Human performance and automated operations: A regulatory perspective

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SUMMARY

The petroleum industry is becoming increasingly dependent on digital systems, and the companies have ambitious plans for increased use of digital technology – along the entire value chain. Increased levels of digitalisation present major opportunities for efficiency in the oil and gas industry and can also contribute to enhanced levels of resilience to major accident hazards. At the same time, new risks and uncertainties may be introduced. Based on developments in the industry and society in general, the Norwegian Petroleum Safety Authority (PSA) has in recent years pursued targeted knowledge development related to digitalisation and industrial cyber security. The PSA's follow-up activities related to digitalisation initiatives in the industry have been based on input and experience from several knowledge development projects. In this paper we will give insight into the main regulatory strategies we have used to follow-up initiatives in the industry, present results from audits on automated drilling operations and discuss the results from the follow-up activities in light of current regulatory development.

KEYWORDS

Automated operations, Automated drilling and well, Artificial intelligence (AI), Human-Automation interaction, Cyber security, Human performance.

Introduction

Norwegian Petroleum Safety Authority´s (PSA) goal is to follow-up that the petroleum activity gives high priority to safety, health and working environment when digital technology is developed, assessed, and implemented in the companies (PSA Dialogue, 2018; PSA, 2019).

The PSA has carried out several studies and research activities aimed at various aspects of digital technology and cyber security. Over 20 studies and knowledge reports relevant for the development and use of digital technology have been published on the PSA's webpages (Ptil.no). Studies and reports are developed in collaboration with external research. The findings are used as part of our prioritisation and planning of audits and follow-up.

One of PSA's main areas of concern is related to how increased automatization effect human performance in drilling operations. Based on results from studies and developments in the industry, the PSA has in recent years initiated several supervisory activities targeting automated drilling and well operations.

Automated systems and human performance

The level of automatization in operations ranges from systems, where personnel have overall control over most operations, to systems that work completely independent from human intervention (Johnsen et al. 2020; Kaber, 2018). Despite increased automation, the industry will in many cases use systems where personnel have an important role in monitoring them. If an unforeseen situation arise, personnel must evaluate and control a complex situation without having sufficient time, knowledge or overview (Ottermo et al. 2021; Johnsen et al. 2020).

Companies in the petroleum sector implement more advanced digital technologies such as artificial intelligence (AI) and machine learning (ML). Increased use of automated systems may introduce new types of risks and vulnerabilities (Johnsen et al. 2020; Endsley, 2019; Endsley, 2023). Most near misses and incidents involving human automation operations arise from a mismatch between the properties of the system as a whole and the characteristics of human information processing (Endsley, 2019; Endsley, 2023). Development within digital technologies have altered the human-computer interface. On one hand, it has contributed to a reduction in manual and physical tasks. On the other hand, it has changed the demands with regards to cognitive processing (Johnsen, 2020; Ernstsen, 2021; Longo et al., 2022). According to research within human factors engineering it is essential to incorporate a strong focus on how humans use digital technology in a safe way. To do this, knowledge on human cognition should be included in early technology development (Johnsen, 2020; Ernstsen, 2021).

Several researchers argue that effective digital systems rely on selection of a data model which has a line of reasoning that explains it's behaviour – thereby optimising human performance. As such, it is important to consider methods for evaluating the user interaction and interpretation of the data model (Endsley, 2023; Bansal, 2019). A human-centred design can mitigate high mental workload, lack of situational awareness, alienation, knowledge degradation and fatigue that may negatively affect people's ability to monitor and intervene when needed. This will not only strengthen safety but also make the operation more reliable and efficient (Johnson, 2020; Ernstsen, 2021; Endsley, 2019).

Safe and effective interaction between human and technology is important for ensuring safety. Important factors in this regard are mental models, transparent computer models, trust in technology, and function allocation (Ernstsen, 2021). Literature and development of EU artificial intelligence (AI) regulations points to the importance of developing digital systems that are human-centred. Interesting areas of research have developed in line with the advancements in digital technology. One of the areas receiving increased attention is research within explainable artificial intelligence (XAI) (The Royal Society, 2019). As advanced digital solutions such as AI technologies become embedded in decision-making processes it will be important to ensure individuals developing AI, or subject to an AI-supported decision, understand how the system works. AI solutions applied today can produce precise results, however their reasoning is also highly complex. AI models that are so complicated that experts cannot fully understand them are called black-box. As such, XAI involves developing solutions where the human operator can interpret and understand why a system takes certain actions, decisions or makes predictions. (The Royal Society, 2019; European Commission, 2019). As researchers continually try to develop more transparent digital solutions there has also been an increased attention on the need for XAI to draw on insights from social sciences. For example, Miller (2019) argues that XAI should ensure knowledge about how humans' natural way of presenting and evaluating information are included when advanced data models are developed.

