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A Human and Organizational Perspective on Interoperability in the digitalization of safety-instrumented systems

Dorthea Mathilde Kristin Vatn

Software Engineering, Safety and Security, SINTEF Digital, Norway. E-mail: dorthea.vatn@sintef.no

Maria Vatshaug Ottermo

Software Engineering, Safety and Security, SINTEF Digital, Norway. E-mail: maria.v.ottermo@sintef.no

Solfrid Håbrekke

Software Engineering, Safety and Security, SINTEF Digital, Norway. E-mail: solfrid.habrekke@sintef.no

Shenae Lee

Software Engineering, Safety and Security, SINTEF Digital, Norway. E-mail: shenae.lee@sintef.no

Mary Ann Lundteigen

Department of Engineering Cybernetics, Norwegian University of Science and Technology (NTNU), Norway. E-mail: mary.a.lundteigen@ntnu.no

To ensure a safe, effective, and reliable process energy sector, it is necessary to accelerate the digital transformation and simultaneously ensure that health, safety, and environment (HSE) considerations are being accounted for. While Industry 4.0 has a vision to facilitate the intelligent networking of machines and processes focusing on the technological challenges of interoperability, Industry 5.0 focuses on understanding how digitalization efforts affect human and organizational aspects. As the process energy sector is a domain where loss of safety can lead to severe accidents, it is critical to understand how implementation of new technologies influences workflows and human-technology interactions in all phases of the lifecycle. This aligns with the sociotechnical perspective, which states that in order to understand safety as an outcome of operations, both technical and social aspects should be considered. A thorough understanding of human and organizational aspects is crucial when working with complex technological challenges related to interoperability. The ongoing research project on the digital lifecycle management of interoperable safety systems (APOS 2.0) with stakeholders in the Norwegian process energy sector seeks to increase interoperability from design to operation of safety systems, while also considering human and organizational aspects. Interviews were performed with 11 informants with different roles representing vendors, engineering companies, and operators within the Norwegian oil and gas industry. The aim of the interviews was to explore challenges and opportunities arising from a sociotechnical perspective, covering both human and organizational dimensions. The interview notes were subject to a thematic analysis, and the results point towards several challenges and opportunities arising from a human, organizational, as well as a life-cycle perspective. We suggest that by paying attention to these aspects early in digitalization efforts, stakeholders both within the process energy sector and other related industries might be better equipped to maintain and improve the overall HSE.

Keywords: Interoperability, Safety instrumented systems, Sociotechnical theory, Human factors, Industry 5.0, Process energy sector, Safety-critical systems.

1. Introduction

Loss of safety within process industries that handle hazardous processes can lead to severe accidents. To ensure both a safe and effective energy sector, ongoing digital transformation needs to simultaneously ensure that health, safety, and environment (HSE) are properly accounted for when new technology is introduced. This is paramount when increasingly introducing digitalization to this sector, made possible through the Industry 4.0 digitalization initiative.

The Industry 4.0 initiative has focused on enabling more efficient manufacturing and production through technological advancements that facilitate intelligent networking of machines and processes. Industry 4.0 has been named the fourth industrial revolution (Raptis et al., 2019), explicitly pointing at its inherent change potential for manufacturing and production processes across industries. According to Indri et al. (2018) Industry 4.0 can be characterized by six design principles relating to interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity. While Industry 4.0 has been claimed to be technology-driven, the introduction of Industry 5.0 is regarded to be value-driven, recognizing that industries should consider societal goals beyond economic growth, and ensure that production aligns with environmental considerations in addition to the well-being of industry workers (Xu et al., 2021). Therefore, the Industry 5.0 initiative embraces the importance of understanding how the increasing digitalization made possible through the Industry 4.0 initiative affects human and organizational aspects. Starting off from such an understanding is important when addressing the impacts of digitalization within safety-critical domains.

