Author accepted manuscript version of the publication by Dorthea Mathilde Kristin Vatn, Stig Ole Johnsen & Mina Saghafian. In Proceedings of the 33rd European Safety and Reliability Conference. 2023.
Published version: http://dx.doi.org/10.3850/978-981-18-8071-1_P016-cd

# Challenges and emerging practices in design of automation

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Automation is expected to improve efficiency, as well as increase safety and quality. However, as more automation is added to a system, the lower the situation awareness of the operators may be. In safety critical systems this could have severe effects. Recent accidents illustrate that poor design and poor implementation of automated systems may contribute to accidents. This underlines the importance of investigating the role and use of design guidelines and best practices of human-autonomy interfaces, to ensure that these systems are designed in a way that aligns with human capabilities.  Semi-structured interviews with 14 experts involved in design were conducted to identify challenges in design when introducing automation, as well as identify emerging practises in use. The interview notes were subject to a thematic analysis, and this resulted in the two main themes, "Challenges in design " and "Design in practice", which each has its associated sub themes. The themes underline the need to update methods and standards to overcome challenges, as well as ensuring that best practices are used. There is a growing awareness that introduction of automation requires regulation, innovation and development in design methods and standards, and a key element in these methods and standards will be involvement of users through user centred design.

*Keywords*: design, safety, automation, autonomy, human factors

## 1. Introduction

Increased Level of Automation (LoA) is expected to improve operational efficiency and contribute to lower costs associated with reduced workforce, as well as increased safety and quality consistency (McLeod, 2022). We use the concept of LoA from the automotive industry, going from level 1 - no autonomy to level 5 – full autonomy (SAE, 2018). But as more automation and a higher LoA is added to a system, the lower the situation awareness of the operators, and the less likely they will be able to take over control when needed and as such expel meaningful human control (Endsley, 2017; Santoni de Sio & Van den Hoven, 2018). In safety critical systems this could have severe effects, and several recent accidents illustrates that poor implementation of meaningful human control in automated systems and remote control is a significant accident cause such as from Deepwater Horizon and Boeing Max (CSB, 2016; CSB, 2019; Endsley, 2019).

As the level of automation and the capabilities of autonomy increase, the frequency of human intervention will be less. But for the foreseeable future there will be some level of human-system interaction, and the success of these semiautonomous systems will be highly dependent on human-autonomy interfaces (Calhoun, 2022; Endsley, 2017; Schneiderman, 2020). Parasuraman and Riley (1997) state that automation challenges sensemaking, and requires more, not less, interaction design, interface design, and attention to training. This is in line with Schneiderman (2020) pointing out that well-designed technologies that both offer high levels of computer automation as well as high levels of human control can increase human performance.

Proceedings of the 33rd European Safety and Reliability Conference
*Edited by* Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio

*Published by* Research Publishing, Singapore
ISBN: 981-973-0000-00-0 :: doi: 10.3850/981-973-0000-00-0 esrel2023-paper

Keeping a close look at the human factors, as well as the wider socio-technical aspects in the design of new technologies is important. This could contribute to counteract that the introduction of automation changes the operator's role and tasks in unanticipated ways and increase mental workload, and as such become a safety risk (Dekker & Woods, 1999). Even though automated systems are thought to relieve operators of mental workload, there are several examples that these systems increase the mental workload in an unsustainable and safety-reducing manner (Lee et al., 2017). Operators might also often face multiple autonomous systems based on different levels of machine learning, and it poses challenges on the operator who needs to develop and maintain a sufficient mental model of the different systems. The different systems may also be different in terms of their transparency and degree of explainable Artificial Intelligence (AI), making it difficult for the operator to understand the working of the system and as such prepare the operator to take over control when needed in safety critical situations (Endsley, 2017). This underlines that there are several research needs connected to human-automation research and points towards the importance of investigating design guidelines of human-autonomy interfaces to ensure that these systems are designed in a way that aligns with human capabilities, both strengths and weaknesses.

