Proceedings of the 35th European Safety and Reliability & the 33rd Society for Risk Analysis Europe Conference
Edited by Eirik Bjorheim Abrahamsen, Terje Aven, Frederic Bouder, Roger Flage, Marja Ylönen

doi: 10.3850/978-981-94-3281-3_ESREL-SRA-E2025-P8084-cd

Human Factors and Design Principles for Safe Remote Operations in the Petroleum Sector

Mina Saghafian

Department of Technology Analysis and Innovation, Institute of Transport Economics.
Department of Design, Norwegian University of Science and Technology (NTNU), Norway.
Email:Mina.Saghafian@ntnu.no

Gunhild Birgitte Sætren

Business School, Nord University, Norway. Email: Gunhild.b.satren@nord.no
Department of Organisation, Leadership and Management, University of Applied Sciences, Norway

Stine Thordarson Moltubakk

University Library, NTNU, Norway. Email: Stine.moltubakk@ntnu.no

Lene Elisabeth Bertheussen

University Library, NTNU, Norway. Email: Lene.bertheussen@ntnu.no

Jooyoung Park

Department of Design, NTNU, Norway. Email: Jooyoung.Park@ntnu.no

Ole Andreas Alsos

Department of Design, NTNU, Norway. Email: Oleanda@ntnu.no

Stig Ole Johnsen

SINTEF Digital, Norway. Email: Stig.O.Johnsen@sintef.no

The petroleum sector is a safety-critical sector that is increasingly investing in automation and remote operation technologies to increase the safety and efficiency of its processes. For a safe and resilient transition, the petroleum sector would benefit from integration of human factors approaches to optimize system design in complex human-automation interactive systems. While most research focuses on the investigation of failures and accidents in complex systems, our aim in this paper is to explore the design strategies that enhance the overall system performance. We consider this a successful design. The research question that we posed was: what human factors principles can be deployed in interactive automation and remote operation systems design in the petroleum sector? This paper is part of the Meaningful Human Control (MAS) project where a larger literature review was conducted to identify successful design principles across various sectors. This article zooms in on the petroleum sector literature. Following a set of inclusion criteria, we have selected a representative sample of articles to be included in analysis. A total of nine articles were selected for full-text analysis, using the thematic analysis method. Interventions deployed and recommended in the petroleum sector were derived from the articles. The results showed the importance of predesign stage, inclusion of the right expertise early on. Furthermore, Human-Centred Design guidelines should be applied. All the stages must be peer-reviewed, and verification and validation tests must be conducted throughout the design process. Additionally, organizational human factors principles, which are key to successful automation and remote operations in the petroleum sector, should be incorporated.

Keywords: human factors, human-centred design, automation, remote operation, petroleum.

1. Introduction

Automated control systems can be highly beneficial in offshore drilling rigs due to the complexity of their operations (Haas, 2013). However, advanced automated systems introduce new challenges, as they are more difficult to comprehend and intervene in when unexpected events occur. By considering human factors and design principles in the development of human–automation interactive systems, the full potential of both the human agent and the automation agent can be utilized.

Accidents and unwanted incidents in the industry clearly indicate that a focus on human factors and human-centred design could be beneficial. For example, a design and implementation process that did not sufficiently involve end users from the early phases led to the evacuation and shutdown of an oil and gas platform, which remained closed for several months (Sætren et al., 2016). A well-known petroleum sector accident where lack of human-centred design played a role, is the Deepwater Horizon accident (National Commission, 2011). Another example is the collision between the Sjøborg supply ship and the oil and gas platform Statfjord A (Petroleumstilsynet, 2019). Cognitive challenges were key factors in all these accidents. Proper integration of human factors expertise into the design process of these systems could have prevented these accidents.

