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Experiences Of Safety And Reliability In Remote Control Of Safety Critical Operations From Oil And Gas, Automated Transport

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Abstract

We have explored experiences of safety, reliability, and security in remote control of safety critical operations in oil and gas, autonomous shipping, autonomous metro, road transport, space operations, and aviation. Our aim has been to identify best practices of design, use of standards and operations to achieve safety, efficiency, and usability. It is suggested to establish remote operations based on scoping process building on the benefits of automation/AI and human abilities, i.e., a user centered design approach, highlighting the need for "situational awareness at a glance" when operators are removed and well-designed alarms. Low workload must be addressed. Training to handle unexpected events and defined situations of dangers, are needed.

Keywords: remote control, user centered design, safety and reliability, alarms

1. Introduction

We have performed a review of recent experiences and publications describing remote operations. Experiences that can improve safety, security and reliability of remote operations are discussed. This paper summarizes our findings. Remote control consists of removing the human operator from a controlled process to a geographically remote site. In the process industry most control actions are performed remote based on sensor data, thus remote is nothing new. Often this is only a step in a continuous process, i.e., implementing only more remote.

1.1. Definition of concepts related to remote operations

In the following we have described the concepts we are using such as remote control, support, and monitoring:

- Remote control: a process, task or equipment is controlled, operated, or managed from another geographical location. Several terms are used to describe the location such as "ROC-Remote Operation Centre" or "OCC-Onshore Control Centre", remote control is used in the same way as remote operation.
- Remote support: a process, task or equipment that is supported from another geographical location. This could be regular tasks such as planning or technical maintenance (from Remote Maintenance Centre - RMC) or other special operations. Remote support is usually an on-going task.
- Remote supervision/monitoring: Supervising or monitoring operations from a remote central, this is usually interrupt-controlled and is initiated via alarms or other means in which case the operators must acquire situational awareness and perform necessary actions. As an example, this is done by the road traffic centers of tunnels, where they monitor whether critical situations occur where there is a need for intervention.
- Local operation: is a process, task or equipment is performed physically locally.

Ongoing remote control or remote support does not depend on the level of automation in the system, however increased level of automation has made it more relevant to move and centralize operations due to decreased workload and possibility of remove people from harm's way.

In the event of a special danger or accident situation occurs, the situation can possibly be supported or handled by a remote emergency center that has special expertise in providing remote support or providing local (physical) help in crisis situations. Thus, the need for collaboration with an emergency center must be addressed.

1.2. Performance goals of remote operation

The performance goals describe what we want to achieve by implementing remote operations. The following performance goals have been used through review of literature, interviews, and discussions with the stakeholders based on the requirements used to prioritize remote operations. The stakeholders have been management, operators in the sharp end (involved in remote) and regulatory authorities involved in oversight of operations.

Table 1. Performance goals of remote operations.

Goal	Description
1) Reduce operational costs	Cost reduction through centralization or manning reduction.
2) Improve HSE	Improve safety by removing operators from direct harm or dangerous exposure.
3) Verify remote	Verify that the remote operations are possible and fulfills existing HSE.
4) Improve efficiency and quality	Improve efficiency and quality by transferring manual operations to better operations by automation (of tasks fit for machine handling) and thus remove need for human physical intervention.

1.3. Safety challenges related to (more) remote operations

Challenges related to remote operations has been mentioned in literature, at least from the time of Bainbridge (1983). Human factors, as mentioned in Lee et al. (2017), describes key challenges. The safety and reliability challenges that must be explored and discussed are related to the increased distance between the process that is managed, and the challenges posed by organization, human factors and technology used to support the operation when it is performed remote. Key issues are:

A. Situational awareness may be impacted by reduction of rich information to the operator, and thus reduce the ability to establish good situational awareness i.e., understand present and future status, Endsley (1995). Sensory input that is needed could be direct sight, smell, sound, atmospheric conditions, temperature, vibrations, information from other humans in the environment/ peer support, and rich information from other equipment to understand what is going on.

B. Handling the unexpected due to "Out of the loop" challenges. This means that the operator is slower to identify a problem with system performance and slower to understand a detected problem (Moray, 1986). This may be due to getting less rich input, but also due to having more processes to control. The out-of-the-loop problem can result in catastrophic consequences in novel or unexpected situations (Sebok and Wickens, 2017).