For industries managing hazardous processes, it is critical to understand how implementation of new technologies influences workflows and human-technology interactions in all phases of the lifecycle. This aligns well with the Industry 5.0 initiative. While the term "Industry 5.0" was formally adopted by the European Commission in 2021 (EC, 2021), it is worth noting that the underlying ideas of the initiative also resonates with theoretical perspectives that have deep-rooted foundations, such as the sociotechnical perspective (Mumford, 2006; Karltun et al., 2017). Within the safety-critical domain it is important to have a sociotechnical starting point as this perspective explicitly states that in order to understand safety as an outcome of operations, both human, technological, as well as organizational aspects should be considered (Karltun et al., 2017). Therefore, in line with an Industry 5.0 perspective, a thorough understanding of human and organizational aspects is crucial when working with complex technological challenges relating to Industry 4.0.

This paper explores how interoperability as a central underlying design principle of Industry 4.0 relates to human and organizational aspects. By having a sociotechnical starting point building on the human, technology, and organization (HTO) framework by Karltun et al. (2017), the paper aims to answer the following research question:

Which challenges and opportunities arise from a human and organizational perspective when seeking to increase interoperability of tools and information in the oil and gas industry?

To answer this research question, we first present how interoperability is considered among the stakeholders in the Norwegian oil and gas industry and how follow-up of safety systems serves as a concrete yet rewarding and complex use case. Next, we present the sociotechnical Human-Technology-Organization (HTO)-framework (Karltun et al., 2017) that has served as the theoretical background for our work, before we present how we performed a qualitative interview study during the fall 2024 with participants within the Norwegian oil and gas sector, as part of the research project on digital lifecycle management of interoperable safety systems (APOS 2.0). We elaborate on how we applied a thematic analysis to the interview notes to elucidate current challenges and opportunities arising from a human and organizational perspective and present the results as themes with excerpts from the interview notes. We end the paper by outlining our four key contributions following from the work.

2. Background

This section first outlines interoperability in the context of the APOS 2.0 project, specifically focusing on digital lifecycle management of safety systems. Next, we bring in a sociotechnical perspective on interoperability through the HTO-concept (Karltun et al., 2017).

2.1. *Interoperability in the context of APOS 2.0*

APOS 2.0 is a collaborative research project aiming to increase interoperability from design to operation of safety systems, covering three overarching goals. The first goal relates to the development of standardized information models and templates for functional safety based on the

Industry 4.0 framework. The second goal relates to digital twins and Asset Administration Shell (AAS) and submodels to facilitate and test the adoption of Industry 4.0 for safety systems. The third and last goal relates to developing new work processes for functional safety to enhance the transition from a manual to a digital workflow based on the Industry 5.0 human centric solutions.

Safety instrumented systems (SIS) are installed to prevent or mitigate the consequences of hazardous events. Many of these systems are implemented by electrical, electronic, and/or programmable electronic technologies, with interaction to mechanical systems and systems for communication and human interface (Rausand, 2014). Examples of typical safety instrumented systems are gas detectors, level transmitters and logic solvers

Since SIS are among the most vital safety barriers for reducing the likelihood of hazardous events and/or mitigating their consequences on a process facility, it is important to verify their integrity. However, with the complexity of the technologies involved it can be challenging to ensure that SIS are designed, maintained, and operated in accordance with the specified performance requirements (Rausand & Hoyland, 2003). Currently, the information about the SIS is mostly contained in paper documents or proprietary systems. These systems and documents are maintained, interpreted and updated in different phases of the lifecycle by several stakeholders. One of the most important documents following requirements in IEC 61511 (IEC, 2016) related to safety systems is the Safety Requirement Specification (SRS). This document contains mandatory information for each safety instrumented function (SIF) implemented by one or more SIS systems, such as process shutdown systems (PSD), emergency shutdown systems (ESD), and fire and gas (F&G) systems. Oftentimes, this document exceeds 1000 pages, making it difficult to read and maintain. Misunderstandings or failure to keep this document updated can in a worst-case scenario result in erroneous operation and even fatal accidents. Therefore, moving to more efficient digitalized formats where information can be exchanged seamlessly between systems and lifecycle phases, can improve the follow-up of the safety instrumented systems. This requires a lot of technological groundwork to ensure that a machine or human is able to interpret the same piece of information in exactly the same way. This paper focuses on the interoperability which IEC 63278-1 (IEC, 2023) identifies by the following facets: Semantic, policy, behavioural, transport, and syntactic.