Research supports the early integration of human factors in design processes to prevent accidents and improve system efficiency and usability (Bennett & Flach, 2019; Carayon, 2006; Endsley, 2019). Accidents often occur due to a limited understanding of real-world use cases and workflows. Studies emphasize that involving end users throughout the design and implementation stages, especially during the planning phase, reduces costs and increases effectiveness (Beuscart-Zéphir, 2007; Vredenburg et al., 2002).
Despite the availability of human-centred design (HCD) methods, the petroleum sector faces challenges in their timely application (Ernstsen et al., 2021; Sætren et al., 2016). Human factors experts are often excluded from early design phases, and key principles of classical design approaches inadequately address ergonomic, cognitive, and organizational aspects (Johnsen et al., 2017; Johnsen & Winge, 2023). To achieve better outcomes, it is vital to involve all stakeholders affected by design solutions and adopt a broader perspective on HCD. This practice should not be limited to learning from failures but should instead serve as a proactive measure to design safe automated and autonomous systems based on established literature findings to optimize safety, performance, and user satisfaction (Lee et al., 2017). The aim of this review is to present a general account of some of these principles found in the literature.

2. Method

This review paper examines recent literature relevant to the research question: What human factors and design principles contribute to successful automation and remote operation in interactive systems in the petroleum sector?

This paper focuses on a subset of a broader systematic literature review (SLR) conducted as part of the Meaningful Human Control (MAS) project, which explores digitalization and automation design applications in safety-critical sectors, with the scope of the project being on transportation and petroleum system in particular. Since transportation focuses on transport of goods and passengers, we decided to group them separately from the petroleum sector that has its own particular operations, such as drilling operation. However, similarities in approaches and design principles exists, for example regarding the remote centre operation design.

The search was conducted in November 2022 using Web of Science, Scopus, Dimensions, Compendex, and IEEE databases. Employing the PICO (Population, Intervention, Control, Outcome) framework, the research team developed and refined a search string through iterative testing before executing the final search. Duplicates were removed, and the remaining abstracts were screened and evaluated for relevance. See Saghafian et al. (2025) for a detailed description of the process. A total of 378 publications remained, with the majority of articles focused on the transportation sector. The remaining papers that met the inclusion criteria within the petroleum sector were selected for further analysis. An overview of this process is provided in figure 1.

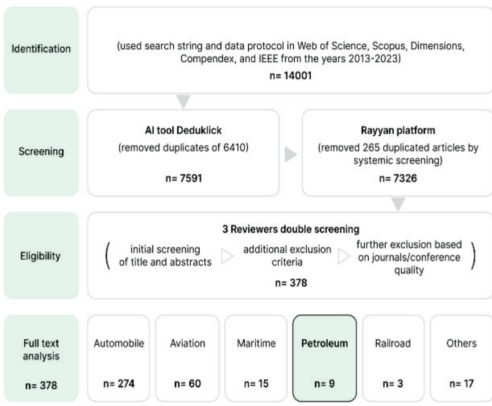

Fig. 1. The overview of the SLR process.

The selected articles (see Table 2.) were analysed thematically to derive information on what was considered successful system performance and what principles were associated with that.

Table 1. The overview of the articles selected for thematic analysis

Author	Year	Reference Type
Aitken et al.	2017	Conference
Amezaga et al.	2020	Conference
Antonovsky et al.	2014	Journal
Carpenter, C	2022	Journal
Haas, D	2013	Conference
Henriksen et al.	2016	Conference
Hoyle and Peres	2017	Journal
Patel et al.	2020	Conference
Thorrud et al.	2020	Journal

There were six steps in the analysis following Braun and Clarke (2006) recommendation: (1) reading the full text, (2) coding the parts of the article that were relevant for the research question, (3) grouping the codes together, (4) review them and recategorize them based on their underlying common thread, (5) define the groups as themes and finally (6) writing the themes and subthemes (See figure 2).

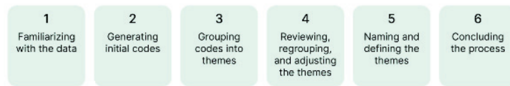

Fig. 2. The overview of the thematic analysis process.

3. Results

Amongst the derived themes, we choose to focus on two relevant themes in this paper:

(i) what does successful system design entail?

(ii) what human factors and design interventions can lead to successful system performance?

3.1. *Defining successful system properties*

To identify successful design principles, it is essential to define success based on sector-specific literature. However, the concept of successful design varies across industries and stakeholders, making it difficult to establish a universal definition. A practical approach is to derive the definition from the sector's own discourse.

