles, structures, and responsibilities

Digitalization/technology development in the industry involves more interaction, sharing and application of data, and integration of processes. One consequence of this is that interfaces between actors become more unclear – where an operator, for example, develops algorithms for using physical equipment owned by a supplier. Such a trend presents problems for aspects like the division of responsibility and ownership. However, the technology is at too early a development stage to permit being specific about future organization models in the industry:

> *... as this technology develops, the interface between us and the operator is starting to get vague again, right? ... So that interface is fluid today, and the service companies are also producing their own software bits, then the rig suppliers arrive with their automation initiatives. So it’s important to get a very controlled change process then. And it’s not given how the cards will be dealt out when we’ve been through this journey.*

This issue will also become more relevant with the increasing extent of digitalization for physical equipment (internet of things) mentioned above. Key issues here will relate to the division of responsibility, risk, profit distribution (business model), and so forth. According to the participants,

Table 2 Summary of findings

Human factors	
Influence	- Reduction of physical workload - Early warnings of risk and error - Risk of work alienation and black-boxing - Changing competence requirements (both employees and managers)
Dependence	- Balance of trust in technology with critical perspectives o Requires testing and involvement of employees - Management of resistance/opposition to change
Organizational factors	
Influence	- Increase in distributed work o Potential for transfer of experience and learning across work locations o Reduced waiting time o Easier building of expertise/specialists o Changing distribution of competence between onshore and offshore locations o Changes in work schedules o Reduction of informal communication channels - Changes in roles, structures, and responsibilities o Changes in interfaces between actors o Changes in distribution of risk, ownership, and profit
Dependence	- Strategic perspectives on competence development/ sustainment and recruitment o Building of digital competence of higher-level managers/executives to change the conservative industrial culture - Focus on interaction, coordination, and integration of work processes across organizational boundaries - Focus on communication and information sharing o Balance of security issues and data/information sharing and openness - Management of complexity and variance in technological maturity among partners o Management of different operating models - Balance between strategic/integrating approach to technology development and incremental progress - Power structures and business models may influence technology adoption

such issues have not been prominent so far, but attention is being devoted to work on future models for co-creation.

4.3 Summary of findings

The results show that the implementation and use of digital technologies both influence and depend on a number of human and organizational factors. A summary of the findings is presented in Table 2.

5 Discussion and implications

The findings presented above show that implementation and use of new digital technologies in the petroleum industry are associated with changes in organization and conduct of work. Regarding human factors (i.e., H-T relationship), digitalization implies that roles are developing towards a larger expertise gap between onshore organizations and offshore installations, which poses significant demands for expertise, awareness, training, and communication. Similarly, conditions related to the balance between trust in technology and sensible skepticism are seen as important. A key aspect in this regard concerns the risk of work alienation and black boxing, where users of digital technologies can lose their overview and understanding of work processes and may thereby also make wrong choices in abnormal and crisis situations. This is furthermore an important aspect considering the recent development of artificial intelligence/machine learning and the associated risks of black boxing of work processes. Machine learning becomes increasingly difficult for humans to understand (Faraj et al. 2018), and Waardenburg et al. (2022) explain in this regard that "earlier 'rule-based' technologies, such as expert systems, reflected the expert knowledge that was coded into them (Forsythe 1993), and developers could explain their outputs. In contrast, through machine learning, the input data and the knowledge of developers are autonomously transformed into algorithmic predictions." (p.59). Such technologies can hence subsume key work practices and entail an increased risk of users not questioning or understanding how the technologies work (Anthony 2021). An increased gap of knowledge between actors involved in the same work processes and those who need to interact, like between offshore generalists and onshore specialists, may amplify the safety risks associated with black boxing of new digital technologies.

