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# Challenges and Opportunities of Implementing the Operators' Perspective: Experiences from Automated Drilling Projects

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In this paper we highlight experiences from two cases of drilling automation, emphasizing the importance of understanding work and human factors in the design and implementation of automated systems. Automation is advancing as a means to increase efficiency, quality and safety in various industries, including petroleum. However, there has been limited sociotechnical studies of automation in the petroleum industry. Experiences from other domains indicate that gradual automation in collaboration with users has improved efficiency, safety and user satisfaction. Using thematic analysis of interviews with technology providers, consultants, drilling operators, and project leaders, we found that from the outset of the projects, a balance between technology optimism and understanding of human limitations and experiences was critical. Furthermore, we identified several challenges and potential remedies in areas such as user involvement, system integration and alarm handling, use of appropriate methods and standards, sensemaking of automated systems, and competence and training of operators. The case studies illustrate a need for improved management of human factors in the development and implementation of automated technology in the petroleum industry. The concepts of work-as-imagined (WAI) and work-as-done (WAD), and the potential gap between these, are useful to highlight the importance of applying the appropriate human factors expertise and methods for such development.

*Keywords*: Safety, Human Factors, Design, Drilling operations

## 1. Introduction

Automation and autonomy are proliferating in many areas, and while there is a promise of increased efficiency in automated operations, there is at the same time a potential for reducing the operators' control and understanding of what is going on inside the systems. Implementation of automation has often been driven by the excitement and possibilities generated by new technology, however, both humans and machines have limitations. Thus, designing work for operations where humans and machines interact demands careful consideration of the different weaknesses and strengths of both actors (Lee et al. 2017). In this paper, we explore experiences from the development and implementation of two state-of-the-art automation projects for drilling in the petroleum industry. The overall aim is to examine how human factors perspectives affect automation of drilling operations.

Over the past few decades sophisticated solutions for remote operations, automated drilling and handling of drilling equipment have been introduced in offshore oil and gas drilling. There is especially an increase in the use of onshore control centres that, to varying degrees, remotely control the offshore operations. This has gradually changed the traditional tasks of drilling from manual operation of machinery to more use of computer-based solutions (Ciavarelli, 2016). Drilling is seen as a particularly suitable area for the development and use of automated solutions, as there are several possibilities for improvement and development, e.g., drilling in formations that were earlier too challenging, potential for more efficient drilling and the possibility of replacing humans with robotics and remote control and thus remove humans from dangerous situations (Godhavn, 2011). There are however also risks in introducing automation in drilling operations. Automated operations in drilling relay on operators being fallback “pilots” (Cayeux, 2021), and by changing and removing operator responsibilities there are challenges with regards to ensuring adequate mental models of the operations and sufficient situational awareness for the operator. Over time this can result in a situation where the user is unable to intervene should an incident occur.

In general, increasing levels of automation leads to more supervisory roles of operators, and the people that oversee the systems are more and more "out of the loop", leading to challenges with sensemaking, situational awareness and insufficient knowledge of systems (Endsley, 2012; Borst et al., 2010). Insufficient situational awareness has already been identified in several drilling incidents (Sneddon et. al, 2013) and Robert et al. (2015) found this to be a contributing factor in the Macondo accident, as drilling personnel had a lack of understanding of critical signals and insufficient mental models of pressure tests conducted before the events unfolded. As offshore drilling is a dynamic activity, continuous situational awareness and cooperation is an important factors, especially when introducing automated operations. As indicated in Iversen et al. (2013) there is a correlation between the degree of automation and the risk of errors in training simulations of partially automated drilling operations.

The design and presentation of the right information has been highlighted as an important reason for why critical signals are perceived in drilling and well operations (Roberts et al. 2015). Removing people from the physical operations will also lead to some lost information for the operators such as tactile information in vibrations, sounds and smells. To compensate for this, sufficient information about the status of the autonomous system should be provided to the operators (Endsley, 2012). Visualization of complex processes can also facilitate better mental models for drilling personnel (Wylie et al., 2018).

