2020:01442 - Open

Report

Automation and autonomous systems: Human-centred design in drilling and well

Author(s)

Stig Ole Johnsen, Siri Holen

Asbjørn Lein Aalberg, Knut Steinar Bjørkevoll, Tor Erik Evjemo, Gorm Johansen, Thor Myklebust, Eivind Okstad, Alexey Pavlov, Thomas Porathe.

SINTEF Digital

Safety and Reliability

2020-12-15

SINTEF

SINTEF Digital

Postal address:
Postboks 4760 Torgarden
7465 Trondheim

Switchboard: 40005100

info@sintef.no

Register of Business Enterprises:
NO 919 303 808 MVA

Report

Automation and autonomous systems: Human-centred design

KEY WORDS:
MTO
Human factors
Automation

VERSION	DATE
2020-12-15	2020-12-15

AUTHOR(S)
Stig Ole Johnsen, Siri Holen,
Asbjørn Lein Aalberg, Knut Steinar Bjørkevoll, Tor Erik Evjemo, Gorm Johansen, Thor Myklebust, Eivind Okstad, Alexey Pavlov, Thomas Porathe.

CLIENT(S)	CLIENT'S REF.
Petroleumstilsynet	IKT2020

PROJECT NO.	NUMBER OF PAGES AND APPENDICES:
102022397	116+ 24 pages in appendices

SUMMARY
This report is based on an assignment commissioned by the Petroleum Safety Authority Norway (PSA) with the theme of human-centred design and human-machine interfaces in the development and implementation of autonomous systems in drilling and wells. The report summarises the review and findings from the project. Through the project, we have seen that automation has generally been successful where it has been introduced in well-defined areas, gradually and in interaction with users. In the petroleum sector, automated systems can contribute to better utilisation and more efficient drilling,and provide support for the earlier detection of failure events via automation of the drilling process. The positive user-centred development of automation should be continued based on lessons learned from pilot projects. It is recommended that references to standards as outlined in the report be updated. In order to address HSE, the principles of meaningful human control should be applied.

PREPARED BY	SIGNATURE
Stig Ole Johnsen	
CHECKED BY	SIGNATURE
Maria Vatshaug Ottermo	
APPROVED BY	SIGNATURE
Anita Øren	

REPORT NO.	ISBN	CLASSIFICATION	CLASSIFICATION THIS PAGE
2020:01442	978-82-14-06420-9	Open	Åpen

SINTEF

History

VERSION	DATE	VERSION DESCRIPTION
Status meeting 3	11.06.2020	Review of structure and content in status meeting 3
Status meeting 4	19.08.2020	Review of report in status meeting 4, for use in workshop
Status meeting 5	30.10.2020	Review of report in status meeting 5
Status meeting 6	23.11.2020	Review of report in status meeting 6
Report	15.12.2020	Report version 15.12.2020

Contents

SINTEF

1 Summary of the report

This report is based on an assignment commissioned by the Petroleum Safety Authority Norway (PSA) with the theme of human-centred design in the development and implementation of autonomous systems in drilling and wells. PSA's aim behind the assignment was “to help ensure that the petroleum activity gives high priority to safety, health and working environment when digital technology is developed, assessed and implemented in companies across the industry”. The report reviews and gathers findings from the project activities:

- Literature review of theory and experience of automation in other industries
- Investigation reports from relevant areas
- Acquisition of information from the oil and gas industry, via interviews and other sources
- Regulations and standards used by the oil and gas industry
- Workshop (with participants from PSA, the industry and the project group)

The work was carried out in close collaboration with the industry by a multidisciplinary project group with expertise in drilling and wells, technology, organisation and human factors. The group consisted of ten participants from SINTEF (Technical Cybernetics, Petroleum Technology, Safety and Reliability, Digital/Software Engineering) and NTNU (Petroleum Technology and Design).

1.1 Key terms and knowledge

The safe operation of automated systems must address more than reliable technical solutions. Safety is dependent on a holistic system perspective, including an assessment of technology, organisation and human factors. The level of automation will lead to different requirements for users and their surroundings. The technical system with user interfaces via monitors or more comprehensive control rooms must be viewed in the context of organisation relating to use of the system, such as the delegation of responsibilities, procedures and people with knowledge. In addition, the infrastructure surrounding the system must be included, e.g. physical barriers and essential technical support for operations (such as networks and sensors); see Figure 1.1.

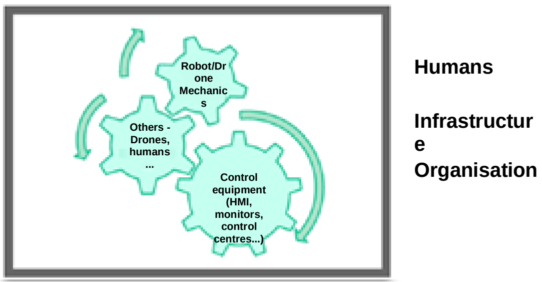

Figure 1.1 Automation from a system perspective

The aim of automation is to carry out a process or operation automatically, so that it controls itself to a greater or lesser extent. The term ‘autonomy’ refers to the ability of a system to make its own decisions, without the involvement of external systems or operators. The design and safety of autonomous systems is influenced by the degree of automation, or "Levels Of Autonomy" (LOA). LOA can be used to understand challenges linked to the safe use of automated systems; see Table 1.1. The various levels describe the responsibility between the operator and the system, where there is gradually less interaction with human operators with higher levels of automation. Fully automated systems, i.e. autonomous systems, control themselves using fixed software or artificial intelligence (AI). Specifications for design and control must be revised according to the level of automation. For example, when operators have an active role in the process (*in-the-loop*), there is ongoing control, but when a human is only brought in as and when necessary (*out-of-the-loop*), control and understanding must be established.

Table 1.1: Overview of the level of automation and the interaction between operator and system.

Level	Automation	Operator	System
1	No automation	All operations	Warns, protects
2	Limited support	Controls "In-the-loop"	Guides, supports
3	Tactical, monitors	Involved – continually monitors "On-the loop"	Controls within well-defined boundaries
4	Automated support Strategic	"Out-of-loop" interruption-determined, prompted by the system	Operates independently, but can hand back control
5	Autonomous	Fully "out-of-loop"	Operates independently – switches to safe state itself

Increased automation requires a greater understanding of human factors (HF). Parasuraman and Riley (1997) found that automation requires a thorough analysis of the tasks that are to be performed and a better human-machine interface (HMI). Automated solutions also require tailored training. It requires better handling of non-conformities and appropriate information when the automation fails, as was pointed out by Bainbridge (1983).

Important theories regarding HF and how to design safe systems are described in:
- Lee et al. (2017) "Designing for People", and in Endsley (2019) "Human Factors & Aviation Safety", with a description of interaction with human operators and technology
- Barrier thinking in Reason (1999) "Organisational Accidents and Safety Culture"
- Handling of the unexpected, as described in Hollnagel et al. (2006) "Resilience engineering"

Human Factors (HF) were important for the project. We have used the definition from the International Ergonomics Association (IEA): "*Human Factors is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance*"

The petroleum industry and supervisory authorities are mindful of HF. This is for example described through Sections 20, 21 and 34a of the Facilities Regulations, which covers ergonomic design, the interface between man and machine, including information presentation, as well as control and monitoring systems. Insufficient focus on human factors has led to numerous accidents and incidents with catastrophic consequences and costs, such as:
- Macondo, Deepwater Horizon – 11 dead, losses in excess of USD 60 billion
- Helge Ingstad – estimated re-acquisition cost of NOK 11 billion, where situational awareness did not match the environment
- Boeing 737 Max – 346 dead and enormous losses due to poor design of automation

An important prerequisite for avoiding accidents is good design. A systematic analysis of the investigation reports available indicated that a high proportion of all accidents and incidents are caused by poor design, Kinnersley (2007), Moura (2016).

The level of automation and the establishment of safe and appropriate solutions are determined most cost-effectively during the early phases of projects. Figure 1.2 presents change costs in different phases of projects (Samset, 2001), indicating that it is most cost-effective to utilise resources on good design and testing at an early stage. The cost of project activities and changes rises approximately exponentially.

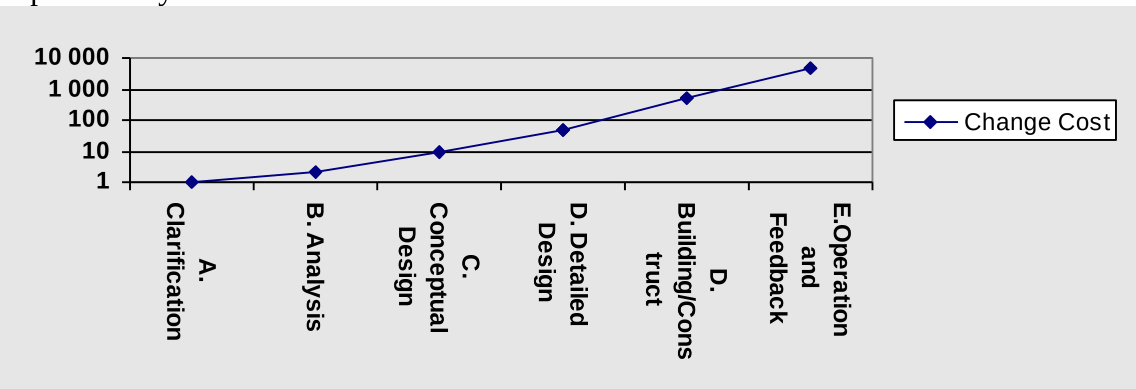

Figure 1.2 Change costs depending on phase (Samset, 2001).

1.2 Findings from literature review and experience of autonomy

The aim of the literature review was to collate knowledge concerning automation and autonomous systems and human-centred design in drilling and wells. We have also collated relevant experience of autonomy from other industries.

Situational awareness (SA) is described by Endsley (1995) as three levels: perception of *elements* of the current situation (level 1); comprehension of their meaning (level 2) and projection of their status in the near future (level 3). Situational awareness must be an integral part of design, and Endsley (2019) has outlined a number of aspects and principles that should be followed during the development and design of automated systems, including:

- Prioritisation of reliability and resilience/robustness of autonomous and technical systems
- Users should always be able to take over control of systems
- Transparent systems that show the state of the automated systems at all times
- The systems' user interfaces must provide support for the interpretation and management of simultaneous alarms

When new technology is introduced, it is important that the organisation concerned has built up the right prerequisites to enable new technology to be managed. Common weaknesses include a lack of clarity regarding roles, responsibilities and communication (Milch and Laumann, 2016). In addition, there may be a low level of risk perception and awareness relating to new challenges (Sætren and Laumann, 2015). The principles for strengthening interaction in distributed organisations are pivotal to the Crew Resource Management (CRM) training procedures. CRM has gained broad acceptance in many environments and has been a priority in the oil, maritime, aviation and offshore helicopter sectors (Johnsen, 2013).

Practical approaches that should be included in any analysis of HF in the automation of drilling operations are identified in "Drilling Systems Automation Roadmap Report" (DSA Roadmap, 2019):

- Task analysis (with an analysis of tasks and cognitive understanding) to determine priority areas for automation
- Planning of optimal workload and user analysis
- Design of control systems, information screens and visualisation tools for the best possible situational awareness
- Managing drilling personnel's reduced knowledge about the automated drilling process, by adapting the necessary information in human-machine interfaces.

It may be useful to look at other industries that have more experience of automation, design and human factors. Some lessons learned from the aviation, road transport, shipping and rail sectors are:

- The user-centred and gradual introduction of automation leads to safe solutions
- The importance of using HF in connection with increasing automation and the prioritising of meaningful human control of automation
- Physical delimitation of the scope of automated solutions
- High data quality from safe and redundant sensor solutions and infrastructure must be in place for safe and robust solutions
- Ongoing data entry and data analysis from operations are important for risk-based follow-up
- National strategies for automation have been developed for aviation, shipping and road transport. These offer guidance and can provide a secure framework for the introduction of automated systems. No such national strategy for industrial robotisation or the petroleum industry has been developed in Norway

Drilling is a promising area for automation. Automation can contribute to better utilisation by enabling the drilling of challenging wells and drilling in formations where drilling has not previously been possible. It can also contribute to more efficient drilling and provide support for the earlier detection of failure events. However, increased automation of drilling operations can lead to changes in tasks from an active role to a more monitoring-based role. This can contribute to reduced situational awareness (*out-of-the-loop*). Clear information concerning the state of the system and support for the transition between automatic and manual control will then be key factors in ensuring safety. A high level of quality is needed in human-machine interfaces, and the performance of automated systems must be transparent both to facilitate greater understanding of the process and to enable future actions to be predicted.

1.3 Findings from the investigation reports

The project reviewed nine investigation reports where causes linked to automated systems and HF were evaluated in order to gather experiences relating to the investigation methods and causality with proposals for initiatives. Due to the level of maturity and experience, we also looked at investigations with a high degree of automation within areas other than petroleum. Incidents involving autonomous and automated systems from other industries may be of relevance to drilling and wells as regards both investigative methods and findings.

The following incidents were reviewed with the theme of automation and HF:

1. Boeing 737 Max crashed (Endsley, 2019), (NTSB, 2019), (ECAA, 2019).
2. PSV Sjoborg and SFA, collision between ship and platform - Equinor (2019, 2019a).
3. KNM Helge Ingstad collision (AIBN, 2019), look at investigative methods and systems
4. DP operations (Dong, Vinnem & Utne, 2017), look at systems and alarms
5. Road traffic accident involving Tesla (Joshua Brown) in the USA – NTSB (2017)

The following events were reviewed with the theme of drilling & wells and HF:

6. West Hercules - ADS Barents, (PSA, 2019)
7. Macondo Blowout (US-CSB, 2016) and (Tinmannsvik et al., 2011)
8. Pryor Trust – Blowout (US-CSB, 2019)
9. Mærsk Gallant – Well control event (Mærsk Drilling, 2015)

The key findings relating to the investigative methods were the inadequate use of HF expertise and the methods used. Little attention was paid to the way in which the humans involved perceived the incident. The reports make little reference to design as a cause, which could lead to a lack of learning in order to prevent similar events in the future. The quality of investigation reports produced by independent boards such as accident boards (AIBN, NTSB, CSB) was high with regard to a holistic MTO perspective. In particular, the reports on Deepwater Horizon (CSB), Helge Ingstad (AIBN) are considered to be of particularly high quality. PSV Sjoborg (Equinor) had a good system perspective.

The key findings relating to causality amongst the accidents were that the systems did not provide sufficient information and/or did not issue alarms and notifications in a way that was understandable to users. The investigations indicate that HF must be better integrated into development processes, and that users need to be given a more central place in the design, testing and approval of the systems. The systems described in many of the reports were fragmented, and the coordination and integration of interactive systems needs to be improved. In a number of the investigations, the organisation was also fragmented and the delegation of responsibility unclear in respect of important tasks, issues which can be overcome through better integrated technical systems, clearer organisation and better training.

1.4 Key findings from the interviews with the industry

In consultation with PSA, two development projects were selected for the acquisition of information from the industry. Both of these projects have been under way for a long period of time and concern the automation and robotisation of functions on drill floor. Personnel involved in the projects and experts in automation and HF in the petroleum industry were interviewed. During these interviews, both challenges and positive experiences were identified with regard to user participation and HF.

The challenges relating to the projects were:

- Complex interfaces between operators and systems
- Technology-driven development without user involvement led to the creation of inappropriate systems
- A lack of planning led to expensive changes at a late stage in the project
- Poor use of technology to ensure meaningful human control
- Uncertainty amongst users concerning what is happening behind the systems/automation
- In some cases, existing alarms had not been assessed/updated in connection with the new systems that were developed
- Some underprioritising of training as project activities

Experiences with a positive effect:

- When human factors were prioritised by management
- Clear delimitation of the project in terms of scope and responsibility
- Good dialogue with PSA regarding work processes and training
- Strong user involvement at an early stage

1.5 Reflections linked to the regulatory framework

This review discusses the technological anchoring of the regulations. The function-based regulations and ever-changing picture regarding the parties involved are then discussed.

Technological anchoring of the regulations
The provisions in the regulations covering the petroleum industry, associated guidance and standards are often technologically based. Sections 20 and 21 of the Facilities Regulations note that human error must be avoided, an approach to safety management that can be associated with a *safety-I* mindset which focuses on the causes of failure. Use of the barrier concept can also illustrate anchoring which is to some extent technological in nature in the way it is practised. A somewhat more *proactive* approach to safety management, such as that represented by the 'resilience engineering' tradition, as well as the 'sensemaking' perspective, may be useful complementary frameworks for the safety-I mindset. PSA also notes that there is a need for clearer and more applicable HF standards linked to automation, which highlights the issue of how professional expertise relating to HF can be made more visible in connection with the formulation of regulations in the future.

Functional requirements and what is actually good enough
The functional requirements in the regulations set out the level of safety that must be attained, but not how. The functional requirements stress that each company is responsible for planning and carrying out its activities in such a way that the safety objectives are achieved. The petroleum industry is currently characterised by a large number of new companies, many of which have little or no previous experience of the industry. It is therefore becoming increasingly important to clarify the requirements stipulated in the regulations and, with regard to human factors and technology automation, standards should be an important resource. The review of the regulatory framework indicates that the highlighting of relevant HF standards and what these standards mean in practice for the parties involved could be strengthened. The project has also identified a need amongst the parties involved for a more active PSA, in terms of both supervision and dialogue.

1.6 Summary of key standards that should be given more attention

Key recognised standards relating to interaction design for control systems that should be incorporated into the regulations are as follows:

- ISO 9241 series: Ergonomics of Human System Interaction
  - ISO 9241-210 (2010) Human-centred design for interactive systems
  - ISO/TR 9241-810 (2020) Robotic, intelligent and autonomous systems

Alarm management is a vital prerequisite for managing complex operations, and best practice within alarm management should be followed up via EEMUA 191, for example.

Good practice for risk assessment and safety should be applied. The standards that address this area are:
The securing of infrastructure and systems should be addressed via the IEC 62443 standard and the certification schemes it recommends based on framework conditions provided by NOROG 104.

A gap between actual practice and HF standards was highlighted during the interviews. User-centred design and meaningful human control should be applied as principles in connection with the introduction of automation where the human still has an important role to play. This is described in IEA/ILO (2020)

1.7 Summary of findings and initiatives from the workshop

As part of the project, a workshop with 20 participants was arranged, during which findings made during previous activities and proposed initiatives were discussed:

- There is a need to improve the level of expertise relating to human factors within the petroleum sector, amongst operators, clients, management, supervisory authorities and consultants/suppliers
- The focus on technology must be balanced against user-centred design
- Good practice must be specified using HF standards
- Accident investigations should cover HF, human perception, design and the appropriateness of the design.
- Near misses should be more identified and analysed to a greater extent
- More attention should be paid to lessons learned concerning successful factors

1.8 Summary of key findings and proposed initiatives from the project

In the following, we have described the key findings from the activities, This is followed by a list of proposed initiatives.

Strong technology focus: There is a strong focus on the development of technology (automation) and the opportunities that this presents regarding efficiency during the operating phase. At the same time, we have observed that there is a lack of knowledge and follow-up of human factors (HF), particularly as regards cognitive factors, situational awareness and organisational factors, such as training and the analysis of altered tasks. (Ergonomics – physical working environment, has been well-covered). This can lead to complex systems that are difficult for users to manage and compromise HSE.
[T1] Improve level of knowledge and follow-up of human factors
Initiative: Raise the level of knowledge concerning HF and its utility value. Knowledge and follow-up of HF must be integrated into development when new technology is specified and designed in all parts of the organisation

User-centred development with an emphasis on HF has been successful and resulted in positive progress: Development projects for automated systems with a focus on user-centred development results in positive feedback with engaged users. Best practice should be supported and strengthened further. At a general level, we know that sectors that have focused attention on user-centred development and human factors have established high levels of safety and efficient systems with a high utility value.
[T2] Greater prioritisation of user-centred development.

Initiative: Greater prioritisation of user-centred design, supported by good practice (As described by ILO/IEA (2020) and standards such as ISO 11064, ISO 9241, and ISA 101).

Need for stronger focus on meaningful human control: Automation can help transfer tedious, dangerous, difficult and dirty operations from operators to machines/automation, but it also reduces user involvement and understanding. Automation can have positive financial effects. Automation can lead to the development of more complex systems, and users do not always understand what is happening in their systems. This can make it difficult to take over control and establish a safe state when systems fail. This requires a focus on ensuring that human operators are able to intervene, understand the situation and take over control when automated systems fail.
[T3] Meaningful human control.
Initiative: Technology must be designed to support "meaningful human control".

Data acquisition from automated systems may be inadequate: Experience from the introduction of automated systems indicates that data collection and logs are often inadequate. At both operator level and at overarching authority level. This could lead to a lack of sufficient data which forms an important basis for risk-based supervision.
[T4] Data reporting and analyses for strengthening risk-based development. *Initiative: Ensure systematic data reporting and facilitate the analysis of operations***.**

Poor learning between investigations and development/design/supervisory practice concerning human factors: When investigating incidents, the technical factors are often reviewed, but there is little analysis of the human factors (such as situational awareness amongst those involved) or system design. Failure to involve HF expertise in investigation teams could result in investigations not identifying HR causes or root causes linked to poor HF in design. This could result in a failure to learn lessons linked to HF and poor design.
[T5] Investigations should include HF and design decisions: *Initiative: Investigations into incidents should include a knowledge of HF and an assessment of design.*

1.9 Summary of proposals for further work

Below, we have listed proposals for further work that have emerged following discussions during the project which should be prioritised. The proposals are described in the appendix:

- [V1] Review of possible gaps and recurrent findings from accident investigations.
- [V2] Investigations concerning strategy for robotics and automation generally which include drilling and wells at national level.
- [V3] Review of the need to prioritise holistic MTO in connection with the integration and remote control of critical systems.
- [V4] In-depth study from RNNP, analyses events from autonomous systems.
- [V5] Lessons learned from successful transformation projects (automation/digitalisation).
- [V6] Supervisory series linked to the use of HF in connection with automation/digitalisation.
- [V7] Detailed analysis of the development of automated drilling operations.

2 Introduction

This report is based on an assignment commissioned by the Petroleum Safety Authority Norway (PSA) carried out by SINTEF and NTNU, with the title: *IKT2020 - Automation and autonomous systems: Human-centred design and the human–machine interface in the development and implementation of autonomous systems.* The aim of the assignment was to collate and summarise knowledge concerning human factors in the development, testing, implementation and use of new automated technology/autonomous systems that will be useful/critical for drilling and well operations. In this report, we have collated knowledge and experience relating to automated systems in both the petroleum industry and other industries, and assessed relevant regulations and standards applicable to the Norwegian petroleum industry. Abbreviations and terms are explained in Appendix A.

Both prioritisation and delimitations were linked to safety and human-centred design relating to drilling and wells where, as part of a process of development, designs have been placed according to recommended standards issued by the PSA (e.g. ISO 11064). This process of development is in line with the structure of the regulations, which extend from general premises to details; from the Framework Regulations, via the Management Regulations, the Facilities and Activities Regulations to the Technical and Operational Regulations.

This report documents the results of the assignment. The report consists of:

- Summary of the report
- Introduction with review of key terms and knowledge
- Literature review
- Review of investigation reports
- Collection of experience from the industry
- Reflections and proposals linked to supervision and the regulatory framework relating to automation
- Relevant standards and guidelines
- Workshop – automated systems and human factors
- Findings with proposals for initiatives and further work

The work was carried out in close collaboration with the industry by a multidisciplinary project group with expertise in drilling and wells, technology, organisation and human factors. The group consisted of ten participants from SINTEF (Technical Cybernetics, Petroleum Technology, Safety and Reliability, Digital/Software Engineering) and NTNU (Petroleum Technology and Design). The findings from the project’s activities are to some extent similar to those from the literature review, investigations, interviews and workshop. Recurrent findings from the various activities strengthen the conclusions. Findings and conclusions are traceable. Proposed measures, such as User Centring-T3, are shown in square brackets [T3].

The results are based on inductive analyses (i.e. analyses based on empirical data), as well as deductive analyses (i.e. analyses based on relevant theory of human factors), in addition to the project group's assessment. The methodology was based on action research, where practice and what the parties involved actually do underpin the conclusions (credibility).

2.1 Project delimitation - automated systems in drilling and well operations

The safe operation of a system covers more than just technical safety. By ‘systems’, we mean the technical system, associated user interfaces (via monitors or more comprehensive control rooms), the organisation surrounding the use of the system (i.e. delegation of responsibility, training and procedures), human operators involved in managing the system and the infrastructure surrounding the system (e.g. physical barriers and any technical infrastructure that supports operations such as sensors, and communication networks). Figure 2.1 outlines the system perspective.