C. Safety and reliability of high-speed data communication with appropriate security between local and central control facilities. By moving the control to a remote site, the volume of data from the remote site may be more voluminous, i.e. (more data capacity needed) due to the need to include more rich data such as pictures (CCTV), sound and other rich data. The requirements for up-time, transfer-speed, response/acceptable delay, and security may lead to significant costs in communication. Net-operators can outsource operations and may be dependent on a network of collaborators with different awareness of security, that must be controlled.

D. Boredom trough reduction of workload. Remote operations are often implemented due to reduction of workload and/or increased automation. Reduced workload may lead to boredom and reduced vigilance. Periodically, high workload will occur, overstretching human performance (Bainbridge, 1983).

1.4. Scope and issues of interest in exploring remote operations

The industry experience to be explored has been selected based on prioritization of remote operations and length of experiences. We have examined remote control of safety critical operations in oil and gas, autonomous shipping, autonomous metro, road transport, space operations, and aviation.

Themes of interest have been performance goals, and how to control safety and security issues to reduce probabilities of occurrence and reduce consequences of an unwanted incident. Performance goals has been costs; Improvement of HSE; verification i.e., check that that the remote operations are possible and fulfils existing HSE; and check if remote have improved efficiency or quality. Safety issues selected has been situational awareness; the handling of the unexpected; safety and reliability of communication, and issues related to stress/boredom.

2. Methodology

We have performed a literature review to identify key issues in remote operations, explored accident reports involving remote support and gathered experiences of remote operations and remote support through interviews of selected areas and explored reports from safety authorities related to remote operations.

3. Results – findings and discussions

The findings are summarized in each area of experience, from oil and gas, metro, road transport, aviation, space travel and marine/maritime area. For each area we have suggested best practices.

3.1. Results from the oil and gas industry

Several oil companies have implemented land based remote control of offshore platforms, where they monitor and control various processes on the platform (such as start and stop of production, gas compression, management of production capacity, and general production control). Remote control has been performed in in the EU from 2001 (Ergos, 2001) and in Norway from 2018 (Valemon, 2018). Quality assurance, i.e. verification and validation of remote control has often been done via the CRIOP method (Johnsen et al. 2011) in Norway.

In drilling, there is extensive use of land-based operations centers which plan the activity in connection with drilling operations. Remote control has so far not been carried out. In the past, more sophisticated solutions for automated drilling and handling of drilling equipment have been introduced, and this has gradually changed the traditional work tasks from manual operation to mechanical and screen-controlled solutions (Ciavarelli, 2016). The driller sits on the drilling platform and controls the operation with direct observation of the drill deck. Some drilling operations have been automated, with varying degree of success, often due to missing user involvement. Automation not controlled by the user has led to near misses. Physical automation of heavier operations on drill decks is undergoing pilot testing and must gain acceptance from users and authorities.

3.1.1. Practices of design, standards, and operations

Use of standards varies; however, safety is prioritized. In practice there has been a design phase before implementation, and many projects are performing verification and validation using CRIOP (Johnsen et al, 2011). The safety authorities in Norway, Petroleum Safety Authority, have prioritized the use of design standards for control rooms such as ISO 11064, and alarms standards such as EEMUA 191. (Facilities regulation §10 and § 34a). Through interviews of practitioners (Vatn, 2023), we found that successful design often was based on a user centered approach, using the iterative and user-centric approaches defined in ISO 11064 and ISO 9241-210.

3.1.2. Performance goals and safety issues oil and gas industry

Related to the reduction of operational costs, the experiences have been varied, in general there are cost reductions. In one case (Ivar Aasen) the land based remote operational center has been moved offshore due to high operational costs and possibilities of collaboration with other control centers offshore, Adressa (2023).

No reduction of HSE has been identified. However, when partly remote operations have been implemented without removing all control and people from danger, accidents have happened. Ramos et al. (2020) described the Tosco accident, that resulted in one operator fatality and 46 people injured. Not all temperature data were accessible from the remote-control room, some of the readings could only be obtained at the local field panels, exposing people to local exposure. Remote operation in oil and gas has been verified through successful operations in several installations, (Ergos, 2001) (Valemon, 2018). We have found no special reports highlighting improved efficiency and/or quality. It has been pointed out that remote equipment should need less maintenance.

There is a need for improved control systems to give better understanding of the operational situation. There should be strict requirements for both user-friendliness and robustness for control systems to be used in remote control.

