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Human Factors and safety in automated and remote operations in oil and gas: A review

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This paper explores the Human Factors of automation and remote operations through review of safety literature. The literature was selected through keyword search and snowballing. We have prioritized empirical papers and safety issues based on a systemic perspective. Automation is designed to assist the operators in high and low workload situations. When unexpected events occur and automation fails, it can lead to loss of situational awareness (SA) and reduce system safety. The motivation for remote operations has been to reduce costs and remove operators from hazards. We have not found any systematic literature reviews of safety related to automation or remote operations. Findings indicate that poor design is a root cause in about 50% of the cases. Challenges found in accident investigations are that too many causal factors are categorized as human error. Suggested good practice of user centric design in control facilities are ecological interface design, eye tracking, and design of few and appropriate alarms. There is a lack of communication between system developers and end-users. There is still the challenge of vigilance when monitoring highly automated systems. Automation seems to support safety when it is based on careful design. We see the need for exploration of remote operations and automation in safety critical operations and suggest selecting specific cases together with the industry to document experiences and safety challenges.

Keywords: Automation, Safety critical systems, Performance, Human Factors

1. Introduction

1.1 *Background and challenges*

Automation and remote operations are increasing in the oil and gas industry. This paper aims to understand the risks and uncertainties for safety critical operations from a human factors' perspective when automation and remote operations are implemented.

When discussing risk reduction, we base our scope from Lund and Aarø (2004), i.e., that risk reduction must be based on a broad set of actions – including regulation, technical design, training and human awareness of the situation.

In the oil and gas industry, management and control of automation and remote operations take place in control centres or control facilities. Automation or remote operations can change the workload and perceptions of the human operators that must make sense of what is happening during normal and safety-critical situations. Remote operations make the operator more dependent on information systems and clues from the digital environment, distant from the physical operations with physical models, sight, vibrations, smell, and sounds, as mentioned in Porathe et al (2014). Risk can be reduced by moving the operator from dangerous environments. Remote operations may reduce commuting and office-related energy consumption, helping to reduce risks of commuting, lower carbon emissions and conserve resources. Remote operations may also promote diversity and inclusion by removing barriers and providing opportunities for caregivers, individuals with disabilities, and those in remote areas to participate in the workforce.

Increased automation may reduce the workload but creates an "out of the loop" environment, removing the operator from direct control as automation takes control. As mentioned by Bainbridge (1983), the 'ironies of automation' is a set of unintended consequences as a result of automation, that could detrimentally affect human performance on critical tasks. Automation might increase the challenges of human performance issues, rather than eliminate them. When the unexpected happens and automation fails, the operator may not understand the situation, due to poor sensemaking or being "out of the loop".

We are interested in exploring how the design and operation of the control systems influence safety. To improve the handling of safety-critical situations, there is a need to address the situational awareness (SA) and training to enable operators to deal with the unexpected. None of these issues can be understood in isolation from the human, technological or organisational context of which they are part. We see Human Factors (HF) as a discipline that can support meaningful human control. An often-used definition of HF, from HFSE, is "… the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance". Rules and regulations create key framework conditions for HF engineering and the subsequent design and operations of control systems. Important goals of relevant rules and regulations from a safety perspective are:

- The need to formulate industry good practice as rules, in order to force laggards into line.
- The need to formulate rules in order to raise the standards higher.
- The need to formulate rules when the consequences of failures are significant.

Analysis and prevention of accidents are based on accident analysis models. The models determine the perspective of the accident analysis and guide the conclusions and improvements, as described in "What-You-Look-For-Is-What-You-Find" by Lundberg et al. (2009). In the Human Factor Analysis and Classification System (HFACS) Shappell & Wiegmann (2000), human factors issues are systematically explored. Accident analyses are often based on Reason's (1997) "Swiss Cheese" model of accident causation. This model includes technical and organisational issues but does not include exploration of the design phase or how sensemaking is taking place, Endsley (2003).

We see "human error" as a symptom of trouble deeper inside the system (Dekker 2001, 2002). To understand failures, you must study features of people's tools, tasks, and operating environment.

The theory of HRO-High Reliability Organisations (Rochlin, 1996) argues that high reliability and avoidance of errors is an organisational trait, thus human error is a symptom of organisational issues. We argue that accidents and successful operations are impacted by organisational issues, and that accidents may be prevented by designing and implementing systems that support the user.