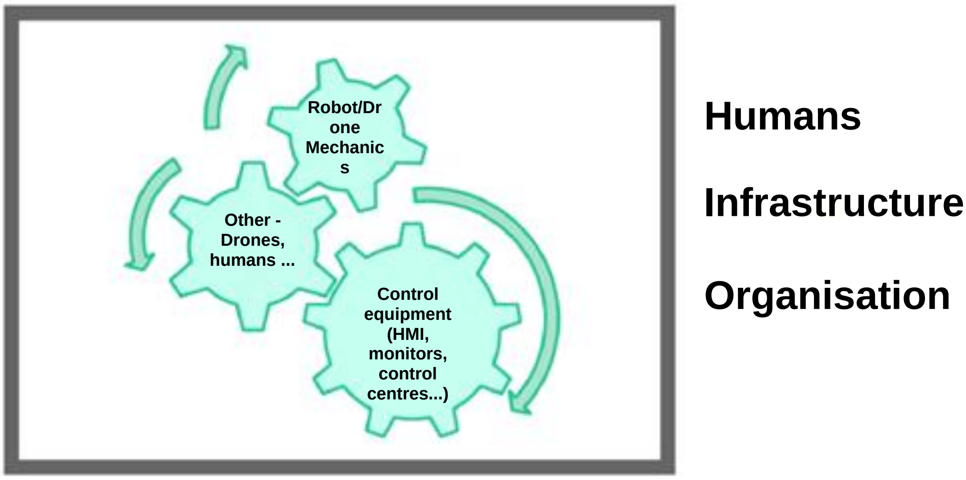

Figure 2.1: Automation from a system perspective

The aim of automation is to carry out a process or operation automatically, so that it controls itself to a greater or lesser extent. The terms ‘autonomy’ and ‘automation’ are widely used interchangeably. Different levels of automation have been defined which have different levels of interaction with humans, where autonomous systems control themselves. Successful automation must be based on realistic requirements regarding man, technology and organisation (MTO). This also includes responsibilities, training and appropriate procedures/routines that humans can follow.

The PSA's aim behind the assignment is “to help ensure that the petroleum activity gives high priority to safety, health and working environment when digital technology is developed, assessed and implemented in companies across the industry”.

Systems that carry out operations automatically can fail, and operation of such systems often depends on procedures and training relating to use of the systems. It is known that the BOP (Blow Out Preventer) in the DeepWater Horizon accident was not closed down in the well. After the blow out had occurred, when the Emergency Disconnect System (EDS) was to be activated, there was confusion in the control room over permission to activate EDS (US-CSB, 2016). The detailed description of the sequence of events which took place in the control room illustrates the importance of documenting in detail how the parties involved handled and perceived the incident. The sequence of events illustrates that managing incidents well requires more than just technology; it also requires human actions supported by organisation, including the clear delegation of responsibility and procedures that operators have been trained on.

2.2 Different levels of autonomy

Autonomy involves the ability of a system to make its own decisions, without involving external systems or operators. Reference is often made to different "Levels Of Autonomy" (LOA). There are many such classifications (Vagia et al., 2016). The classifications are often adapted to different areas,and are standardised within the discipline to varying degrees. It may therefore be appropriate to summarise the various levels within autonomy using a simplified table; see Table 1.1. This is based on SAE (2018) taken from the automotive industry. LOA is an important overarching starting point for the design of systems with interfaces and procedures. The subdivision is coarse and must be supplemented with detailed analyses. Automation is a characteristic of the entire system (see Bradshaw et al. (2013)), with interaction between all MTO components. LOA can provide a useful starting point for discussions concerning autonomy, Onnasch et al. (2014), Corbato et a. (2018), Kaber (2018) and Endsley (2018).

Table 2.1: General overview of levels of autonomy and the interaction between operator and system.

Level	Autonomy	Operator	System
1	No autonomy	All operations	Warns, protects
2	Limited support	Controls (In-the-loop)	Guides, supports
3	Tactical, monitors	Involved – continually monitors "On-the loop"	Controls within well-defined boundaries
4	Automated support Strategic	"Out-of-loop" interruption-determined, prompted by the system	Operates independently, but can hand back control
5	Autonomous	Fully "out-of-loop"	Operates independently – switches to safe state itself

Increased automation requires a greater understanding of human factors (HF). Parasuraman and Riley (1997) found that automation requires a thorough analysis of the tasks that are to be performed and a better human-machine interface (HMI) adapted to LOA. Automated solutions also require tailored training. It requires better handling of non-conformities and appropriate information when the automation fails, as was pointed out by Bainbridge (1983).

A system will often alter the level of autonomy during an operation. In order to select a level of automation, human limitations and opportunities must be taken into account. For example, as described in the principles from "Fitts list" (De Winter et al., 2014; Lee et al., 2017):

Humans surpass machine with regard to

- complex assessments
- learning
- improvisation
- adaptation
- detection of deviations in patterns

Automation surpasses humans with regard to

- consistent collection and interpretation of sensor data
- rapid response
- exhausting tasks
- following detailed instructions consistently

Important themes for future automation are flexible and adapted to automation, i.e. where it is possible to change the level of autonomy according to need/knowledge, and adaptive autonomy where it is possible to alter the level of autonomy independently of the status of the operator (stress level, fatigue and attention), and the use of AI. However, this requires high-quality analyses and can lead to operators not understanding what is going on, giving inappropriate feedback and causing accidents.

2.3 Effects of initiatives and improvements

The assignment from the PSA prioritises the early phase for new technology, i.e. the design phase. There is considerable scope for influence during the early phases, e.g. concept selection, project delimitations, analyses and design. It is during these phases that what is to be done and how is determined. This applies to both ready-made solutions (which must be integrated) and the development/adaptation of new technology. Given the impact and costs associated with measures and improvements, it is therefore important that the early stages are prioritised, not least because the scope for influence is greatest during the early stages and the cost of changes rises approximately exponentially (particularly as regards changes and troubleshooting offshore). The enclosed Figure 2.2 presents change costs based on experience (Samset, 2001). A change cost could amount to USD 1-10 as part of the initial analysis, USD 10-100 at the design stage, USD 100-1,000 during construction and USD 1,000-10,000 during operation. This applies to construction projects, software projects and change projects.

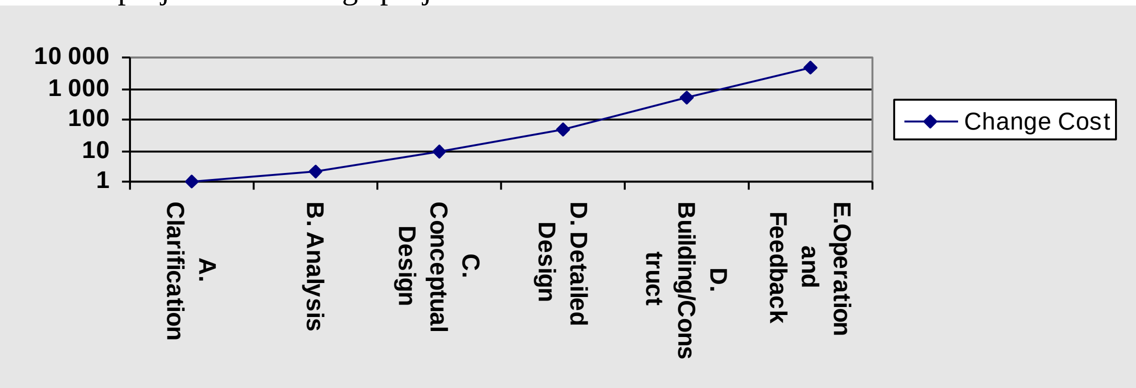

Figure 2.2 Change costs depending on phase (Samset, 2001).

The scope for influence is greatest during the early phases A, B, C and then decreases, while costs increase.

2.4 Accidents and human factors from an MTO perspective

There are many different theories and models to explain why accidents happen. Historically, the risks and causes of accidents have been understood from different perspectives, from the view that it is predominantly humans which makes the mistakes, to the view that accidents are more often the result of technical, organisational and human factors (MTO). In recent decades, greater awareness has thus emerged that a holistic MTO perspective is needed when understanding and preventing accidents, i.e. a system perspective. The current perspective is that human error[1] is a consequence of complex reasons linked to a range of factors, including poor design and organisational, technical

[1] *"Human Error"* is a contentious term which has been widely used in the past. Today, the interpretation of the term has changed from a view where humans are the cause of errors to a view where the term indicates that the design of the system is sub-optimal: *"Human error is a symptom of problems with the system, being an effect rather than a cause"* (Dekker, 2002).

or human framework conditions (Dekker 2002; 2004). This means that MTO factors must be taken into account both during the development of new systems and during operation.

The term ‘human factors’ (HF) has been defined by . In this report, HF is used in the context of specific methods and standards, while HF is used as a broader term which also includes aspects relating to human factors over and above specific methods.

Human factors can be divided into a number of areas as outlined in Figure 2.3:

- Cognitive factors (perception and thinking), which include task analysis, mental workload and situational awareness (SA)
- Ergonomic factors, which include physical conditions, temperature, air quality, workplace design, working position, etc.
- Organisational factors, which include work processes, communication, CRM, group collaboration

A systematic review of ten projects on the Norwegian continental shelf which looked at drilling cabins found that human factors relating to the areas of cognitive and organisational factors had been given little consideration, while physical ergonomics had been extensively considered (Johnsen et al. 2017), see Figure 2.3.

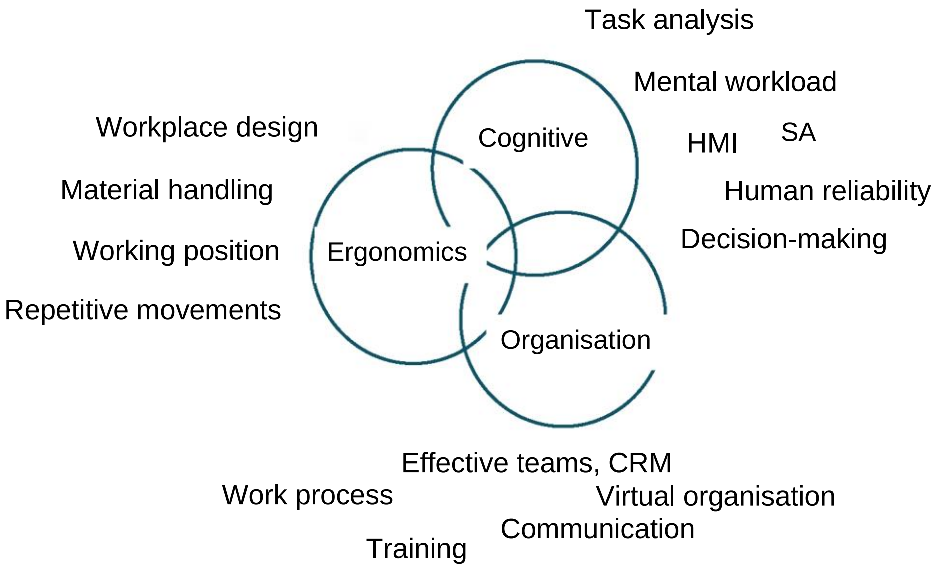

Figure 2.3: Human factors in the term ‘MTO’ (Karwowski, 2012)

An important prerequisite for avoiding accidents is good design. This view is put forward by a number of proponents, including Norman (2013), who says *“Human Error? – No, poor Design”*. A critical review of major accidents and investigation reports found a number of root causes which could be traced back to design (Gard, 2020). A systematic analysis of available investigation reports have indicated that a high proportion of all accidents and incidents are due to poor design (Kinnersley et al., 2007; Moura et al., 2016). Nevertheless, design is rarely considered as part of an investigation.

Important theories regarding HF and how to design safe systems are described in:

- Lee et al. (2017) "Designing for People", and in Endsley (2019) "Human Factors & Aviation Safety", with a description of interaction with human operators and technology
- Barrier thinking in Reason (1999) "Organisational Accidents and Safety Culture"
- Handling of the unexpected, as described in Hollnagel et al. (2006) "Resilience engineering"

These are key perspectives from, amongst others, Dekker (2019) – "Foundations of Safety Science".

Barrier management is an important perspective that is used in the petroleum sector to improve safety relating to oil recovery (PSA, 2017). The technique and perspective are ideally suited to the process industry, and are well-adapted to operation with physical barriers. The perspective also enables organisational and operational factors to be addressed, and can be further strengthened in combination with methods that put the human at the centre. A number of perspectives are often needed to understand accidents and incidents and how they can be managed. Examples of this can be found in the methods collated in Rosness et al., 2010. Lessons learned and developments arising from successful events are well-described in Buckinghamand Goodall (2019).

In order to manage unexpected incidents in autonomous systems, principles from resilient practice have increasingly been applied. Autonomous systems rely on good data from sensors, but sensors can fail and provide inadequate information. Moreover, situations may arise which the automation is unable to handle. Resilient practice is based on principles such as redundancy, flexibility, reduction of complexity and overview of safety margins (Hollnagel et al., 2006).

2.5 Importance and effect of human factors

The petroleum industry and supervisory authorities are aware of human factors, e.g. through Sections 20, 21 and 34a of the Facilities Regulations. The Regulations cover ergonomic design, the interface between man and machine, including information presentation, as well as control and monitoring systems. In Norway, there has been a tendency to concentrate on physical ergonomics, and ergonomics has to some extent been considered to include the discipline of HF. However, HF is an wide-ranging discipline. Key areas within HF related to increased automation are cognitive and organisational factors. HF impact a wide range of areas such as the working environment, safety, efficiency and productivity, and is a key element in connection with the introduction of technology.

A lack of focus on HF has led to numerous accidents and incidents with disastrous consequences and costs. Incidents which are referred to in this report include:

- Macondo, Deepwater Horizon – 11 dead, losses in excess of USD 60 billion
- Helge Ingstad – estimated reacquisition cost of NOK 11 billion
- Boeing 737 Max – 346 dead, huge financial losses

2.6 Strategies and frameworks linked to automation and autonomy generally

In the following, we present an overview of frameworks provided by strategic documents that describe a roadmap relating to automation and autonomy.

There are varying degrees of maturation and attitudes towards autonomy in the petroleum industry, and there are no overarching strategy documents concerning automation within the field amongst government agencies. In the following, we have therefore looked at strategies for autonomy from other fields.

Aviation has taken the lead in the introduction of automated solutions. On the roads, automation has been introduced in cars, buses and lorries with a high level of activity internationally. In Norway, strategies and frameworks for higher levels of automation and autonomous systems have been linked to specific areas such as road transport and the maritime industry. A strategy has been drawn up for airborne drones, but within other areas, there are no explicit strategies or measures at national level, e.g. within industrial automation. The use of drones in the petroleum sector, in the High North, is discussed in Bakken et al. (2019) and Johnsen et al. (2020), on behalf of the PSA.

Norwegian industry has long had a strategy of reversing the trend of “flagging out” (i.e. placing production abroad) by adopting cost-effective robotic technology and digitalisation. Priority areas have included robotic welding (in shipping, salmon pens and steel substructures for oil platforms), mobile robots (for transport and handling), automated drilling and heave compensation in crane systems. The petroleum industry has taken the lead with regard to the use of automated underwater vehicles, such as ROVs, which are remotely controlled, semi-automated robotic solutions. In this field, Norway has become a leading international player.

Within the field of automated drilling, industrial players have focused on purpose-built mechanical equipment: Top Drive, which is the drilling machine which rotates the drill string; draw works - the winch which raises and lowers the drill string; iron roughneck which is used for connecting drill pipes forming drill string; and machinery that retrieves and handle stands and other segments in the drill string and bottom hole assembly.
In addition, there are systems and procedures that support the operator by providing better information and control.

The petroleum industry has also invested in remote control and support within selected areas, such as the Ivar Aasen platform which is controlled from the shore.

Internationally, remote control and operation is more widespread than it is in Norway. In the process industry generally, the trend towards remote control/operation has been under way over the last 20 years, with positive experiences. There has been no systematic assessment of experiences gained within the petroleum sector or process industry as regards the impact of remote control on HSE.

Automation and robotisation are relevant to many fields, but establishing robust and safe automated systems is expensive and requires investment in infrastructure. Aspects of automation have been described in the Government's Strategy for Artificial Intelligence - AI (2020).

Frameworks and development plans for the use of autonomous systems in air and both on and under water are outlined in a number of strategy documents. A number of government agencies, including the Ministry of Transport, have established a goal of eliminating obstacles which delay the use of new technology (e.g. for autonomous ships). It has therefore allocated funding for tests and improvements to automated vessels via pilot projects and research. Key documents concerning the development and use of autonomous vehicles/drones are the Norwegian National Transport Plan 2018-2029, the Norwegian Government's Ocean Strategy entitled "New Growth, Proud History - " (2017) and Norway's Drone Strategy (2018), which covers airborne drones.

Automation is increasingly being used in ship systems, and Norway is leading the way with a number of established test areas along the coast, Autonomous Ships (2019). Government authorities have been working to develop the legislation, and a spotlight has been placed on eliminating legal obstacles to the use of autonomous ships; ref. the Norwegian Act on ports and territorial waters (a new version of which came into force in 2020). The Norwegian Maritime Authority has also started to develop regulations to support safe and environmentally friendly autonomous sea transport.

The Norwegian Maritime Authority uses risk-assessed operating concepts, where the first step, delimitation of the area via a "Concept of Operations" (CONOPS), is a key element (Norwegian Maritime Authority, 2020). In addition, risk assessments (Pre-HAZID, HAZID) will require testing and approval by an independent third party before automated solutions can be put into operation. DNV-GL (CG-0264, 2018) has a detailed description of CONOPS which describes the operation with route, level of autonomy, staffing, control and responsibility.

As regards airborne drones, key framework conditions are established by Norway's Drone Strategy (2018), the Norwegian Civil Aviation Authority's "Regulations on remotely piloted aircraft, etc" (Lovdata, 2015) and the EASA's new regulation concerning drone operations and certification (EASA, 2019). The Norwegian Drone Strategy refers to a desire to boost efforts relating to safety work, partly by making drone operators part of the safety culture that otherwise permeates aviation. An example of this, from Lovdata (2015), is the "Regulations on remotely piloted aircraft, etc". These Regulations establish well-defined requirements regarding competence and certification in order to be permitted to operate different types of automated drones.

3 Literature review and experiences of automated solutions

The aim of this chapter is to identify the knowledge base and trends within automation and safety, based on generally accepted international practice and research. We begin with an overview of recognised theory concerning human factors. Experience and good practice from automation and autonomy from sea, air, road and rail are then described, followed by a presentation of findings concerning technology and autonomous solutions in drilling and wells. We conclude with a summary of findings and proposed initiatives.

3.1 Human factors in system development and operation

In this section, we present research literature concerning HF of relevance to automated systems. The literature primarily originates from domains other than petroleum and drilling and wells, but the principles are nonetheless transferable. The literature review starts with key terms such as situational awareness and sensemaking. Human-machine interfaces and alarms are also systems that need to be developed with the user in mind. This becomes particularly important in connection with the introduction of automated technology. We then look at organisational factors, before concluding with a presentation of methods and perspectives that can be applied in the development of automated systems that address HF in an MTO framework.

3.1.1 Situational awareness (SA) and sensemaking

Situational awareness (SA) is a term that is used to refer to the understanding that a person has during an event. Situational awareness can be considered in the context of errors, such as failing to understand critical signals relating to a process which is being monitored, inadequate interpretation of information, insufficient understanding of one's own and others' responsibilities, and inadequate communication within teams. The term is often used in connection with human interaction with automated systems.

Endsley (1995) describes situational awareness on three levels: perception of *elements* of the current situation (level 1); comprehension of their meaning (level 2) and projection of their status in the near future (level 3). External influences that have implications for situational awareness can include workload, fatigue and stress (Kaber et al., 1998).

Situational awareness as a term is used in a wide variety of contexts. It is used in oil and gas, nuclear power, shipping, police, aviation (pilots/traffic control), the health service, crisis management, accident investigations and the armed forces. Within the aviation sector, it has been observed that, automation leads to reduced situational awareness (Endsley 1996, 2015). This is linked to the fact that humans who are supposed to be monitoring processes where they are not actively controlling the systems may face challenges with regard to maintaining attention levels, because they are no longer actively involved in the work processes (*out-of-the-loop*).

In order to focus on topics within SA, a distinction is sometimes made between the process of establishing situational awareness (the SA process) and the situational awareness itself. The SA process can also be described as sensemaking. In this report, we use the term "sensemaking" to refer to the process of achieving SA, referring to the way in which people obtain information from their surroundings and collate it to create a holistic picture of a situation, and then act in accordance with their understanding. "Sensemaking" is a volatile term, and it is also the world in which the parties involved strive to form an understanding. The framework seeks to capture aspects of this volatility, such as the operators' search for order, retrospective interpretations, reasoning and rationalisation of events, and how assumptions concerning underlying factors influence interpretations of situations (Weick, 2001). In order to gain a holistic understanding of how humans may act in different situations, it is therefore necessary to include human, technical and organisational factors in the analysis. "Sensemaking" is also closely linked to resilient systems (robustness), and the two concepts support each other (Kilskar et al., 2019). In Figure 3.1, we have placed sensemaking as a result of design and training in the context of existing organisation, technology.

Figure 3.1: "Sensemaking" is influenced by design, training and surroundings and is the process for achieving SA (SMACS, 2020)

Lack of situational awareness has been identified in connection with many drilling incidents. A study which looked at SA amongst drilling personnel in pressure tests conducted before the Macondo accident found a correlation between a lack of understanding of critical signals and inadequate mental models of the incident (Robert et al., 2015). Failures in understanding were linked to a lack of information and misunderstandings. The reasons for inadequate situational awareness are linked to workload, working environment, disruptive elements and lack of experience.

In another analysis of drilling-related accidents, it was found that 67% of events could be linked to the perception of elements in the situations (level 1 SA). Approximately 20% and 13% of accidents could be linked to the current situation (level 2 SA) and future situation (level 3 SA) respectively; Sneddon et al., (2013). This study found that particularly high stress levels and fatigue could lead to poorer situational awareness amongst the drilling personnel.

Investigation reports should consider situational awareness as one of a number of human factors. For examples of methods that support the SA perspective, see CIEHF (2020) and AIBN (2019). Given the importance of SA during accidents, investigations should analyse SA, [T5].

Although increasing levels of automation reduce workloads, problems relating to situational awareness and system understanding have arisen as a result of automation (Borst et al., 2010). Aviation accidents have occurred due to a lack of understanding of autonomous systems amongst pilots (Endsley, 2012). Ambiguous information, uncertainties regarding intentions and inappropriate handling of unexpected events are linked to deficiencies in situational awareness. A study that looked at the relationship between automation, workload and situational awareness in simulated experiments with air traffic controllers found that a high level of automation led to a long response time amongst air traffic controllers when detecting conflicts in the system (Edwards et al., 2017).

The theory linked to situational awareness (Endsley, 1995; 2019) and sensemaking (Weick, 2001) forms part of the HF that can be used to improve designs and solutions for automated systems. Users should be involved in the development process in order to determine their situational awareness during critical operations [T2]. Endsley (2019) has outlined seven principles from SA that should be taken into account in the development and design of automated systems [T3]:

- Reliability and resilience/robustness are particularly important for autonomous and technical systems
- Users should always be able to take over control of systems
- The systems must be transparent and show the state of the automated systems at all times
- Training must be sufficient in order to provide understanding and underpin trust
- Avoid increasing cognitive load, workload and disruptive elements, and make tasks easy to perform.
- Alarm notifications must be unambiguous
- The systems' user interfaces must provide support for the interpretation and management of simultaneous alarms

Endsley (2019) also notes that the testing and validation of user interface designs is a critical part of the development process, which must include (i) both normal and abnormal events, including automation failures and recovery, (ii) a representative sample of users who have not been involved in the development process, and (iii) tests on objective indicators of human performance, such as what actions are taken, time used, workload and situational awareness.

Because drilling offshore is a dynamic activity, it is important that both situational awareness and cooperation amongst operators function optimally. Iversen et al. (2013) conducted a simulation of a semi-automated drilling operation. They analysed how unexpected behaviour by the automated systems can lead to "*mode confusion – i.e. when the actual automation mode of a system differs from the user's expectations"*, i.e. the users do not understand what is happening in the system, which can lead to mistakes being made. The results indicated that there was a correlation between the level of automation and the risk of errors. They noted that the oil and gas industry can learn from the aviation sector which has conducted research relating to the issue.

3.1.2 Human-machine interfaces (HMI) and alarms

Although automation as a concept seeks to remove the human from the process, there will be an expectation in most automated solutions that the human should have a monitoring role, and thus should be able to intervene as and when necessary. It is therefore necessary to apply technology that enables this to happen in an appropriate way. This takes place through the human-machine interface (HMI) which operators use to interact with the automated systems and processes. This interface must present information in such a way that those responsible for monitoring the systems have the information they need to understand what is actually happening, presented at the right time and in the right place. A framework that describes interaction between drillers and automation in the drilling process can be found in de Wardt et al., (2016) and Wylie et al., (2018).

In connection with the development of automated processes, it is necessary to evaluate whether new opportunities for errors are being introduced (Flaspöler et al., 2009). Many automation-human interfaces do not provide enough information about the status of the autonomous system itself, and give little feedback about the state of the system that is being monitored; Endsley (2012, 2017, 2019). For example, tactile information about systems and processes can be lost when humans are removed from physical processes such as vibrations, sounds and odours. The systems can also provide too much information, and it is therefore important to follow the principles of meaningful human control and, as mentioned by Endsley (2019), avoid increasing cognitive load, workload and disruptive elements, for example.