In one case the operator mentioned that there can be three simultaneous alarms with the same cause, but with different text and it is therefore difficult to understand. There is no hierarchy of alarms, and there are alarms that cannot be acknowledged. Many unnecessary alarms are challenging. The alarm systems should be improved.

Related to Situational Awareness; Qi et al. (2013) suggested that it is important to support workers with early warning systems. Information presentation needs design of appropriate data sensors, thoughtful HMI presentation of data, and effort used to establish good alarm design and avoid too many alarms. Experiences shared from the operators have been that some of the systems have a poor user interface with a long response time, the need to override manual settings and screens that lock. There should be strict requirements for both user-friendliness and robustness for control systems to be used in remote control.

When operating several units from the same control room, the operators believe that it must be easy to distinguish between the units. Operators are skeptical of integrated visualization of information from two different separate units, and no one wants one common large screen image or alarm list for two different devices.

It is also mentioned that the video conferencing system may be too complicated if an accident occurs, and you need fast and good communication to get a common understanding of the situation. Online communication has worked, but it has been a challenge to establish who you will communicate with, availability requirements and requirements for competence for those you will collaborate with who sit at a distance.

Those who sit in a remote-control center quickly lose operational competence and neither the operators themselves nor the others in the offshore team experienced that control room operators can now do a full-fledged field operator job on his annual trip.

Stable and secure communication solutions have been a challenge. To have operationally stable networks, it is important to establish an SLA (Service Level Agreement) with the service provider. There may be many subcontractors connected to data communication, and security may fail due to security awareness not being established at all subcontractors.

Related to boredom, the operational experience has been that the operators have had little to do, so they must be given more tasks. e.g. proposes that the control room operators be able to operate several fields from the control room, given that a staffing assessment is made based on a workload assessment. The operators want more frequent training with Defined danger and accident situations (DFU).

3.1.3. Issues of best practice

User centered design based on task analysis and workload assessment is a significant start. Design and operation should be based on a continuous prioritization of safety to identify trends and safety challenges. Practical methods are user centered iterative processes, such as ISO 11064, ISO 9241-210 and alarm handling (EEMUA 191).

3.2. Results from unmanned rail vehicle – rail, train, or metro

Unmanned operation of freight train is in planning and pilot testing. Boussif et.al (2023) mentions remote control of freight trains. The remote-control room is a replica of the driver cabin found on trains with video and communication equipment. The HMI (human machine interface) has been tried to be standardized based on existing drivers cabin, a standardization that should simplify control of all types of remote-controlled trains.

Unmanned Metro has been operational since 1980. At the start of 2019, there were unmanned metros in 37 cities with 48 lines, a total of 674 km, (Johnsen et al., 2019). An example in Europe is the light rail in Copenhagen, which is unmanned (i.e., an unmanned train without safety personnel on board) and controlled via a manned control center. In the control center, there are four or five people supervising the traffic. In case of technical problems, there is always a team of line people that can be dispatched to perform repairs. Although the trains are not equipped with drivers, there are stewards at stations and on most trains that help passengers, perform ticket controls, and assist in emergency situations. A challenge related to assessment of unmanned metro, is the lack of systematic data reporting and documentation of minor incidents - there are no statistics that systematize and summarize the use with the number of passengers and length of transport at an international level. There are also no agreed taxonomies for data reporting related to minor incidents.

3.2.1. Performance goals and safety issues – rail, train, or metro

Establishment of remote operated metro systems has been costly with significant investments. The operational design domain must be sufficiently protected from other traffic, and there is need to avoid that passengers get access to the rail (protected enclosures, double doors). There is need for remote operational centers with staffing during all operational periods (24h/7 days a week.). However, the operational costs of remote metro systems have been 10% to 30% lower, Wang (2016).

Related to the HSE, there have been no accidents or serious HSE incidents in operations from 1980 to 2020, (Johnsen et al., 2019). Some minor incidents such as unexpected stops without injuries have been reported in newspapers, but no incidents with HSE consequences have been reported. The operational experiences have been good.

Situational awareness has been supported by extensive use of CCTV and training to handling of the unexpected, such as fire that may lead to heavy casualties. Reliability and usability of the communication system is important for unmanned operations involving many passengers, Wang (2016).

3.2.2. Issues of best practice

The limitation of operational design domain have been fundamental in establishing a high level of safety, in addition to the continuous supervision of operations. Key issues have been systems to support situational awareness in the control center using CCTV and the focus on communication between the passengers and the operators in the control center.