Literature within the petroleum industry indicates that a well-designed automation and remote operation system enhances efficiency by reducing the time required to detect errors (Carpenter, 2022), thereby minimizing risks and costs. Effective design also simplifies operations, making them faster and safer (Amezaga et al., 2020). A key factor in success is the shift from reactive to predictive systems, particularly concerning alarms and notifications (Aitken et al., 2017). Additionally, corrective maintenance should be based on accurate problem detection and the application of the most effective solutions (Antonovsky et al., 2014).

Another critical aspect of successful system design is the seamless integration of multiple systems. In the petroleum sector, various organizations, contractors, and stakeholders operate with distinct systems and tools. A well-designed system must feature an open architecture that enables interoperability, allowing operators to manage operations safely, efficiently, and easily from a remote human–machine interface (Amezaga et al., 2020).

3.2. *Human factors interventions*

A number of subthemes were identified that help understand what interventions have been associated with desired system outcomes. These can be considered as lessons learned from executed system developments.

3.2.1. *Develop thorough ConOps*

Successful design starts with planning and a well-thought-out concept and requirements set that is documented. This is referred to as the concept of operations (ConOps) (Haas, 2013). This document outlines the specific problems that needs to be addressed, the end goal, the user needs and how these needs are going to be addressed, the system architecture and requirements and the possible constraints, and the demands of the various stakeholders that will be impacted by the system. The validation and verification of the requirements are critical details in ConOps as well as strategies to deal with defects in the system. Additionally, a Failure Modes Effects and Criticality Analysis (FMECA) should be conducted to see how the design concept can be modified. A successful design process must track back to the ConOps where the needs and requirements are outlined in detail. Traceability is an important theme throughout the design process that ensures that each requirement can be checked with a parent criterion in the ConOps. It makes sure that the design satisfies the requirement (Haas, 2013).

3.2.2. *Aim for open architecture*

A system architecture consists of the expected performance and functionalities, the use of technology, the interfaces, and the design decisions that are also addressed in ConOps (Haas, 2013). A successful system design enables the integration of all the subsystems in an open architecture operational model that allows all the equipment from various stakeholders on the rig to be plugged and operated from a common interface (Amezaga et al., 2020). The equipment and the interface integration should be designed in a modular and standardized way (Patel et al., 2020). It is beneficial to design the system based on existing infrastructure and with the integrability of the system in mind.

3.2.3. *Follow human-centred design guidelines*

One of the HCA design guidelines concerns the shared control. This refers to systems where a human operator and the automation share (Henriksen et al. 2016). One way to design for shared control is to determine under what conditions do operators experience higher levels of stress and have lower reaction time, or higher propensity for making mistakes due to stress measures for example through body temperature (Carpenter, 2022).

Another way of designing for control is to determine the Level of Automation (LoA) at the design stage and to decide on how to allocate functions between the human and the technology. Function allocation can be done based on Fitts's list (Fitts, 1951) that allocates the task to human or the machine (Henriksen et al., 2016).

A well-designed Human-Centred Automation (HCA) system enhances both comprehensibility and predictability for human operators, ensuring they can effectively interact with automation (Henriksen et al., 2016). If an operator needs to investigate an anomaly or inspect a specific issue, the system should save the point of departure and allow an easy return to normal operations, minimizing the effort required for intervention (Henriksen et al., 2016). Additionally, automation can be designed to monitor human actions and help prevent errors. Research shows that automated systems detect failures faster than human operators (Carpenter, 2022). Aitken et al. (2017) describe an automated system that identifies operational stalls or when predefined limits are approached. It then notifies the operator and allows manual intervention as long as safety thresholds have not been exceeded. However, if the system detects that operational limits have been breached beyond a safe margin, it will take necessary action without waiting for the operator to override.

3.2.4. *Ensure transparency and consistency*

Although transparency is not explicitly mentioned in the reviewed literature, it is implied through the need for observability, comprehensibility, and predictability in system design. Operators must clearly understand the system (Henriksen et al., 2016), and in complex environments, relevant information should be presented intuitively and holistically (Thorrud et al., 2020). Transparency should extend beyond the operator to include other systems and interfaces, ensuring seamless communication between hardware, software, and the environment (Haas, 2013). Additionally, predictability and consistency are key. The operator's commands should always produce the same, immediate, and safe response in a predictable and consistent way (Henriksen et al., 2016).