Although there are complex technological challenges related to achieving interoperability in the context of safety instrumented systems, we also acknowledge that there evidently will be human and organizational aspects that need to be considered.

2.2. A sociotechnical lens on interoperability

Sociotechnical theory has a starting point that the interdependencies between social and technological factors shape how work is performed. In this perspective, safety as an organizational outcome is created by the interaction between both technical as well as social factors (Karltun et al., 2017). The Human-Technology-Organization (HTO) concept is built on this foundation and has become a well-established and unifying concept within several safety-critical domains, after initially being developed to improve the overall safety at nuclear power plants (Karltun et al., 2017).

The HTO-concept departs from the underlying understanding that safety is an outcome relating to both technical as well as social aspects but make it explicit that work activities should be "*described, analysed, and understood by describing the interactions between three sub-systems – human, technology, and organization – each of which is possible to describe on its own right*" (Karltun et al., 2017, p. 183). In this perspective an individual can be approached from four different levels, as a biological energy processing system, as an information processing system, as a psychic subject with a unique history, and lastly as a member of social groups. By elucidating these four levels, Karltun et al. (2017) clearly demonstrates that "*human interactions involve a combination of physical, cognitive, psychological and social aspects*" (p. 183). The technology component in the framework is treated rather generally, as the means to "*transform input to output using artefacts, procedures and methods*" (Karltun et al., 2017, p. 183), and organization is defined as a coordinated social entity with an identifiable border recognized by a purpose of reaching some common goals.

Applying the HTO framework as an analytical lens to the aim of achieving interoperability of safety-instrumented systems will enable us to pay attention to how technology affects its users, both the individual worker, as well as individuals as members of different stakeholder groups. It also enables us to dwell on the interactions residing in the interdependencies between the technology and organizational issues. Figure 1 illustrates how the different goals of the APOS 2.0 projects fit into the overall HTO-framework, and how interoperability as the core concept in the context of this specific study could be understood in the intersection of a human, technological as well as organizational perspective. The figure illustrates that the first and second goals of the project mainly are related to solving the complex technological challenges associated with achieving interoperability, while the third goal is more closely connected to the human and organizational aspects.

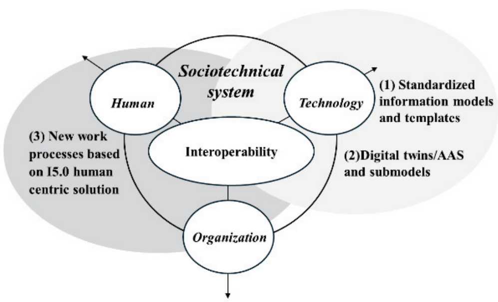

Fig. 1. A sociotechnical lens on interoperability.

3. Methods

To answer our research question, we performed 11 semi-structured interviews during the autumn of 2024. The informants were recruited through the APOS 2.0 project participants, specifically targeting individuals in the organizations with insights into ongoing digitalization efforts relating to functional safety and its impacts on work processes. The interviews were conducted using Microsoft Teams, and each interview lasted around one hour. Two or three interviewers were always present in the interviews, ensuring that thorough notes were taken. The interview notes were then subject to a thematic analysis as presented by Braun and Clarke (2007). Thematic analysis is a stepwise and flexible method to analyse qualitative data and can be used in both a deductive and inductive manner. In the context of our work, by having a sociotechnical starting point through the HTO-framework, we applied a deductive approach in our analysis. In the analysis we first read through the interview notes several times to familiarize ourselves with the interview notes. Secondly, building on the sociotechnical HTO-concept, we deductively coded aspects relating to human and organizational issues. Thirdly, we identified themes among the initial codes. Subsequently, in the fourth step, we reviewed these themes, evaluating their alignment with the broader set of interview notes. Lastly, we defined and named the themes, writing a coherent text presented in the results section of how the themes collectively address the research question, forming the foundations for the analysis.

4. Results

This section presents five themes providing an answer to the question on which challenges and opportunities arise from a human and organizational perspective when seeking to increase interoperability. We first present (), next ().