Human Factors engineering as a scientific field offers several methods to be used in design processes of safety-critical systems. Involvement of the user in an iterative manner is considered key to successful design (Lee et al., 2017, Begnum, 2021). However, human factors methods are often poorly understood and seldom used by design practitioners (Schønheyder, 2019; Shorrock & Williams, 2016). Part of the challenge might lie in the different barriers Shorrock and Williams (2016) have identified in the applicability of human factors methods. These barriers relate to the accessibility of the methods, the usability of them, as well as contextual constraints being about practitioners not seeing the relevance of human factors research to their own practice. According to Lurås et al. (2015) part of the challenge lies in the design practitioner's lack of vocabulary and authority in advocating new design to industrial stakeholders. It might also be a contributing factor that different industries do not understand or prioritize the need to focus on these topics (Puisa, et al., 2018). Even though design practitioners are well known to the user perspective through iterative design methods like the method Double Diamond (British Design Council, 2019), the challenge might lie in the fact that design of safety critical systems also requires knowledge and compliance with rigorous safety requirements and standards. Bridging the gap between the scientific fields of human factors and design seems to be an important way forward.

With this as a background our research objective is to identify safety challenges in design when introducing automation by interviewing different stakeholders involved in design. As most industries hold similar expectations of how they will benefit from introducing more automation (McLeod, 2022), we also aim to identify existing and emerging design practises in use, so that these can be shared and used in learning lessons. We pose two research questions: 1) What do different stakeholders in the industrial and academic field of design identify as major safety challenges in design when automation is introduced? 2.) What is done to overcome these challenges in terms of design practices?

## 2. Method

This study is part of the Norwegian Research Council funded project: MAS - Meaningful Human Control of digitalization in safety critical systems. The MAS project employs the ideals of Participatory Action Research (PAR) aiming at creating a joint learning and reflection process between researchers and the various stakeholders holding an interest in the problem under study (Greenwood & Levin, 1998). The MAS-project has broad participation of different stakeholders having an interest in the findings and discoveries made in the project, ensuring that the issues highlighted are close to real-world practice. In regard of this specific study, semi-structured interviews were done with experts across industry and academia to shed light on the research questions forming the basis of the study. The interview notes were then subject to thematic analysis (Clarke et al., 2015).

### 2.1. *Participants and interviews*

Participants were recruited through the Human Factors in Control (HFC), involving participants agreeing to support the MAS-project specifically, as well as other participants working in industries having an interface with design of automation and remote control in safety critical systems. A total of 14 interviews were conducted. Most of the interviews were conducted by video conference, using Microsoft Teams. The interviews lasted between 1-2 hours, and most of the interviews were conducted with two researchers present to take notes and to ensure follow up on relevant topics. After each interview the interviewers spent time to do a thorough “write-up" of the notes.

### 2.2. *Analysis*

The interview notes were subject to thematic analysis (Clarke et al., 2015) to find common themes across the data material. In the first step in thematic analysis, the aim is to familiarize with the text, which is done by reading the data material several times while taking notes. The second step involves coding, a process in which units of meaning are given short names (Braun & Clarke, 2012). In the coding process, we mainly dealt with the explicit meaning in line with a semantic approach. As we worked through the interview notes we made decisions on whether new units of meaning were possible to code with the existing codes or if they required new codes. In the third step we found themes that reflected the data in a coherent manner as well as answered the research questions. After identifying the themes, step four and step five were conducted involving naming themes and summarising the results.

## 3. Results and discussion

The thematic analysis resulted in themes and subthemes that helped answer the two main research questions about the challenges and the practices in design.