3.2.5. *Support proactive situational awareness*

Thorrud et al. (2020) emphasize the importance of situational awareness by ensuring operators receive relevant information for better decision-making. Automated systems should detect discrepancies between theoretical and actual data (Carpenter, 2022) and communicate them effectively, typically via alarms. However, alarms without sufficient context can hinder rather than help, making it difficult for operators to diagnose issues. Additionally, false alarms can overload operators cognitively, reducing their ability to respond effectively (Thorrud et al., 2020).

In high-risk environments like offshore drilling, split-second decisions are critical, as errors can lead to severe injuries, fatalities, and significant financial losses (Hoyle, 2017). Operators must process multiple information sources under pressure, making alarm design crucial. Instead of relying on retrospective diagnoses, systems should proactively enhance situational awareness through sensors, transmitters, and trend visualization of both normal and deviating patterns (Thorrud et al., 2020) and help distinguish false alarms and improve decision-making.

3.2.6. *Perform verification and validation tests based on ConOps and FMECA*

Patel et al. (2020) emphasize that designers must anticipate new risks, especially when transitioning from manned facilities to remote operations and implement mitigation strategies accordingly. To improve system reliability early on, Haas (2013) recommends conducting a Failure Modes, Effects, and Criticality Analysis (FMECA) during the design phase, allowing potential issues to be addressed before implementation. For validating new technology, Patel et al. (2020) advocate using Technology Qualification (TQ), a structured approach that includes design verification, validation testing, material selection, construction monitoring, and life cycle management. Additionally, several reliability strategies should be integrated into system design, such as maintenance analysis, minimizing downtime, optimizing inspection time, selecting the best corrective actions for various failure scenarios, and prioritizing predictive maintenance over reactive maintenance (Patel et al., 2020).

3.2.7. *Test and evaluate the system design stages*

Simulator testing plays a crucial role in evaluating system resilience and training operators in safety-critical environments. It allows for controlled fault introduction to assess tolerance, resilience, and safety boundaries (Haas, 2013). Aitken et al. (2017) suggest enhancing simulations by incorporating real-time operational data. This refines programmable logic controllers that intervene when performance deviates from target. This approach improves automation predictability and reliability for operators.

Throughout the entire product life cycle, peer reviews are essential to ensure objective feedback on design modifications (Haas, 2013). However, designers must be cautious of over-automation, as some tasks still require human supervision due to cost or complexity (Henriksen et al., 2016). This aligns with the compensatory principle from Fitts's list (1951), which emphasizes balanced task delegation between humans and automation. Additionally, designers must adopt a long-term perspective, prioritizing safety and design reliability over short-term pressures of time and budget constraints (Haas, 2013).

3.2.8. *Update industry-wide standardization and guidelines*

The literature highlights the importance of standardization and guidelines in the petroleum sector. While several industry standards exist, further standardization is necessary for remotely operated, minimally manned, and unmanned facilities (Patel et al., 2020). Standards evolve over time to address emerging challenges, and implementing standardized verification and validation tests can help reduce automation-related accidents (Haas, 2013). Another key aspect is the need for standardized system design and integration to enable seamless cooperation among multiple interfaces and systems. Amezaga et al. (2020) stressed the importance of standardizing interfaces in the petroleum sector. The current lack of standardized equipment and interfaces has led to redundant equipment in hazardous red zones on rigs, further complicating an already complex system. Lessons from the aerospace industry demonstrate how rigorous software standardization contribute to safe, reliable, and high-performing systems, allowing human-technology collaboration under extreme conditions (Haas, 2013). These established standards could serve as a model for the petroleum sector to enhance its standardization processes, improving both safety and operational efficiency.

4. Discussion and conclusion

The aim of this paper was to identify human factors and design principles and practices that enhance the success of human–automation interactive systems in the petroleum sector. The research question was what human factors and design principles contribute to successful automation and remote operation in interactive systems in the petroleum sector?