4.1. *Interoperability's reliance on mutual adaptation*

Interoperability might be understood as being narrowly concerned with developing templates and standards (following interpretation in e.g. (Indri et al., 2018), aiming for data flow with minimal human intervention. However, several of the interviews also revealed that interoperability affects work processes directly. This clearly underscores both human and organizational dimensions. For instance, informant 1 states: "[*Interoperability*] *is about digitalization of everyday activities and how we use it in operations offshore* (I1)". This aligns well with a sociotechnical understanding (Karltun et al., 2017) as well as an Industry 5.0 perspective (Xu et al., 2021) underscoring that the final work processes involving new digitalized tools will be a result of adaptation between systems and work processes. For instance, informant 9 emphasizes the following: "*When you introduce a new digital tool, then either the work process would need to be adapted to the tool or the other way around. In practice, it will be a bit of both. You can't make a tool that doesn't affect the work processes, limit, or make them drift in a certain direction. It will be a process of adaptation, and it requires time*." (I9)

Building on this, interoperability often involves a process of mutual adaptation emphasized and made visible through technological infrastructure already present within the organizations that provides certain constraints both to what can be developed and used. This is illustrated by informant 4 pointing at the computerized maintenance management system (CMMS) as a system providing certain constraints affecting how work processes can be performed. "*Some time ago we tried to say, "forget the limitations of the CMMS, just think of how the ideal work processes should be". It was a good idea, but it has not worked, the work processes must have been adapted to the CMMS*" (I4).

4.2. *Interoperability's impact on sharp end users*

There are many technological challenges that need to be solved to achieve interoperability. For example, the informants made a note on how the attempts of moving from SRS in written formats to digitalized versions must consider the users at the sharp end. For instance, a digitalized version of the SRS might appear as more "black box" for some users. Informant 7 pointed out how a new software tool for reliability calculations "hides" the underlaying calculations, and therefore some users prefer Excel versions: "*The mathematical part of the calculations doesn't exist. (…) Some people are not happy with the tool – don't like the digital part, and this is partly because we don't do the calculations with this tool anymore. The tool is more like a black box and some like the Excel version better. They feel they lose the underlaying calculations, and that the limitations are lost.*" (I7)

In addition to pointing out that the "black box"-ness of digitalized systems might create reluctance to use novel tools and systems, some informants also pointed out how skepticism to new tools generally could stem from previous experiences users might have encountered with new systems. For instance, informant 1 pointed out how deploying unfinished products that do not function adequately can lead users to lose trust in digital tools overall: "*It might be skepticism (…) I think we have rolled out too many unfinished products. Then you lose trust in the tools you receive. The overall aim should be that the mechanic at 60 years should see the usefulness of the system"* (I1). In relation to this, several informants also pointed at *relevance* as an important design principle. When approaching the design of novel digitalized solutions presenting SRS, different user groups might perceive different parts of the SRS as useful. "*Different groups might potentially want information [in] different ways, but they learn. But I guess ideally, we all want the information that is relevant for us*" (I3)

While it was noted that there will be a mutual adaptation process of both the new systems and the work processes in which they are part of, several also emphasized that users would require training to effectively learn how to use the new tools. For instance, informant 7 stated: "*[This tool] is a new tool and requires training to access it*." (I7) and informant 2 stated: *"[Going from SRS in PDF to a digital format] will make the information accessible to more people, but they would need training*" (I2). In addition to the learning aspect, a note was made on the importance of acknowledging that some knowledge and experiences will never fully be captured in digitalized systems. Informant 4 underscored: "*Often the challenge is to understand the history – not just the last version but how you ended up with that solution and which requirements it had back then. (…) Some of the documentation is old and deficient. You would need to bring in knowledge of the context."* (I4) This invites us to also carefully reflect on how different users might approach digitalized tools with different knowledge and experiences. It also emphasizes the importance of taking contextual aspects that digitalized systems are not able to capture into account.