Experience from the aviation sector suggests that it is important to avoid the unnecessary use of alarms, (Endsley, 2019). Too many alarms can lead to uncertainty and challenges in narrowing down what the problem actually concerns. Inappropriate alarms are also a known issue within both the petroleum industry and the maritime sector. For example, there have been a number of incidents involving dynamic positioning systems where inappropriate alarms have been a contributory factor in accidents (Dong et al., 2017). In a human-automation interface, appropriate alarms must be perceived to be real and relevant, and operators must be able to make effective and appropriate decisions based on such alarms (Wylie et al., 2016).

IT/OT solutions can provide support for decisions and help operators to identify problems, but designing such solutions for dynamic systems in offshore oil and gas production (OESI, 2016) is a challenging task. Within the automation of drilling operations, the human-machine interface (HMI) has been identified as one of the most important factors for successful operation (Wylie et al., 2016). The design and presentation of the right information has been highlighted as a key factor in ensuring that critical signals are understood in drilling and well operations (Roberts et al. 2015).

Based on knowledge from automation in the aviation sector, Endsley (2017) summarises four key points for the appropriate design of human-automation interfaces and functions:

- HMI must present the information that is needed to enable decisions to be made
- The information must be clear and present the state of the system, including modes and system limits
- The system must provide support in the transition between modes, and indicate whether it is necessary to switch between automatic and manual operation
- The system must provide information on what the automation is doing, to increase understanding of the process and enable future actions to be predicted

Endsley (2017) also notes that complexity, involvement and workload will have a fundamental impact on interaction between the human and the automated system. Complexity will often be a consequence of many functions and modes which have been incorporated into the system, and can lead to unexpected behaviour by the system, along with inadequate mental models of the system amongst users as a result. In turn, this will lead to an inability to interpret information and predict necessary actions.

The visualisation of complex processes can facilitate better mental models amongst drilling personnel (Wylie et al., 2016). When integrating multiple systems into automated drilling processes, it must be ensured that the information from the processes is presented in an understandable way for drilling personnel. They must monitor the systems, but not be overloaded by too much information (Thorogood, 2009). These systems are often provided by different suppliers, and the systems should both be able to communicate with each other and present coordinated information to the operators.

Within the automation of drilling operations, a number of solutions have been developed which can support the interaction between drilling personnel and technical systems, such as automated procedure systems (Dashevskiy et al. 2020) and decision support in position calculations in directional drilling (Chmela et al. 2020). The development of technology for decision support can lead to greater situational awareness and better interaction between human and automation, but it is essential that these systems are also developed based on methods that take into account human factors [T3]. The technology should be developed in interaction with users [T2], and testing and validation are essential.

Research is also being conducted into dynamic methods for adapting automated systems. Within the aviation sector, the possibility of using *eye-tracking* to identify situations where eye movements indicated that the pilots were experiencing *automation surprise* – i.e. the pilots did not understand the information being provided by the automated systems (Dehais et al. 2015). Neurophysiological signals have also been used to adapt automated systems to take account of the stress levels of operators. A research project concerning adaptive automation used stress signals from air traffic control tower operators to activate a simplified user interface and reduce alarms when operators were experiencing cognitive overload (Aricò, 2016). However, the technique must be used with caution, but it can be an important tool when systems are designed to support meaningful human control [T3].

3.1.3 Distributed organisations

Distributed organisations are relevant in a variety of contexts linked to automated drilling. The operation of oil and gas installations is an extensively distributed process, with numerous players and subcontractors involved in operations as operators, contractors, rig owners and service providers. There is also a trend towards integrated operations within operating companies where more functions are being transferred onshore. At a general level, the complex picture of stakeholders involved in operations and projects will present numerous challenges, particularly as regards communication, uncertainties relating to roles and responsibilities, common understanding of goal attainment, the integration of systems and data from multiple suppliers, as well as data security. In the development of new technology for this industry, it is therefore particularly important that cooperation and communication between the necessary parties involved is facilitated, that the user perspective is addressed from the start, and that all suppliers have the same understanding of goal attainment in the project (de Wardt, 2016). It should for example be agreed that automated technology must improve both safety and operational performance, and that automation is not an independent goal itself.

Experts on human factors involved in development projects can also place a spotlight on common challenges associated with interorganisational collaboration and complexity, such as a lack of clarity over roles and responsibilities, and poor communication (Milch and Laumann, 2016). In a study by Sætren and Laumann (2014), the researchers followed a project which developed and implemented automated drilling, in order to look at acceptance of the new technology amongst drilling personnel. In this study, the authors concluded that there may be too much trust in the new technology, which has led to low risk perception and awareness of possible challenges. Drilling personnel were heavily dependent on receiving sufficient information from the developers. However, in an associated study, the researchers found that the developers had little understanding of who the end users were before implementing and testing the technology (Sætren et al., 2016). This was due to insufficient coordination of information relating to human factors in the development of the technology and prioritisation of the technical aspects of safety, as opposed to user-friendliness, for example. This led to an increase in costs, a low level of user-friendliness, and a poor understanding amongst users of risks and safe use of the system.

Collaboration during the development and testing of automated systems between equipment suppliers and operators, in addition to the involvement of users, is therefore an important prerequisite for the safe development of software [T2]. In order to address this perspective when conflicting goals arise in the development of new technology (e.g. between efficiency and user opportunities and preconditions for understanding automated technology), it may be necessary to involve experts in human factors in projects throughout the implementation process [T1] (Sætren and Laumann, 2015).

3.1.4 Organisational factors in introduction of new technology

With the introduction of new technology, the organisation of work and the role of the humans will change. As a result of the introduction of solutions for automated drilling operation, fewer people are required to perform operations, and tasks will change. It will be necessary to examine how these tasks are formulated in order to take account for human’s strengths and limitations. In the aviation sector, it has been found that systems which are initially perceived to be "almost completely safe" still challenge the organisational boundaries and practices when autonomous systems are introduced (Oliver et al., 2017). It is in unknown and unexpected situations that problems with automation arise. This must also be dealt with at both a human-centred level and an organisational level, with interaction between many parties, not just through the development of technology. It is therefore important to allow iterative development where changes are introduced gradually and lessons are learned on many levels [T2].

Training, confidence in the process of change and he technology are organisational factors that must be taken into account in connection with the introduction of automated and autonomous systems.

The assumptions and plans that form the basis for many work processes must correspond with the competence and expectations of users, which can be ensured through user-centered development and the step-by-step introduction of new technology. It is important to facilitate good learning within organisations in order to prevent accidents and incidents. Iversen et al. (2013) found in a study that used simulations of an automated drilling system that it may be advantageous to have drilling personnel with a level of knowledge that extends beyond the level that is common today. They concluded that personnel will need to have deeper theoretical and practical training and competence concerning downhole phenomena, along with an understanding of the design and operation of autonomous control systems.

When drilling personnel are no longer manually involved in drilling operations, their knowledge of operations can gradually fade. This can be counteracted by appropriate and clear human-machine interfaces. Misunderstandings and errors relating to expectations can be linked to the design of procedures and the handover of information between individuals and teams. Training based on situational awareness and human factors can improve interaction (Antonovsky et al. 2014). Training concerning such non-technical factors through Crew Resource Management (CRM) training will help to promote good cooperation between operators. CRM training is afforded a high priority within the oil industry (IOGP, IWCF), the maritime industry, the aviation industry and the offshore helicopter sector; see also Johnsen (2013).

3.1.5 MTO perspectives in development

Prioritising efficiency can lead to a narrow focus on the development of technology, to the detriment of safety. There may be challenges associated with using HF when the level of expertise is low and the budget is limited. To ensure that sufficient attention is paid to HF, requirements and follow-up in the regulations (HSE, 2015) will therefore be important, and the industry itself must follow up HF.

To ensure the adequate inclusion of HF, it is important to view safety from a perspective that places an understanding of operational conditions, technological assumptions and the individual operator's tasks in context. It will not be enough to focus on one of these elements, as safe work can be facilitated through an interaction between the various parties involved and functions. This is also a fundamental principle in barrier management, where the interaction between technical, organisational and operational barrier elements should be capable of safeguarding barrier functions (PSA, 2017). In accordance with Section 5 of the Management Regulations, barriers must detect emerging incidents, prevent the development of a chain of events and limit the scope of damage. The introduction of automated systems will impact on barrier functions and elements, e.g. some barrier functions will be transferred from humans to IT/OT systems. This will lead to changes in the design of barrier systems and the delegation of responsibilities. The barrier perspective can help to analyse whether barrier functions are weakened or strengthened through this change, and whether the values that are to be protected (human, environment, equipment) become more or less vulnerable after the implementation of automated systems.

System theory is another holistic perspective which is applied by safety experts, and a number of hazard analysis methods have been developed based on this perspective. System theory is based on the view that it is not possible to isolate and analyse only certain parts of a system without losing our understanding of how the system behaves when the various parties involved and components interact. For example, the Systems-Theoretic Accident Model and Process (STAMP) uses this perspective (Leveson, 2011). The Systems Theoretic Process Analysis (STPA) hazard analysis method and the Causal Analysis based on Systems Theory (CAST) investigation method are based on STAMP (Leveson, 2011, 2019). STPA has been demonstrated in the development of autonomous systems such as robotic solutions used in space travel (Leveson, 2011) and autonomous ships (Wróbel et al. 2017). Examples of use in risk assessments compared with other methods for autonomous ships are discussed in Nilsen et al. (2018) and Torkildson et al. (2019). CAST reveals relationships and interactions between technology and human control opportunities; see for example Leveson (2016) - "CAST Analysis of the Shell Moerdijk Accident".

CIEHF (2020) provides an up-to-date overview of methods used within HF in order to learn from accidents. The "Human Factors Analysis and Classification System" (HFACS) is also highlighted in this overview. HFACS is a framework for analysing human errors based on Reasons' model of latent and active errors (Reason, 1990; Wiegmann and Shapell, 2001). The framework was originally developed for the US armed forces for analysing aviation accidents, and has been used to analyse accidents in civil aviation (Wiegmann and Shapell, 2001) and other industries. Organisational influences, prerequisites for actions and analysis of the actions concerned form part of HFACS. The method supports the HF perspective in investigations [T5], along with those referred to in CIEHF (2020).

"Resilience Engineering (RE)" is an approach that analyses the ability to handle the unexpected in a dynamic system, and how to switch to a safe state using a holistic MTO perspective (Hollnagel, 2006). This approach attempts to learn from what is successful and works, referring to it as 'Safety-2' (in order to complement the Safety-1 perspective, which is based on learning from what goes wrong). RE assesses the dynamic aspects of different parties, technology and organisations, and can be used to investigate how variations can represent not only opportunities, but also challenges in the introduction of automation. RE has become widespread in technical fields such as software development to ensure robust systems. RE/Resilience has been widely accepted at the overarching level within the UN and EU, (Pęciłło, 2016). RE can also contribute principles in the development of AI systems in order to achieve better control and safety. An example of this is to apply the principle of "reducing complexity", by dividing systems into a number of components. Having a number of AI components which handle basic functions can make it easier to understand and control a system, rather than having a fully integrated AI system.

A literature review of the status of autonomous systems in 2020 (state of the art) identified four challenges associated with automation: 1) access to reliable and robust systems; 2) interfaces with human operators; 3) the need for AI which supports robustness and safety; and 4) reliability in unstructured environments (Johnsen & Kilskar, 2020).

It has been observed that automated systems often have little tolerance for errors or the unexpected in the surroundings. This may be because they have sensors that do not capture all the information or because the system/automation does not understand new situations. As a result, more attention has been paid to principles from "Resilience Engineering" which can be used to create more robust automated systems [T3b].

Quality assurance of the development process is essential, particularly as regards human factors during design and operation. CRIOP (2011) is a commonly used method of conducting independent quality assurance (Aas& Skramstad 2010). CRIOP is an MTO method that contributes to verification and validation of the ability to safely control and operate control systems and control rooms, based on the ISO 11064 development method and the barrier perspective. A key part of CRIOP is the quality assurance of documents such as task analyses, workload analyses, working environment/ergonomics, quality of alarms and HMI. The method should be used early in projects, during the clarification and detailed design stages, as well as during the operational stage. When the method is used at an early stage, it allows any design deficiencies to be corrected as early and cost-effectively as possible.

Other methods and approaches that should be included in any analysis of human factors in the automation of drilling operations are identified in "Drilling Systems Automation Roadmap Report" (DSA Roadmap, 2019). These are:

- Task analysis (with a review of tasks and cognitive understanding) to determine priority areas for automation
- Planning of optimal workload and user analysis
- Design of control systems, information screens and visualisation tools for the best possible situational awareness
- Planning to combat inattention ("complacency")
- Managing reduced knowledge levels about automated processes amongst drilling personnel by incorporating the necessary information into HMI
- Managing drilling personnel's trust in systems relating to status reports, alarms and system reliability
- Communication of uncertainties and intentions in automation to drilling personnel in order to facilitate good mental models of the process

The theory that we have identified provides clear support for the importance of raising the level of knowledge concerning human factors [T1], the importance of delimiting what is automated [T3a], the importance of user-centered design [T2], the importance of meaningful human control [T3], and good practice for investigations.

3.2 Automated transport solutions with transfer value

In the following, we document experience gained through the use of automated solutions on sea, air, road and rail which have relevance and transfer value for the petroleum sector, drilling and wells. They are all areas with experience of automation; they prioritise safety highly. The aviation industry in particular has developed good practice in the field of HF.

We have listed experiences from the transport domains, primarily from the period 1980 to 2020. In the conclusion, we summarise experiences that have transfer value as regards the automation of drilling operations and wells.

3.2.1 Unmanned metros

Unmanned metros has been operating since 1980. At the start of 2019, there were unmanned metros in 37 cities, with 48 lines and a total route length of 674 km. One obvious example is the Copenhagen Metro, which is unmanned and operated via a manned control centre. As regards safety, the following is noteworthy:

- There were no known accidents or serious HSE incidents between the opening of the metro in 1980 and 2020
- The area of operation has been limited. The tracks are isolated from other traffic, so the line uses reserved tracks. There are physical barriers along the track and double doors to prevent users from getting onto the tracks or becoming stuck
- There is a central control room which is manned continuously during operation, with monitoring of all traffic and non-conformity management
- Inadequate systematic data reporting and documentation of minor incidents – there are no statistics which systematise and summarise usage, including passenger numbers and passenger-

kilometres at international level. There are also no agreed taxonomies for data reporting linked to minor incidents

Experience that can be transferred is the need to define the area of operation in order to minimise risks, to establish barriers and protections that prevent accidents and incidents, and to ensure that there are control rooms or operators who can intervene when the unexpected happens.

3.2.2 Autonomous road vehicles

Unmanned/autonomous vehicles have been in use in pilot projects and research for many years. There are many examples. We have for example looked at automated guided vehicles (AGV) for goods transport at St. Olav's Hospital, which began operating in 2008/2009. As regards safety, the following is noteworthy:

- No known accidents during the period 2008/2009 to 2020
- The area in which goods are transported is mainly limited to a dedicated basement floor, but AGVs also take the lift up to specific pick-up zones. The zone of movement of the AGVs is to some extent isolated from other traffic
- The sensors on the AVGs do not have a clear understanding of their own dimensions and have a limited range of vision. They do not always detect or see objects or other traffic, such as bicycles, pallets or forklift trucks. The problem with forklift trucks is that there is a considerable distance between the underside of the forks and the ground, which means that the sensors do not "see" the truck.
- There has been a spotlight on learning and the establishment of barriers in order to reduce accidents and incidents. Examples of barriers include the addition of "skirts" beneath forklift trucks, so that they can be seen by the sensors fitted to the AGVs.
- The AGVs communicate or "talk", i.e. they announce that they are approaching, so that pedestrians and other road users can take appropriate action, which impacts on the level of trust in the systems and reduces alienation
- A central control room has been established which is manned continuously during operation (two people), with monitoring of all traffic and non-conformity management
- There is insufficient systematic data reporting or documentation of minor incidents – there are no taxonomies for data reporting and challenges in obtaining an overview to lack of data capture

Experience of autonomous systems with, amongst other things, traffic on ordinary roads has been collated by a number of stakeholders and has improved our understanding of autonomous systems, as listed below:

- Google Cars collected data from 2008. Between 2009 and 2015, Google Cars drove 2,208,199 km with an accident rate of 1.36 per million km, about one third of that for human-operated vehicles (Teoh et al. 2017). This illustrates the importance of data reporting in order to determine risk levels. The introduction of more autonomy indicates that a reduction in accident rates is possible. In Norway, there are three deaths per billion km driven on the road network generally, while the corresponding rate in the USA is 7.3 deaths. This indicates that measures such as training and regulatory improvements can be implemented in order to improve safety levels; new technology such as autonomy will not in itself improve safety - it must be supported by other measures.
- There has been uncertainty as to whether the implementation of automated solutions in critical areas has improved safety, as indicated by the 2019 QCS report relating to Tesla's introduction

of automated steering assistance via the "Autosteer Driver Assistance System". Initial reports indicated that autopilot (Autosteer) reduces accidents by 40%, while a more thorough analysis of the data indicated that the activation of Autosteer increased the collision rate by 59%. It is therefore important to have good independent data reporting that has undergone quality assurance
- Automotive manufacturer Tesla has installed partially automated features in their cars. Data concerning their use is collected by Tesla and used for development and learning purposes in order to create safer and better systems. This is user testing placed in a system, which can lead to positive developments in the long term
- New types of accidents have emerged – "rage against the machine", where other motorists collide with autonomous cars because they do not behave as expected (Teho et al. 2017)
- Partial data reporting and documentation of incidents has been established by the US authorities (National Transportation Safety Board – NTSB). This has also been done in Norway in connection with pilot projects for the testing of autonomous buses and cars. The experience indicates that autonomous solutions require greater investment in infrastructure to ensure that autonomous vehicles receive support in order to avoid collisions
- Most autonomous cars are manned by drivers sitting in the car monitoring the situation. It should be noted that the reaction time before a human intervenes ("out of the loop") varies from 2 to 26 seconds – i.e. there are challenges associated with taking control as the systems are designed at present (Eriksson et al., 2017)
- Autonomous vehicles have been in use in the mining sector since 2008, with good experiences as regards HSE. Pilot projects are under way in Norway with good experience from operations in 2019; see the www.hfc.sintef.no meeting in May 2019 concerning Brønnøy Kalk
- Experience of sensors and software (AI) used in autonomous vehicles indicates that it is difficult to detect/interpret all obstacles/challenges in traffic situations. There is a general expectation that it takes longer. The expert view is that it will take 10 years for the systems to reach a level where they are able to deliver full autonomy (Wozniak, 2019; CNBC, 2019). It is therefore necessary to delimit the area of operation and develop supporting infrastructure in order to utilise autonomous vehicles and solutions.

Experiences that can be transferred to other areas are as follows:
- Delimit operations so that risks are minimised and develop and adapt infrastructure to autonomous operations
- The quality of sensors and systems is continually being improved – misinterpretations occur, so systems should be made more robust (e.g. redundant) and barriers should be established that prevent accidents and incidents
- Autonomous systems can fail, so it must be ensured that control rooms or operators are in place who can intervene when the unexpected happens
- Establish systems for data reporting and learning from new incidents
- Safety is improved not only through the technology, but through a holistic MTO approach

3.2.3 Autonomy within shipping

Norway has been very proactive in establishing autonomous solutions in shipping, and is a leading player on the international stage. Norway had three test areas for autonomous ships in 2020. There had previously been a total of six test areas worldwide, but this number increased significantly

during 2020. Interesting pilot projects include Yara Birkeland, which will be operational from 2021. This vessel is 75 metres long and will be able to carry 150 containers, which will remove approximately 40,000 lorries/year from the road network. A gradual transition to autonomous control of Yara Birkeland is planned, with manned operation onboard initially supported by an onshore control centre. Other projects include Asko, which is aiming to build two sea drones to replace 150 lorry trips per day between Østfold and Vestfold. They will cross Oslo Fjord electrically and emission-free from 2024. The electric and autonomous cargo vessels will have capacity to carry 16 articulated lorries. It is estimated that emissions will be cut by 5,000 tonnes of CO_2. There will also be two million fewer kilometres driven every year.
In Trondheim, a pilot, known as AutoFerry - an unmanned ferry connected to a control centre which will operate locally from 2021 - is planned following the testing of a pilot ferry in 2020. Little experience has been gained of larger autonomous ships, although there is some experience of unmanned ferries where some accidents have occurred linked to overloading.

Some experience has also been gained of smaller autonomous surface ships used for mapping and seismic surveys, for example, which have proved to be successful within their respective fields. Wrobel et.al. (2017) reviewed 100 accidents involving ships and assessed the risks that would have applied had the ships been unmanned/autonomous. The analysis was speculative, but indicated that although the probability of accidents would be reduced with autonomous ships, the consequences could be greater, e.g. in the event of grounding or fire due to there being no humans present who could improvise or manage the accident at the scene. DNV-GL has conducted a risk assessment concerning autonomous ships for the European Maritime Safety Agency (EMSA), where issues such as missing alarms, sensor failure and "out of the loop" problems were identified as possible risk areas. Proposed measures included better alarms, prioritisation of resilience, stronger focus on HMI interfaces, and greater use of verification and validation (DNV-GL, 2020).

ROVs have long been used in the petroleum sector, and a specific standard has been developed for their use - NORSOK U-102 (2003). We have not found any systematic reviews of ROV incidents, some have been reported by the International Marine Contractors Association (IMCA). There have been isolated incidents involving the failure of cables used to control/support ROVs, and inadequate formal methods for risk assessments have been identified in connection with the use of ROVs.

Based on the limited experience that has been gained concerning autonomous/automated ships, it is too early to identify experience that can be transferred. Lessons learned include:

- Define operating areas in order to minimise risks and develop and adapt infrastructure to autonomous operations
- Plans must be drawn up to take account of the fact that autonomous systems can fail, to ensure that control rooms or operators are in place who can intervene when the unexpected happens
- For operation, appropriate alarms and good HMI should be established to contribute to better situational awareness
- Establish systems for data reporting and the learning of lessons from new incidents
- Risks must be assessed and managed when it could take some time for human operators to intervene. Examples include grounding, fire and collisions,

3.2.4 Autonomy within the aviation industry – manned aviation and remotely controlled drones

Manned with automated functions

The level of automation in aviation is high, and today's pilots are supported by many automated functions. "Ordinary" aviation has an extremely high level of safety, and passenger transport by aircraft is the safest mode of transport. Airlines belonging to the International Air Transport Association (IATA) suffered no accidents ("hull losses") in either 2012 or 2017. Automation within aviation has been implemented gradually with the support of systematic research relating to HF, and must be described as being successful from a safety perspective.

The high level of safety is the result of well-developed infrastructure, systematic data reporting, control centres, standardised aircraft, comprehensive regulations, the prioritisation of HF methods, thorough testing and certification, systematic training and the learning of lessons following accidents. However, there is still a need for human intervention, and challenges have been encountered establishing situational awareness in connection with non-conformities when pilots have been "out of the loop" and then had to get back in again.

Unmanned – Unmanned Aircraft Systems (USA) – control from control centres

UAS have been in operational use for surveillance purposes since 1970. Data has been collected from large (industrial) drones via the Department of Defense (DoD). Analyses of collected data from Waraich et al. (2013) and Hobbes et al. (2014) show:

- **The accident rate is approximately 100 times higher with UAS than with piloted aircraft**, approximately 50-100 UAS incidents per 100,000 flying hours, compared with approximately one incident involving a piloted aircraft per 100,000 flying hours. The most important root cause of these accidents is poor design of control systems and the Human Machine Interface (HMI) due to an inadequate knowledge of HF.
- **The failure rate with UAS is approximately 100 times greater than that with “ordinary” aircraft.** The failure rate - expressed as the "Mean Time Between Failures" - has been high at 1,000 hours - compared with approximately 100,000 hours for piloted aircraft, i.e. the failure rate is significantly worse for drones; Petritoli et al. (2017).

Security is immature as regards UAS. Surveys of accidents and incidents have been carried out (Valente, 2017; Altawy et al., 2016). One possibility is that other operators could take over control of a remotely controlled drone and cause it to land or crash and be destroyed. There is a low threshold for taking over data communication, which would enable data sent between the drone and the operator to be accessed. Because UAS are controlled remotely, they could be used to damage production equipment by crashing or carrying explosives (or the fitting of flamethrowers, which is additional equipment for some drones) without any additional risk for the drone operator. The attack on Saudi Arabia in 2019 resulted in global oil production being cut by 5% for two weeks, Saudi Arabia (2019), Singh (2019).

Regular air traffic has also been disrupted by drones/UAS. A frequently cited example is the incident at Gatwick Airport on 19-21 December 2018. During this period, air traffic was disrupted by drones operating near the airport. More than 140,000 passengers and over 1,000 flights were affected (Gatwick, 2018). The increasing use of drones and autonomous solutions means that the thresholds for intentional incidents is becoming lower and increases the need for evaluations and greater security around vulnerable infrastructure, such as oil and gas installations and airports.