### 3.1. *Challenges in design*

The participants underlined that there are several challenges in design when automation is introduced. Challenges mentioned by the participants could be summarised in the following subthemes: “The premises of technology”, “Invisibility”, “Complexity”, “Resources” and “Piece-by-Piece”. In this section these themes will be presented with extracts from the data material

#### 3.1.1. *The premises of technology*

There is a major challenge that a lot of system design seems to be characterised by technology optimism, a tendency for decision makers to be overly optimistic about the potential for technology to drive successful outcomes (Clark et al., 2015). Technology is developed without the engineers having the user in mind - a user with several human limitations. This practice stands in contrast to Mallam et al. (2022) notion that empathy is a foundational aspect of promoting successful user-centred approaches in safety critical systems. Several participants underlined the challenge lying in a strong technology focus among those developing these systems.

“*The culture in the field is very technologically oriented – technology for technology’s sake. Not for the users to use."* (Informant 11)

Considering design of safety critical systems, it is important to remember that several of our higher cognitive skills shut down when stress-level increases. One important dimension we found was connected to the fact that automation takes over several tasks, making the operator a passive observer, and therefore bringing boredom in as a major challenge in the design of automated and remote systems. This is in line with Veitch et al. (2022) findings in a study of ferry operators and their perception of a newly introduced automated navigation technology. The operators perceived a shift towards having a backup role characterized by "button-pressing", and that this shift led to boredom and complacency among other things.

#### 3.1.2. *Invisibility*

There is a challenge that both the success and flaws of safety-critical systems might not always be visible at a first glance, pointing towards the need for a specific competency in what makes a user-friendly design.

*"It [Design] is a hygiene factor, when everything is in order you don’t notice it (...) The challenge today is those [designs] that look nice on the surface (...) You have to remember that poor*

*design isn't something you could evaluate based on a first impression" (*Informant 8*)*

The notion that the quality of a design might be hidden, goes well along with the notion that the logic in different autonomous systems might appear invisible for an operator. Endsley (2017) points out that operators often are faced with multiple systems with technology at different levels of automation. Successful design should give the operator necessary information of the environment, system, and the autonomy, as well as present the information effectively and in an understandable manner (Endsley, 2017). An important issue mentioned by the informants was the need for an "in depth analysis" of how to handle deviations or breakdowns of automation. Excellent user centred design was often identified by the ability to safely handle unanticipated issues or breakdowns of automation. To evaluate whether a design can successfully transfer the operator in and out of the loop requires competency in both the technology and the human operator, and points towards the need for bringing knowledge of human factors early into the design process.

### 3.1.3. *Complexity*

Design in the context of automated and remote systems adds complexity to the design process. The complexity can be explained by the many different systems operators meet at the same time, and the fact that these systems make and are dependent on lots of data. Many new systems are added to the old ones, and this is an important part of the new complexity operators are faced with. It is challenging for the operator to interact with many different systems based on different interaction principles.

*"Many different automated systems – different logic in them – a lot is going on – they are on different screens. The systems are treated separately."* (Informant 7)

Different systems based on different logic and on different levels of automation might challenge the operator's ability to develop accurate mental models and therefore affect the ability to execute control actions and to keep the system in line with operator goals (Endsley, 2017). This might in the context of safety critical operations contribute to disasters, such as the Boeing 747 Max Accident in 2017 (Endsley, 2019).

### 3.1.4. *Resources*

Resources was mentioned to be one of the major obstacles for implementing user-friendly designs. This poor availability of resources was viewed as a paradox because a poor design often turns out to be more expensive. This is in line with Samseth (2001) and Boehm (1974) notion that change costs grow exponentially through the development process. Participants underlined the importance of getting it right from start, as changing design in a later phase is much more resource consuming. Resources as a challenge was not all about money and time, but also the lack of access to relevant users.