Successful system design starts from planning and continues after system is in use and expands into standardization. The ConOps play a key role, and they could be based on mature design examples. Open architecture and ensuring integration of systems must be considered. Human-centred design principles, transparency, situational awareness must be incorporated in design. Automation behaviour must be predictable and consistent so that it can be relied on. Using simulation, verification and validation testing, peer-reviewed evaluation throughout system lifetime are necessary. The system design and the industry standards must be kept up to date.

It relies on developing a shared understanding of both the desired outcomes and the process to achieve them. The team of relevant stakeholders collaboratively defines success and participates in co-creating the Concept of Operations (ConOps). When this predesign stage is executed effectively with the inclusion of appropriate expertise, potential complexities and setbacks can be identified early, allowing for expanded system buffer margins and a more resilient design. Adhering to human-centred design (HCD) guidelines is essential, with an emphasis on supporting transparency and proactive situational awareness through design. Peer reviews, as well as verification and validation tests, should be integrated at every stage of the design process. Additionally, applying organizational human factors principles, such as ensuring proper resource allocation, fostering co-creation and teamwork, and integrating multiple systems, interfaces, and workflows is critical for advancing successful automation and remote operations in the petroleum sector.

The regulations should become clearer and more forceful with implementing the validation and verification tests based on ConOps, including peer-reviewed and approved design steps and practices. What is missing here in the literature reviewed, is the importance of designing for relationships between the agents that will be interacting with and through the system after a system is built and put into use. In other words, the system design must consider how various stakeholders will be interacting and how this might change, and how it may be managed best. This is aligned with organizational human factors where technical support, training and accountability is emphasized. This is when co-creation can be perpetuated. Indeed, a shift from user-centred design to co-creation is called for (Sanders and Stappers, 2008), especially in complex, multi-stakeholders and evolving systems such as the petroleum sector.

There is not much empirical evidence of specific design interventions that have been proved to have a significant effect on the system outcome. This is partly because in different contexts, successful system design outcome is defined differently. Furthermore, the design guidelines are either very specific and focused on the logarithmic adjustments, or they are very broad and often descriptive. The thematic analyses of the papers could identify some of the good practices but there is a gap in the literature regarding quantifying the impact of these practices on the successfulness of the final system outcome. It seems to be generally agreed upon that HCD concepts such as situational awareness, transparency, and workload are important considerations in design. However, despite measures in place to quantify these variables, they are very context-bound, meaning that every system, user, context, and out-of-design domain event influences these factors differently. More data needs to be gathered across contexts and sectors to create better models of interaction between these variables.

Future research can focus on how to operationalize successful design better and how to measure this success. The difficulty of doing so is that success is not a singular outcome of a singular intervention but a desired outcome of a myriad of elements in the system performing well and interacting well with other elements. Future research can try to simulate the design processes with and without the suggested intervention to measure whether and how they exert an influence. More studies are needed to understand the complex system and to distinguish what exact design development intervention is needed, by whom and when at every level of the system to achieve an overall satisfactory outcome based on ConOps and a predefined success outcome. Furthermore, as automation is increasing across the industry, more research is needed to understand emerging human factors and design principles needs for advances of artificial intelligence in increasingly more automation applications in petroleum sector.

Acknowledgement

This research is funded by Meaningful Human Control of digitalization in safety critical systems (MAS) project, Norwegian Research Council, RCN 326676.

References

Aitken, B., Micheli, R., Ramsey, T., and Dobkins, K. (2017, November). Reducing the impact of experience gap and increasing service delivery by automating the coiled tubing intervention. *Abu Dhabi International Petroleum Exhibition and Conference* (p. D031S092R006). SPE.

Amezaga, F., Cummins, T., and Hooker, J. (2020, February). Automating tubular-running operations to increase rig efficiency. *IADC/SPE International Drilling Conference and Exhibition*. OnePetro.

Antonovsky, A., Pollock, C., and Straker, L. (2014). Identification of the human factors contributing to maintenance failures in a petroleum operation. *Human Factors, 56*(2), 306–321.