Experiences that can be transferred to other areas are as follows:

- safety levels have become extremely high as a result of the gradual introduction of automation. The number of personnel has been reduced, but pilots have been given a key role in dealing with unexpected and complex events.
- prioritisation of HF
- well-developed infrastructure with control centres staffed 24 hours a day, 7 days a week
- systematic data reporting
- comprehensive regulations prioritising thorough testing and certification
- systematic training and learning following accidents.

3.3 Autonomous solutions in offshore drilling and wells

Extensive use is made in the drilling sector of land-based operations centres which control activities linked to drilling operations to varying degrees. Advanced tools are used to control equipment from operations centres situated at great distances way from the rig. Over the past few decades, more and more sophisticated solutions for automated drilling and handling of drilling equipment have been introduced, gradually transforming traditional tasks from the manual operation of machinery to computer-based solutions (Ciavarelli, 2016). There are many reasons why drilling is a particularly suitable area for the development and use of automated solutions (Godhavn, 2011):

- Automation enables drilling of more challenging wells and in formations where drilling has not previously been possible.
- Drilling has the potential (in relation to efficiency improvements) for greater robotisation and automation because it is modernised to varying degrees compared with other industries.
- Drilling involves the use of heavy machinery to handle drill pipe and other equipment. With the increased use of robotics and remote control, humans can be removed from exposure to hazardous situations.
- Drilling always involves a certain level of risk and errors/accidents can have enormous consequences for humans, the environment and the organisations and equipment involved. With the increased use of robotics and remote control, humans can be removed from exposure to hazardous situations caused by such incidents.

Based on Godhavn (2011), automated solutions for drilling can be roughly divided into the following areas, with each area having varying degrees of autonomy, which are considered in the following:

1) Offline models
2) Data infrastructure and quality assurance
3) Handling of machinery
4) Higher level of automation
5) Automated drilling
6) Automated drilling mud handling
7) Automated well control

3.3.1 Offline models

Drilling is a complex operation where the use of models is widespread. Models are used to simulate all or certain aspects of the equipment and process. These models can be used offline for testing equipment and processes, for planning and training purposes ahead of an operation or before the next stage in an operation. Examples of use include the selection of drilling mud properties or the drawing up of plans concerning how a well should be drilled.

One challenge with the use of models is that they simplify reality. A model will never be able to fully reflect reality, and it is difficult to ensure that all parameters are taken into account. Even for accurate and complex models with good parameter adaptation, changes in operating conditions and the actual conditions existing during the drilling process itself will lead to inaccuracies in the model. Such adaptations are often not adequately taken into account during use. There will also always be a trade-off between the complexity of the model on the one hand, and the requirements regarding performance on the other. It is therefore important to involve users with a detailed knowledge of the processes that are to be modelled throughout the development process, and to ensure that the models are tested before being taken into use. This should be addressed through user-centred development [T2].

3.3.2 Data infrastructure and quality assurance

Utilising automated drilling solutions will place greater demands on the use of sensors, data quality, reliability and data communication (Godhavn, 2011). Data is often stored by parties which offer a range of services, such as directional drilling, mud and fluidhandling, cementing, downhole tool handling and sometimes other services such as MPD *(managed pressurised drilling)* and circulation systems. This presents challenges regarding joint access to, and the quality assurance of, data, which has also led operators to set up initiatives to address the problems using integrated platforms.

Sensors are supplied by different suppliers, and the data from these sensors must undergo quality assurance and be compiled in an appropriate manner so that trust in the data can be built up. It must also be ensured that data characteristics such as integrity, completeness, consistency, availability, punctuality, etc. are safeguarded to ensure that systems are operated safely (Data Safety Guidance Version 3.2, 2020). Delays in time and space between tools in the well and models represent one of the most challenging aspects of automated drilling, according to (Sugiura 2015). With low bandwidth, using models in real time (e.g. for transferring data from the drill bit up to the surface) is challenging. Developments are now under way aimed at introducing and commercialising *"wired pipe",* which will provide real-time data from the well during drilling, Equinor (2018). This could solve some of the challenges associated with time delay and low bandwidth.

The introduction of technologies such as 5G can present greater opportunities for data collection from many components, which can provide more support for monitoring, optimisation and remote operation. As the world becomes digitalised and is made "smarter", greater demands are placed on data infrastructure. Large quantities of data lead to a need for efficient access and acceptable response times. Data must be distributed and shared not only between the installation and any onshore operations centres, but also between a complex ecosystem of contributing engineering companies, equipment and drilling mud suppliers, drilling and maintenance firms and consultants. Data sharing presents new challenges relating to ensuring data security both between the parties involved and between OT and IT systems. This sharing requires safety analyses to have been carried out and good systems and procedures to be established which address security and safety between all the parties involved in the ecosystem as described. This integration of systems must be handled through technical, organisational and HF measures as outlined in [T3c].

3.3.3 Handling of machinery

Drilling involves the use of heavy machinery for handling pipes and tubular components. Developments have come a long way with regards the robotisation of drill floor, which now have both semi-automated and fully automated systems for pipe handling. Several robots are often used in such systems, e.g. drill floor robots for moving pipes and equipment around on deck, pipe handlers to assemble pipes, *iron roughnecks* for threaded connections and elevators for raising and lowering pipes. The equipment that is handled is heavy and large forces are involved at times, and remote control and automation enable the need for personnel to be present on drill floor to be largely eliminated, which in turn helps to improve safety. However, there are still certain complex operations where manual work is required, such as repairs and the moving of smaller components. Exacting demands are imposed on the synchronisation of machinery, in terms of both speed and placement, and the opening and closing of end tools, and this can be a challenge to predict and program for every possible situation. According to Flemisch (2012), it is important that automation is focussed on achieving the most effective balance between humans and machines. In such an environment involving the use of heavy machinery, there will be much to gain from physically removing humans from the process, given that remote control can be handled safely and efficiently.

With a greater degree of remote control, more control takes place via screens rather than physical monitoring. In some cases, plans are being drawn up to relocate the drillers cabin away from the drill floor. This makes it important to have systems in place which provide a good overview – and ensure that operators can maintain an overview of the process when looking only at monitors. With a higher level of automation, as outlined with the LOA, drillers may be given a role which involves more monitoring than active management. (I.e. strategic monitoring and the confirmation of sequences of operations.) This can present challenges linked to sense of ownership and knowledge of the process. In the event of an incident where the system fails and a driller has to intervene, either in order to correct errors or to start the process manually, it can be problematic if the driller does not possess the necessary competence or understand what is required. This will particularly be a problem in the case of systems which have worked well over a prolonged period of time, with the result that operators come to trust the system so blindly that they do not see any need to understand the underlying processes or have any training in doing the job manually. It is therefore important that users are involved in development [T2], and that the systems are designed to address the need for meaningful human control [T3].

3.3.4 Higher level of automation

The subsequent discussion and description of the example projects (Cases 1 and 2 in the section on "Collated experiences") illustrates how remote control and automation of certain aspects of the drilling process are being used. This gives an indication of what key parties see as being realistic in the relatively short term. A detailed analysis of whether fully automated drilling operations are possible from a technical, safety and economic perspective falls <u>outside the scope of this report.</u> We do not see any specific technical obstacles to achieving this, but increasing complexity and vulnerability will present challenges that require ongoing learning, and users/operators must be included. Sufficient time must be set aside, and a step-by-step process must be followed towards this end. We also believe it will be necessary to both further develop and upgrade hardware, algorithms, sensors and data transfer systems. The details will depend on the situation, but we anticipate that automation will require more accurate and reliable measurements of what is happening down the well, particularly as regards more challenging wells, with a combination of better data quality and better algorithms for handling the remaining deficiencies in data quality. We have therefore proposed further work in this area, [V7].

3.3.5 Automated drilling

Offline models can be used in real time during operation, with a direct link to the control systems that are controlling or monitoring the drilling operation. One example is automated directional drilling, where non-vertical wells are drilled. This involves drilling along a planned trajectory towards a specific destination. This entails the use of solutions that involve advanced models, where angles are computed and sent down to a local regulator, which uses feedback from sensors to achieve the desired trajectoy (Matheus and Naganathan, 2010). There are also many other examples of technologies which contribute to automated drilling, including the automatic optimisation of drilling parameters such as Weight On Bit (WOB), Rate Of Penetration (ROP) and vibrations which interfere with the drilling process (Nystad, 2020). Other systems focus on avoiding jerky fluctuations in torque and torsional drill string vibrations based on measurements of drill string rotation and torque (Kyllingstad, 2010). Automatic MPD (managed pressurised drilling) and DG (dual gradient drilling) are systems that enable faster and more accurate regulation of the bottom hole pressure (Godhavn, 2011). Drilltronics (Florence and Iversen, 2010) and eControl (Rommetveit et. al., 2010) are examples of commercially available products, where advanced computer models are used to monitor and, in some cases, control drilling equipment. In addition to assisting drillers with decision-making, many tasks can be performed automatically, e.g. passive protection of barriers and safeguards concerning limitations for wells, equipment and process, as well as the active management of machinery.

As mentioned previously, autonomous systems are intelligent facilities that can perform tasks without human intervention. The system then knows its "abilities" and its "state". The system can choose between a set of alternative actions and perform them in accordance with the applicable rules. In order for this to be possible, the system relies on access to a realistic model of the current state of the process and its own behaviour in an interaction with the outside world, often referred to as a "Digital twin" (Rosen, 2015). The phrase "Digital twin" was made widely known by NASA (NASA, 2012) and was defined as follows:

In the case of drilling systems, more data concerning the physical characteristics will be connected, in addition to the advanced mathematical models that are used. Such a real-time system will provide a better understanding of what is happening in the process at all times, which will both contribute to earlier and more reliable detection of hazardous events and enable the operation to be controlled more optimally in order to achieve the goal more quickly. Earlier and more reliable detection stems from the fact that the system itself helps out with the interpretation and understanding of measurements, and that automated operations are performed in exactly the same way each time a sequence is repeated, thus making it much easier to detect non-conformities.

One development which has implications for the use of models is that this can contribute to the relocation of functions to onshore operations centres. This requires systems on the rig to be sufficiently robust and remotely controlled to render the presence of experts on the rig unnecessary. In this regard, operations centres at a number of physical locations may also be used, with some operators being responsible for modelling and parameterisation, others for planning, and others still for operation. This will lead to changes in roles and responsibilities for the parties involved in the event of new technology being introduced, and this could impact on the quality of the processes.

A digital twin is a dynamic concept that often increases in complexity throughout its life-cycle. The models must have as much robustness and flexibility as the system that is modelled. It must for example be developed as the operational system is developed. It must have the ability to deal with errors in input data and adapt to real observations. Like a real system, it can lead to a lack of insight and understanding of the system, which in turn can lead to errors and incidents, particularly in situations where an autonomous system has to be overridden. It is a known issue that automated systems are inferior at dealing with unexpected events compared with experienced operators. With a high degree of automation, human operators receive less training and gain less experience in operating without the automation. These considerations require a step-by-step, robust implementation process, where it is ensured at every step that the automatic systems can cope with unexpected situations satisfactorily, [T2].

3.3.6 Automated drilling mud handling

The drilling mud system consists of equipment on board which contributes to the storage, mixing, circulation and treatment of drilling mud. Drilling mud management has traditionally been a manual process involving two to four people, with some assistance from machinery. With a manual process, operators are exposed to chemicals and other hazards, and the precision of the mixing process is often poorer than in the case of automated systems. Tests on automated solutions, including tests performed at Valhall WIP (Water Injection Platform), have shown promising results in terms of improved working environment for the operators involved, efficient mixing, reduced emissions to the environment and cost savings. Valhall WIP is a ‘category 3’ drilling mud handling system, where the entire mud handling process is automated with minimal human monitoring. By way of comparison, category 1 is an entirely manual system, while category 2 is monitored from a control room or an operator’s station (Gunnerod et al., 2009).

3.3.7 Automated well control

The aim of well control is to maintain an overview and control over unexpected inflows of hydrocarbons into the well, which in the worst case could result in high pressures and blowouts. Loss of well control can cause catastrophic damage to equipment and serious injuries to personnel.

Well control includes the monitoring of uncontrolled inflow to the well bore the well and procedures for preventing and managing such incidents (Godhavn et al., 2011). By comparing flow and pressure measurements with calculations from hydraulic models of the well without inflows or drilling mud loss, such incidents can be detected at an earlier stage compared with detection based entirely on drilling pit level and mud return flow measurements. This approach enables action to be taken sooner, potentially reducing the consequences. Detection can be achieved through the direct observation of trends of actual measurements against values predicted by models. This can be done by drillers, support personnel or automatically via detection software based on the model.

These are complex systems that can fail if HF is not taken into account during development (Ciavarelli, 2016). Overconfidence that systems can deal with any situation can also lead to problems. In the event of an incident where systems drop out or do not function as intended, the system may not be able to provide the necessary support, and personnel may lack the training needed to take over and operate the systems manually. The development of such systems therefore requires us to prioritise human-centred design when such systems are introduced, via user-centred development [T2] and ensure that principles such as "meaningful human control" are applied, [T3].

3.4 Summary of literature and experience concerning automated solutions

Drilling is a promising area both for better data utilisation and the use of robots on drill floor to handle heavy and hazardous operations. Automation can contribute to better utilisation of petroleum resources by enabling the drilling of challenging wells as well as drilling in formations where drilling has not previously been possible. It can also lead to more efficient drilling and provide support for the earlier detection of failure events through the technical solutions in the drilling process. However, it is important to strike a realistic balance between technology and user-centred development, as humans are expected to remain part of these systems for many more years to come. For example, the accepted view amongst experts is that fully autonomous cars cannot realistically be expected within a time frame of ten years (through to 2030) (Wozniak, 2019; CNBC, 2019). This is supported by literature reviews, which note that there are challenges associated with reliability in unstructured environments (Johnsen & Kilskar, 2020).

Human-centred development, with methods which, at an early stage, identify challenges that can arise during drilling operations, i.e. in design and development, must be used. In order to maintain human interaction with the system and allow meaningful human control, experts in human factors should be involved in projects throughout the implementation process and user participation must be ensured from the start, which requires an understanding of HF [T1] and user-centring [T2]. Aviation is an area with a high level of safety and has led the way in the development of the discipline of HF, with a holistic MTO approach. The sector has established the practice and use of methods from situational analysis (SA), control of automated systems and holistic training.

Furthermore, the introduction of autonomous road transport has provided important experience to be gained to help in understanding the challenges associated with the introduction of autonomous solutions, one example being that existing sensors do not provide adequate management information concerning complex and demanding operations. Moreover, in connection with the automation of drilling and well systems, more stringent requirements regarding data quality, reliability and data communication for sensors will be necessary. Sensors are supplied by different suppliers, and the data from these sensors must undergo quality assurance and be compiled in an appropriate manner so that trust in the data can be built up. In addition, sensors and systems that support autonomous operations can also fail, so it is important to analyse the need for resilience/robustness, i.e. to have the capability of managing non-conformities and switching to a safe state when humans are unable to intervene [T3b].

The automation of drilling operations which leads to changes in duties from an active role to more of a monitoring role can contribute to reduced situational awareness (*out-of-the-loop*). In addition, autonomous systems that use digital twins,for example, can increase in complexity throughout their life-cycle. This can lead to a lack of insight and understanding of the system, which in turn can lead to errors and incidents, particularly in situations where an autonomous system has to be overridden. It is therefore essential that users are at the heart of the development of these systems, something that the aviation sector has had good experience of. In this industry, automation has also been introduced gradually, and there is a strong regulatory framework which focuses on thorough testing, verification and validation. User-centring also leads to better user experiences and user satisfaction, (Vredenburg et al. 2002), and in many cases higher productivity (Beuscart-Zéphir, 2007; Sethi,2008) [T2].

The possibility of reduced situational awareness following the introduction of automated systems also impacts on the approach that must be followed during development, as it is essential to ensure that the systems (e.g. HMI) present the information that is needed for decision-making purposes at all times. Clear information concerning the state of the system and support for the transition between automatic and manual control will then be key factors in ensuring safety, something that requires a high-quality human-machine interface. In addition, the presentation of automated systems must be transparent to facilitate a good understanding of the process and enable future actions to be predicted. This can be addressed by applying the principle of meaningful human control [T3].

Another development that has implications for changes in roles and responsibilities following the introduction of more automated systems and models in drilling operations is that some functions can be transferred from the rig to an onshore operations centre. This requires automatic systems on the rig to be sufficiently robust and reliable, and to be remotely controlled in order to render the presence of experts on the rig unnecessary. As a result, automated systems cannot be viewed in isolation and must be supported by infrastructure, interaction with control centres and other parties (drones or other facilities), so that they get help in managing themselves [T3a]. A more distributed allocation of tasks between control functions must also be ensured through an analysis of task delegation during the development process, as well as through procedures and training. When using distributed operations and different suppliers, it is therefore important not to focus solely on the technological systems, but also to follow up the introduction of autonomous systems with organisational steps [T3c].

From the autonomous road transport and aviation sectors, we have also seen the necessity of ongoing data entry and analyses of rich data from operations, to enable an assessment of what works and obtain a sound basis for analysing accidents and incidents. Data collection should include different types of data (including video-recordings) that can be compiled to provide a comprehensive picture of events [T4].

Autonomous systems thus consist of technology (drones, infrastructure), organisation (with risk assessments, procedures and responsibilities) and humans (who must have knowledge and be placed in a situation where they can perform meaningful human control). Delimitations will then be particularly important in order to facilitate the safe use of autonomous solutions, such as clarity as regards what systems can be used for and what constitutes a safe operating area (ODD - Operational Design Domain); see Table 3.1. ODD is therefore key to safe operation(Berman, 2019) and must be designed so as to minimise the risk of accidents and incidents. This includes analysing which systems and tasks can be satisfactorily automated, and ensuring that protection is provided against accidents and incidents, e.g. via barriers. This is of relevance to the development of automated drilling operations, where certain aspects of the process can often be automated, e.g. the partial robotisation of drill floor and the introduction of semi-automated management systems.

Table 3.1 links the various levels of automation with ODD.

- For level 1 with no automation, the need for delimitation (ODD), infrastructure support and support from HMI/Alarms will remain unchanged.
- For levels 2, 3 and 4, it will be necessary to consider delimitation (ODD), support from infrastructure and support from HMI/alarms, where the automation takes over and assesses what needs to be done in the transition between the automation and the human, and what to do in the event of failure.
- For level 5 with autonomous systems, ODD is important in line with support from infrastructure. Here, it is assumed that it will be possible to switch to a safe state in event of failure. Alarms and control must be assessed separately, because there may only be a control centre at overarching level (e.g. from existing overarching traffic control centres/emergency response centres) where emergency response/assistance will be necessary in the event of a collision/failure/fire or other accident or incident.

Table 3.1: Level of autonomy and need for support from ODD, Infrastructure and HMI/Alarms

Level-Autonomy	Operator	System	ODD	Infras.	HMI
1-No autonomy	All operations	Warns, protects	As before	As before	As before
2-Limited support	Controls (In-the-loop)	Guides, supports	Assess	Assess	Assess
3-Tactical, monitors	Involved – continually monitors "On-the loop"	Controls within well-defined boundaries	Increased	Increased	Increased
4-Automated support Strategic	"Out-of-loop" interruption-determined, prompted by the system	Operates independently, but can hand back control	Increased+	Increased +	Increased+
5-Autonomous	Fully "out-of-loop"	Operates independently – switches to safe state itself	Increased++	Increased ++	New-Non-conformity

4 Review of investigation reports regarding methods and findings for drilling and wells

We have reviewed nine investigation reports where we assessed autonomy and HF in order collate experiences relating to: 1) investigation methods, and 2) root causes and proposed measures. For each of the investigations, we assessed whether the investigation was sufficiently broad, i.e. whether it looked at the interaction between human, technical and organisational factors. A particular focus was placed on assessing whether HF was included and whether the investigation assessed causes stemming from the design stage. The investigation reports were selected in cooperation with the PSA. Each event is summarised over two pages.

Due to the greater maturity and level of experience, we also looked at investigations with a high level of automation from areas other than petroleum. Incidents involving autonomous and automated systems from other industries may be of relevance to drilling and wells as regards both investigative methods and findings. The review will therefore consider reports from aviation (with automated control and safety systems), shipping (with highly automated systems, such as dynamic positioning, bridge systems,) road transport (automated vehicles), along with incidents from the petroleum sector (drilling and wells). By way of conclusion, we have summarised key findings from all the reviews.

The following incidents were reviewed with the theme of automation and HF:

1. Boeing 737 Max crashed (Endsley, 2019), (NTSB, 2019), (ECAA, 2019).
2. PSV Sjoborg and SFA, collision between ship and platform - Equinor (2019, 2019a).
3. KNM Helge Ingstad collision (AIBN, 2019), look at investigative methods and systems
4. DP operations (Dong, Vinnem & Utne, 2017), look at systems and alarms
5. Road traffic accident involving Tesla (Joshua Brown) in the USA – NTSB (2017)

The following events were reviewed with the theme of drilling & wells and HF:

6. West Hercules - ADS Barents, (PSA, 2019)
7. Macondo Blowout (US-CSB, 2016) and (Tinmannsvik et al., 2011)
8. Pryor Trust – Blowout (US-CSB, 2019)
9. Mærsk Gallant – Well control event (Mærsk Drilling, 2015)

The following themes and factors are described in connection with the reviews:

- **Description** of each incident, the time at which it occurred, along with the immediate consequences and potential of the incident.
- **Mandate and use of methods in the investigation**, such as who investigated the incident, whether it was an internal investigation, or whether it was carried out by an external party and examined whether quality could have been affected by the way in which the investigations were organised. This may have had an impact on whether the investigations led to an understanding of the situational awareness amongst the parties involved. This understanding could be key to identifying organisational and technical measures.
- **Causes linked to automation and HF**, where we look at the underlying causes (such as design). Could the methods used in the investigations determine whether human factors were adequately addressed during the development phase of the systems involved in the accidents?
- **Discussion and lessons** based on mandate and causes

4.1 Boeing 737 Max

Description of the sequence of events

The enclosed description is based on Endsley (2019) "Testimony to Congress", and a review of the accident reports from the two fatal incidents involving the newly developed Boeing 737 Max aircraft, (NTSC, 2019 and ECAA, 2019). In October 2018, Lion Air Flight 610 crashed into the sea off the coast of Indonesia shortly after takeoff. All 189 people on board were killed. In March 2019, Ethiopian Airlines Flight 302 crashed after taking off from Addis Ababa, killing all 157 people on board. The investigators responsible for investigating the accidents involving the Boeing 737 Max aircraft identified faults in the control system as the source of the accidents. The Manoeuvring Characteristics Augmentation System (MCAS) was a new, automated control system fitted to the Boeing 737 Max which caused the aircraft to place itself in a dive in order to build up speed and avoid a stall. This manoeuvre (the dive) was caused by faults or misinterpretations from sensors. On the Boeing 737 Max aircraft, the MCAS system was activated by a signal from only one Angle of Attack (AOA) sensor, while in other aircraft (e.g. the U.S. Air Force KC-46), signals from two independent sensors are compared. In addition, the system was set up to make continuous corrections, rather than make a single adjustment on each occasion, as used on the U.S. Air Force aircraft. For the Boeing 737 Max aircraft, this resulted in repeated corrections based on erroneous information from sensors without the pilot being able to intervene manually.

Mandate and use of methods in the investigation

Investigations have been carried out by a number of organisations, including the Indonesian National Transportation Safety Committee (NTSC), the Ethiopian Civil Aviation Authority (ECAA) and the National Transportation Safety Board of the United States (NTSB). The ECAA's accident report identified "design" flaws, while NTSC and NTSB looked more at the overall picture. HF experts were involved in the investigations.

Causes linked to automation and HF

NTSC (2019) identified flaws in the design of new, more powerful engines which meant that the aircraft could stall, along with errors in the design of the control systems (MCAS). Certification, maintenance routines and the actions of the pilots on board were also described as contributory factors. ECAA (2019) pointed to flaws in the design of the MCAS software on the aircraft, and as an important lesson to be learned, the following was noted: *"The regulator shall confirm that all probable causes of failure have been considered during functional hazard assessment".* The NTSB (2019) pointed out that faults in the systems led to a large number of alarms and notifications, which confused the pilots on board. Key needs identified by NTSB (2019) linked to design and human factors are:

In order for the aircraft to be re-certified, the system had to be redesigned and pilots had to undergo simulator training. Similar conclusions can also be found in the Endsley (2019) review of the two accidents at a congressional hearing in the United States, where Endsley noted the following:

- A focus must be placed on the use of HF standards and methods which include systematic task analysis with the involvement of users during development and evaluations, etc.
- Need for expertise concerning HF during the development and use of HF methods during the design process.
- Need for user testing with relevant assessment of human performance, and certification.