*"The challenge is resources (...) How much time and people you need. It is also difficult to gain access to users early enough as well as users with relevant experience."* (Informant 8)

Resources in terms of both money and access to relevant users seems to be a major obstacle for successful design in many cases (Saghafian et al., 2021). The informants were all clear about savings in design processes that lead to poor designs often turn out to be more expensive, both in daily operations and in those occasions bad design contribute to accidents. However, clear business models and calculations illustrating real savings in having user-friendly designs seem to be lacking. Bringing this to the forefront seems to be an important way forward. In the work with a ship bridge for a commercial ship supplier, Bjørneseth (2021) pointed out that shipyards having strong cost focus in combination with high production costs due to low initial volume is a challenge for creating successful unified designs for ship bridges. This illustrates the need for simultaneously working with business models and marketing activities, making sure that designs considered as successful in a human factor's perspective, also are that in a business perspective.

### 3.1.5. *Piece-by-piece*

One major challenge in design of automation in the context of safety critical environments is that new technology is introduced in a piece-by-piece manner, and as such new functionality is added without considering the existing system design.

*"I have often experienced that we introduce support systems in addition to what they already have. This is much easier than touching what is already in operation. (...) But then you ended up with adding a new point that competes with everything else that was there before"* (Informant 1)

Design in a piece-by-piece practice stands in direct opposition to holistic design which is seen as an important prerequisite for successful design (Lee et al., 2017; Schønheyder, 2019; Bjørneseth, 2021). In safety critical environments designers often have a reluctance to touch existing designs in the fear of challenging safety, leading to adding new technology without considering what is already present. Standards that focus on the safety of the entire system, not only standards for single equipment seem to be a prerequisite for ensuring holistic design in safety critical environments.

### 3.2. *Design in practice*

The interviews revealed several insights into how design is conducted in practice, as well as pointing towards a growing awareness that introduction of automation requires development in design methods and standards to ensure that human factors are considered in a sufficient manner and early enough. The following subthemes connected to design in practice were identified: "Insight into the user as a prerequisite", "Less is more as a golden rule" and "Standards as a guiding supplement".

### 3.2.1. *Insight in the user as prerequisite*

Knowledge about the users were thought of as an important starting point for all design applications and ensuring this knowledge early in the design process was thought of as a prerequisite for successful design. Informants mentioned the usefulness of working within design frameworks that ensure iterations between users and designers.

*"[Successful design] always follow the decision-making process of the individual operator, and how this information works with other information. Successful design is when the logic and the visuals agree."* (Informant 14)

Beginning all design processes with insight into the individual operator is much in line with well-established standards such as ISO-11064 and it is seen as prerequisite for successful design by design firms (Lee et al., 2017; Schønheyder, 2019). However, bringing the user-perspective to the forefront in technology brings along several challenges as it contributes to a shift from design on the premises of technology to the premises of the users. First and foremost, it requires knowledge about human cognition, both the strengths and the weaknesses. Next, it requires insight into methods that can guide involvement of human factors into designs. This can be achieved by interdisciplinary collaboration in technology development, so that designers, engineers, and human factor specialists are included in design processes. Another useful way forward could be to include some basic training in human factors as a part of education programs for engineers working with autonomous technology.

### 3.2.2. *"Less is more" as a golden rule*

"Less is more" was highlighted as a golden rule for many of the designers and this stands out as an opposite to the challenge that new technology often is added to a system without someone thinking of the totality. An important prerequisite for being able to live up to the "less is more" rule is to include the designer in the design of a system from the beginning, and as such being able to work with design in a holistic manner.

"*The main rule for all designs, is simplicity. Less is more. Good design is minimalistic."* (Informant 6)

Several of the automation design principles Lee et al. (2017) have developed are much in line with this minimalistic “less is more”- approach. For instance, clear definition of both the purpose of automation and its operating domain is seen as a perquisite for successful design, as well as simplification of the mode structure. “Simplicity” was also one of the guiding design criteria for the ship bridge Bjørneseth (2021) developed, a ship bridge that gained a lot of positive user feedbacks, as well as a design prize (Danielsen et al. 2019).