3.3. Results from unmanned autonomous road transport

Unmanned/autonomous transport, with remote support, has been operational in pilot projects and a focus of research for a long time. One case is the Automated Guided Vehicles – AGV for transport at St. Olav hospital, where they started operations in 2008/2009 (Johnsen et al., 2019). Another case utilizing remote operation of trailers in mines (transporting minerals) has been Brønnøy Kalk in Norway. They have good HSE experience, see www.hfc.sintef.no - 2019. In the period 2019 to 2023 they operated with a safety driver in the cabin of the truck. The safety driver was removed after four years of operational experience in September 2023.

3.3.1. Practices of design, standards, and operations

There is varying prioritization of Human Factors, Tesla, as an example, has not involved Human Factors experts in their design. Use of standards varies a great deal. There are challenges with the quality of AI systems (poor risk assessments, poor specifications, poor knowledge level, poor coding, poor testing). Risk assessments have been highlighted as important, both related to risks of operations/transport, and related to remote operations. (A broad set of standards are discusses from IEEE 7000 «Integrating ethical and functional requirements to mitigate risk and increase innovation in systems engineering design and development» to ISO TR 23786:2019, assessing the risks related to solutions for remote access to road vehicles.)

3.3.2. Performance goals and safety issues

The establishment of remote operated transport systems has in some instances been costly with significant investments, to establish an operational domain without too many hazards.

Regarding safety at Brønnøy Kalk, there have been none reported safety issues in the period 2019 to 2023 with a safety assistant in the driver seat. Control of the vehicles has been performed locally, by the operators. Regarding safety for AGVs at St. Olavs hospital, it can be mentioned that there have been no known accidents in the period from 2008/2009 to 2020.

A central control room has been established at St. Olav with continuous staffing during operation (with 1 to 2 people), with monitoring of all traffic and handling of deviations. The operational design domain has been limited, it has been a separate basement floor, thus the movement area for the AGVs is partially isolated from other traffic. Sensors on AGVs do not have a clear understanding of their own dimensions and have a limited field of vision. They cannot always detect or see objects or other traffic, such as bicycles, pallets or forklifts. The problem with forklifts is that there is a high gap between the underside of the vehicle and the ground, which means that the sensors on the AVG do not "see" the truck.

There are no taxonomies for data reporting, and there is a lack of systematic data reporting and documentation of minor incidents from the AVG´s- thus challenges in getting an operational overview due to lack of data capture. However, the transport solution has worked well with support from the control room.

Establishment of situational awareness in an automated car or in a control center is challenging. The sensors and software (i.e. Machine Learning/ML) used in autonomous vehicles have difficulties in detect/interpret all obstacles in traffic (such as some obstacles in road maintenance, or shadows that may lead to braking). There is a general expectation that it will take a long time to develop systems to establish good situational awareness in all situations. Expert assessments are that it will take at least 10 years before the systems have reached such a level that they can deliver full autonomy (CNBC, 2019). Selection of appropriate operational domains and development of supporting infrastructure are necessary to be able to successful utilize autonomous vehicles.

The handling of the unexpected is a challenge during high speed, since response time in remote operations may be critical. The reaction time before the human takes over ("out of the loop") in an autonomous car with a driver who is passive varies from 2 to 26 seconds ; there are challenges associated with taking over control as it is designed today (Eriksson et al., 2017). This calls for systems giving "situational awareness at a glance". Several fatal accidents have happened due to the challenge of unexpected traffic, or poor situational awareness from the systems.

Reliability and robustness of the data network may be a challenge. In Sonstebø et al. (2023) it was pointed out the need for reliable wireless data transmission with low latency for video and data transmission (especially for remote controlled systems). This requires good availability and robustness in the mobile network (4G/5G). In addition, it was a need to clarify the responsibilities when something happens. (It was mentioned that when the degree of autonomy is high, the responsibility should lie with the automated system or even software manufacturer).

3.3.3. Issues of best practice

The definition and follow-up of the operational design domain have been fundamental in establishing a high level of safety of remote, in addition to the continuous supervision and learning from operations. Quality of sensors and systems is under development, misinterpretation occurs, so the systems should be robust (and redundant). In addition, barriers should be established to prevent unwanted incidents. Autonomous systems can fail, so it must be ensured that there are actors who can intervene and control vehicles when the unexpected happens. The control room should have access to systems that give you a good overview of the entire situation.