Bennett, K. B., and Flach, J. (2019). Ecological interface design: Thirty-plus years of refinement, progress, and potential. *Human Factors*, *61*(4), 513–25 https://doi.org/10.1177/0018720819835990

Beuscart-Zéphir, M-C., Pelayo, S., Anceaux, F., Maxwell, D., and Guerlinger, S. (2007). Cognitive analysis of physicians and nurses' cooperation in the medication ordering and administration process. *International Journal of Med Inform*, *76*(1) 65–77. DOI: 10.1016/j.ijmedinf.2006.05.022

Carayon, P. (2006). Human factors of complex sociotechnical systems. *Applied Ergonomics*, *37*(4), 525–35.

Carpenter, C. (2022). Automation reduces human error in influx detection and well control. *Journal of Petroleum Technology*, *74*(05), 77–79.

Endsley, M. (2019). Testimony to the United States House of Representatives hearing on Boeing 737-Max8 Crashes — December 11, 2019. *Human Factors and Ergonomics Society,* December 2019.

Ernstsen, J., Aulie, E. G., Sætren, G. B., Stenhammer, H., and Phillips, R. (2021). *Et menneskesentrert syn på kognitiv teknologi i petroleumsindustrien.* [A human centred perspective on cognitive technology in the petroleum industry – our translation]. Safetec Report n. ST-16407-2.

Fitts, P. M. (1951). Human engineering for an effective air-navigation and traffic-control system.

Haas, D. (2013, October). Offshore rig integrated system and software requirements verification and validation. In *SPE/IADC Middle East Drilling Technology Conference and Exhibition*. OnePetro.

Henriksen, E. H., Schjølberg, I., and Gjersvik, T. B. (2016). Adaptable joystick control system for underwater remotely operated vehicles. *IFAC-PapersOnLine*, *49*(23), 167–172.

Hoyle, W. S., and Peres, S. C. (2017, September). Situation awareness offshore: Relevant influencing factors and risks. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 61, No. 1, pp. 1700–1701). Sage CA: Los Angeles, CA: SAGE Publications.

Johnsen, S. O., Kilskar, S., and Fossum, K. (2017). Missing focus on human factors: Organizational and cognitive ergonomics – in the safety management for the petroleum industry. *Journal of Risk and Reliability*, *231*(4), 400–10.

Johnsen, S. O., and Winge, S. (2023). Human factors and safety in automated and remote operations in oil and gas: A review. In *Proceedings of the 33rd European Safety and Reliability Conference*, edited by Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio Copyright ©2023 by ESREL2023 Organizers. Published by Research Publishing, Singapore ISBN: 981-973-0000-00-0 :: doi: 10.3850/981-973-0000-00-0 esrel2023-paper

Lee, J. D., Wickens, C. D., Liu, Y., and Boyle, L. N. (2017). *Designing for people*. ShangHai, 173.

National Commission (2011). Deep water. The Gulf oil disaster and the future of offshore drilling. National commission on the BP Deepwater Horizon oil spill and offshore drilling. GPO-OILCOMMISSION.pdf (govinfo.gov)

Patel, H., Kalghatgi, S., Feijo, L., and Scott, R. (2020, May). Unmanned/minimally manned floating deepwater installations: Design and safety considerations. *Offshore Technology Conference* (p. D031S032R006). OTC.

Petroleumstilsynet (2019). Investigation of collision between Sjøborg supply ship and Statfjord A on 7 June 2019. 001037045 Granskingsrapport (ptil.no)

Sætren, G. B., Hogenboom, S., and Laumann, K. (2016). A study of a technological development process: Human factors – the forgotten factors? *Cognition Technology and Work*, *18*(3), 595–611.

Saghafian, M., Vatn, D. M. K., Moltubakk, S. T., Bertheussen, L. E., Petermann, F. M., Johnsen, S. O., and Alsos, O. A. (2025). Understanding automation transparency and its adaptive design implications in safety–critical systems. Safety Science, 184, 106730.

Sanders, E. B. N., and Stappers, P. J. (2008). Co-creation and the new landscapes of design. *Co-design, 4*(1), 5–18.

Thorrud, B., Abrahamsen, E. B., and Selvik, J. T. (2020). Safety-instrumented systems in oil and gas improved situational awareness with embedded signature curves in mimics. *International Journal of Performability Engineering, 16*(5).

Vredenburg, K., Mao, J-Y., Smith, P. W., and Carey, T. (2002). A survey of user-centered design practice. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 471–478). https://doi.org/10.1145/503376.503460