1.2 *Definitions and terminology*

Critical operations in the relevant control facilities include processing of dangerous substances such as oil and gas, in operations such as drilling, and through control of collision energy such as from nearby supply ships. We use the term safety-critical to denote situations or operations that, if they go wrong, have a large potential for causing harm to people, property, or environment. Systems used are process control systems, emergency shutdown systems, drilling systems including safety systems, and control systems in general such as on a ship bridge.

Safety is related to accidental harm, while security is related to intentional harm. Safety is defined as: "the degree to which accidental harm is prevented, reduced and properly reacted to" (Firesmith, 2003).

Resilience Engineering (RE) is an important strategy to handle unanticipated incidents. Hollnagel, Woods and Leveson (2006) define resilience as "… the intrinsic ability of a system to adjust its functioning prior to or following changes and disturbances, so that it can sustain operations even after a major mishap or in the presence of continuous stress". Handling of unanticipated incidents and the capacity to continue to operate safe is a key ability when automation and remote operations are increasing.

1.3 *Human Factors issues*

Human Factors (HF) is a large scientific field, used extensively in the aviation industry to improve safety, this best practice can be utilized in the oil and gas industry. HF is an important foundation for understanding the human role in operations and critical tasks. As described in Karwowski (2012), HF consist of ergonomics (workplace layout, working postures); cognitive issues (mental workload, decision, information systems, task analysis) and organisational issues (communication, effective teams/Crew Resource Management, work processes, etc.).

1.4 *Scope and Research Questions*

Our aim is to establish an overview of scientific papers and reports of accidents related to automated and remote operations, and if possible related to design. Research questions (RQ) are:

- RQ1: What are the key safety causes of accidents involving automation in control systems – and can these be mitigated by design?

- RQ2: What are the key safety causes of accidents involving remote operations in control systems – and can these be mitigated by design?
- RQ3: What is the relationship between design and accidents, i.e., is (poor) design a significant contribution to accidents?

2. Methodology and approach

We have based this paper on a literature review (including snowballing from relevant papers), a review of reports from the Petroleum Safety Authority (PSA), and interviews with HF experts in the oil and gas industry.

The scope of the literature review was to explore relevant papers exploring Human Factors lessons from accidents involving automation and remote operations. The literature review was based on keyword searches for publications in Web of Science, SCOPUS, and Google Scholar for the years 2000-2022. The searches resulted in 80 papers, followed by a review of the abstracts prioritizing the papers in three categories (from low relevance, medium and high) by two researchers, selecting 25 papers with high relevance. Papers with high relevance were analysed and further relevant papers were selected based on snowballing.

Keywords used were accident, disaster, incident, occurrence, blowout, injury, safety, risk, hazards, offshore, oil, gas, petroleum, Human Factors, situational awareness, sensemaking, cognitive, digitalisation, remote, autonomy, automation, telerobotics. We have also reviewed reports from PSA using keywords "Alarms" and "Remote Operations", limiting to the period 2020-2023.

3. Results and discussions

In the following section, we have documented the findings from the literature review, the results from the interviews, and the analysis of PSA reports.

3.1 *Findings from the literature review*

In the following we have listed findings structured in the following categories: Design, Automation, Alarms, Remote Operations, and Methods and accident analysis. The Methods and accident analysis are included to point out the need for improved accident investigations as basis for learning.

Design

Searching for literature on design causes of accidents we found two general articles discussing the root-cause contribution of design to accidents, Kinnersley et al. (2007) and Moura et al. (2016). Based on a review of accidents in aviation and nuclear industry Kinnersley et al. (2007) concluded that approximately 50% of all accidents have root causes from design. Moura et al. (2016) found that “Design failure” is the most frequent contributing cause for major accidents, around 60%.

Meshkati (2006) pointed out the need for ecological interface design, and the need to analyse task demands vs capability of the operator to handle difficult deviations (including alarms). It could be a need for more than one operator to be involved.

Lootz et al. (2012) studied hydrocarbon leaks on Norwegian offshore installations in 2002-2009. They found that between 30 and 40% of the leaks could be related to unfortunate design features and could have been avoided with a different design. A better understanding of human reliability and human machine interfaces (HMI) could be useful in the industry’s efforts to reduce the number of incidents.

Thorogood et al. (2015) discuss the principles underlying the concepts of Human Factors, and pointed to the need for CRM training, to help support situational awareness, and the need to integrate HF in design, in operations evaluations, and in accident investigations. Sandhåland et al. (2015) found that poor situational awareness, (based on level 1), were causes in 13 of 23 accidents, assumed to be a result of poor interface design or insufficient training, highlighting the need for a careful SA analysis of accidents. The accidents came from supply ships in oil and gas industry.