There is a need to follow up the safety of operations of automated vehicles, through improved regulation based on systematic learning and documentation of actual incidents. There is a need for remote surveillance of automated vehicles, since automated cars may be a hindrance to Fire trucks, Police and other emergency vehicles.

3.4. Results from autonomy in aviation – manned aviation, remote towers, and remotely piloted drones

The Aviation domain has been defining and developing the science of Human Factors, that has helped in supporting safety, usability, and efficiency. Remote support in aviation has been done from control towers towards manned piloted flights, remote operation of landing sites (from remote towers) and to control automated drones.

Related to remote towers, Avinor in Norway has implemented remote operations of airfields. The implementation has been based on a thorough Human Factors analysis. They decided in 2014 to implement Remote Tower at 15 airports. It was staged implementation starting operations in Q4 2019 – planned ending Q3 2024. The overall program cost is 130 million EUR. Issues mention has been that remote towers are more than equipment; the technology is important but not the only enabler to make operations a success, a key issue is the consideration of the human is to make this a success or safety and business expectations.

UAS-Unmanned Aircraft Systems, with control from the control center has been operational since 1970 for surveillance purposes, and has increasingly been used to perform maintenance, transport of goods and supplies.

3.4.1. Practices of design, standards, and operations

Aviation used for personnel transport is highly standardized with strong international rules and regulations. The automation in aviation has been carried out gradually with the support of systematic research within human factors and must be characterized as successful from a safety perspective.

3.4.2. Performance goals and safety issues

Piloted flights have been an area of high safety and passenger transport by plane is the safest form of transport. The airlines within the International Air Transport Association (IATA) had no major accidents ("No hull losses") in 2012 or in 2017. The high level of safety is a property of the whole system, issues that are highlighted are the well-developed infrastructure, standardized aircraft, systematic data reporting, control centres, comprehensive regulations, prioritization of human factors methods, a "no blame" culture trying to find reasons for human variation, thorough testing and certification, systematic training, and prioritization of learning after accidents. There has been systematic implementation of automation in aviation, and today's pilots are supported by many automated functions. Even in a highly automated environment, there is still a need for human intervention. Challenges have arisen in establishing situational awareness due to deviations when the pilots have been "out of the loop" and then when they must get “back in the loop” and assume control.

Establishment of remote operated towers should document long term cost benefits. In Nystrøm et al. (2019) it is argued that the potential cost savings from introducing remote towers are uncertain particularly in the short and medium run, in relation to opening for more competition. However, the operational cost may decrease by 10%, LFV (2018). HSE of remote towers are prioritized, and no issues have been identified so far, and the operations are being tested through staged implementation.

Data from UAS operations has been collected from large (industrial) drones via the Department of Defense (DoD). The analyzes of collected data from Waraich et al. (2013) show that it is approx. 100 times higher accident rate with UAS than with aircraft with a pilot approx. 50-100 UAS incidents per 100,000 flight hours, but approx. 1 incident with piloted aircraft per 100,000 flight hours. The most important root cause of these accidents is poor design of the control system and human-machine interface, due to poor knowledge of human factors.

The system failure rate - expressed in terms of time between failures ("Mean Time Between Failures") has been 1,000 hours for UAS, while it is approx. 100,000 hours for manned aircraft, i.e. the failure rate is significantly worse for drones, Petritoli et al. (2017).

Security is an issue for UAS. Surveys of adverse events have been carried out (Valente, 2017; Altawy et al., 2016). Some drones have backdoors that send signals to outside actors (such as China) with data of position of operator and/or data collected. (A significant security risk in a crisis or in a war). Other actors can also take over control of a remote-controlled drone and cause it to land or crash and be destroyed. There may be a low threshold for taking over the data communication so that you gain access to data sent. Since UAS are remotely controlled, they can be used without much risk to the drone operator to destroy production equipment by crashing or carrying explosives (or flamethrowers – which are optional equipment for some drones). The attack on Saudi Arabia in 2019 reduced world oil production by 5% during two weeks, Saudi Arabia (2019), Singh (2019).