Discussion and lessons
The accident reports present a broad and complex picture of the events that unfolded. The reports identify several layers of causes of the accidents, highlighting the importance of appointing an investigation group with a wide range of expertise. The design of the systems was not sufficiently adapted to meet the needs of users, and the flawed design of control systems and software (MCAS) led to pilots finding it difficult to act correctly in any given safety-critical situation. An attempt was made to simulate the accident retrospectively, but even in a simulator (when the cause was known), the aircraft lost 8,000 feet in altitude before the pilots were able to regain control of the aircraft. In other words, the expected action by the pilots would not have prevented the accident from occurring at altitudes of below 8,000 feet. This shows the importance of having a design that are based on meaningful human control and the systematic testing and certification of new solutions. The accident also demonstrates the importance of systematic training and simulator-based training of critical scenarios in connection with automation.

Three key points from the investigation:
- The importance of breadth in the investigation, particularly the inclusion of HF experts who can identify deviations from good practice and assess design [T5]
- Weaknesses in the design of the control system – it was not sufficiently adapted to the needs of the users/pilots in critical situations and did not follow recognised standards [T2], [T3]
- The importance of certification, training and testing of critical scenarios based on knowledge of human limitations [T3]

4.2 PSV Sjoborg and Statfjord A (collision between ship and platform due to DP position loss)

The enclosed description of events is based on Equinor (2019) and Equinor (2019a).

Description of the incident
At 01.50 on Friday 7 June 2019, the supply ship Sjoborg lost its DP position during a loading operation in Statfjord A and collided with the installation's drill shaft south and lifeboat structure. More than 20 DP alarms were received within 45 minutes of the incident, overwhelming the recipients. Statfjord A was undergoing a turnaround maintenance and had 276 people on board. Damage to the lifeboat station resulted in 218 people being evacuated to surrounding installations by helicopter. The incident delayed the start-up of Statfjord A by 17 days. No one was injured during the incident, but a sailor on Sjoborg was hit by a loading hose when the wire to which the hose was attached failed, and the hose went overboard. If another part of the hose, such as the connector or weak-link, had hit the sailor, the incident could have had fatal consequences.

Mandate and use of methods in the investigation
The primary aim of the investigation was to contribute to a constructive learning effect in order to prevent recurrences and improve HSE levels. The investigation team's mandate was to:
- Ascertain the sequence of events and the background to the events
- Identify triggering and underlying causes, as well as causes linked to learning and management
- Identify deviations from governing documentation
- Identify barriers that failed or were inadequate, as well as barriers that worked

- Assess notification and emergency response factors
- Assess the overall potential of the incident
- Check for similar incidents/circumstances and the transfer of experience from such incidents/circumstances
- Make recommendations and propose action relating to the incident/circumstances

In its work, the investigation team adopted a system-oriented approach. This meant that the investigation would not necessarily identify individual errors as causes, but focus on systematic factors where they existed instead. Examples of this include circumstances that allowed a series of technical faults to occur, the basis for erroneous decisions during operation, design factors, operational practices or organisational circumstances.

Causes linked to automation and HF

After reviewing the accident report (Equinor, 2019) and presentations (Equinor, 2019a), we highlight the following factors:

- Insufficient quality in system integration probably contributed to the fact that the crew on the bridge and in the machine control room were in an unclear situation. The system integrator had overall responsibility for the coordination and integration of different systems so that these worked together as a single DP system.
- Prior to this incident, a relatively large number of alarms were received in a relatively short period of time (20 DP alarms within 45 minutes). Some alarms also disappeared, and some alarm messages did not provide a comprehensive description of the problem. Overall, it was considered to be challenging for the crew to understand the consequences of the alarms and the resultant need for any action.
- The alarms were not perceived to be sufficiently serious to interrupt the operation. The lack of experience of abnormal situations amongst the crew, combined with the fact that a critical alarm had not been passed on to the crew on the bridge and in the engine control room, may have contributed to this. The responsibility and understanding of roles were not highlighted – the responsibility for DP lay with the captain/mate on the bridge. A definite need to raise the level of knowledge concerning HF linked to alarms and alarm management was identified, along with a need for systematic training in order to understand existing alarms.

Discussion and lessons

Although the investigation had a broad system-oriented approach, explicit links were not traced back to the design phase in this investigation. However, it seems clear that there were deviations in relation to the design of alarm philosophy. Alarm standards such as EEMUA 191 specify that the maximum number of serious alarms that can be dealt with is six alarms per hour, not 20 within 45 minutes, as in this case. The poor alarm system and associated alarms meant that the quality, quantity and frequency of alarms provided an unclear picture of the situation prior to the collision. Since insufficient training had been provided concerning the alarm systems and alarm management, the operators were faced with a challenging situational picture.

Similarly, system integration and system testing of the entire system is a key aspect of the design work, an area where the maritime industry is often weak (Danielsen et al., 2019). During the commissioning phase, it is normal for the shipyard to perform this role, with the shipping company taking over the role during the operational phase. The importance of the system integrator throughout the lifetime of the vessel is underlined by the fact that modern DP vessels are built with a relatively large number of complex software-based systems. System integration must be followed up and tested as systems change and are maintained. Inadequate holistic integration of many systems meant that the crew on the bridge and in the engine control room were facing an unclear situation, which became difficult to manage.

Three key points from the investigation:

- The investigation was carried out based on a system-oriented approach in the work, with an assessment of technical circumstances, decisions, practices, and operational and organisational factors. This should be an approach to investigations that should be suitable for drilling and wells
- During the development of the systems on Sjoborg, insufficient attention was given to the holistic integration of the systems. There was also a lack of life-cycle thinking in relation to software updates and system integration. One essential measure is to coordinate information from important systems [T3c]
- The alarms were poorly designed and subsequent training was inadequate [T3]

4.3 KNM Helge Ingstad

Description of the incident

The frigate Helge Ingstad (HI) and the tanker Sola TS collided in Hjeltefjorden at 04:01:15 on 8 November 2018. There were seven people on the bridge of Helge Ingstad that night. The responsible officer of the watch (OOW) had taken over responsibility at 03:56, shortly before the collision. The tanker Sola TS had four people on the bridge, including the pilot. Sola TS left the terminal at Sture at 03:36. The traffic on Hjeltefjorden was being monitored at the time by Fedje Vessel Traffic Service (VTS) Centre. Three other ships were near the Helge Ingstad and Sola TS, so the traffic picture was complex. No serious injuries occurred as a result of the accident, but the frigate sank and was later condemned. The frigate originally cost NOK 4,000 million, and the cost of procuring a new ship has been estimated at NOK 11,000 million. The cost of salvage and removal is not included.

Mandate and use of methods in the investigation

The investigation was conducted by Accident Investigation Board Norway, the public investigation commission in Norway, which published the first part of its investigation report in 2019 (AIBN, 2019). The members of the investigation group possessed a wide range of expertise, including expertise within HF, and themes such as safety culture, situational awareness and cognitive and organisational challenges were discussed in the report. The aim was firstly to identify the causes of the incident and how the parties involved understood the situation as it developed, and secondly to identify proposed measures without focussing on personal blame. We have reviewed the report with key parties in the Accident Investigation Board Norway and in the Royal Norwegian Navy.

Causes linked to automation and HF

The accident was influenced by the systems on the bridge that the vessels used (electronic charts, radar, VHF radio) and human factors. The timing of the incident (in the middle of the night, just after a shift changeover) and the situational awareness of those involved had a decisive impact on the outcome. The following key factors are considered to have influenced the accident:

- Poor analysis and design of the bridge based on task analysis (i.e. Human Factors-based design standards)

- Poor design of the bridge and control systems. The person responsible on the bridge (OOW) could not see his own position on charts (ECDIS)/radar while using VHF. VHF was installed retrospectively on the Helge Ingstad (as an update) without the involvement of experienced naval officers as users. The design of the VHF system was altered on one of the ships, with an experienced user present on the bridge when the update was carried out. During the update, the VHF system was repositioned close to the ECDIS/Radar system, so that the responsible officer could see his own position while communicating via VHF. There are a total of five vessels in the same class.
- The time of the accident, 04:01 at night (five minutes after the shift changeover) was demanding because it occurred at night at a time when there was a lot of traffic around. (There were three oncoming vessels on the port side)
- Poor analysis of the workload of the officers on the bridge, with many alarms being triggered (which resulted in training being carried out alongside challenging navigation at night)
- A high mental workload on the Helge Ingstad leading up the accident, with eight alarms during the final ten minutes leading up to the accident, combined with heavy traffic. The alarms were linked to three vessels on the port side. (Sola TS came from starboard side)
- High noise levels on the bridge, not in accordance with recommended ergonomic standards, which made it difficult to achieve a common situational awareness
- It was difficult to observe the vessel they collided with because the bow of the Sola TS, when viewed from the bridge looking forward (as much as 200 metres away), was in darkness and not illuminated by floodlights. It was also noted that three out of the seven officers on the bridge had a good/adequate view
- The Sola TS did not notice that it had cast off in the ECDIS system until some time after it left the pier, which meant that the ECDIS system on the Helge Ingstad had inaccurate information at times and indicated the Sola TS as an object that was still in port
- Poor critical intervention from Fedje Vessel Traffice Service Centre in order to update the situational awareness of all the parties involved and a lack of clarity regarding emergency procedures

Discussion and lessons

Many aspects relating to HF and design were uncovered during the investigation of the Helge Ingstad accident. The investigation team had a broad composition and adopted a system perspective. This accident was not directly linked to automated control, but relevant weaknesses can be seen in the advanced technological support systems that contributed to the accident. When reviewing many shipping accidents, we have observed that the quality of bridge control systems has been less than optimal and, amongst other things, that the design and use of electronic chart systems (ECDIS) led to a number of accidents (Johnsen et al., 2019). The design of the bridge systems was not adequately adapted to the needs of users, presumably due to a lack of analysis and design of the bridge (control room). As a result, the location and design of electronic charts (ECDIS) and radar was not appropriate in relation to the VHF system. Excessively high “noise levels" on the bridge hampered communication, and an inappropriate alarm philosophy and the design of alarm systems on the bridge led to a large number of distracting alarms immediately before the accident. The lack of interaction between Helge Ingstad, Sola TS and Fedje Vessel Traffic Service Centre regarding the emergency situation/procedures due to darkness and uncertainty over observations/circumstances were also contributory factors in the incident not being managed satisfactorily.

Three key points from the investigation:

- The investigation covered a broad range of disciplines, as the situational awareness of the parties involved was thoroughly reviewed and tested, documented best practices [T5]
- Weaknesses in the design of the bridge and the working environment (noise, location and quality of equipment, many alarms). Together with the workload of the parties involved in safety-critical operations, this led to fragmented interaction and poor understanding on the Helge Ingstad, which should have been addressed via better user-centred design [T2] and more attention being paid to systems that support meaningful human control [T3]
- A lack of understanding of roles, the unclear delegation of responsibility and poor provision for a common situational awareness during the emergency resulted in inadequate interventions between the parties involved, which should be addressed through better integration of key systems and better organisational cooperation [T3c]

4.4 Nine DP incidents

The scientific article "Improving safety of DP operations: learning from accidents and incidents during offshore loading operations" by Dong et al. (2017) describes the causes of nine Dynamic Positioning (DP)-related accidents that occurred between 2000 and 2011. The nine accidents are linked to collision and "drift-off" incidents and have been reported to the Petroleum Safety Authority Norway.

A drift-off incident is an event that can be categorised as a "loss of position", where the vessel is pushed away from its initial position due to thruster forces, which in turn can lead to collisions. Incorrect location information, DP control errors, thruster errors, and operator error can be primary or secondary causes of the loss of position. The accidents that have been reviewed occurred during loading, either during direct transfer as in the case of tandem loading and/or with the aid of loading buoys. Two of the accidents resulted in collision, three were purely "drift-off" incidents, while four are categorised as "other". Six of the accidents occurred during loading, one accident during connection, one during disconnection, and one accident upon arrival.

Mandate and use of methods in the investigation
In the article, the reports on the nine accidents were reviewed using an MTO analysis. The detailed methods used in the nine reports are not discussed further. MTO analysis comprises three basic methods:

(i) a structured event-cause diagram; a description of the sequence of events, triggering causes, and root causes are identified and placed vertically above the events. Triggering causes are often technical and human in nature, while root causes can often be linked to organisational factors,
(ii) change analysis; describes how the events in the accident chain are non-conformant
(iii) barrier analysis; identifies human technical and administrative barriers that have failed or are inadequate.

The main questions in the analysis are:

- What could have broken the chain of events?
- What could the organisation have done previously to have counteracted/prevented the accident?

Causes linked to automation and HF
A key finding is that the accidents were linked to a combination of technical, human and organisational factors. *Technical causes* linked to hardware, software and design of DP systems can be identified in all accidents. Examples include software errors in DP control systems, faults on diesel generators, errors in position reference systems, and faults on auxiliary machinery.
Human error, which includes DP operators at the sharp end, design teams and maintenance teams, is linked to interaction with the technical causes and falls under three categories:

- An initial action that causes a failure in the system.
- Response action where an attempt is made to rectify a fault in the system, particularly in the case of technical faults or external situations such as meteorological conditions or ships on collision course.
- Latent action, where an action affects (but does not initiate) a technical fault, e.g. during maintenance.

Organisational factors are related to different parties involved in the development and operation of DP systems, such as operators, verification bodies, sellers and government authorities. The operator organisation was involved in seven of the nine accidents as a result of inadequate training, poor procedures, inadequate inspections, etc. Verification bodies were a contributory factor when a fault was not detected during testing, and sellers were involved in cases where equipment was incorrectly adapted and inadequately followed up after installation.

Discussion and lessons
Five of the accidents had inadequacies and errors in connection with the development and implementation of software as a contributory cause. These accidents were caused by a combination of several contributory causes, and the design-related causes are presented in Table D.1 (annex). The information given about the specific accidents in the article is somewhat ambiguous and generic, e.g. the phrase "inadequate design of the DP system" was used, which is not very specific. However, on an overarching level, the causes are described as the provision of insufficient information to the software design teams and inappropriate design of human-machine interfaces for the presentation of information and the design of alarms. These causes can be viewed in the context of challenges linked to cooperation between different parties and a lack of expertise concerning human factors during the development phase. Inadequate barriers for the identification and management of hazardous situations are associated with insufficient testing following the installation of new DP software, and a lack of functionality in software to detect incorrect input.

In order to counteract the causes identified in the accidents in the future, the authors suggest using hazard analysis methods which extend beyond a reliability-based perspective when designing DP systems. Actual system functions should be included in the analyses and assessed against objectives for designing the systems. For example, Systems Theoretic Process Analysis (STPA) is proposed, which is a perspective that includes human, technical and organisational factors. Such perspectives should be used as input as regards which user case should be developed by users and developers for the testing of systems in the early stages. Other areas that should be reinforced according to the study are the focus on holistic barrier management (MTO), relevant risk information such as background information for decision-making and the development of online risk monitoring and decision support systems.

Three key points from the investigations:

- Lack of holistic design of control systems – key information missing - inadequate ergonomic design of control systems, and inadequate human-machine interfaces – difficult to obtain an overall overview ("situation at a glance").
- Alarms are difficult to understand and can lead to poor situational awareness and should therefore be designed in accordance with established standards to ensure meaningful human control [T3].
- Complex systems that require the system to be validated, tested and certified based on critical scenarios during development and following installation. There was also a lack of provision in software to identify incorrect input

4.5 Fatal road traffic accident involving a Tesla (Joshua Brown) in the USA - Investigated by NTSB

Description of the incident

The collision occurred at about 16:40 on Saturday, 7 May 2016, when a 2015 Tesla Model S, on US Highway 27A, collided with a trailer that had swerved across the path of the Tesla. The trailer was approx. 20 meters long, white in colour, and there was considerable clearance between the trailer chassis and the road, making it difficult for the Tesla's sensor system to detect the obstacle. The Tesla continued for approx. 120 metres after the collision. The driver of the Tesla, Joshua Brown, 40, was killed instantly in the collision. (This accident is often referred to using the driver's name). The total duration of the Tesla's journey was 41 minutes, the Tesla's autopilot had been turned on and had been active for 37 minutes, while the driver had his hands on the steering wheel for a total of 25 seconds during the period that the autopilot was active (see the enclosed Figure 4.1.) The accident is described in a separate report; see NTSB (2019) and presentation NTSB Price (2019).

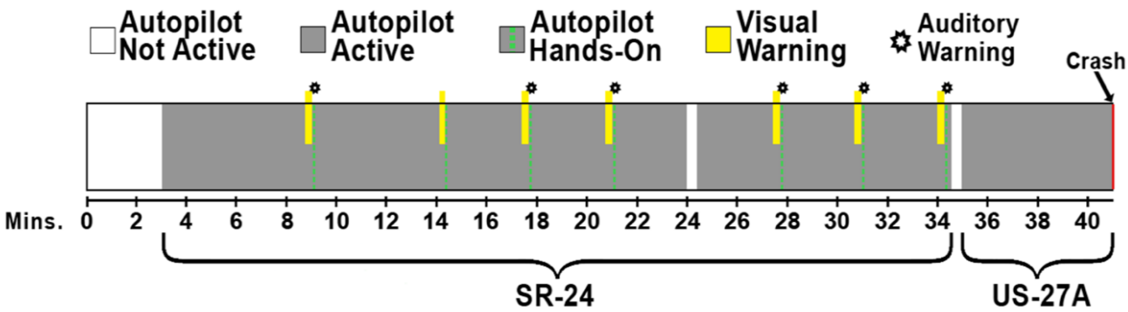

Figure 4.1: Log showing warnings and when the driver had his hands on the steering wheel, NTSB Price (2019).

Mandate and use of methods in the investigation

The investigations were conducted by the US National Transportation Safety Board (NTSB), which is an independent transport accident investigation commission. NTSB noted that there were challenges associated with the collection of data for the accident analysis, and NTSB therefore recommended that data collection and data reporting from autonomous systems be prioritised and given a stronger focus.

Causes linked to automation and HF

There were a number of complex causes of the accident, but the key factors in our view were as follows:

- Overconfidence in the autonomous driving solution on the part of the Tesla's driver, and a lack of training to ensure the proper use of automation solutions
- Failure of the trailer to comply with the obligation to give way and to stop for traffic coming from the right. The trailer also had a high clearance above ground level, which made it difficult for the Tesla's sensors to detect it
- Poor design of autonomous systems on the Tesla, as the solution permitted the car to drive at high speed without the driver having his hands on the steering wheel (contrary to the driving instructions issued by the manufacturer, Tesla)
- Infrastructure not adapted to autonomous solutions in that, for example, that there was no communication between the vehicles that were in close proximity to each other (vehicle-to-vehicle - V2V), the trailer was not fitted with "skirts" underneath, making it difficult for the Tesla's sensors to detect the obstacle caused by the trailer, and the sensors on the Tesla did not have an adequate "field of view".

Discussion and lessons

At a general level, the NTSB noted the following challenges with a higher level of autonomous solutions:

- Autonomous systems should be designed so that they provide a complete status overview to the driver/pilot (i.e. enabling them to achieve situational awareness at a glance); systems must be capable of triggering alarms in advance of a hazardous situation; systems should be robust (resilient), so that they are capable of switching to a safe state or ensure that there is a "fail-safe" system
- Users must be trained in the correct use of autonomous systems and have an appropriate level of mistrust/trust, i.e. users must maintain manual knowledge, so that they can take over in an emergency

Previous analyses have indicated that intervention by the driver in such a situation can take between 2 and 29 seconds, which means it should be impossible to remove your hands from the steering wheel at such high speeds. Furthermore, there were no redundant sensors which could have provided a better overview – this became a "single point of failure" when the sensor did not detect the trailer.

Three key points from the investigation:

- The driver had too much confidence in the automated driving system supplied by Tesla, and was directly exposed to misinterpretations by the sensor due to weak redundancy [T3b] and poor HF monitoring [T3].
- The design of the system was not adapted to the safety-critical tasks that were being performed [T3]. Lack of redundant sensors and infrastructure [T3a]
- The ongoing data collection and reporting from the sensor in the car during the events before and during the accident contributed to the understanding, learning and actions of the event [T4].

4.6 West Hercules

Description of the incident

At 22:46 on 16 January 2019, the Lower Marine Riser Package (LMRP) was inadvertently disconnected as the bottom hole assembly was about to pass down through the blow out valve

(BOP). It was the ADS (Automatic Disconnect System) that incorrectly disconnected the LMRP and BOP (Blow Out Preventer). The cutting valve in the BOP was automatically activated upon disconnection of the LMRP, and the fluid (seawater) from the riser was drained (dumped) into the sea. The shear ram did not cut the drill string due to the presence of drill collar in the shear ram during activation. The incident occurred while the well was secured with casing and a cement plug. There was no risk of discharge from the reservoir. Had the incident occurred later when hydrocarbons were present, the situation could have resulted in discharges into the external environment (PSA, 2019).

Mandate and use of methods in the investigation

The incident was investigated by PSA and Seadrill, the latter with assistance from Equinor. SINTEF has only seen the PSA's report (PSA, 2019). PSA believes that Seadrill's report does not describe the full potential of the incident,and considers that the reports largely contain coincident observations. The PSA has investigated direct and underlying causes, including the history of ADS use over a number of years. The investigation was carried out from land and involved the PSA interviewing 20 people. In addition, the investigation was based on technical investigations carried out by the parties involved themselves.

A Synergi case (1092560) for ADS (Automatic Disconnect System) was created in 2012. However, the PSA's research group did not find any evidence in 2019 that the deficiencies identified in the Synergi report concerning the need for risk evaluations and user involvement had actually been followed up. The PSA considers ADS to be a safety-critical system in its investigation.

Causes linked to automation and HF

The incident occurred as a result of the ADS system erroneously disconnecting from the LMRP and BOP during preparations for the drilling of a new section. The ADS system is an automatic system that will disconnect the riser if communication between the BOP and the rig is not adequately safeguarded during the operation. The ADS system will then act as a safety barrier if rapid disconnection becomes necessary in the event of bad weather,and should also secure the well by closing the BOP. The causes of the incident included the following:

- Inadequate risk management: The HAZOP that was carried out did not include an assessment of uncertainties linked to human and organisational factors, such as the need for essential training/experience of ADS amongst the personnel responsible, or the significance of the additional work that the system entailed in connection with installation and use. An important point was that an operator locally on the rig installed/adjusted the valve, and that the existing procedure for this was inadequate.
- Absence of a quality control process covering the automated function that ADS entailed from the drilling contractor.
- An incorrectly mounted trigger valve on the ADS resulted in the system giving an inappropriate indication of disconnection of the LMRP from the BOP, even though the conditions for this were not met. (The ADS system will indicate disconnection if the angle of the flex joint exceeds a pre-set angle, 6 degrees in this case.)
- Change management MOC – Lack of control linked to upgrading of the BOP and installation of the ADS system on West Hercules. High workload/scope of work on the rig combined with inadequate procedures and knowledge of ADS.
- Obligation to ensure compliance - Deficiencies associated with the fulfilment of the obligation to ensure compliance obligation, partly linked to competence and risk assessments.
- Maintenance – Deficiencies in maintenance routines for the ADS system.

Discussion and lessons
The investigation paid little attention to design. No details are given regarding the direct cause of the accident except than that it was stated as being due to an incorrectly mounted valve (trigger valve). It is not clearly stated when this valve was incorrectly installed. (The valve was installed/adjusted by personnel on board). Because no description is given of how the incorrect installation was performed, it is also difficult to determine whether the design could or should have been different, so that, for example, it would have been impossible to fit the valve incorrectly. Although the investigation does not consider this issue directly, non-conformities in training and procedures were identified.

Regarding the design of the BOP control system, the investigation report states the following: " It was not sufficiently known within the organisation that the shear ram would close when the LMRP was disconnected from the BOP due to the activation of ADS, even though the BOP control system was set in a mode where it would not close." The report does not consider this issue further. It remains unclear whether this is a design weakness in the overall control system. A description of this activation and the strategy should have been assessed in advance.

The report notes that procedures relating to testing, installation and maintenance of the ADS system appear to be inadequate. It is unclear whether the design ensures that periodic testing is taken into account.
It is also noted that measurements were taken during the installation on board which did not correspond to the results according to the FAT. There also appears to be a lack of validation and process for quality control of the automated function that ADS entailed from the drilling contractor (HF operational). In addition, training was inadequate, and insufficient experience had been gained of the use of the system amongst the personnel responsible with regard to ADS, as well as insufficient understanding of the organisational circumstances and the added work that the system entailed.

Three key points from the investigation:

- Inadequate assessment of design decisions [T5]. The investigation does not explain why the valve was fitted incorrectly or whether it could have been the result of poor design. Similarly, there is no explanation as to why the system was designed so that the cutting valve would close when the LMRP is disconnected from the BOP due to the activation of ADS, even through the BOP control system was set in a mode where it should not close. The system should have been designed so that it was made clear that the BOP was activated when the ADS system was activated.
- Inadequate understanding, procedures, test routines and training linked to the installation and use of ADS (Automatic Disconnect System) – including the risk assessment of errors in the ADS system and assessments of human factors, such as task analysis and workload [T3].
- Failure to address the “see to it” obligation linked to design, risk assessments and review of FAT for ADS. It should have been established as a framework condition that ADS was to be supplied ready-installed by suitably trained personnel, as the installation was a challenging task [T3].