#### 3.2.3. *Standards as a guiding supplement*

Standards and guidelines were mentioned by most of the participants as an important part of the design processes. However, the practical usefulness of standards was viewed somewhat differently. Several participants underlined that standards lag behind the current status in technology development and that having standards is not enough to ensure successful design.

*"Regulations are only there to keep your back free – to prevent Deepwater Horizon and get a stamp (...) We use ISO and NORSOK, but you can create a poor system and be in line with guidelines"* (Informant 14)

The participants mentioned that standards and regulations do not seem to keep up with the rapid technology development, leaving users with a system characterized by complexity and risky practices. There is an inherent challenge lying in the fact that standards should be so specific that new technology easily could be validated, and quality assured, but not contributing to undue restrictions and constraints in technology development. Process oriented standards such as ISO 11064 and ISO 9241-210 having iteration and user involvement as guiding principles could in this perspective be a good way to overcome these challenges related to rapid technology development. The different views on standards are much in line with Ingvarson and Hassel (2023) conclusion that the effect of standardization is not clear in the scientific literature. However, a process-oriented standardization of principles of iteration and user involvement may contribute to a balanced focus on possibilities in new technology and the challenges it might pose on the humans interacting with the technology (Johnsen et al. 2020). In addition, the role of the regulator should be mentioned and ensuring human factors requirements in regulations are important to ensure that standards are used.

### 3.3. *Future implications*

The resulting main themes that answered our research questions provide a multifaceted picture of the current challenges in design of automation and remote systems, as well as design practices in use. Many of the challenges the interviews revealed point towards inclusion of users early in the design process as a useful mean to overcome several challenges in design. Including users early in the design process increases the likelihood that the developed solutions are effective and safe for the intended audience (Mallam et al. 2022). The results also point towards several challenges related to structural and organizational factors as well. To ensure that users are included early in a design process, organizational and structural aspects need to facilitate this. The challenge related to resources point towards the need to develop insight into business models to support successful design. Gaining a deeper insight into barriers for including human factors into technology development from a decision maker perspective could be an interesting research questions to follow up on. However, gaining insight into how standards, rules and legislation could push the industry towards the production of technology that are compatible with human factors is also important.

### 3.4. *Methodological considerations*

This study employs a qualitative approach and as such the quantitative validity criteria objectivity, reliability and generalizability are not applicable for this study (Yardley, 2015). Validity is still an important concept to discuss, but in terms of validity of a qualitative approach. Triangulation by interviewing different informants with different backgrounds enable us to investigate the research question from different perspectives, and as such counteracts converging on a single, consistent account. By involving experts across industries, academia, and consulting firms we seek to achieve that our findings have practical implications for the design practices in the context of automated and remote systems, and as such have impact and importance. By conducting both interviews and analysis in a team, as well as keeping a paper trail of the work we seek to achieve both coherence and transparency.

In this study we used written interview notes as a base for the thematic analysis, and this was considered having several benefits in the context of this study. As our topic touches design in the context of safety critical environments and safety practices, our experience is that some participants become restricted and hesitant to share when recording is conducted. It was also considered beneficial to prioritize broad participation rather than using limited resources on transcribing. Prioritization of broad participation is in line with the PAR approach forming the basis of the MAS-project and our aim to involve many different stakeholders. The use of interview notes taken during and immediately after interviews have also in some instances been reported to be superior to exclusive use of transcribed audio recordings (Halcomb & Davidson, 2006).

## 4. Conclusion

This study illustrates that there are several challenges in design when automation is introduced. The results underline the importance of ensuring that human factors are considered in an early phase of technology development to overcome several of the challenges new automated technology might pose on operators interacting with the technology. The results also underline the need to update design standards to overcome these challenges. Bridging competency in design with competency in human factors might be a fruitful way to move forward to ensure the necessary development in both design methods and standards related to automation. However, gaining a deeper understanding into structural and organizational aspects that can facilitate this seems to be an important precondition.

**Acknowledgement**

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

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