4.3. *Interoperability's impact on the organization*

Our analysis gave insight to several of the addressed organizational issues related to interoperability. Topics covered touch upon aspects related to culture, organizational processes, and collaboration. One of the challenges of achieving interoperability is lack of standardized and similarity of formats of data relevant to the same proprietary systems. In relation to this, a note was also made on the cultural differences. These differences were both related to how standards are used and whether the facilities are onshore or offshore. The same informant also pointed out that digitalized systems require well-defined processes, supported by clear responsibilities and adequate resources to maintain it: "*[Systems] are not built in the same way, so what you aim to compare is not comparable to begin with. Additionally, there are cultural differences between facilities (…) Good IT-systems don't help if you don't* *have processes surrounding it, and responsibilities. And you need time and resources to maintain it."* (I2).

Some informants experienced that the introduction of digitalized systems for the SRS, stimulated new disciplines, not usually collaborating, to discuss and find suitable solutions for new features and application interfaces. As informant 3 emphasized: "*We found our way of collaborating and understanding one another (...) when coming from different backgrounds that requires discussion and time, process takes time (...)*" (I3).

Also, the aspect of how organizations introduce new digitalized solutions were considered as fundamental, especially focusing on the importance of ensuring a process where the gains of a solution are clearly and explicitly communicated from the start. As informant 9 clearly pointed out; "*When a company buys a digital tool – the value of it – the company needs to sell the value of it – if the tool is good – you need to understand why it saves time. [It should be] a demand – you should use it - and it should be a positive experience*." (I9).

4.4. *Interoperability's impact on the life cycle*

An important contextual dimension that applies to the oil and gas industry is that digitalization initiatives involve a huge amount of old equipment, and corresponding outdated data formats. As such, data associated with SIFs is in reality a combination of outdated and new data formats and informant 5 underscored this as a challenge facing the whole life cycle in the future. "*In the coming future we will have to live with both old platforms and new [data] formats – a mixture of information in old and new formats – upgraded SIFs – and single equipment that needs to be exchanged in old formats*" (I5)

Some also pointed at challenges related to specific parts of the life cycle. Informant 5 pointed out that the time pressure the contractors face, is an important challenge that might hinder their ability to deliver information in a format that is needed for the rest of the life cycle: "*[to facilitate interoperability] we need to address what challenges the contractors face. It is not about competency, but the time pressure they live under is a stressful setting for them. They don't have the set-up to deliver."* (I5)

In addition, the size of the projects was mentioned as a significant challenge for achieving interoperability. Many projects have now become extensive and consequently the projects are split up into separate deliverables from different suppliers. This has resulted in systems being developed with disparate parts that do not communicate to begin with. As informant 6 expressed: "*Many suppliers want to have their own solutions (...) It has been adverse that large projects have been [so large and consequently] concerned about dividing the deliverables in pieces to different suppliers. Then there has been little understanding of making a system that communicates*."(I6)

An important dimension relating to the life cycle perspective also became evident when an informant said that a positive and collaborative climate characterizes the Norwegian oil and gas sector. *"(...) it is very interesting to learn from each other – we had a topic at ONS [conference]. I think our industry in Norway have a solid tradition of learning from each other and cooperate on topics related to digitalization*" (I1)

4.5. *Overarching gains and challenges*

Through our analysis, we found several overarching gains and challenges to how interoperability can increase safety and efficiency. However, we must expect a transition time where the efficiency gains might not be so visible.

Several of the participants believed that digitalized processes could reduce the risk of human errors associated with the manual entry of information. For instance, informant 6 stated: "*The yearly test of ESD and PSD systems [requires] shutting down the whole facility. 2000-3000 notifications that have to be manually registered in the system. Large likelihood of writing something wrong. Want more integrity in the numbers [and] avoid systematic errors.*" [I6]

It was also pointed out that interoperability is a means to ensure that information is handled in a clear and coherent manner, which implicitly might be regarded as important to ensure that information is correct. "*[Interoperability] can ensure that we have everything in one place, for instance a set point for a transmitter, one single source of truth so you don't forget to update at several places. When information is written here and there it only creates a mess*" (I5). Other also underscored that a digitalized version of the SRS could help reduce systematic failures, ultimately decrease the likelihood of costly shutdowns, for instance informant 3 stating: "*There will be efficiency gains in terms of follow-up goals. By fixing systematic failures we might prevent costly shutdowns – that will have real practical consequences*" (I3)