4.7 Macondo-blowout

Description of the incident

On 20 April 2010, an oil and gas blow out occurred on the Deepwater Horizon mobile offshore drilling rig in the Macondo Field in the Gulf of Mexico. The accident resulted in the loss of 11 human lives and the spillage of almost five million barrels of oil, as well as an estimated financial loss of USD 61.6 billion. The accident occurred when the crew on the rig was in the process of completing a well for temporary abandonment. This involved leaving the well in a safe state, so that a production facility could return for completion and the start-up of production from the well at a later date.

Mandate and use of methods in the investigation
The Macondo incident has been comprehensively analysed in a number of investigation reports. In addition to Tinmannsvik et al. (2011), we have used the investigation that was subsequently carried out by the U.S. Chemical Safety and Hazard Investigation Board (US-CSB, 2016), in which experts on Human Factors participated. This was an independent investigation in line with investigations conducted by the Accident Investigation Board Norway, and identifies the need for HF. SINTEF was engaged by the PSA in 2010-2011 to systematise various investigations immediately after the Macondo accident, and other similar accidents that had occurred previously. The aim was to build up a knowledge database and contribute to learning and improvement that could reduce the possibility of similar incidents occurring on the Norwegian continental shelf (Tinmannsvik et al., 2011). The project adopted a multidisciplinary approach to the MTO. The STEP method was used to map incidents, as well as the sequence of events and interaction/communication between the parties involved. Human factors, such as poor communication, contributed to the sequence of events turning out as they did.

Causes linked to automation and HF
The accident was multifaceted and complex. Both barriers and the interaction between technical, organisational and operational barrier elements were inadequate. A key component like the BOP was unable to shut down the well. When attempts were eventually made to activate the EDS system, this system did not work either. It is difficult to identify individual factors. We can highlight a number of parts of the system that indicate failure linked to HF.

- *A well kick continued for approximately 45 minutes without either offshore or onshore personnel detecting it, even though the data indicated that a well kick was occurring* (Tinmannsvik et al., 2011). This indicated both poor design and a lack of situational awareness or "sensemaking".
  The well monitoring system on the Deepwater Horizon had not been adequately rehearsed. An example: "The personnel on board the rig had to perform manual calculations of the amount of drilling fluid, instead of having automatic measurements of the net flow rate from the well, as the flow rate was directed outside the instrumentation. Inadequate systems and poor situational awareness may have contributed to this".
- With regard to the situational awareness: Simultaneous operations were performed which prevented (continuous) monitoring of data during critical phases of the operation. Personnel from the operator, drilling contractor and service company were not sufficiently vigilant in relation to the possibility of loss of well control upon displacement of drilling fluid from the well (which was carried out as part of a "negative well test" of the downhole cement plug). The personnel on the drilling rig did not have sufficient experience or training to interpret irregular pressures during the "negative pressure test". There was a lack of communication between the operator and the drilling contractor, both before and during the final displacement phase (negative pressure test).

Discussion and lessons
There are many lessons to be learned relating to HF from the Macondo event. We have highlighted those that were prioritised by the commission (taken from US-CSB, 2016):

- HF was given insufficient consideration in relation to HSE and risk assessments.
- Insufficient integration of HF in design and operation: "Human factors versus design is mentioned, and it is noted that API 75 is inadequate in the following respects:
- The challenges associated with the companies' HSE roles and responsibilities were highlighted:
- The US-CBS investigation report notes the following: "Need for better monitoring of the systems, which could conceivably be achieved through a combination of improvements relating to sensors, software for the interpretation and presentation of measurements (including reliable alarms), and having better support for operators.

The design and use of the systems utilised on the Deepwater Horizon was not sufficiently adapted to the needs of the users. HF and processes had not been given sufficient consideration during the development of the systems on board the drilling rig. This became apparent through the poor situational awareness based on the existing well monitoring systems. Critical screen displays depended on the right person seeing the right data at the right time. Training was also inadequate, and interaction and communication between the various groups was poor. Personnel had little experience of interpreting irregular pressure measurements during negative pressure tests and inadequate training in interaction in connection with complex technical systems.

Three key points from the investigation:

- Key factors linked to the overall picture emerged during the US-CSB (2016) investigation. They highlighted the breadth and complexity of the accident and identified important MTO factors. They were independent and had a broad range of expertise [T5].
- More attention to HF in design [T3].
- Training and routines that support ongoing risk assessment and interaction in distributed teams, including understanding of alarms [T3c].

4.8 Pryor Trust - Blow out and subsequent rig fire

Description of the incident
On 22 January 2018, a blow out from the gas well and subsequent fire occurred on the drilling rig at Pryor Trust 0718, a land-based oil and gas field located in Pittsburg County, Oklahoma, USA (US-CSB, 2019). The fire killed five workers who were inside the drillers cabin on the rig. The blow out occurred about three and a half hours after the drill string had been removed ("tripping") from the well. The cause of the blowout was the failure of both the primary barrier (hydrostatic pressure exerted by the drilling fluid) and the secondary barrier upon activation of the BOP. The latter was due to inadequate detection of well inflow.

Mandate and use of methods in the investigation
The U.S. Chemical Safety and Hazard Investigation Board (US-CSB) investigates incidents with the aim of identifying the causes and issuing safety recommendations following incidents in the petroleum and chemical industries. The blow out from the Pryor Trust well 1H-19 was the subject of a detailed causal analysis which identified 13 main groups of causes, many of which were influenced by a "human in the loop" (human factors). The analysis is presented as a detailed

description of the causal relationships, with references to recommended measures for each of the causes. US-CSB also developed its own Bow-Tie diagram which illustrates the planned barriers for blowout prevention. Many of the causes of the incident were linked to the failure of these barriers. The causal analysis is further documented in an ACCIMAP diagram, presented in an appendix to the investigation report. The ACCIMAP analysis also places responsibility for the various causal factors within the organisation, amongst the parties involved.

Causes linked to automation and HF

The following important causes and contributory HF factors are of note:

- Underbalanced drilling was carried out without the necessary planning, equipment, skills or procedures, and thus the prerequisites for the appropriate management of the well were not in place when the primary barrier to prevent gas inflow was lifted.
- The driller had not undergone the necessary training regarding the use of a new tripping procedure to support the monitoring of possible gas inflow during the operation.
- The equipment was set up differently than normal during the trip out of the drill string, which led to confusion and the misinterpretation of well data during the process and resulted in a possible indication of gas inflow being overlooked.
- The drillers on both the day and night shifts decided to deactivate the alarm system, which could have detected the possible signs of gas inflow and imminent blow out. The alarm system was not appropriately designed to alert personnel to hazardous conditions under different operating conditions (e.g. drilling, circulation and tripping out of hole) and caused many "false" alarms, which probably also led the drillers to deactivate the entire system.
- The operator had not specified requirements for barriers in connection with underbalance drilling, or as regards how drilling personnel should respond in the event of the loss of a barrier in the current well state. This was a contributory factor behind why the drilling rig and its crew were neither adequately equipped nor operationally sufficiently well-prepared to carry out such operations.
- Looking at the accident reports and the analyses in retrospect, it is clear that human factors and processes had also not been adequately taken into account during the development of the systems involved in this accident.

Discussion and lessons

The incident clearly indicates a lack of situational awareness regarding well control and the ability to perceive the actual condition of the well during the withdrawal operation. The well was underbalanced during the operation, a condition which was neither adequately observed nor understood. Based on the report, it is apparent that human factors and processes were not adequately taken into account during the development of the systems involved in this accident. It was the inappropriate design of the alarm system that caused many "false" alarms during the operation, which contributed to the driller frequently deactivating the system. The crew in the field had also not been trained on this type of operation, and the necessary planning and preparations for the operation were not carried out in advance. Planning, training and execution of the operation were not adapted to the existing systems, procedures or knowledge levels. The operators did not realise that the volume of drilling fluid flowing out of the well (throughflow) was not in proportion to the volume that had been pumped into the well minus the volume of the drill string itself when the string was tripped out of the well. This was actually a clear indication of inflow and possible gas volume in the well, but no one realised this until it was too late (ref. the ACCIMAP analysis in the investigation report).

Three key points from the investigation:

- The design of the drilling systems and the alarm system was inadequate, with little attention being paid to human factors. The alarm system was shut down during critical operations [T3].
- Lack of training in advance of a safety-critical operation and a lack of situational awareness during the operation.
- Lack of risk assessment and planning of a safety-critical operation, with a lack of establishment and follow-up of barriers.

4.9 Mærsk Gallant – Well control event

Description of the incident

A well kick of approx. 12 m^3 occurred on the Maersk Gallant rig during dynamic pore pressure tests using MPD (Managed Pressure Drilling) equipment. One problem was that the sensor measuring the pressure upstream side of the MPD choke (PT4) began to show an excessively high value, causing the MPD valve to open. When the driller observed the measured pressure near the drill bit (MWD) and the pump pressure fall simultaneously with an abnormal impact on the drilling torque, he closed a valve in the BOP, an UPR (upper pipe ram) of the VPR (variable pipe ram) type, in order to protect the well against kick. It subsequently became apparent that the UPR was not was not providing a sufficient seal, with the consequence that fluid leaked up to MPD valve and the PCD (pressure control device) sealing the annulus around the drill string during drilling). When PCD valves cannot be opened, probably due to the pressure from the well, it was decided on drill floor that the valves should remain closed, however this message never reached the PCD operator, who opened the valve manually. This resulted in overflow of the trip tanks, which was detected but not understood. Several valves were opened and closed before the driller eventually regained control by closing the annular BOP.

Mandate and use of methods in the investigation

The investigation's mandate was to review the incident with the aim of identifying the triggering and underlying causes of the incident which could contribute to learning and prevent recurrences in accordance with the Section 20 of theManagement Regulations. The investigation team applied the main principles of "Kelvin TOPSET" root cause analysis in combination with a timeline. The method focuses on technology, organisation, human, comparable events, environment (surrounding events) and time. It is a step-by-step process which includes the phases of planning, scrutiny, analysis, establishment of recommendations and reporting. The method identifies "human factors" operationally, such as lack of communication, situational awareness and risk understanding amongst various personnel groups during the incident.

Causes linked to automation and HF

The report identified the following root causes: Insufficient understanding of risk and inadequate planning; Insufficient robustness when rigging the cable to pressure sensor PT4; Alarm functions for pressure sensors not sufficiently robust; Insufficient information about shut-off volume for BOP functions; Lack of expertise and experience; Inadequate compliance with MPD procedures; Insufficient communication; Insufficient reliability of BOP, UPR and VBR.

The following factors are considered to be the most important in connection with automation and HF:

- Errors in measurement values from sensors caused the automatically controlled MPD valve to open too much, resulting in the pressure in the well becoming too low. A lack of redundancy and well head pressure are mentioned.
- The lack of situational awareness, probably linked to the fact that the MPD system adds considerable complexity, caused the correct response to be delayed. Inconsistency between different measurements was not understood and the operators did not have an adequate understanding of the automatic systems.
- Poor communication between the companies, possibly linked to a lack of affirmative communication and unclear command lines or distrust between personnel.
- Inadequate compliance with procedures, including permission for two pressure reductions before inflow during the first reduction had been circulated out.
- The prioritisation of efficiency, on getting the job done, may have caused some of the problems.

Discussion and lessons
The report refers to a number of root causes with specific measures, but the issue of why so many causes contributed to this accident does not appear to have been considered. There are a number of aspects that can be linked to the fact that the design of the systems should have been better adapted to the operators in order to obtain an overview of the situation. For example, the alarms concerning the full trip tank were not understood, and the drill floor did not have sufficient overview to detect or understand what was happening. There was also inconsistency between three sensors that appear to be part of the MPD equipment which did not trigger any alarm, suggesting that a more robust algorithm should be developed.

Clarification of responsibilities regarding roles is also important and linked to having a good and updated overall picture of the situation. In situations involving components from different suppliers, the entirety must be considered, and it is natural to think that both the driller and the MPD manager should have an overview of the entire situation and communicate regarding this in the event of changes in the situation. Similarly, it is important to facilitate good communication during operations where many parties are involved. During an MPD, it is common for more companies than usual to be involved on the rig, e.g. personnel from the MPD supplier and the companies which supplied the RCD *(rotating control device*). Due to space restrictions, these personnel typically remain in their container offices, with a radio link to the driller on the same or different channels, which can hamper communication. As long as the rig is not designed for MPD, it is difficult to do anything about this.

Monitor(s) showing an overall image of the physical system are useful to enable an overview to be obtained more readily and to enable the focus to be placed on non-conformities and critical situations. This is especially important in the case of MPD, where there are more parties involved, more pipes, valves and pumps, as well as more procedures than usual. Previous experience suggests that, although overview displays are useful for the driller and MPD manager, they are not developed or tested until it is too late to provide the necessary overview in critical situations.

Three key points from the investigation are:
- Poor design/design of systems (screens), alarms, collaboration, and physical organisation of workplaces to provide a good overview of what is happening – leading to a lack of situational awareness (associated with MPD) for the driller [T2] [T3].

- Poor communication and interaction between the parties involved (suggesting inadequate procedures and training, training concerning critical scenarios) and poor allocation of tasks between the parties involved (critical tasks should not be spread out across many parties with demands for a high level of precision in communication) [T3c].
- Poor design of alarm philosophy, and inadequate alarms. The alarm indicating the full trip tank was not detected and the driller received too many alarms in the driller's cabin during the incident and did not realise that the trip tank was full [T3].

4.10 Summary of results from the review of investigations

At a general level, it can be said that learning lessons from incidents is a challenging process (ESReDA, 2015). In order for this process to work, it must consist of several steps such as: *Reporting* (in this context, we can ask whether all relevant incidents are reported), *Analysis* (is there a sufficiently broad MTO analysis which includes HF?), *Planning* of measures which actually improve safety, *Implementation* of the measures, and *Monitoring* to determine whether the measures are effective and being followed up and whether lessons are being learned. With regard to learning, this can impact on both individuals and organisations. At individual level, learning about safety is normally assessed on four levels (Kirkpatrick, 1979): (1) Personal assessment of learning (satisfactory, unsatisfactory); (2) Has anything new been learned; (3) Have there been any changes in behaviour, or were the lessons of any significance for behaviour; (4) Are there any organisational implications –was safety improved.?

In Table 4.1, we have compiled a summary of findings based on Investigation method and Causes. We have divided the investigations into two areas: i) areas with a high level of automation, and ii) from drilling and wells.

Table 4.1: Summary of findings from the investigations

Case	Investigation method	Causes and proposed measures [Tx].
High level of automation		
Boeing 737 Max crashed	Good breadth as regards HF and included assessment of design [T5].	Design not adapted to users; Need for certification, and testing of critical scenarios; [T2]; [T3].
PSV Sjoborg - SFA, collision	Good breadth in the investigation with a comprehensive MTO assessment;	The design of the bridge system was fragmented, with many different systems; Many different alarms that were not understood (inadequate training). [T3]; [T3c].
KNM Helge Ingstad collision	Good breadth in the investigation with an assessment of situational awareness [T5].	Weaknesses in the design of tasks on the bridge (noise, quality and location of critical equipment, alarms, workload); Lack of clarity as regards roles and common situational awareness – inadequate intervention. [T2]; [T3]; [T3c].
DP operations	No remarks	Lack of holistic HF design of control systems to provide a good overview in all situations; Alarms often difficult to understand; Inadequate testing of critical scenarios combined with inadequate training of the crew on the bridge. [T3]; [T3c].
Tesla (Joshua Brown)	The thorough data collection improved understanding of the incident [T4];	The operator had too much trust in the autonomous system; The system was poorly designed, with the result that it was possible to hand over too much control to the autonomous system. The infrastructure around the autonomous solution was not adapted to autonomous vehicle driving; [T3a]; [T3]. [T3b]; [T4].
From Drilling and Wells		
West Hercules - ADS Barents	Inadequate assessments of the design of valves/control systems; [T5].	Lack of training, assessment of workload and understanding and risk assessment of ADS; Failure to address the “see to it” responsibility in connection with the implementation and use of ADS. [T3];
Macondo Blowout	Breadth in the investigation with HF and MTO assessment;	Lack of focus on HF during the design stage; lack of training relating to interaction in groups. [T3]; [T3c].
Pryor Trust – Blowout	No remarks	Design of the systems inadequate, with poor HF design (alarm system deactivated) leading to poor situational awareness; lack of planning of critical operation; lack of training in advance. [T3].
Mærsk Gallant – Well	No remarks	Poor design to facilitate a holistic understanding (poor design of information/HMI for overview, poor physical design of meeting places); Poor communication between key operators (little

		affirmative communication) – Poor design of alarms. [T2]; [T3]. [T3c].

4.11 Investigation method

The mandates for the investigations were consistently similar to those used for the incidents in the petroleum industry which we reviewed. A recurring feature was that the investigations found what they were looking for, and it is open to question whether this is desirable (Lundberg et al., 2009).

The larger, more comprehensive incidents, such as the Macondo incident, were reviewed by independent accident boards. Such investigations have a broad remit, with a multidisciplinary investigation team which aims to examine an incident from the angle of different disciplines and/or perspectives. In this regard, findings relating to HF causes and lessons have also become more prominent amongst conclusions. However, this is less applicable to intracompany investigations, where there appears to be a lack of expertise relating to Human Factors (such as how situational awareness is established and best practices for the design of the HMI-Human Machine Interface). There is often a lack of information in the reports concerning the professional background of the members of the investigation team. In typical company investigations, it is common to list names and positions/roles (representatives of the company/affiliation). In only a minority of the investigations, such as those conducted by the PSA, the Accident Investigation Board Norway and NTSB in the USA is information provided concerning the expertise of the investigation team members.

Investigations of the "accident board" type (e.g. the U.S. Chemical Safety and Hazard Investigation Board) appear to be mature and thorough due to the breadth of perspectives, the independence of the parties involved, professional gravitas and emphasis on understanding the pattern of action. It appears to be an advantage that investigations are conducted by independent parties, with nothing to defend, based on a system perspective with a range of expertise, often with cognitive psychologists with a knowledge of HF on the investigation team.

In addition to clarifying the actual sequence of events, determining the direct (triggering) and underlying causes of the incident is key. It is equally important to recommend measures in order to prevent similar incidents from occurring in the future. The methods used in the investigations varied. It is common to use a timeline documenting activities and sub-events from planning, or the period leading up to the incident, via the sequence of events through until normalisation of the situation after the incident. Reflections linked to design are often absent from reports.

Recommendations – investigation methods
In connection with the review of the investigation reports, we also looked at other relevant analyses and reports on lessons learned from incidents. In the report by the Safety Forum (2019), entitled *Læring etter hendelser* (Learning after incidents), two aspects in particular are proposed which correspond with our observations:

- **Recommendation 1** [T5]: The investigation team should possess expertise concerning human factors, organisational factors and corporate governance on an equal basis with technical

expertise. (This should be incorporated into existing guidelines and procedures for investigations.)
- **Recommendation 2** [T5]: Companies and authorities should use investigation methods where the question to be answered through the investigation is 'why did it make sense to act in the way they did?', rather than 'what did they do wrong?'

We also make the following recommendations:
- **Recommendation 3 Consider design during investigations** [T5]**.** Where possible, the investigation team should assess whether the design of the system had weaknesses which led to the accident, e.g. does the design provide a good overview, was the system designed with multiple indications of the status of the process?
- **Recommendation 4: Independence.** Major investigations should be conducted by, or in cooperation with, independent parties. Local investigations can benefit from external resources which make the group more independent.
- **Recommendation 5: Consider the degree of hindsight and repetitive findings**,[V1]**.** After an incident, it can be easy to point out that the incident was caused by inadequate risk assessment or lack of action relating to a risk, because we know what happened. "Inadequate risk assessment" may therefore be a simple point to highlight, but what was the underlying cause? Why were the risks that the probabilities/consequences concerned not dealt with? Similarly, we have seen a significant number of findings which crop up in accident reports year after year. We see no reflections regarding findings that are repeated – it is easy to point to "non-compliance" - but were the methods used inadequate, with the result that no changes were made, or is it unclear who must /should learn lessons? Is it the operators, the investigators, the supervisory authorities or those who design the regulations/procedures?

4.12 Causes identified by the investigations

Many investigation reports primarily focus on technical and organisational factors,and pay little attention to human limitations and possibilities. If human factors such as how they used systems or understood the situation are not analysed - how can one then identify technical and/or organisational improvements? If the investigation describes the situational awareness of the operators during the incident, one can better understand the support provided by the technology/systems and the support from the organisation. Moreover, investigations are often naturally concerned with “the sharp end”, rather than decisions linked to design, e.g. why was the system designed so that it was possible to install a component incorrectly?

From the systematisation of causes, lessons and measures, we have identified the following:
- poor situational awareness amongst those involved at the sharp end
- poor interaction within distributed teams
- poor design of equipment and poor alarms which are sometimes deactivated
- inadequate/demanding training
- inadequate reporting of automation errors which lead to excessive trust

Recommendations - causes identified by the investigations

Recommendation (a): HF expertise must be included when systems are introduced/created from the earliest stages at which automation is discussed and planned [T1]. One aim of this is to take into account human possibilities and limitations (IEA/ILO, 2020), ISO 11064.

Recommendation (b): User-centred design should be given a high priority during the development of systems where humans operate or intervene [T2]. In such projects, the development of the systems (design) must follow established methods for Human Factors i.e. design based on task analysis, HMI standards, step-by-step/iterative user-centred design, and systematic user testing during the process (see ISO 11064).

Recommendation (c): Meaningful human control [T3]). In complex systems, the entirety should be analysed well before specific areas are built/programmed. Systems must be capable of providing a complete overview in a simple and clear way, i.e. "situation at a glance". Good interaction design is therefore important (see ISO 9241 and ISA 101). Innovation-driven or user-driven design must be supplemented by task analyses and safety analyses in order to address safety (Smith et al., 2020) and methods for interaction design (Hollifield et al., 2008). The assessment of mental workload and staffing is a natural part of the development process for the systems and should be included as part of stress tests/reviews of critical scenarios.

Recommendation (d): Coordinated development of interacting systems/Holistic integration [T3c]. Users should be able to readily obtain a complete overview of critical areas. When multiple systems are automated, users must monitor several systems, requiring the interfaces to be developed in a standardised way and present safety-critical information in a coordinated manner. This could for example be handled through the coordinated development of control systems (Danielsen et al., 2019), or through establishing standards for coordinated interfaces (Nordby et al., 2019).

Recommendation (e): Training concerning interaction in distributed teams and simulator training should be given a high priority [T3c] – e.g. based on principles from Crew Resource Management (CRM). Examples of areas referred to from Deepwater Horizon included little experience and training in interpreting irregular pressure measurements during negative pressure tests (need to check with others), inadequate cognitive and skills training in interaction with complex technical systems and inadequate communication between operator and drilling contractor during negative pressure testing. Critical scenarios should be specifically reviewed where several organisations/locations are involved.

Recommendation (f): Critical systems should be certified or undergo systematic verification and validation with user participation. [T3]
As part of testing procedures, systematic verification and validation should be carried out in a number of stages, a) during problem definition, and b) during design/prototyping to ensure that the system has good user anchoring and resolves the key issues. A thorough system test should then be carried out, including a review of a wide range of critical operations/situations to ensure that the system is capable of handling unexpected events (CRIOP, 2011). User testing during the design phase is particularly important, as it entails lower costs and can ensure that the right approach is adopted at an early stage.

Recommendation (g): An alarm philosophy must be in place for critical systems. An alarm philosophy becomes more important in connection with automation [T3]. When systems are automated, the human is removed from the minutiae of control, and re-enters when something unexpected happens which the automation is unable to handle. An alarm philosophy should therefore be included in the design of the entire system and planned at an early stage, rather than as a problem afterwards. Absent and poor alarm management is a recurring issue amongst the investigation reports. Alarms are often deactivated because they disturb the operator, either because there are simply too many alarms or because the alarms are incomprehensible and cannot be trusted. EEMUA 191 states that up to six alarms per hour can be handled, i.e. one alarm every 10 minutes. This is a demanding target and assumes input from the start of the development process.

Recommendation (h) Higher levels of automation may require more support from the surrounding environment/infrastructure [T3a]**.** As automation levels increase, it is important that operating areas and prerequisites for safe operation are documented, as described in the Operational Domain/Design of the Operation Area (ODD), taken from SAE (2018). Experience from the safe operation of automated tasks in general indicates that the area of operation must be delimited and adapted so that sensors are able to detect obstacles, so that traffic from humans is limited/prevented, and so that there is a form of control centre which must be staffed in order to solve problems. Automated systems must be able to switch to a safe state in the event of faults or non-conformities.

5 Collated experiences and developments with an emphasis on HSE from the interviews

The aim of this activity was to collect and analyse experiences and developments linked to automation projects in the petroleum industry. Relevant projects and industrial players were selected in cooperation with the PSA. We also interviewed experts in automation and HF in order to bring out experiences and developments. We selected experts who are employed by the companies (and work on standardisation) and who have been involved in many development projects in the petroleum industry over many years.