Key takeaways have been that design is a significant root cause of accidents, and that design issues and HF issues should be a part of accident investigations. Analysis of SA must include the different information the operator needs to handle critical tasks, derived from various sources. High performance design of HMI to build SA in critical operations are described in Hollifield et al. (2008).

Automation

Ciavarelli (2016) highlighted the need for collection, analysis, and display of safety critical data such as well-test, and other operational data, with better human-interface technology, and improved operational procedures. In addition, they highlighted the need to identify critical Human Factors hazards and risk mitigation procedures, in addition to continuous technical training.

Gressgård et al. (2013) explored drilling automation. The driller's role is complex, involving many tasks and communication with several organizations. Regarding the operators' perceptions of the drilling automation system, discussions of the appropriate amounts of signals are necessary for the system to be efficient in reducing complacency and operator inattentiveness. An increase in use of automated aids leads to an increased need for well-functioning communication with support personnel. It is important to explore how work-shift arrangements may influence automation-induced complacency. Working hours and fatigue problems should be taken into consideration. Use of technology should reduce complacency thus the use of alarms should be dynamic and easily configurable (emphasizing adaptability). Development and implementation of automation must take an interorganizational perspective, since use of automation may involve design of work processes of several organizations. Experience and training are important when there is room for (and need for) overriding of the system. As irregular situations cannot be induced in a real setting, there is a need to train to be able to handle automation failures.

Atchison (2021) described the design of an automated well control system and summarises the outcomes of a comparative HF analysis between automated well control and traditional well control. The outcome of the comparative analysis highlights a significant reduction (ca. 90%) in the human failure risks that automated well control brings to well control, indicating that the designed solution should be tested and explored in operation.

Lyons et al. (2017) described an automatic ground collision avoidance system on the F-16 that has avoided four operational disasters, i.e. a system working during safety-critical operations.

The literature review by Cummings (2021) points out that AI and automation can augment humans in safety-critical operations. However, this should not be mistaken for the ability of AI and automation to replace humans. This is much more difficult. Because AI cannot use reason to understand cause and effect, it cannot predict future events, simulate the effects of potential actions, reflect on past actions, or learn when to generalize to new situations. Since AI/ machine learning has the inability to replicate top-down reasoning to resolve uncertainty, AI-enabled/ automated systems should not be operating in safety critical systems without significant human oversight.

Funk et al. (1999) found that key factors of accidents and incidents were inadequate understanding of automation and poor transparency of automation in aviation systems.

Calhoun (2022) summarize the benefits of adaptive automation based on a few studies. The studies show that adaptable automation was preferred over adaptive automation, and that adaptable automation resulted in improved task performance and less perceived workload.

Key takeaways regarding automation are the possibilities to reduce risks, but automated systems cannot be expected to handle safety critical operations faultlessly without human oversight. To prevent automation failures, the user role must be a part of the design and the users must be involved early in design. Furthermore, failures must be systematically identified, and the operators must train to handle failures. Human Factors engineering becomes more important i.e., perform design based on a task analysis of critical operations, in order to establish distribution of responsibilities, determine workload, HMI design and alarm design. Adaptable automation seems to be beneficial for task performance/reasonable workload and needs to be explored further.

Alarms and control rooms

Bjerkebaek et al. (2004) documented that poor alarm handling persists. The results demonstrate that the safety critical function of the alarms in a crisis situation may be seriously impaired. This is when the operator is in most need of a well-functioning alarm system. A follow up through an alarm-audit/inspection was done in 2021-2022 by the PSA in Norway (PSA, 2022), of the control rooms at most Norwegian facilities and land plants. Only one installation got no remarks.

Walker et al. (2014) performed a review of 1/3 of North Sea control rooms. They revealed persistent issues around alarms, and poor support /preparation provided to operators in non-routine and emergency situations. HMI evaluations were based on Ravden (1989), alarm handling referenced EEMUA-191.

Key takeaways from alarms and control rooms are the persistence of alarm issues and the need to engineer alarms based on best practice standards, and improved support /preparation to operators in non-routine and emergency situations.

Remote operations

Key issues that impacted remote operations from de Almeida et al. (2020) were missing research of Management of Change, permits-to-work and work-as-done (vs work-as-imagined) to understand safety challenges. They highlighted missing functionality in remote operations. Examples were that the status of pump operation were not available remotely, and that the valves in the cargo system did not have a remote indication of position and could not be remotely operated. To manage operations, the operator had to communicate with a field operator.