Another interesting area of research is the Human-centred artificial intelligence (HCAI) framework. This framework is focused on system design and the development of reliable, safe and trustworthy systems in safety-critical operations. Ensuring both high levels of human control and high levels of computer automation to increase human performance are highlighted as critical topics (Shneiderman, 2020). As digital technology becomes more complex, an important area for future automation is system design that is flexible and adaptive to the current status of the operator, such as stress level, fatigue and level of attention (Johnson, 2020).

Automated systems in drilling and well

In the last decade automatization has been a key driver for increased drilling performance, reduced well cost and improved safe well delivery. Several automated solutions have been developed and implemented, gradually changing work tasks and processes from manual operations of machines to automated solutions. For example, digital technology is increasingly being applied to support the driller in analysing, interpreting, and making decisions for further actions. Technologies in automated drilling solutions can include offline and realtime models such as; digital twins of the wellbore and geology, simultaneous multi machine control, physical models of wellbore mechanics, automated fluid handling and well control. Each area has varying degrees of autonomy (Ottermo et al. 2019).

On the Norwegian continental shelf Equinor first tested Automated Drilling Controls (ADC) together with Transocean in 2017 (Offshore Technology, 2019), and has since expanded its use of the technology to the majority of its contracted mobile drilling units. The main benefits of drilling automation are reduced overall cost, consistency of operations through reductions of errors and reduction of people required on board (Hereira, 2021). Over the last years there has also been some interesting research developments related to autonomous drilling. The world's first autonomous drilling was demonstrated in 2021 by a research group from the Norwegian Research Centre (NORCE). The autonomous drilling system was tested both in a virtual environment and at a test rig, called Ullrigg (Mihai et al., 2022).

The Drilling Automation Roadmap, a joint industry project backed by the SPE Drilling Systems Automation Technical Section (DSATS) describes that automation enables drilling of more challenging wells and drilling through formations that has not previously been possible. Drilling for hydrocarbons is a high-risk operation, involving high pressures, heavy equipment, and operations in harsh environment. Thus, errors and accidents can have enormous consequences for humans, the environment and the organisations and equipment involved. With increased use of robotics and remote control, human presences and exposure to hazards can be reduced. However, the consequences for environment remain.

In the following we will give insight into PSA's follow-up initiatives in the industry and discuss the results from the follow-up activities.

Methods

As a regulator, the PSA use different methods and approaches in our follow-up of the automatization initiatives. Within drilling and well operations, we have executed several audits related to automated operations and human performance over the past years. The PSA ideally follow digitalisation projects from early design phase to testing / qualification, building and implementation. To understand development of overall risk, the PSA assess whether the companies are pursuing their operations prudently and in accordance with the regulations. The PSA also see to that the companies actively promote Health, Safety and Environment (HSE) when digital solutions are implemented.

This paper explores the findings from three audits. The objective of these audits were to assess whether companies prioritized safety and human factors when digital technologies were deployed and implemented. This included issues related to human performance, compliance with regulatory requirements for the implementation and use of automated drilling operations, robotisation of pipe handling and digital well planning. The audits were aimed at drilling and well operators, rig owners and related service companies.

The auditing teams from PSA were multidisciplinary, ensuring a holistic human, technology, organisation perspective. The audits were carried out as a combination of document reviews, meetings, semi-structured interviews with operating companies, drilling contractors and service companies as well as field observations conducted onshore and offshore. Both operating personnel and management were interviewed. Information collected through the document reviews, interviews and field observations from the audits were structured and analysed. Where the observations constituted lack of compliance to regulations, non-conformances were issued. Common issues and findings from these three audits were systematically assessed and categorised into main topics, forming the basis for the results presented in this study.

27 interviews and 10 group sessions and meetings were performed. Examples of topics that were highlighted in interviews were: Technology qualification basis, risk and technology assessments, organisational analysis, and other requirements and acceptance criteria for safe development and implementation. Other topics included how new technology was applied in the drilling and well operations, impacts on HSE effects and how risk was handled if or when the technology failed. We also assessed how implementation of new systems impacted work assignments, tasks, and processes. Further how personnel had been trained, and prepared for changes in technology, organisation, and work execution.