Often systems for automated drilling systems are provided by different suppliers, and a challenge during development is then to ensure communication between the systems and a coherent presentation of information to the operators (Thorogood, 2009). This requires the use of sensors, sufficient data quality, reliability and data communication (Godhavn, 2011). When developing automated processes, it is necessary to evaluate whether new opportunities for errors are introduced (Flaspöler et al., 2009) e.g., introduction of too many alarms will contribute to uncertainty and confusion in stressful situations (Endsley, 2019). Use of best practice standards are often missing (Izadi et al. 2009), and inappropriate use of alarms has been found to contribute to accidents in the petroleum industry and the maritime area (Dong et al., 2017).

Sætren and Laumann (2014) conducted a study that examined the development and implementation of an automated offshore drilling system, with a specific focus on how drilling personnel perceived and accepted the new technology. The authors found indications of over-confidence in the new technology, which consequently led to a low risk perception and lacking awareness of possible challenges in the drilling crew. On the other hand, developers of these systems had a low understanding of the end-user needs before implementing and testing the technology, leading to dangerous situations in operations (Sætren et al., 2016). These studies indicate that there is a discrepancy between how the users and the developers of new technology perceive the operations and the functionality of the new technology.

A relevant theoretical framework in this regard is the work-as-imagined (WAI) and work-as-done (WAD) (Hollnagel, 2017; Hollnagel 2022). These concepts describe the discrepancies between the conceptual thinking in planning and developing of work and operations as they are performed. This thinking is in line with safety-II thinking, where the inevitable variability in how operations are performed are seen as something that should be highlighted and leveraged as a positive for ensuring safety during operations (Hollnagel, 2017). The explicit and implicit assumptions made during development are consequently embedded in new technology and affects human-machine interaction and use (Danielsen, 2021).

## 2. Method

The data collection presented in this article, was conducted as part of a project for the Norwegian Petroleum Safety Authority (PSA) (Johnsen et al. 2020). This article presents the results from interviews related to two projects of automation in drilling. The two projects regarded process-based decisions support, semi-automated systems (parameter monitoring), and for one of the projects robotization of the drill floor. More details may be found in Johnsen et al. (2020).

A total of 12 ten in-depth interviews involving 27 professionals related to the two cases were held. Professionals included personnel from the line of responsibilities from the operator, the rig, the supplier of the drilling system (including technical personnel, consultants, HF experts), the drilling service company (including operators of the system), and the service provider (of automation system/ICT system), and finally industry experts on HF.

A thematic based interview guide was developed in collaboration with the PSA. Key issues explored in the interviews were project background, purpose, organization, user involvement in design and testing, collaboration with the regulator, risk analysis, user perceptions, use of standards and methods, experiences from testing and use, training experiences. Previous experiences from automation projects were also discussed and there is thus also some findings that are more general than those related to the specific cases.

The analysis of the interviews was a simplified thematic analysis, first individually by the researchers then collectively where findings were discussed and agreed upon.

## 3. Findings

In this section, we present the main findings from interviews. The thematic analysis resulted in the following themes:

- Interfaces & Collaboration
- Abundance of alarms
- Understanding the system
- Technological optimism versus user needs
- Competence and training

### 3.1. *Interfaces & Collaboration*

Developing and operating automated drilling systems requires the participation of a variety of actors including suppliers, design companies, operators, drilling system operators, service companies, rig owners, and other organizational units. This in itself is a contributor to complexity in the projects, regarding management and communication. In addition, the informants explained that a particular issue related to fragmented projects were the integration of new systems and technology into an existing network of systems on the installations. Lack of good system integration was mentioned in several of the interviews. For example, interfaces on screens in the drilling cabin was developed by one system provider whereas the system for automated process control systems was supplied by another, and a robotic system from a third – all with different logic and design of e.g. screens. In the end this contributed to a lack of understanding and confusion, especially in the case of alarms. Integration was deemed difficult partly based on a lack of systematic approach involving all actors, and importantly, that system developers might not exhibit interest in collaborating with others due to the proprietary and commercial nature of their work.

In one of the projects, the company strived for maintaining only one system provider. Informants claimed that this was an important element in reducing complexity. This approach allowed narrowing the scope and avoiding fragmented systems.