In the following, we have described the procedure, case projects, use of methods and standards. We have described the challenges faced by the projects, factors for success and finally - proposals for conclusions – what lessons can we learn? In the descriptions, it is the analytical considerations of the researchers that are visible. Where themes from the interviews are reproduced directly, this is indicated by the use of "the respondents explained", "one operator pointed out", "in one project, it was stated that" and other similar phrases.

We prepared an interview guide in cooperation with the PSA, partly to map out methods which are used to address the operator's role, safety and provision for meaningful interaction with the automated system. The points that were reviewed during the interviews were as follows:

- Brief background concerning the PSA's project (this assignment), then from the respondents about their project and the use of methods
- Description of the system, purpose, risk analysis, process, organisation - anchoring (from users, HF experts)
- How do developers collaborate with users of the system (during design, testing, etc.)? Has user testing been carried out (e.g. of safety-critical scenarios?) What expertise is involved in the development/design phase?
- How is responsibility allocated locally (drill floor/driller's cabin)/centrally in the new system?
- What methods and standards are used, e.g. for alarm management, in order to create optimal user interfaces (e.g. High Performance HMI)?
- How is training and the development of new expertise (collaboration with other operators, monitoring of automated tasks) planned and integrated?
- Project experiences (improvements to the system, changes to work processes) and how alarm management and unexpected events are handled?
- How is system integration with all the other systems carried out?
- What is the interaction and dialogue with the supervisory authorities like?

In consultation with the PSA, we looked in detail at two cases (development projects) which concern the automation of different functions/areas of the drill floor. These are two projects that have been under way for a considerable length of time, with a number of sub-projects and systems. The two cases will first briefly be examined in this section, but the findings that are later presented will not be linked directly to the case concerned, or to the operators involved. In addition, some of the findings are based on experience gained through similar projects. This particularly applies to findings from the interviews of independent HF experts. A total of 10 interviews with 27 respondents were conducted, all digitally (via Microsoft Teams). The distribution of respondents was as follows:

- Two operators, with six respondents
- One rig owner, with three respondents

- Five system suppliers, with 14 respondents
- Two independent HF experts (i.e. two respondents)

5.1 About the case projects – description and purpose

A brief description is presented below of the ADC and Performinator case projects. The projects collectively concern the following areas: (1) Process-based decision support, (2) Semi-automated systems (parameter monitoring), and (3) Robotisation of **drill floor**.
The case entitled "Automatic Drilling Control (ADC)" covers: (1) Process-based decision support, and (2) Semi-automated systems; while the Performinator project covers (1), (2) and (3) - Robotisation of drill floor.

Case 1: Automatic Drilling Control (ADC)

The ADC project comprises a number of sub-projects and associated systems which seek to achieve automated control of the drilling process. The project particularly concerns the provision of automated support to the driller, rather than robotising the drilling process itself. ADC consists of data collection through wired pipe, automated calculations and measurements, historical data and calculations. A digital twin of the well has been created, which helps in decision-making during operations based on the data stream. The digital twin is also used in the monitoring of drilling equipment. PSA (2019b) cites ADC as an example of the increased use of digital well planning and automated drilling operations. Implementing ADC gives the driller more decision-making support than is common with traditional drilling processes. The aim of this is to improve operational safety and efficiency. The respondents from the ADC project refer to the project itself as a "software project", rather than as a robotics project.

Case 2: Performinator

The Performinator project is trialling the robotisation and streamlining of heavy operations on the drill floor. The project concerns a raft of changes (PSA, 2020);

- Robotisation of pipe handling on the drill floor and pipe deck (five electrically operated robots)
- Relocation of the drillers' cabin to the office module on the other side of the rig
- Camera surveillance of the drill floor by remote control from the driller's cabin
- Robotic barriers for automated/electrical enclosure of the drill floor using sensors to avoid the need for humans to be present in the red zone
- Reduction in the number of manual lifts, reduced risk of injury to personnel on the drill floor and pipe deck, as well as reduced number of lifting and crane operations.
- A new driller's cabin is planned on the other side of the rig (remote control of the drill floor)
- Replace the old drilling control system with a new pipe handling system which follows the digitalisation strategy (full robotic pipe handling system consisting of a tool pack and a new automated drilling control system to enable autonomous drilling).

5.1.1 Aim of the projects

According to the respondents, the aim of the projects was to improve both safety and efficiency. It is believed that automation contributes to positive effects, particularly linked to the removal of the "four D's"; i.e. handing over to automated systems tasks that are Dirty, Dangerous, Dull, and/or Difficult. In particular, the robotisation of drill floor will be linked to reducing/eliminating exposure (hazards, environmental damage and stress) amongst personnel, while the remote control of drilling operations will reduce exposure to major accident risk amongst personnel in the driller's cabin. The projects and the various suppliers appear to have somewhat different approaches and starting points. Some want to limit detailed control tasks and reduce the workload imposed on operating personnel, while others say they are working to eliminate the presence of humans in the long term (reducing human error and HSE exposure). In both projects, responsibility for decision-making still remains with the driller, e.g. when the automated system stops. Both projects therefore deal with process-oriented decision support and semi-automated processes at an overarching level, and still rely on continuous monitoring by the driller. This means that the human and organisational aspects of the systems will be important considerations during both the development and operational phases.

The two projects have used slightly different procedures and project organisations. One of the projects decided to use a single main supplier, while the other project used several suppliers. In both cases, the systems have been coordinated via a project manager. The projects also adopted slightly different approaches to development. This applies to design methodology, the parties that are brought in and the standards and methods that are applied. This can be both a strength and a weakness, and should be a starting point for discussing best practice during project implementation.

A number of parties have been involved in changes, development and operation of drilling systems. The two projects in this project are managed by the operator, but the system will ultimately be operated by a rig owner. Drilling system suppliers specialising in automated/robotic technology are contributing to the development solutions. The operators own the processes and are driving the projects forward. As the figure below shows, there are a number of links in the chain and parties involved in the development processes. The interfaces between the parties and the associated challenges were highlighted in many of the interviews. (This will be described in more detail below).

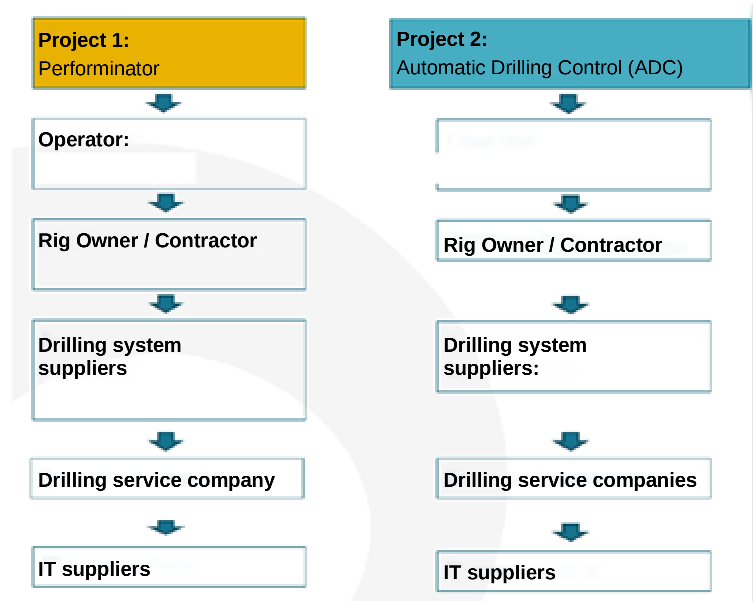

Figure 5.1 The projects which were selected as cases. Facsimile: PSA.

5.2 Methods, standards and guidelines used in the projects

During the interviews, we requested standards, guidelines or specific methodologies which were used during the development of the systems, particularly methods for addressing human factors, design, ergonomics and the risks associated with the system. The methods and techniques that are used determine both the quality of project implementation and the quality of the system's design. In this context, the term ‘methods’ is used to refer to descriptions of processes (i.e. activities as described in ISO 11064), while ‘the term techniques’ is used to refer to descriptions of how solutions are designed (e.g. task analysis, barrier analysis, interaction design, etc.)

The entirety of the interview material indicates a fragmented range of methods, techniques and standards used by the various parties involved depending on their professional background. It varies depending on whether they have a background in technical safety, human factors or design. Some methodological standards are mentioned, e.g. ISO 11064 (2000), ISO9241 (2020) and Norwegian Design Council standards (2020). These standards address different themes and different aspects of the development. Based on the discussions concerning training, testing, alarm management and interaction design, there appeared to be a lack of understanding of how these activities should be placed in the development process. It was mentioned that, although procedures/work processes/responsibilities came in late, the projects received positive support from the PSA to discuss this at an earlier stage in the project. As a general rule, around one third of resources are allocated to development (programming); one third to procedures/organisation and one third to testing (user testing, system testing). The projects did not appear to have such a complete overview of input needs. The planning of procedures and testing came too late, and the scope appeared to be somewhat unclear. The formulation of responsibilities/work routines and testing should be planned and outlined at an early stage in a project, not as final activities or as a consequence of technical programming. Testing and clarification of procedures can lead to a need for reprogramming and reductions at a late stage. This is more expensive than if it is done earlier in the project. References to typical challenges associated with projects and estimation guidelines can be found in Nelson (2007), NavalCenter(2008) and Johnsen (2008).

No reference was made to techniques such as good practice for interaction design, such as Hollifield et al. (2008) *“The high performance HMI handbook”* or key themes, such as *“Safety Critical Task Analysis”* from Smith et al. (2020). No reference was made to the use of "eye-tracking" as an aid in the design of screens either. Thus, no agreed lists of good practice appear to have been drawn up. Good user-centred design is important, but it assumes that a systematic task analysis has been carried out and good standards established for interaction design and alarm management.

Most parties mentioned *some* applied standards and guidelines, but there were considerable differences between the different projects. The NORSOK I-005 standard; System Control Diagram (SCD) was mentioned. This describes an approach to creating a total system design based on functions such as P&ID. The standard describes the techniques and standard for the design of diagrams. Some parties have used the CRIOP method as support to get on the right track.

Existing alarm philosophies are often used for new automated systems. The PSA's standard YA-710 was mentioned and is used. This standard is openly available. This could present challenges if the alarm design is not updated during system development – it was mentioned during an interview that "when there are 100 alarms in the old system – there will be 100 alarms in the new system", which is an example of the importance of a holistic scope with well thought-out interfaces between the various systems.

The following standards/guidelines/methodologies were mentioned by the respondents:
- ISO 11064, ISO 9241, Methodology from the Norwegian Design Council (2020) and Design Thinking from the Design Council (2007)
- Agile methodology (no ISO standards exist here)
- Verification and validation via CRIOP (2011)
- The YA-710 alarm standard, EEMUA 191 and existing alarm philosophies used by customers

5.3 Challenges faced by the projects relating to automation

In the following, we describe findings from the interviews together with our assessments/analyses which identify some challenges associated with the projects. These are described collectively under the following points:
1. Interfaces between operators and systems
2. Technology-driven development
3. Insufficient application of methods that structure the project work and Insufficient application use of techniques for meaningful human control/HF
4. What happens behind the systems/automation
5. Alarm management that safeguards control
6. Competence and training

5.3.1 Interfaces between operators and systems

There are a number of points which deal with interfaces between different suppliers, design companies, operators, drilling system operators, service companies, rig owners and other organisational units. In addition, there is a dimension that partly overlaps with this that is linked to the interface between multiple systems, particularly new systems that are to be incorporated into a wider existing network of systems on the installations. A general point would be that, in many cases, the operator's obligation to ensure compliance responsibility could have been incorporated into these interfaces to a greater extent.

System integration
The systems that are developed for drill floor often consist of many subsystems. In many cases, these subsystems are supplied by different suppliers, and it is vital to ensure good cooperation between the client and the system supplier to ensure that the systems are integrated and used appropriately. During a number of the interviews, a lack of good system integration was mentioned, along with the fact that this integration is difficult to achieve in a good way. Another challenge is that the subcontractors in the chain are not always aware of, or understand, the requirements imposed by the legislator.

In particular, one project described a learning process where the operator eventually acknowledged that dealing with several system suppliers with regard to the same drill floor was both complicated and challenging. This was particularly linked to system integration, e.g. where user interfaces in the form of screens are provided by one or more suppliers, while automated process control systems are supplied by another. Different suppliers often design screens and the logic between the various screens differently, with the result that it can take time to identify the problem if non-conformities are encountered.

The respondents believed that the PSA should encourage a proactive approach to bringing people together in order to discuss system integration and concrete plans systematically and as early as possible. According to the HF experts we interviewed, it would in this context be useful to draw up guidelines for different phases, which provides for verification and validation at the end of each phase. The aim of this is to enforce the demands to bring people together a little more – to establish mandatory design workshops and prioritise verification. One of the respondents pointed out that CRIOP was a suitable mechanism for supporting system integration, as the method facilitates the bringing together of suppliers and disciplines.

Collaboration between system suppliers

As explained above, one of the reasons for challenging system integration is the lack of cooperation between system suppliers. For example, the nature of the projects may be such that various suppliers are responsible for supplying control systems, while another is responsible for the actual technology that is developed (e.g. the robotic system). However, the actual work processes relating to the systems will be the responsibility of the rig owner and operator. During the development process, all the parties involved should be brought together to exchange information and think collectively. One point that was highlighted during interviews is that the drilling system suppliers are in competition with each other, and as a result there appears to be little interest in sharing negative experiences or challenges with other suppliers. Competitive advantages may be taking priority over transparency in some areas. As a result, it may take time for best practice to become widespread, and the ability to deal with non-conformities may deteriorate due to the limited sharing of experiences. Users have stressed that working with one responsible supplier has been a key prerequisite in the success of the project work.

Alarms from new systems – interfaces with existing systems

A number of the parties that we interviewed gave the impression that alarm systems and alarm philosophy, as well as tidying-up and training concerning alarms, are not always integrated into development projects. Some of the respondents explained that existing alarm systems and philosophies are often used. It appears that, in some cases, this has led to large numbers of alarms being triggered when the old alarms are connected to the new ones. Respondents explained that new alarms had been added which were not "intuitive" and that training and documentation relating to the new alarms and alarm texts had been inadequate. The phrase "too many alarms" was a recurring theme in the interviews.

The suppliers explained that alarms in connection with new systems are integrated with existing alarms in combined systems/existing PLC (Programmable logic controller) and from SAS (Safety and automation systems). It makes sense to combine alarms in common and existing interfaces, but this can result in alarms not being reviewed in a holistic way. This appears to have been given little attention. One possible contributory factor here is that it can be a major, complex and labour-intensive task. This is a time-consuming process and is sometimes carried out as individual reviews rather than continuously as new systems and fields are added.
The responsibility for satisfactory alarm management will rest with the person who has operator responsibility/ obligation to ensure compliance responsibility. There are many examples of major

and minor accidents caused by poor alarm management. This will therefore be an important interface to clarify.

5.3.2 Technology-driven development

Some of the respondents expressed great optimism about the future prospects for fully automating drill floor by allowing robots to take over repetitive tasks on decks, which will also help to improve safety. One of the challenges of involving humans (drilling crew) in modern drilling operations is stated as being the fact that weak signals in the event of non-conformities can easily be overlooked due to subjective assessments. A number of respondents referred to a preoccupation with technological development and the fact that it is technology that is driving development processes, rather than the needs of users. The consequences of this can be a process without sufficient involvement of users and expertise from experts on human factors. For example, it emerged during interviews with operators that incidents that have occurred in connection with the systems have not been discussed with participants with expertise in human factors. It was also noted by HF experts that a number of projects have utilised expertise and capacity relating to the human aspect at too late a stage, e.g. when 10% of the development process remains. At this stage, not enough changes can be made to the basic design. The HF experts in particular were concerned that the development process does not given sufficient consideration to human factors (human strengths and weaknesses). The development process appears to be driven by technological optimism. The results of the interviews indicate that the respondents generally believe that some system suppliers consider expertise relating to human factors to be important, while operators tend to make less use of such expertise internally.

Some respondents described examples of systems in other projects that had been developed with little technical drilling or user-oriented input. Examples of systems originally designed for onshore drilling have been developed by engineers without the involvement of end users, and the respondents stressed that this was very cumbersome for the user (this was based on past experience, the actual reasons were not given.) It also emerged during the interviews that some developers lack expertise concerning how to involve users in development and testing. The issue of user testing was mentioned as an example; the point should be to identify and test weaknesses in the system using systematic methods, rather than just get the acceptance of individual users. The developers who were interviewed pointed out the importance of having access to users and conducting systematic interviews with many such users. One positive example that was mentioned was a case where the developers were given several weeks to conduct systematic interviews with experienced users in order to collect and analyse experiences and user wishes. This improved the quality of the systems.

Another particular challenge highlighted by one of the suppliers was that the level of technological understanding in the oil industry is low outside its own scope. This was linked to the introduction of robotics. The supplier explained that it was challenging to get people to understand what robots can and cannot do. Extensive experience has been built up of the use of robots in other industries over the years, and it is believed that existing risk methods and standards could also be applied in the petroleum sector. There should be no need for any new standards or methods specific to the oil industry.

It was mentioned that a "standard" robot had been developed many years ago, which is adapted through minor modifications for each customer. The drilling and well sector faces a number of challenges that are not faced by other industries. Considerable customisation is necessary and no two rigs are identical due to the considerable variation in rig designs. In other industries, the trend is for off-the-shelf products to be created which can be sold to everyone. The oil industry is accustomed to bespoke solutions. It is therefore challenging for the industry to deal with standard products when it is accustomed to so much customisation.

During one of the interviews, the respondent mentioned that the fact that regulations, standards and procedures are adapted to current (old-fashioned) technology represents a challenge. This can result in those who carry out local maintenance and HSE departments "lagging behind a little". As regards standards, it was mentioned as an example that those who certify equipment onboard are considered to have little or no experience of robotics. This makes it difficult to get equipment certified when new technologies such as electric robots are used, instead of conventional hydraulic machinery for pipe handling. Those who certify equipment must possess relevant expertise in the field. If this is non-existent, there are both risks and uncertainties associated with the technology, and it takes up an enormous amount of time for the projects.

Participation in groups working on standardisation (ISA, ISO) can be a good arena for learning more about issues and solutions for both companies and public authorities (the authorities will typically participate as observers in such groups.)

User involvement at a sufficiently early stage

As a general observation, the respondents gave the impression during the interviews that good practice linked to early and good user participation should have been established and applied to a greater extent in the processes relating to technological development. During the interviews, we heard examples of advanced and expensive systems that were never used because of what was referred to as non-existent or low-quality user involvement. Similarly, examples were also given of projects that were rejected at the design stage due to input from users. This shows how important user involvement is in order to achieve successful projects.

One of the system suppliers highlighted challenges associated with actually gaining access to end users. This could be viewed in the context of the complex organisational interfaces within the projects. Furthermore, it points to a need for practices/methodology which ensure that the right players meet and cooperate at the right time during the development process.
In one of the projects examined in this study, there was considerable evidence of strong user participation at an early stage.

5.3.3 Poor use of methods to structure the project work and weak use of techniques for meaningful human control

Poor mapping can lead to a failure to understand what the general and detailed flows in operations should be like. Some examples were given which indicated that some aspects of systems had to be redesigned because user needs had not been adequately understood at the outset. The respondents referred to a number of challenges relating to sequencing and content in the development activities in the projects, as mentioned previously, the delegation of responsibility, planning of work processes and how user testing should be carried out.

It was noted that the delegation of responsibility and work processes came about more as a consequence of the technology. It was also mentioned that work processes are considered to be difficult to work with. A start should ideally be made at an earlier stage, but with R&D it is often a little unclear how much is being altered. It is apparent that work processes must be formalised in a better way than has been done to date, as inadequate work processes lead to uncertainty and confusion on the rig. Rigs also often struggle to identify weaknesses and deficiencies. The introduction of new technologies will always impact on work processes and, insofar as the technology can be adjusted and adapted, it would be natural to ensure that this is done at as early a stage as possible, not least in order to reduce costs. Some of the respondents wanted the PSA to help place the point about work processes and training on the agenda at an early stage in the process. We have received positive feedback from projects where the PSA has been involved in establishing responsibility for work processes and training.

Methods such as ISO 11064 contain best practices regarding the nature and timing of activities that need to be carried out in order to avoid resource-intensive additional work. Method descriptions will also contain descriptions of how tasks such as user testing should be performed.

Techniques such as "eye-tracking" are important in that they test how, in practice, users view fields on a screen in order to use the screen information, and how they find important information. None of the respondents interviewed indicated that eye-tracking technology is being used to improve human control. This is the case both during the design phase (e.g. in order to develop a good interaction design based on eye movements), and during the operating phase (e.g. to identify lack of vigilance). Examples of the use of "eye-tracking" to systematise information from many different systems can be found in Rolls Royce's project on Unified Bridge (2018) and the Norwegian Armed Forces’ experiences relating to high-speed boat navigation (Hareide, 2019).

5.3.4 What goes on behind the systems/automation?

A central theme in human-machine interaction is whether or not the human has an adequate understanding of what calculations/functions the system performs, if any, or how it performs them. For example, research in the aviation sector has shown that, at higher levels of automation, incidents have occurred (even though safety levels generally improve) which have escalated or not been rectified because the pilots did not understand what is happening to the aircraft.

The respondents noted that it could be a challenge to understand what was going on inside the automated systems. They mentioned that, when systems are automated, operators can lose situational awareness and fail to understand what will happen in the next stage. Users brought up this issue during the pilots, and they believe that this represents one of the biggest risks associated with new technology. The operators spend a lot of time training onshore in simulators and in classrooms, and will have an instructor with them during their first few months out on the rigs.

The respondents in our study explained that the systems have been switched off manually on occasions when they could have been used. This indicates that there is either no understanding of the systems’ areas of use and/or a low level of confidence in the systems. In addition, automated processes are switched off when limitations are exceeded, and it is then up to trained personnel to decide on further action. Respondents explained that, although they would like more help when determining subsequent actions through artificial intelligence, this feels a long way into the future.

One important point to follow up going forwards concerns the opportunities and knowledge that the operators have to take over when the automation fails or shuts down due to limited values.

Sufficient manual experience and expertise are then needed to take over in combination with good situational awareness (with an understanding of what is going on in the systems.)

5.3.5 Alarm management that ensures control

The sound development and management of alarms is of course important in all forms of management and control of critical processes. Alarms are equally important both with and without automation, but automated systems can often operate closer to the limits. If an automated system fails close to limit values, appropriate alarms and procedures will be even more important, as the human would then have narrower margins within which to operate. Based on the interviews, it appears that the systematisation of alarm management is not given sufficient priority during the development phase. This includes interfaces with existing alarms, the high number of alarms and the difficulty of understanding alarms.

Users have had to spend a long time searching for the fault. The wording of the alarms is not clear to users, although this situation has gradually improved, as has been noted.

5.3.6 Training

Many of the respondents were concerned about a number of issues linked to training. At a general level, it can be noted that technological development means that some platforms and rigs have to perform more complex operations than they were designed for. An example of this is "managed pressure drilling", where more companies and more equipment than is customary are involved offshore, which can result in roles and responsibilities becoming unclear. Training will be particularly important in such cases. The transition from manual to automated task execution has obvious implications for the skill requirements imposed on users. It is perhaps easier to underestimate the importance of competence and training in the management of situations when an automated system is unable to cope with the challenge and it is necessary to switch to manual task management.

This is challenging when the human operator has been out-of-the-loop. One of the system suppliers believed that it would not be necessary to train crews once robots had been introduced. This may indicate that a low level of understanding regarding the challenges associated with the interface between automated control and user management. Respondents in the study explained that the job now feels increasingly like a control room job and that it is noticeable that operators get less manual experience.

The main impression from the interviews was that user training is a low priority amongst the projects. There is a tendency for crew training regarding automated systems to be considered a less important requirement. It could be argued that many of the projects lack a standard way of determining whether the level of competence is sufficient to perform the tasks satisfactorily, e.g. based on a task analysis and a workload assessment. During one of the interviews, it emerged that drilling managers have been sent offshore without any training on the systems due to inadequate planning relating to holiday scheduling, cover staff/stand-ins, etc.

During the interviews, the respondents explained that scenario training is not used to any great extent, i.e. reviews of critical events/scenarios. One of the respondents explained that they had not “got around to thinking about it".

Advanced training simulators with extremely realistic responses and appropriate team exercises are in use and have been used ahead of challenging operations, but have perhaps not been used enough? It is a question of whether simulators should be used to a greater extent for training drilling crews to interact with automated drilling equipment, and that certification requirements should be introduced in the same way as they have in the aviation industry. During the interviews we conducted, there were indications that there are variations between companies as regards the extent to which simulator training is used. One of the system suppliers also offers simulator training, but it is unclear to what extent it is actually being used. One question which should be asked is whether it would be difficult in terms of time and cost to prioritise simulator training for the industry?