Several regulatory requirements in the Norwegian petroleum Health, Safety and Environment (HSE) regulations are relevant when following-up companies with regards to the development and use of automated drilling. The regulatory requirements listed in below table are relevant for technology development, ergonomic design, the interface between human and computer as well as control and monitoring systems.

Table 1. Relevant regulations when auditing companies in the industry

Regulations	Section in regulations
The Management Regulations	Section 16 General requirements regarding analyses Section 18 Analysis of the working environment
The Facilities Regulations	Section 9 Qualification and use of new technology and new methods Section 10 Installations, systems and equipment Section 20 Ergonomic design Section 21 Human machine interface and information presentation Section 34a Control and monitoring systems
The Activities Regulations	Section 21 Competence Section 23 Training and drills Section 24 Procedures
The Technical and Operational Regulations	Section 21 Human-machine interface and information presentation Section 33a Control and monitoring system

The management regulations stipulate that the industry bears the responsibility to actively prevent harm or danger of harm to people, the environment or material assets in accordance with the HSE legislation. This includes internal requirements and acceptance criteria that are of significance for complying with requirements in the regulation. In addition, the risks shall be further reduced to the lowest extent possible. The regulation requires the companies to manages all risks when implementing new digital technology. It also stipulates that technical, organisational solutions must be developed in a Human, Technology and Organisational (HTO) perspective.

In the next section the results from the audits have been categorised into six main topics.

Results

Technology development and technology qualification

Limited attention is paid to human abilities and prerequisites when developing digital technology. Human abilities and prerequisites are often not considered or included in the technology development process (PSA, 2018; PSA, 2021; PSA, 2022). The development of digital solutions was outsourced to subcontractors and / or digital solutions were bought "off the shelf" and retrofitted to existing systems. This was done without sufficiently ensuring that the technology was appropriately qualified for its intended use, which resulted in "safety risks that flew under the radar" (PSA, 2022). Even though new digital solutions often required limited technical installation, our findings show that they pose significant implications for operations and human performance, and thus require due assessments.

Increased complexity and interfaces

Digital technology and drilling automation solutions are complex and can be difficult to understand for personnel. Functionality is coded and integrated in the software, and thus hidden from users, as well as those who perform risk assessments of operations. Although some of the individual digital technologies implemented could be perceived as relatively understandable, the sum of these - and how they interacted with each other – were less transparent to the user (PSA, 2021; PSA, 2022). We found non-conformances concerning lack of integration between the controls systems, and deficient integration between different user interfaces in the driller's cabin. Weaknesses in the Human Machin Interface (HMI), high alarm rates, and ongoing installation, troubleshooting and implementation of upgrades and software changes while the rig was in full operation contributed to fatigue and stress. Further the increased complexity contributed to reduced situational awareness, both for the operator and other partakers in the drilling operation (PSA, 2022). Operating personnel also expressed a sense of insecurity, and fatigue related to scale and pace of change. It emerged that for most workers in the companies where a high degree of automation was introduced, there were also several changes and digitalisation initiatives impacting other areas of their workday (PSA, 2021; PSA, 2022).

Measuring performance and learning

Technology provides an increased opportunity to measure performance. However, we found that the focus, scope and level of reporting contributed to increased time pressure and negatively impacted human performance. The use of Key Performance Indicators (KPI) were mainly geared towards efficiency and speed. For example, it was common to use KPIs and micro KPIs where individual work tasks and operations were measured in minutes and seconds. Status and progress on individual KPIs were presented in daily meetings. However, the companies were unable to show how learning from the KPIs were used to improve the technology, or in other ways contribute towards overall risk reduction (PSA, 2021; PSA, 2022).

Legal requirements and standards

There was a lack of knowledge and clarity with regards to interpreting regulatory requirements in a human-centred design approach. Therefore, in some of the cases, relevant subject matter experts had not been included at an early stage in the technology development. Furthermore, there seemed to be a lack of understanding of how the functional requirements in the HSE regulations were applicable in the AI domain (PSA, 2022; PSA, 2018). The PSA experience that the industry calls for standards and methods for a human-centred approach to digital technologies. Moreover, there also seems to be a lack of industry understanding of how functional requirements in existing regulation may also apply for digital solutions.