Ramos et al. (2020) described the Tosco Avon Refinery accident, that resulted in the death of one operator and 46 people injured. The paper highlighted the poor quality of the HMI systems (HMI output was inadequate) and the combination of remote and localized operations. Not all temperature data were accessible from the control room, some of the readings could only be obtained at the local field panels, exposing people to the danger of high energy in local accidents.

Qi et al. (2013) analysed a few cases which resulted in human fatalities due to lack of remote oversight and early warning systems. The authors suggested that it is important to support workers with remote monitoring and early warning systems. However, information presentation needs design of appropriate data sensors, thoughtful HMI presentation of data, and time used to establish good alarm design and avoid too many alarms.

Johnsen et al. (2005) discussed key challenges of remote operations based on early discussions and experiences of pilot projects. Key issues mentioned were HAZOP of design of remote operations, the establishment of situational awareness, appropriate “management of change” involving experienced actors and clarity of organisational issues (responsibility, procedures). HF aspects of remote operations are further explored in Henderson (2002).

Korsvold et al. (2009), identified several key issues in remote support of drilling operations, trying to build a shared real-time collaboration environment supported by collective learning. Three principal kinds of learning dimensions are essential for developing improved collaborative capabilities - labelled How-, What- and Why-learning(ibid). Control of operational risks in drilling are dependent on maintaining a collective and accurate SA

Card et al. (2016) highlighted the importance of situational awareness, assessing Human Factors and ensuring that the team is functioning in an optimal manner.

Key takeaways from remote operations is the need to implement genuine remote operation without the need for local operation (of safety critical issues). Other takeaways are to establish relevant data sensors, thoughtful early warning/ information presentation/HMI, and good alarm design all to sustain appropriate SA.

Methods and accident analysis

Aas (2009) highlighted the need to use HFACS in the Oil and Gas industry in accident analysis, since it focuses on the need to understand HF causes as a signal of deeper troubles from the system. Too many causal factors are categorized as human error.

Theophilus (2019) suggested to adapt HFACS to the Oil and Gas industry by adding relevant HF issues from that specific industry such as contractors, Management of Change, and international regulations, areas that have been identified as important for safety.

Tabibzadeh et al. (2015) pointed out that AcciMap is a systematic methodology that can be generalized and applied to major mishaps in the oil and gas industry, both in upstream and downstream. It is pointed out that AcciMap helped to identify that organizational factors were the root causes of accumulated errors and questionable decisions made by personnel or management inside and outside the organisation.

Key takeaways have been the need to understand human errors exploring HF, to improve the quality of accident analysis ensuring that both issues related to man, organisation and technology is included.

3.2 *Findings from interviews*

In addition to the literature review, we have performed interviews in industry and among designers/HF experts, to discuss experiences and safety challenges of automation and remote operations. Key issues from the interviewees are:

- HF experts are not always involved early in the problem definition phase or concept phase of installations. Key HF principles and HF standards (Industry guidelines, best practice methods) are often missing in the solution, impacting ergonomics, cognitive issues (SA), workload or organisational issues. As a result, visualisations may not be grasped "at a glance".
- The principle of "user driven design" is seldom used. Design is often done in a network of actors not sufficiently involved in the actual operations. An ideal process would ensure that request for proposals is based on user needs and that HF, safety and resilience are evaluated.
- Digital Twins (DT) has been implemented in the Oil and Gas industry. In some instances, the quality of DT has been poor. From two installations/control centre the experiences have

been that "DT is not in use, and no one has found it useful." This may be because the DT is covering only some functionality, and not enough process information. Practices of design and implement DTs should be improved.

3.3 *Findings from PSA inspections*

We have explored alarm reports. PSA (2022) documented a review of the use of alarm systems at 54 installations both at drilling facilities, onshore facilities, and at production facilities. Only one installation did not get any suggestions to improve operations of alarms (Why one operator had no comments were not explored or discussed but could be useful related to learning from good practice.)

- The alarm systems are often poorly designed, and the systems may be subject to alarm flooding, i.e., alarm philosophy missing.
- PSA observe that the alarm systems often do not meet the company's requirements and that there are high alarm rates and many standing alarms. This suggests that there are deficiencies in both the follow-up of the system and the understanding of the effects that high alarm rates and many standing alarms can have on the working conditions for the operators.
- Comments often used were that the companies had inadequate assessments of perceptual and cognitive limitations including the total workload for the control room operators.