Some informants also underscored that having a digitalized system that removes boring manual work would free up time that important personnel could use on other more important and value-creating tasks. Informant 9 stated: "*No one wants to do the boring manual work ... it is a secretarial job, you would need to have a certain competency [in functional safety], but it is so boring that most people will avoid it (...) It is hard to find the people with the right competency to do it, and then these people can use their time on more value-creating activities*" (I9)

While the interviews sought to address both challenges and gains as ultimate outcomes of increasing interoperability, most of the informants mentioned only the gains of the process forward. Here, an important dimension related to the efficiency gains was made by one of the informants: The transition time when moving from SRS in PDF's to digitalized versions. In a time period of transition this will most likely make them less efficient. As informant 5 stated: "*[The business opportunity] of interoperability is that you ensure that the information you get is correct. This is important because an incorrect set point might increase the likelihood that a production facility must shut down. But during the change process it will probably not make us more efficient*." (I5) This serves as an example of the change processes that both the users and the organization(s) as a whole would need to go through to achieve interoperability. It also emphasizes that although digitalization is sought to ultimately lead to efficiency gains, the change process will have a "cost" in terms of time and resources. This was also made evident by informant 8 highlighting the importance of having sufficient time to build trust in new tools. The informant used an example of a digitalized tool introduced to help the maintenance organization go from calendar-based maintenance to condition-based maintenance: "*If you continue as before [with calendar-based maintenance] then you will not save anything. You will need to understand the work processes (...). The suppliers would need to understand the work processes of the operators and what is being tested manually (...) Then trust should be built within the maintenance organization to change from calendar-based maintenance to condition-based maintenance, but this takes time. If they receive a lot of error messages and don't trust the system, then they will go back to the calendar-based maintenance.*" (I8)

5. Discussion

The thematic analysis of the interview notes–was used to summarize and illustrate important challenges and opportunities of interoperability arising from a human and organizational perspective. With support in figure 2, we have outlined three key contributions from our research.

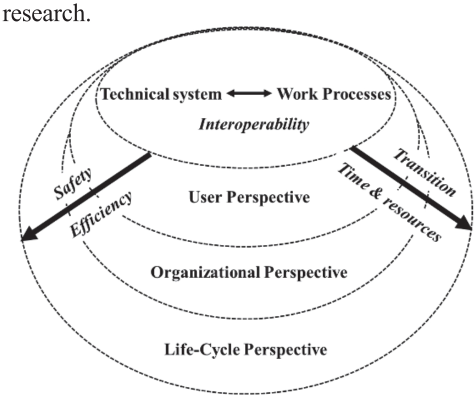

Fig. 2. Interoperability as sociotechnical challenge

Firstly, interoperability at its core can be perceived as a two-sided concept that on one hand is closely linked to the development of an underlying technical system, but on the other hand is also deeply connected to the work processes. As such, in the context of interoperability, development of technical systems should always be seen in light of the work processes they are intended to become a part of. *Secondly*, safety and efficiency are regarded as two main outcomes in a gain perspective when seeking to enhance interoperability. However, there will also be challenges related to a transition period requiring time and resources for organizations seeking to enhance interoperability. *Thirdly*, when approaching interoperability in the process energy sector with a sociotechnical perspective (Karltun et al., 2017), the user perspective, the organizational perspective, and the life-cycle perspective on interoperability are all important. The user perspective on interoperability brings in user scepticism about increased "black box"-ness of digitalized solutions. Also, many users might have previous negative experiences with unfinished digital solutions that might cause reluctance to new systems and tools. Therefore, the importance of considering the user aspect in early development stages of systems is important, as well as providing the necessary training when systems are deployed. The organizational perspective points at the existing reality many organizations face, with many established systems already in place. This imposes certain constraints on what can be developed, and challenges work with interoperability. Also, cultural differences relating to how standards are used, as well as how operations are performed on different facilities are important to consider. Lastly, the Norwegian oil and gas sector is known for its collaborative climate, which create a basis for achieving interoperability. This is a characteristic that might be advantageous for the petroleum industry when working with the overarching challenge of digitalization and interoperability initiatives.

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