3.4.3. Issues of best practice

The support through control towers is well-developed with control centers manned 24 hours 7 days a week. The level of safety of manned airplanes has become extremely high as automation has been gradually introduced and remote support has been extended. The flight cockpit has a mature and very good user interface based on Human Factors Engineering from the Second World War (then there were many accidents due to Human Error). Development has been based on a user-centric approach. Personnel has been reduced, but the pilots have been given an important role in handling the unexpected and complex. The reason for the high level of safety is due to systematic data reporting, standardized aircraft, comprehensive regulations, prioritization of human factors, a "no blame" culture, thorough testing and certification, systematic training, and prioritization of learning after accidents. The experiences from UAS, highlights the need for systematic learning of best practices when implementing new technology, utilizing human factors-based design of the control system and improved human-machine interface.

3.5. Results from Autonomy and control room from space travel

Space travel is based on a high degree of automation and autonomous solutions that have been a prerequisite because there are such long distances and such large delays between control rooms on earth and equipment in space. The mission control center (MCC) of space travel is the control hub for monitoring space operations/satellites. The satellites are built to be robust, with as much maintenance-free technology as possible, and the equipment has a high degree of redundancy.

3.5.1. Issues of practice

We have interviewed actors involved in building a control center for ESA (European Space Agency) in Norway. The control center was built based on standard human factors knowledge and use of standards such as ISO 11064. The manning of the control center was dependent on activities and experiments on the space station. ESA has developed a verification and validation methodology based on the CRIOP method, used in a few projects.

Only about 10 percent of the MCC operator's time is spent controlling and monitoring, while about 75 percent is spent planning, organizing, and updating procedures. The remaining 15 percent is dedicated to own training and education. The control room operators practice dangerous situations via simulator training, where unexpected events require quick thinking and logical responses (IFE, 2020).

3.6. Relevant experience from the marine and maritime area

Remote operations can be seen as a process where you are moving the controls on ship bridge (and the machine room) to an onshore control center, thus the quality and issues of existing operations are important to have as a background. Remote operation of ships is increasing, several pilot projects have been initiated such as ships plannen to be autonomous (Yara Birkeland, ASKO, AutoFerry) and Remota, a remote operating centre.

3.6.1. Practices of design, standards, and operations

There is not so much focus on Human Factors in shipping. In a report from the National Audit Office (2023) in Norway it is highlighted that "The number of accidents at sea has increased. Human factors are reported as the direct cause of many of the accidents involving commercial vessels. Our investigation shows that the Norwegian Maritime Directorate's supervision is not sufficiently adapted to uncover poor working and living conditions." This says something about the need to strengthen the prioritization of Human Factors to understand challenges that need to be addressed also in remote operations.

In the PhD work from Danielsen (2023): "Usability in Ship Bridge Design –A Mission Impossible?", it was pointed out that usability of bridge design was poor and not user-centred. This can be a challenge when designing the ROC for an automated ship, using existing practices from bridge design.

3.6.2. Performance goals and safety issues

Cost-effectiveness is important when establishing ROC, as investment must be made in equipment and communication solutions. When there are few ships to remotely control, operating costs can increase, and the om-shore operators may have low workload (due to a high degree of automation). Cost reductions can be achieved by sharing a ROC between several operating ships, but then there is a need to achieve standardization of technical equipment and communication solutions across the industry. Initiatives such as "open remote" should therefore be followed by all subcontractors to autonomous ships. (see https://www.sintef.no/globalassets/project/hfc/documents/openremote.pdf)

Autonomous solutions/AI are not error-free, and safety-critical operations must always involve human controllers/operators who can quickly intervene. However, if standardization is established, less risky operations needing no interaction with the ROC in normal operations, can maybe be handled by getting support from an emergency response center. Use of existing emergency response centers can lead to lower costs.

3.6.3. Issues of best practice

Bjørneseth (2021) gives a status of best practice for bridge design via "Unified Bridge". The experience was that existing bridge designs led to complex and many different systems that could lead to cognitive overload in stressful situations and accidents/collisions/groundings. They therefore created a bridge system based on HF standards such as ISO 11064 and ISO 9421-210, which ended up in "Unified Bridge", a bridge system that received several design awards and which receives good feedback from the bridge crew. This after 5 years of experience when they have based themselves on user-centered design as a principle. The experience is transferable to control rooms for remote control of ships, i.e. to get a control system that increases situational awareness and gives a faster and better overview of what is happening, the "Unified Bridge" principles can and should be followed.

Veitch et al. (2021) describes the design process for the Shore Control Lab at NTNU, that is now used to control autonomous ships. The standard ISO 9241-Part: 210: 2019 was used as the human-centric design process with good effect.