### 3.2. *Abundance of alarms*

The informants noted that new systems had the tendency to bring with them new alarms; “too many alarms” was a common statement. Further, a capacity to revise and integrate new alarms into existing alarm systems and alarm philosophy were not always developed or budgeted in such development projects. Informants noted that novel alarms were not “intuitive”, and that information or training about the alarms were inadequate.

### 3.3 *Understanding the system*

As automated systems in nature are designed to perform operations with as little as possible interference from operators, informants explained that front-line operators may have inadequate situational awareness during operations. It can be a challenge to understand what the automated systems are doing and why. This can cause operators to lose track of the next stages in the process and is especially a challenge when unexpected occurrences happen. In addition, informants described situations where the automated systems have been switched of, despite being fully adequate for operation, which may indicate low understanding or low confidence in the systems' capabilities.

Several of the informants noted issues regarding understanding what the system does and their calculations behind. As a result, the systems were in cases left unused when they could have been appropriately used. The lack of understanding of the operations of the systems also contributed to issues when the system reached operating limits and was turned off automatically. Then the operator needs to decide on further actions with an impaired situational awareness. The informants claimed that real help from automated systems in determining subsequent actions was long ahead.

### 3.4 *Technological optimism vs. attending to user needs*

The purpose of projects was from the operator and developers stated to be increased safety and efficiency, and reduced exposure of operators to hazardous situations. However, from the interviews efficiency and possibilities of developing new technology were the most important driver for change. Several of the informants from company level indicated a great optimism in the future prospects of a fully automated drill floor. However, operator informants claimed that such technology-driven development came at the expense of focusing on the actual needs of the users. This was showcased by relevant HSE or HF expertise not being involved early on, particularly in one of the projects. In general, the HF experts interviewed noted that projects often involve facilitation of human factors in the last 10% of a project, leaving little or no room for altering fundamental design issues.

The technology-driven development also manifested itself by the lack of attention to the work processes in use, which the company management and developers faced with great difficulty in one of the projects. The inevitable problem is to foresee how work should be done after technology has been implemented. Despite of the uncertainty in such development projects, informants noted that it should have been attended to in early project phases to avoid surprises at later stages. One examples of this was given from an earlier project where a robot for handling pipes offshore had been developed without adequate user-involvement. It was sent back onshore because the drilling crew simply refused using it. This example also shows the importance of involving personnel for increasing acceptance and trust in the automated technology, in addition to making a helpful system.

One of the projects did have an early user involvement, partly stemming from having a flexible budget. The informants emphasized the importance of being able to carry out the project without a fixed price contract, as new user needs emerged continuously. Related to this, early dialogue with the authorities (the PSA) was also deemed as a positive support for the projects, as the authorities emphasise ensuring safety in terms of user involvement and training.

### 3.5 *Competence and training*

Generally, transitioning from manual to partially automated task execution needs new skills and competence. In this case, training was perceived as crucial by the operators. However, the overall finding from the cases was that training was given too little emphasis in the projects and thus underestimated. In fact, some informants from system suppliers stated that there was no need for training once robots had been introduced.

An apparent issue was that there is no adequate standard that could be applied to define what competence that is needed, which led to situations where, due to crew rotations and manning issues, untrained personnel had been sent offshore to use the systems. Moreover, training had been viewed by developers and company as something to consider after the system was in the final stages, rather than in earlier phases.

The informants from crew specifically pinpointed the need for scenario-based simulator training to account for lack of experience in situations around system boundaries. Moreover, there was a lack of team-based training in simulators. A potential reason for this was mentioned to be simulator training being expensive and therefore perceived as difficult to prioritise extensively.

However, also positive reflections on how training was planned and executed was given, such as one of the providers having developed a full-scale test facility with the robots that were used on the rig, and where manual take-over could be trained on. Moreover, in one of the projects, a dedicated follow-up team visited the rigs that had implemented the automated system to understand how the systems were used and how the users understood them.

## 4. Discussion

In this section we provide a discussion on the identified challenges, the factors that are contributing to these challenges in development and their underlying causes. In addition, the challenges are seen in context of the concepts of work-as-imagined and work-as-done.