Aligning work processes and technology

The audited parties clearly emphasized that increased use of digital technology offshore is a prerequisite for successful introduction of new ways of working. These changes to ways of working may help to simplify and improve decision support for the personnel involved, but also leads to changes in roles and responsibilities and introduces new competence requirements. For example, the primary work task for a driller changes from manually adjusting drill bit rotation and fluid flow, to monitoring and being ready to intervene if the automated drilling process fails or needs adjustments. However, we found that the audited parties had challenges with succeeding in adapting and changing work processes at the same time as the automated solutions were introduced. This resulted in a mismatch between the technology and the work processes. Further we found that the audited companies had not established routines, or defined in the written work tasks, how long at a time executing personnel should remain in the operator's chair. Even when loss of situational awareness for the operator was identified as a risk, we found that evaluation and mitigating actions were neither identified nor implemented. Several non-conformances were identified concerning procedures and work processes, including high workload, lack of training and role unclarity (PSA, 2021; PSA, 2022).

Risk assessments in operations

Risk assessments conducted for addressing local operational risk factors, when introducing new technology and ways of working were deficient. For example, there was an expectation that the automated mode was the default for operations. However, interviewees reported that the threshold for assuming manual control or choosing to conduct operations manually was high, and not clearly defined in procedures, risk assessments and risk registers. Risk factors related to changes in mode were not identified or evaluated. Operating personnel were often unaware of risks related to changes in mode between manual and automated operations (PSA, 2021; PSA, 2022).

Discussion

This paper has presented results from the PSA's audits and follow-up of automated operations and human performance in automated drilling technology and operation.

Results from PSA's audits and studies show that digital systems are complex and can be difficult to understand for operating personnel (Johnsen, et al. 2020; Ottermo, et al. 2019, Erntsen et al. 2021; Gressgård et.al 2018; PSA, 2021; PSA, 2022; PSA 2018). AI and digital models which are coded and integrated into a software are less transparent to the operator using the technology. This implies that human performance in digital systems relies on a system that can convey the systems actions in a transparent manner. Lack of transparency and explainability in the interface can lead to operators experiencing inability to interpret information and predict system behaviour and automated action (Endsley, 2023). Understanding and being able to predict drivers for human performance is a key issue in the context of safety-critical behaviour and designing technology that can mitigate undesirable mental states (Endsley, 2023; Roberts et al., 2015). Factors such fatigue, distractions, and stress, can have an adverse impact on operators working memory and task performance (Johnsen et al. 2020). In a high-risk industry, such as the petroleum industry, minute decisions can have severe consequences. Thus, managing these risks are critical for achieving a prudent level of safety, and a priority for the PSA.

Researchers argue that complexity, involvement and workload affect the human-automation interaction (Johnsen et al., 2020; Endsley, 2019). Therefore, it is necessary to examine how new work tasks are designed. Further how the design of new work process takes human's strengths and limitations into account. This is in line with findings from the PSAs audits. Introduction of automated drilling systems in some cases created a perceived distance between the operators and the risk factors associated with the work task, e.g. well control. The operators found that they to a larger degree were in a pacified state, supervising and monitoring the system conducting the operations – as opposed to actively taking part in the operation. Some described it as they were losing their "feel for" the well, and that it could be difficult to maintain good situational awareness that included well control factors. This is in line with research showing that automated systems can lead to impaired mental models and reduced situational awareness (Ottermo et al., 2020). Another area of concern in the literature is that automation may increase the overall mental strain on the operator (Johnsen et al. 2020). Our findings further showed that increased automation could also be a driver for prolonged sessions in the operator's chair, and that this imposed a mental strain, reducing operator's vigilance and sense of situational awareness.

The audited companies that were early adopters of technology, tended to digitalize across business functions and utilities. Meaning that the same worker whose primary work tasks were affected by introduction of automation, was also exposed to several other new digital solutions in other and remaining work tasks (PSA, 2021). As a regulator we are concerned that the sum of changes contribute to a state of digital fatigue, even if none of the changes or systems by itself can be considered overwhelming. Systems that are primarily seen as safe, still challenge the organisational boundaries and practices when autonomous systems are introduced (Oliver et al. 2017; Johnsen et al. 2020). Problems with the automated system often occur in unknown and unexpected situations. Reports highlights that this must be dealt with at a human-automation level as well as on an organisational level, which includes considerations of interaction between many stakeholders (Johnsen et al., 2020; Endsley, 2017; Gressgård et al., 2018). Training, trust in the change processes and the digital technology are organisational factors that must be followed up when introducing automated and autonomous systems. The importance of having a lifecycle perspective (e.g. assessing and evaluating risk in early development and in operations) is critical with regards to preventing negative impact as well as optimizing opportunities that digital technology provides (NIST, 2023).