In the PhD work from Hoem (2023)– "Risk Assessment in the Design Phase of Maritime Autonomous Ships – a Human-centred approach", the value of a CRIOP scenario analysis was assessed to be high, so it is recommended that the CRIOP scenario - analyzes are carried out to check that the "Work as done" perspective is taken care of.

3.7. Relevant experience from the Helge Ingstad accident

The Helge Ingstad accident may be interesting to discuss since the manned bridge had a different situational awareness than the VTS (that could be seen as a remote monitoring center) and the people on the bridge of the Sola TS that they collided with.

KNM Helge Ingstad and the whole crew on the bridge did not observe the crossing ship Sola TS neither by map (ECDIS) or radar and collided with the Sola. Sola TS were late in communicating with KNM Helge Ingstad and did not explain their position (on starboard) in relation to KNM Helge Ingstad. The VTS did not understand that KNM Helge Ingstad did not observe Sola TS and did not intervene to avoid the collision.

A key issue in the accident was differences in situational awareness between the actors, a slow common understanding of what could happen, and poor communication between the involved actors based on missing clarity in responsibility in a crisis and poor communication protocols. If remote operations had been used, some sort of "situation overview at a glance" should have been present and shared, also giving a forecast of future situation. In addition to alarms that was usable, i.e., giving warning of future collision, based on experiences from seafarers ensuring that alarm overload was avoided. Procedures for communication in an emergency should be used, to ensure that the risks were highlighted, and mitigating actions were understood by all actors.

4. Summary of results and recommendations for further work

Based on our exploration of remote operations and remote support we have seen that the quality of the planning, design and implementation has been a key factor for success. Involvement of key stakeholders and users as early as possible has helped sharing best practices and supported the design of good solutions.

The first step should be to define the goals of remote operations, remote support and adapting the system to human capabilities and limitations. A summary of key Human Factors issues is given in Lee et.al (2017), and should be used to ensure meaningful human control when remote operations are planned.

The scope should be defined early, one way of doing this is to specify the operational design domain (ODD), or operational envelope - to document operational scope and limitations. This should include operational responsibilities, especially during emergencies.

Good practices of design processes are found in standards such as ISO 11064 and ISO 9241-210. These standards support the involvement of users, i.e. user based design based on human factors (HF) knowledge. A summary of relevant HF methods is described in Stanton et al. (2017). Use of best practices should be verified and validated through CROP (Johnsen et al., 2011).

A key issue is to ensure human situational awareness under all conditions, especially when workload is low. The manning requirements must be based on tasks analysis, including workload to handle situations of defined hazards (DFU). The use of high-performance HMI (Human Machine Interfaces) is needed to support situation awareness "at a glance", see Hollifield et al. (2008). When several units are operated from the same control room, the operators believe that it must be easy to distinguish between the units. Those who sit in a remote-control center quickly lose operational competence.

Remote operations may be costly, thus standardization and collaboration may help to reduce development costs and operational costs.

Deviations must be handled appropriately; thus, alarms and communication procedures and equipment must be suited to the identified safety critical tasks. Alarms must be unambiguous and easy to understand and should follow best practice as described in EEMUA 191 (2013).

There is a need for reliable data transmission with low latency for video and data. CCTV may be needed to support situational awareness in remote operations; thus, the placement of cameras needs to be designed so that they cover all relevant areas and can be easily maintained. Procedures for communication and placement of equipment (location and quality of microphones and speakers) must be designed to support reliable communication such as closed loop communication with the stakeholders in emergency situations.

More automation and autonomy used in remote operations requires higher system reliability, thus there is a need to implement reliable systems that work under all relevant operational conditions. Data sensors used must be both reliable, fault-tolerant, and robust. The automated or autonomous system must report if it has difficulties in interpreting its surroundings.

Continuous learning and development of remote operations is needed, thus systematic data collection and incident reporting and analysis must be established to ensure dissemination and learning of successes and failures.

Although there is a lot of experience from remote operations there is still a lack of systematic knowledge to handle the challenges of low activity (when all is operating as planned) in combination with handling emergence situations when the unexpected are happening. Systematic training of emergencies in combination with development of appropriate HMI solutions, alarms systems giving situation "at a glance" are needed. In addition, there is a need to establish 24/7 emergency centres that can share data and assist when highly automated and low manned installations are operated.

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