### 4.1. *Challenges in operation*

Findings from interviews showed some issues during operations or testing of the automated systems, such as the systems being hard to understand, which again led to them not being used in situations where they could have been. Lack of situational awareness during operations has earlier also been found as a contributing factors to accidents both in drilling and in other industries such as aviation and maritime (Sneddon et al., 2013; Endsley, 2019; Sandhåland et al., 2015). Considering that traditionally technology is dependent on the operator as executioner of safety-related actions in a task, automated technology will to a larger degree perform these tasks. Thus, seeing that the operators are still interacting or at least supervising the operations, the operators understanding and ability to take over manually when needed is just as important to facilitate in design of the operations.

Several factors may be seen as contributing to why the systems were seen as hard to understand; issues in system integration, abundance of alarms difficult to trace, and lack of appropriate training.

### 4.2. *Contributing factors*

System integration issues was particularly seen when new systems were integrated with other existing systems in a manner that led to an unclear presentation of important information, something that has been pointed to as a challenge also in earlier research (Thorogood, 2009). This is a challenge partly because the lack of standards used for communication between drilling equipment (Ottermo, 2021). A related issue arises when there are several suppliers involved in developing a system for automation. Lack of appropriate management of system integration during development will lead to challenges in operations.

Another issue related to the design of the systems identified in the interview was the approach used to implementing fitted alarms to the system. The projects did not use a defined approach or standard such EEMUA (2015) to design alarms to the new systems, but rather continued with the approach that was developed for the already established systems. Inappropriate use of alarms is already known to contribute to confusion in critical situations and a contributing factor to accidents in the petroleum industry (e.g. Dong et al., 2017).

A re-occurring approach with regards to training was based on thinking that the projects aimed to “remove” humans from the operations, and thus training being less important. However, the transition to automated task execution changes skill requirements for the operators, both for understanding the operation process and for being able to take over when the automated systems fail. Struggles with determining what level of competence needed from the operator were mentioned, in addition to having enough trained operators available for all shifts. This underscores the need to have a sufficiently long-term perspective when planning for automated operations, including the rotation schedules of offshore operators. Although training should not be seen as a primary strategy to control hazards in operations (ILO/IEA, 2021) it is important to have an effective and continuous approach to training, and as seen in one of the projects having available a full-scale training simulator before and during implementation, was seen as valuable by both developers and operators.

In simulations of partially automated drilling operations a correlation between the degree of automation and the risk of errors are found (Iversen et al., 2013). This indicates that the design of automated systems should be evaluated with regards to the introduction of new errors, such as those identified in this study; system integration, alarms and training (Flaspöler et al., 2009).

### 4.3. *Underlying factors*

Development of intelligent machines is often the driver for digital transformation (IEC, 2020), something that is also seen in the interviews of this study. The projects have had a general focus on developing technology for efficiency, and not necessarily developing technology as a support for the operators. When the focus is on the development of the technology and less on how the technology should support the operators the work process will not be facilitated in a way that accounts for the human and machine abilities and limitations. In general, the projects did not have a clear process of development and important topics within planning for human factors in operations such as tasks analysis, workload assessment and scenario development were not in focus. Work processes that do not sufficiently plan for the user and the inclusion of operators' perspectives can result in frustration for user of the systems and in the end lead to noise during work, instead of support for safe work (Ottermo, 2021).

Planning of the development work processes influence how well the end-users and their feedback are included. Some of the challenges with involvement of the right expertise at the right time might be attributed to the nature of R&D work, that inherently holds several uncertainties. However, the general feedback from Human Factors experts interviewed in this study is that their expertise is introduced too late in the process. The early inclusion of this expertise could mitigate some of the conflicting issues that are seen when the focus on technology sometimes overshadows the operators needs (Sætren og Lauman, 2014). Early user involvement is recommended during model development and before integration/implementation in control systems (Erntsen et al., 2021). Often the need for changes in the software and systems are seen after they have been in use for a while. If the development of automation software is seen as a product to be delivered, and not a tool that should be updated the possibilities for improvement might be hampered, something that should be accounted for also in the project contracts.

How and when to involve users in the development process is core to approaches such as User Centred Design and Human Factors, e.g. through supporting incremental improvements (Vredenburg et al. 2002). One of the projects in this study had prioritized resources for early involvement of such expertise and performed the development projects in steps using agile methods with feedback over several iterations which gave positive results. These user centred development approaches also support increased productivity (Beuscart-Zéphir, 2007).