Regarding organizational factors, the results show that a lack of clarifications relating to roles and responsibilities between involved companies, as well as organizational conditions such as shift patterns and workplaces, represent significant obstacles to implementing changes and exploiting the potential that digital technologies represent for both efficiency improvements and risk reduction. The findings support previous research which acknowledges that organizations need to realign work and organizational models in order to benefit from digitalization (Günther et al. 2017). The study also finds that companies have large quantities of data and that digital technologies and systems for data exploitation are available, but that there are significant organizational barriers to technology adoption and strategic use of data throughout the supply chain. The finding is in line with Fernandez-Vidal et al. (2022) who found that despite a pressing need to digitalize their operations, major European oil and gas companies lack coherent digital transformation strategies. The results indicate in this regard that organizational culture, power structures, and business model protection can work towards preserving traditional ways of organizing and conducting work, and hence obstruct the implementation of work processes and routines that involve multiple companies. Consequently, the design of incentive systems related to the development and use of new technologies and systems needs special attention in complex inter-organizational work processes. The results hence imply that a supply chain perspective is essential to assess the role of organizational factors for implementation and use of digital technologies in industries characterized by inter-organizational work processes, as also pointed out by Monteiro (2022).

A consequence of the organizational barriers to technology adoption seen in the study is that improvement initiatives can be limited to incremental and silo-oriented innovations. Realization of the potential (i.e., achieving more radical/disruptive innovation based on digital technologies) requires changes in collaboration processes and forms as well as business models. Necessary adjustments are thereby not being confined to company-specific (internal) operations and work organization. Seen through the lens of the HTO perspective, the results imply that industrial characteristics and conditions (power structures, business models, and culture) are highly influential for the H-T relationship. These factors hinder integrative innovation across supply chain stakeholders and may in this way result in technological diversity because of differences in operating models, work methods, and incentive systems. Human operators consequently need to manage differences in technologies and associated work processes. This again, may influence the opportunities for competence development and specialization of employees, and result in competence gaps between onshore and offshore personnel.

Concerning the relationship between digital technologies and new organizational forms and work methods with significance for HSE in the petroleum industry, most of the available research in this area has concentrated on integrated operations (IO) (Chen et al. 2014). The companies generally pursue advancements in technologies related to decision support, automation, and interaction, which may positively influence risk assessment and handling, reductions in physical risk exposure, and improved information flow and planning of operations (Almklov and Antonsen 2020; Trzaska et al. 2021). However, digitalization involves more complex communication settings and requirements for information sharing and is associated with increased organizational complexity. The study points in this regard to the importance of balancing efficiency and safety concerns, and the need to develop organizational structures and processes that reduce the risk of work alienation and black boxing to be able to safely manage unexpected situations.

6 Conclusions

In many sectors, substantial resources are being invested in realizing the potential that digitalization represents. This article has analyzed digitalization as a trend in the petroleum industry, concentrating on changes in work conduct and organization. The study shows that digitalization will involve radical changes to the way the petroleum industry works, and that successful implementation of technologies depends on the ability of people and organizations to adapt rapidly. The level of success can be related to the ability to implement changes in work content and form as well as expertise requirements, while at the same time retaining trust in technology and coping with uncertainty. Potential obstacles to realizing the digitalization potential are resistance to change, organizational culture, and business model protection. The study emphasizes in this regard that digitalization often requires implementing new forms of collaboration and information sharing horizontally and vertically across the industry and that clarifications related to work processes, roles, and responsibilities between the various companies in the supply chain present significant obstacles to technology adoption.

Furthermore, the study illustrates that several factors related to the connection between technologies and human operators may have implications for HSE and major accident risks in the petroleum sector. Viewed overall, the article shows that digitalization as a field is diverse and cross-disciplinary and that a need exists for systematic and long-term research to map its risks and HSE consequences. If relevant cross-disciplinary issues are to be identified, such subjects as digital innovation, worker participation, and various HSE outcomes represent highly interesting fields for future research.

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Data availability The data that support the findings of this study are available from NORCE Norwegian Research Centre, but restrictions apply to the availability of these data, which were used under licence for the current study and so are not publicly available. The data are, however, available from the authors upon reasonable request and with the permission of NORCE.

Declarations

Conflict of interest The authors declare no competing interests.

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