In a technology-intensive industry we have found there is an uncertainty with regards to how the regulatory requirements should be understood. This is not isolated to the petroleum industry (Gressgård, 2018; EU Commission). EU efforts are also being prioritised on ensuring sufficient regulations for digital technologies such as AI. The newly proposed EU regulations require development and use of AI to be human-centred, trustworthy, and based on ethical principles. The EU proposes a risk-based approach to division into risk categories. This means strict regulation of so-called high-risk AI systems. Furthermore, risk management throughout the life cycle of the system for AI technology must be established, including requirements for development, testing, evaluation, and implementation of risk-reducing measures (EU Commission). In 2020, the Norwegian government published a national strategy for AI. In line with the EU regulations this strategy highlights the need to tackle potential challenges such as data quality, transparency and autonomy when developing and using AI. In recent years recommended practises for performing verification and assurance activities for data driven algorithms (DNV-RP-510) management of risk in AI (NIST-AI100-1), and qualification of digital twins (DNV-RP-A204) have emerged. However, as these are relatively new contributions in the standardization domain, their informative effects on regulators and sectorial directives and regulation are yet to materialize.

Although the PSA consider its current regulation relevant within digital domain, we continually evaluate the regulations applicability. Furthermore, it is important that our regulation refer to the appropriate and relevant standards in relation to digital systems. It is expected that norms and standards are at the forefront of the digital development. This is an industry responsibility, and a part of what the authorities must assess in relation to regulatory development. In the way forward, there is a need for to assess and conclude what AI means in terms of regulatory activities and regulations. For the PSA it is important to contribute to the safe use of advanced digital technology such as AI in high-risk context. An important part of this is ensuring up-to date requirements for the development, deployment, and use of AI systems. This may include requirements covering transparency, explainability, and assessments of systems, as well as requirements for cyber security. The PSA will continue to assess whether the companies are pursuing their digital endeavours prudently, in accordance with the regulations and actively promoting Health, Safety and Environment (HSE) when digital solutions are implemented.

Future directions:

Going forward it will be relevant to evaluate how knowledge on human performance apply to the cyber security domain. Digitalisation and automatization of real-world physical assets may impact achieved level of safety (Nelson et al., 2021). Automated systems require a high level of availability, connectivity and thus web exposure through network interfaces. A system that is accessible through the web, is inherently more vulnerable to attacks where unauthorised persons access sensitive information or target critical functions from anywhere in the world (Ottermo et al, 2019). As such digitalisation of industrial assets come with a substantial increase in security risk (Rubio et al.2019). Combating this risk entails collection and monitoring of large-scale data sets and logs over network traffic. To detect anomalous traffic and intrusions, AI and machine learning technology is increasingly applied in intrusion detection systems (IDS) (Lee et al, 2022; Rubio et al, 2019). In the same manner as AI systems within drilling and well, AI enabled IDS systems are inherently complex and challenging for human operators to understand. As Lee & co argues *"analysts have little choice but to trust the AI-predicted outcomes. In the field, even a security control center with a high-performing IDS system eventually requires validation by a human analyst.*"(Lee et al. 2022). Thus, there is a need for transparency to support optimal human performance, also in the cyber security domain.

Conclusion

As PSA's follow-up and this study has shown, the petroleum industry is becoming increasingly dependent on digital systems. As digital technology is taking over manual tasks, employees still play an important role for safety in the sector. Increased levels of digitalisation present major opportunities for efficiency and can also contribute to enhanced levels of resilience to major accident hazards. At the same time, new risks and uncertainties may be introduced. This means that several technical, organisational, and human challenges must be systematically followed up to realise the potential offered by digital technology. In the way forward, the PSA will contribute to promote safe use of digital technology. An important part of this is ensuring up-to date requirements for the development, deployment, and use of digital systems.

The companies are responsible for safe operations. Therefore, they must assess vulnerability and risk from an integrated perspective which includes human, technological and organizational (HTO) aspects. Each company must take ownership of and manage the risk related to the implementation of new systems and technological solutions.

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