### 4.4. *Perspectives of Work-As-Imagined and Work-As-Done*

The concept of Work-As-Imagined (WAI) is used to describe how work is represented through procedures, systems and notions, mainly in the blunt end removed from the actual work, while Work-As-Done (WAD) is used to describe how work is done in the sharp end (Hollnagel, 2017). In this study, an indicated gap between WAI and WAD is seen as the automated systems are not being used as intended, meaning that work was not correctly "imagined" in the development process.

WAD and WAI are overarching concepts that can entail different meaning depending on how they are used, WAI can for example be divided into more nuanced concepts such as work-as-prescribed and work-as-disclosed (Shorrock, 2021). One context for WAI/WAD as used here, is that they are used allocentric, meaning the two are separated in space and time as the 'blunt end' imagining the 'sharp end' reality. The contrasting egocentric view concerns an individual's own preconceptions of own work. For WAD, another nuance is that while it is a term used to describe "how work is done", it may be questioned how this can accurately be captured. In this study, WAD could also be seen as a representation of work, as the information about work is based on *descriptions* of operators' experiences in semi-structured interviews, more similar to work-as-disclosed, as mentioned above. Nevertheless, one could argue that the gap between reality and the representation is narrower from the perspective of the operator than from a manager or developer imagining the future work.

The concepts of WAI and WAD are primarily suitable as heuristic tools that may contribute to an increased awareness about a gap between the two. Such a gap will be created if one does not sufficiently consider the practical side of work during development and use appropriate methods for ensuring a correct as possible understanding of how the operations will be executed. These concepts should be used in combination with well know approaches from User Centred Design or Human Factors, that gives more support to identify concrete areas of improvement.

However, it is likely that a focus on closing the gap between WAD and WAI becomes even more important in automated systems compared to other types of technology, since in principle, one is automating core tasks, which was previously done by the operator. The change in work for the operator is therefore so large that it could be increasingly hard to anticipate how work actually will be executed. Automated technology has a particular impact on the operators understanding of what the machine is doing, but also the potential of altering work processes and communication in parts of the socio-technical systems outside the specific automation. Adequate mechanisms for understanding the implications for work as done should therefore be put in place continuously throughout development and implementation.

### 4.5. *Practical implications*

The methods and approaches used in design should make it easy to succeed and hard to fail in safety critical operations. Shorrock (2021) describes an approach using the concepts of WAI and WAD, including understand the actual context of the work-to-be-done, including users in describing work-as-imagined, using repeated incremental steps including testing and then monitoring a potential gap between work-as-done and work-as-imagined.

As mentioned, this approach should be combined with the right human factors expertise, introduced at the right time. This should be planned already at the concept development stages. Methods to include users in an appropriate way are described in resources such as ISO9241-series and ILO/IEA (2021). Another important action for early development phases is using a systems approach to define the limits for what should be automated. This will narrow down the scope and focus development on the most important areas for improvement.

The responsibility for ensuring to closing a gap between WAD and WAI may be seen as a shared one between authorities, project leaders, developers and operators. This also requires increased knowledge about the importance and relevance of human factors for all actors. If this is not prioritized, the development of the technology will get the brunt of the attention in development, as seen in this and other research.

For learning purposes, it is also beneficial to explore the gap between WAD and WAI in both incidents and accident investigations. There is no established systems in place to gather and analyse minor incidents with automated systems in the petroleum industry, which is a missed opportunity for learning and improvement. For accident investigations human factors experts being part of the investigation team will contribute to also situational awareness of the actors during the incident are accounted for.

## 5. Conclusion

Automation, by definition, entails the delegation of tasks from humans to machines. This seems to lead to the risks involved are taken lightly as humans are removed from the immediate situations. For example, in this study of development of automated systems for drilling, tasks related to human interaction with machines or training seems to be underprioritized in comparison with features that are thought to increase efficiency. However, reality is far more complex, and under-focusing on operator needs leads to a gap between work-as-imagined by the blunt end and work-as-done in operations. Thoughtful integration of human factors aspects and collaborative efforts during the development and testing phases of automated systems contribute to reducing such a gap and are prerequisites for the successful development of automated technology.

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