Main findings are the missing HF focus from the start/early on and during operations, with lack of appropriate standards. The poor focus on HF impacts the SA and the workload for the control room operators and may lead to accidents.

3.4 *Reports from Remote Operations*

Remote operational Centres (ROC) and remote supervision in the oil and gas industry have been in place from 2001 within the EU, with several new remote centres from 2017-2018. Remote supervision of gas-assets has been done by Total EP from 2001, performing capacity control and process control (HFC, 2016). Remote operations are possible, and pilot projects by Equinor and Aker BP has demonstrated their usability. We have performed interviews with users and management, and reviewed experience reports from remote operations (IFE, 2022). Key issues found when operations in the oil and gas industry have been:

- Cost reduction have not always been achieved by remote operations.
- The users pointed out that the risks have been on the human side, not the technical side, i.e., there should be strict requirements for user-friendliness and resilience/robustness for systems (especially alarms) to be used in remote control.
- ROC experience indicates low operator workload, the operators want more tasks, such as operating several fields from the ROC. However, when several units are operated from the same control room, it must be easy to distinguish between the units.
- The operators want frequent training with Defined danger and accident situations (DFU)
- New requirements to operational equipment in remote operations has not always been taken into accord. Examples mentioned has been maintenance-free equipment, to reduce periodic maintenance and thus manning needs.
- Operators in ROC quickly lose practical operational competence. When the go offshore they cannot do a full-fledged outside job (such as maintenance) if there is need for rotation in the offshore field on their periodic trip.

Experiences from aerospace (IFE, 2020) document different use of time, in the mission control centre (MCC). 10 percent of the operators time is spent on controlling missions, 75 percent is spent on procedures (planning, updating), and 15 percent is used on training and education. MCC workers practice responses in simulator training, to build resilience where unexpected events require fast thinking and logical responses.

4. Discussion and conclusion

In this paper we have discussed HF of automation and remote operations through review of safety literature containing empirical experience. In the following we have reflected on the research questions and at the end summarized our suggestions and implications.

Regarding key causes of accidents involving automation (RQ1), we found that automation may reduce risks in critical operations. Automation has been extensively used in aviation. However, poor understanding of automation has been found to be causes of accidents. Due to limited implementation, we have not found that automation causes accidents in oil and gas. Automation creates the need for more thoughtful design and human factors engineering. Automation failures and the user role must be a part of the design from the start. Automated systems cannot handle critical operations faultlessly without human oversight. It is a need to systematically identify failures, design the system to be able to support deviations and train the operators to handle exceptions. Adaptable automation seems to be beneficial and needs to be explored further.

Regarding key causes of accidents involving remote operations (RQ2), we have not found that remote operations increase the risks of accidents or causes accidents. Safety may be improved by removing the operator from danger. However, if remote operations are imperfect, i.e. needing local manual operations close to dangerous energy, then safety is not necessarily improved. There should be strict requirements for user-friendliness and robustness for systems to be used in remote control, and design of alarms must be performed based on good practices.

Regarding the relationship between design and accidents (RQ3), some papers have highlighted that poor design has been the root cause or contributing cause to accidents in approximately 50% of cases. User centric design seems to reduce accidents. Good practices of user centric design are ecological interface design, use of eye tracking, and careful design of appropriate alarms. However, there is a need to explore and gather more data related to the role of design in accident investigations and to systemize design lessons from accident investigations into actual practice and work as done.

We did not find any systematic safety reviews of remote operations, or automation. To improve our understanding of the safety challenges related to remote operations and automation we are going to perform specific case-studies involving use of remote operation and automation. There is a need to examine the involvement of end users in design and implementation of automation (using AI) in the Norwegian petroleum industry. Especially during the earlier phases, discussing the design of the operational domain i.e., algorithms and training data. Involvement in the later phases (offshore testing, implementation, use and improve), may create potential deficiencies, safety problems or quality challenges. We need to explore safety challenges in depth and also gather (thick) success stories in collaboration with the industry. Other industries such as rail may also be explored.

Based on our review, successful automation and remote operations needs to prioritize HF from the problem definition through design and implementation. Thus, there is a need for regulation to ensure use of HF best practices. To help laggards to come into line, HF principles should be a part of regulation, ensuring that HF are considered from start to operations. If accidents happen there is a need to go behind the "Human Error" label and explore the accident with HF experts and examine the role of poor design.

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