The development of relatively complex automated systems on drilling rigs which require specialised training represents a general challenge. Given the offshore rotation that takes place, the replacement of contractual partners and job changes, a lack of standardisation amongst systems could be an issue. It would then be challenging to ensure that drilling personnel possess the relevant expertise when moving between platforms/rigs, for example. A certification scheme for drilling operators and drilling crew could be one way of overcoming this challenge. During the interviews, the respondents gave the impression that there is little or no *team* training in connection with automated systems. It may also be that the current systems are currently relatively simple in nature and that training considerations will become more relevant as systems gradually become more complex. There have also been some positive experiences of training, which are considered further below.

5.4 What factors appear to have been the most important/positive for the projects?

All the parties who were interviewed expressed a positive view towards the fact that the issue of human factors in autonomous/digitalised systems is being placed on the agenda. The respondents referred to a need for a competence boost amongst both developers and certification organisations as regards human factors in autonomous systems. Some respondents also wanted to see more contact with public authorities in connection with development projects, while others believe that the PSA has been clear as regards requirements and expectations. In both projects, information was collected which indicated that there are numerous aspects which have contributed to those involved having a positive view of developments and implementation. The issues which were highlighted were as follows:

- Human factors prioritised by management
- Clear delimitation of the project and what constituted priority areas
- Good dialogue with the PSA
- Strong user involvement at an early stage
- Positive experiences with resources allocated to training
- Nuanced prospects with automation and robotisation of drilling operations
- Follow-up of human factors from operators represents a challenge

5.4.1 Human factors prioritised by management

The projects prioritised human factors and had a user-centred approach to development. One of the most important factors highlighted by the respondents was that the management prioritised the automation project and allocated funding and resources for its implementation, and that time was set aside for extensive dialogue and interviews with users. The respondents also pointed out that it was important to be able to carry out the project without having a fixed-price contract, as new user needs emerged on an ongoing basis and there was mutual learning between those involved.

5.4.2 Clear delimitation of the project and what constituted priority areas

It was noted that it was important that the framework conditions were established, such as clarity in the distribution of responsibility and a limited number of parties involved, at the same time as the introduction of technology was carried out via clearly defined sub-projects. In one of the projects, the operator stressed the importance of having a single operator for the solution that was being delivered and reducing problems associated with fragmented systems which provide different types of information. In the same project, the user perceived a clear delimitation as regards what the automation was contributing to during operations and which areas were being given priority.

5.4.3 Good dialogue with the PSA

The respondents who were frequently in contact with the PSA through meetings appreciated this dialogue and considered it to be a positive source of support for the project. The PSA helped to place a focus on the need to consider work processes and what aspects the training should cover. There was a desire for the PSA to encourage delegation of responsibility, work processes and training to be considered at as early a stage as possible (in accordance with good practice for project implementation).

5.4.4 Strong user involvement at an early stage

User participation is an important factor in ensuring that systems are perceived as being satisfactory and functional during operation. In one of the projects, the supplier has used agile "methodology" involving short iterations with end-user participation. From the user's perspective, developers have seemed responsive and taken into account the feedback they have been given. Experiences are collated from test users and then prioritised for coordinated feedback to the developer. By involving users at an earlier stage in these systems, it has also been possible to reject inappropriate solutions at an early stage, also leading to a financial incentive for early feedback from users. In one of the interviews, the respondent stated that the later versions of the software were "virtually unrecognisable" compared with the first version that was presented. It was also mentioned that other previous systems designed for drilling had been developed by engineers without the involvement of end users and ended up being cumbersome for users. During the interviews, the respondents did not refer to any challenges associated with managing the transition between automated operation and manual control, but they did mention that users now gained less manual experience. This transition is a known issue from other automated systems and should be managed as a risk by projects during both the development and operating phases.

5.4.5 Positive experiences with resources allocated to training

Some of the respondents referred to positive experiences of training and learning. For example, one developer has a full-scale test facility with robots which is used on the rig. In this case, users receive training regarding drill floor procedures, including situations where the robots is unable to determine what is happening, rendering it necessary to switch to manual mode. Another important aspect of the training is the reduction in work rate for robots in situations where humans are nearby, as cameras are not good at detecting the presence of humans. In one of the projects, users of the automated system have also been followed up following implementation. The rig owner has had a separate team which has travelled around rigs that have introduced the system in order to investigate whether the systems are being used as intended and ensure that users correctly understand what the systems should do. According to the respondents, this was seen as being positive.

5.4.6 Nuanced prospects with automation and robotisation of drilling operations

There are divided opinions over the future prospects for automation and robotisation of drilling operations. The robotisation of drill floor is considered to be a positive factor in improving safety levels by allowing robots to take over repetitive tasks, and enabling humans and the drillers cabin to be moved away from the drill floor. However, full automation is seen as being a long way off, as existing rigs are not designed for such automation and some tasks still have to be performed manually. Some respondents were finding that the previous trend towards relocating operational decisions onshore had reversed, and that the focus was now more on providing the drillers cabin with the support it needed. Data security was identified as an important reason for local control. As data security improves, it is likely that more tasks will be moved onshore and that drilling will be managed more as a process.

5.4.7 Follow-up of human factors from operators represents a challenge

Some of those interviewed found that the necessary attention to human factors is not reflected in the initial budgets of the projects. Technological development is given a higher priority during the initial phase. Although the cooperation between the stakeholders is working well and the need to include human factors is recognised, sufficient resources must be set aside at an early stage to ensure that these factors are given sufficient consideration and included. In other words, it will be important to ensure that the operators who are project owners clarify this need in budgets and follow up projects to ensure that human factors are part of the project. In general, support from management during project development and operators will be essential to ensure that human factors are placed on the agenda during project implementation. The HF experts who were interviewed explained that there are signs that the responsibility for ensuring that human factors are addressed largely rests with the developers, and that this is given little consideration by the management teams of the oil companies. More attention should be directed on ensuring that the project owner prioritises HF based on guidelines and standards.

5.5 Summary of the conclusions – what lessons can the PSA and the industry learn?

The interview review shows that the principal aim of technology projects is to improve safety. Based on the interviews and data collection, we have put forward some key points that the industry and the PSA could include as lessons to ensure that this becomes a reality. The key lessons and the parties they are most relevant to are summarised in Table 5.1.

Table 5.1 Lessons learned after the acquisition of information from the industry

Lessons	Industry	PSA
Use of good methods for planning and managing projects; [T2]& [T3]	X	X
User-centred development with safeguarding of users' skills and knowledge [T2]	X	X
Clearer involvement of the PSA at an earlier stage and during the process	X	X
Focus on ensuring that automation improves safety levels – but addresses the grey zones [T3]	X	
Learning from successful factors/projects [V5]	X	X

5.5.1 Use of appropriate methods for planning and managing projects

The methods used for structuring, planning and managing major technology projects should address interfaces between different suppliers, design companies, operators, drilling system operators, service companies, rig owners and other organisational units, to ensure that challenges are identified during the project in an appropriate way. In all such projects, there are financial and safety benefits to be gained by involving users at an early stage in projects. The use of "agile" development methods, with short iterations and the implementation of feedback, seems to be a good method. However, safety and human factors must explicitly be part of the development process to ensure that these considerations are adequately addressed. This also means that competence relating to human factors must be included. Work processes are perceived by many to be a difficult issue to include at an early stage during projects, an aspect which must be planned carefully from the start. During the interviews, the respondents indicated that work processes are included at too late a stage during projects. User-centring [T2] and methods that support meaningful human control should be supported [T3].

5.5.2 User-centred development with safeguarding of users' skills and knowledge

Users will continue to be part of everyday drilling operations for the foreseeable future. The review of the interviews shows that there are a number of aspects of training which appear to be being given insufficient priority: updating of manual experience, training concerning advanced drilling systems, absence of certification schemes, lack of scenario-based training, challenges relating to standardisation versus the tailoring of technology, and the assumption that little training is needed due to automation. The industry and the PSA should ensure that too much emphasis is not placed on users during the design of systems (i.e. methods for user-centred development should be used [T2]) and that training is needs-based, e.g. based on safety-critical task analysis or some other structured methodology throughout the development process and during the operational phase. This is also linked to the previous point. The certification of training, processes and equipment was mentioned by several respondents as one approach to ensure that the development of autonomous drilling systems satisfactorily addresses safety.

5.5.3 Clearer involvement of the PSA at an earlier stage and during the process

At a general level, there is reason to argue that the PSA should more closely monitor whether operators are fulfilling their responsibilities in connection with major development projects based on new technology. This also appears to be something that is wanted by the industry. In order to have the greatest impact, the PSA should focus most on the early phases. The parties involved should use appropriate methods which structure the project process. Verification and validation of the process can offer significant benefits. During verification and validation, it is possible to evaluate whether the parties involved are using the right expertise and facilitating frequent user involvement at an early stage. It is important that the trust-based system is supplemented by verification and validations. (As an example of this, it was mentioned that HF consultants were tasked with improving HF in one project, by looking at organisational and operational barriers ahead of an inspection by the PSA. When the inspection was cancelled, the operator saw no reason to consider the HF aspects linked to organisational and operational barriers further.)

5.5.4 Focus on ensuring that automation improves safety – but addresses grey zones

As regards whether the introduction of more automated technology and robotics will contribute to higher levels of safety, it is important to point out that it is vital to ensure meaningful human control if the new technology is to improve safety levels, [T3]. The experience that has so far been gained concerning automation generally shows that it offers positive effects for safety, assuming that risks have been managed appropriately. However, there are a number of questions which must be answered regarding certain grey zones which were identified during the review of the interviews, including the extent to which risks are taken into account in the phases between automated and manual handling and the interaction with the degree of both initial and refresher training amongst users. Another grey area is alarm management with new technology. There is also a question as to what extent the projects capture accidents and incidents. The industry should focus on these factors in order to realise the safety benefits.

5.5.5 Learning from successful factors/projects

Many aspects of the projects we have examined have had a positive impact on safety levels, efficiency and quality in connection with the introduction and development of technologies. This is for example linked to early user participation, the follow-up of training, delimitations relating to the use of the fewest possible suppliers, as well as management priorities. The industry should give greater priority to identifying successful factors that other stakeholders and projects can learn from. This could, for example, be achieved through developing best practices and arranging working meetings under the auspices of the industry, [V5].

6 Reflections and proposals for supervision and a regulatory framework for automation

6.1 Structure of the regulations

The Norwegian petroleum industry is regulated through various laws and regulations. The PSA believes that these regulations ensure that stakeholders who intend to carry out key activities during specific phases of petroleum operations must obtain permission, consent and approvals for the work that is to be carried out. According to the PSA, the purpose of such a rules-based system is to ensure that the operations of enterprises on the Norwegian continental shelf are subject to satisfactory management and control throughout the entire life-cycle of projects, including exploration, start-up, development, recovery and completion of activities.

The Norwegian Petroleum Act (*petroleumsloven*) and Working Environment Act (*arbeidsmiljøloven*) are the two most pivotal laws for the regulation of Norwegian petroleum operations. The former concerns general safety requirements, while the latter addresses overarching requirements regarding the working environment. The PSA's supervisory activities are also anchored in the Pollution Control Act (*forurensningsloven*) and the Fire and Explosion Act (*brann- og eksplosjonsloven*), which thus fall within the scope of the supervision exercised by the authority. In addition, there are the governing laws, such as the Pollution Control Act and the Health Professionals Act (*helsepersonelloven*).

It is through regulations that the Petroleum Safety Authority Norway regulates operations on the Norwegian continental shelf, more specifically through specific HSE regulations which cover petroleum operations and through working environment regulations. There are five specific HSE regulations which are applicable, and the supervisory authority has been delegated both authority to prepare and adopt provisions in the regulations, and responsibility for enforcement. The five regulations are:

- The Framework Regulations
- The Management Regulations
- The Facilities Regulations
- The Activities Regulations
- The Technical and Operational Regulations

The scope of the HSE regulations means that, in some cases, issues are the responsibility of several public authorities, which in turn means that the regulations must be viewed reciprocally and in the context of each other, as well as in relation to the governing laws.

Furthermore, the Ministry of Labour and Social Affairs has established six common regulations for the Working Environment Act, *the Working Environment*, Regulations, which in turn are enforced by the Petroleum Safety Authority Norway and the Ministry of Labour and Social Affairs within the assigned areas of authority. The Petroleum Safety Authority Norway points out that the requirements set out in these six regulations must be integrated and followed up through the comprehensive HSE regulations covering petroleum activities. For example, one of the working environment regulations focuses on organisation, management and participation, with requirements relating to risk assessment, employee participation, as well as training and planning of work. The aim is to organise and facilitate the work in such a way that workers are guaranteed a satisfactory working environment. Furthermore, the Regulation on the design and organisation of workplaces and work premises (the Workplace Regulation) covers general provisions relating to the physical design of offices, with the aim of safeguarding workers' safety, health and welfare of workers based on any specific risks.

A key component of the regulatory provisions are the guidelines which are intended to describe how the provisions in a regulation can be fulfilled. According to the Petroleum Safety Authority Norway, these two components (regulations and guidance) must be viewed in context in order to satisfactorily meet the requirements stipulated in a regulation. An important aspect in connection with the provisions in a regulation concerning, for example, human factors linked to automation will be the application of specific norm-based standards in the guidance, which are intended to set out recommendations linked to how regulatory requirements can be fulfilled. Furthermore, standards are only guiding, which means that industry players are also free to choose alternative solutions other than those described in the guidance. However, players who choose a solution other than the standard recommended in the guidance must be able to demonstrate how their chosen solution fulfils the minimum requirements of the Regulation(s), as Section 24 of the Framework Regulation and the associated guidance on the use of recognised norms explains. The guidance concerning Section 24 also illustrates for example that interpretation on behalf of the responsible party is also a factor as regards the level that is considered to be sufficient when an alternative method or approach is chosen which differs from that assumed in the guidance.

Table 6.1 lists the regulations in the form of the HSE regulations and sections where some contain references to standards for human factors in the guidance which are relevant to automation.

Table 6.1 Regulations and examples of sections which explicitly refer to human factors.

Regulations	Sections which refer to human factors	Topics of relevance to Automation
The Management Regulations	Section 13 Work processes Section 16 General requirements regarding analyses Section 18 Analysis of the working environment	MTO perspective Methods for analysis of HSE conditions Relevant use of automation
The Facilities Regulations	Section 20 Ergonomic design; Section 21 Human-machine interface and information presentation; Section 34a Control and monitoring systems	Adapt to use
The Activities Regulations	Section 34 Ergonomic conditions Section 35 Psychosocial conditions	Adapt to use
The Technical and Operational Regulations	Section 21 Human-machine interface and information presentation; Section 33a Control and monitoring system	Adapt to use

A review of the Framework Regulation and Section 17 indicates that it concerns the obligation to establish, follow-up and further develop control systems. This is a topic which is relevant to automation in that users are involved (Table 6.1). The section refers to the fact that employees must contribute to the establishment, follow-up and further development of control systems. A review of the associated guidance for Section 17 indicates that it is explained in more detail that workers' experiences and active involvement are essential prerequisites for an effective control system. However, the detail given in Section 17 of the guidance remains at a general level, but the section also refers to Section 13, where workers' rights are regulated in more detail. It is clear from Section 13 that the employer is obliged to ensure that the collective knowledge and experience of workers of relevance to HSE is taken into account in connection with various decisions. Workers must be given a genuine opportunity to influence the company’s working environment and safety, and concrete plans should also be drawn up for employee involvement in the case of comprehensive cases. However, Section 13 again refers to Section 4-2 and first paragraph of the Working Environment Act, which stipulates that workers and their union representatives must participate in development work linked to the planning and organisation of the work, which involves, for example, the formulation of methods, procedures and instructions relating to their own work situation.

Section 13 of the Management Regulations also refers to the need to ensure interaction between human, technological and organisational factors, in particular that the responsible party must ensure that the work processes and products from these fulfil relevant requirements regarding health, safety and the environment. This means that work processes and interfaces between different processes where HSE is a factor are formalised through clear descriptions. However, the level of detail in the descriptions must be adapted to the importance of individual processes as regards HSE risk, which requires the responsible party to be actively involved and possess expertise. However, the guidance to Section 13 is clear as regards what is meant by ‘work processes’, citing NS-EN ISO 9000. NS-EN-ISO 9004 Chapter 8 is referred to in connection with how a work process should be formulated. The guidance is also clear that HSE and safety consequences arising from interactions between humans, technology and organisations should be systematically assessed against the various phases of the work processes. For example, when describing interfaces between work processes, dependencies should be accounted for, which illustrates the level of detail that the guidance is aiming for.

Section 16 of the Management Regulations focuses on how analyses should be carried out to ensure satisfactory HSE conditions. The section notes that the responsible party must ensure that analyses are carried out which provide the necessary background information to enable decisions to be taken in order to safeguard health, safety and environment. Section 16 also notes that recognised and appropriate methodologies must be used, including the purpose of the analysis, assumptions and necessary delimitations used as a basis for the analysis. There is also a requirement which stipulates that the party responsible for the operation of a facility or onshore installation must ensure that criteria are defined concerning when updated or new analyses will be necessary. New analyses may be required as a result of changes to the framework conditions that formed the basis for understanding the risk associated with the operation.

The guidance to Section 16 notes that the term ‘analysis’ in the Regulations entails a broad understanding, and that more detailed requirements regarding the individual analyses can also be found in other sections of the other regulations. It is worth noting that the guidance stipulates that *recognised* methods and models will involve an almost scientific approach to the quality assurance of method selection, including a requirement for the chosen method to be tested and validated in advance. Furthermore, the guidance stipulates that the representativeness, validity and limitations of the data must be highlighted. As regards appropriate methods and models, the responsible party must start from the purpose of the analysis and the need for decision-making support, which presents the responsible party with a range of choices.

The Management Regulations and Section 18 (analysis of the working environment) stipulates that the responsible party must carry out the necessary analyses to ensure a satisfactory working environment and provide decision-making support in connection with the selection of technical, operational and organisational solutions. However, the focus in Section 18 is placed on the conditions of individual workers, rather than, for example, a future major potential accident linked to a specific choice of technical solutions which entails a high level of automation. Further consideration of the guidance to Section 18 reveals a more detailed description of the factors associated with the working environment which is to be analysed. However, the analysis of the working environment must be viewed in relation to the use of chemicals, exposure to biological factors, mechanical vibrations, and the performance of manual work against the risk of harmful impacts – no reference is made to issues relating to interaction and the use of technology from a human perspective, for example. However, the guidance refers to ISO 11064 Part 1 as a standard that should be followed with regard to analysis of the working environment and the design and staffing of control rooms.

The Facilities Regulations and Sections 20, 21 and 34a address ergonomic design, the human-machine interface, including information presentation, and control and monitoring systems. Both sections (20 and 21) provide general descriptions concerning the intention, noting that the primary aim is to avoid human error. The guidance to the former also refers to NORSOK S-002N and specific chapters, while the latter guidance also describes NORSOK S-002, as well as the standards EN 894 Parts 1-3 and NS-EN 614 Part 1, including specific addenda. For its part, Section 34a stipulates that facilities must have control and monitoring systems which, along with associated alarms, warn of incidents, non-conformities or faults of safety importance. It also stipulates that alarms must be given in a way which ensures that they can be perceived and processed in the time that is required to ensure the safe operation of equipment, facilities and processes. A review of the guidance to Section 34a indicates that this begins by referring to the fact that control and monitoring systems should relate to Norwegian Oil & Gas guideline no. 104 (NOROG 1014) relating to IT protection. Furthermore, it is noted that alarms should be defined and designed in such a way that they are relatively simple to register and understand, and clearly show where any non-conformities and hazards havearisen. At the same time, it is noted that alarm systems facilitate the suppression and reduction of alarms, so that mental overload is avoided during operational incidents and accidents. The guidance notes that the EN 62682 and EEMUA 191 standards should be applied.

Technical and operational regulations explicitly focus on the human-machine interface through Section 21, in which it is stipulated in the regulations that technical equipment for monitoring, controlling and managing machines, facilities or production processes must be designed so as to prevent errors which could have safety implications. Furthermore, it is stipulated that the necessary information must be presented quickly and simply, and that the information that is presented must be correct and readily understandable. It is also noted that the information systems must be dimensioned for both normal and critical situations. The guidance to Section 21 notes that an analysis of the human-machine interface should be carried out, including task and function analyses as necessary. The guidance states that standard NS-EN 614 Part 2 should be applied. Furthermore, it is stated that the design of control rooms should follow the ISO 11064 standard.

6.2 Summary - Structure of the regulations - Some reflections

Based on the findings of the project's activities, as well as the structure and content of the current regulations, we reflect below on certain issues relating to regulations, human factors and automation. The discussions are linked to a technological anchoring of the regulations, followed by a stakeholder group in the sector with a higher degree of complexity, which makes it natural to reflect on the extent to which this can managed through the current regulatory structure. Finally, we discuss the functional regulations, including the level of safety that should be expected amongst operators.

Technological anchoring of the regulations

The way in which a question is asked will often be reflected in the answer that is received. If one considers the content of the regulations, associated guidelines and standards from the perspective of a *thematic emphasis,* it could be argued that, with regard to issues that specifically deal with and could be associated with human factors and technological automation, there is often a technological anchoring. An example is Section 18 of the Management Regulations and associated guidance, where factors relating to the working environment linked to the use of chemicals and exposure to biological factors are given emphasis, while factors relating to human factors interfacing with technological infrastructure are not considered.

Sections 20 and 21 of the Facilities Regulations note that human error must be avoided, an approach to safety which can be associated with a 'Safety-I' mindset, where the idea is to identify causal factors and implement measures to combat incidents in the future, usually by focussing on compliance. This is also reflected in the use of the *barrier concept* in certain sections of the regulations, e.g. Section 5 of the Management Regulations, which gives an account of barriers and refers to organisational barrier elements linked to the maintenance of an effective barrier function. The application of a barrier concept illustrates a certain degree of technological anchoring of human and organisational factors too, along with a preoccupation with avoiding errors per se. In such a context, a somewhat more *proactive* approach to safety management could also be imagined, something that the tradition of resilience engineering and a perspective like sensemaking represent. Such an approach could possibly be viewed in the context of emphasising and acknowledging the understanding of factors which lead to things actually going well in day to day processes. In relation to technical operational regulations and Section 21, it is noted that information systems must handle both normal and critical situations. Section 34a also refers to the need to avoid mental overload, which makes one as a reader want to know what such conditions actually entail, an issue which becomes more relevant with increasing levels of automation for operators and the human-automation interaction.

However, the current regulatory structure is also the result of the expertise that forms the basis for what is emphasised. The Petroleum Safety Authority Norway also notes that there is a need for clearer and more applicable HF standards linked to automation, which highlights the issue of how professional expertise relating to HF can be made more visible in connection with the formulation of regulations in the future.

Functional requirements and what is actually good enough

The characteristic of a functionally based regulatory framework is to identify requirements for functions which indicate the expected level of safety, while leaving it to the stakeholders involved to decide how that level of safety should be attained in practice. According to the Petroleum Safety

Authority Norway, the companies themselves are responsible for complying with the HSE legislation, but are free to decide on their approach themselves. The aim is to make stakeholders in the industry responsible for the planning and execution of operations and, in this context, to facilitate flexibility regarding the choice of methods, approaches and technological development.

The petroleum industry is currently also characterised by numerous new players with little or no previous experience of the industry, which occasionally leads to situations where players have a different understanding of the way in which the regulations are intended to address risks compared with traditional petroleum operators. At the same time, drilling and wells often entail complex processes and, in such a context, particularly in relation to human factors, a good dialogue between the supervisory authority and the parties involved is important. A regulatory forum could also be a resource here. The importance of a common understanding of reality between industry players and PSA must not be underestimated, as the findings from the workshops and interviews confirm.

There is also a paradox associated with functionally based regulation in such a context – on the one hand, the players themselves must take responsibility for the way in which functional requirements are complied with, and there is probably a need to clarify in more detail what, for example, constitutes the minimum acceptable level of safety linked to the human-automation interaction. In particular, it will be important to clarify what requirements the regulations impose, and in relation to human factors and the automation of technology, standards should be an important resource, which raises issues relating to current and available standards within the field of HF (see Chapter 6).

Through the project, a need for clearer standards has been identified in order to support the guidance. In this context, it is, as mentioned above, natural to ask whether standards should be more than guidance, which would lead to a need to revise the current regulatory structure, and as part of this to discuss *where* responsibility for compliance with the functional requirements should lie. However, regardless of this, a stance must still be adopted as to what will be *good enough* linked to the human-automation interaction in a risk-reducing perspective, and how this should be clarified to the industry. The review of the regulatory structure indicates that greater emphasis could be placed on the highlighting of relevant HF standards and what this means in practice for operators. Could more guidance be made available on the Petroleum Safety Authority Norway's website, and if so, could it be formulated in a more applied way? The project has also identified a need amongst stakeholders for a more active Petroleum Safety Authority Norway linked to expertise relating to technology that is being developed - that the safety authority is also able to enter into a dialogue on a daily basis to a greater extent, e.g. with regard to compliance with applicable standards. However, continuous updating with regard to technological advances would represent a challenge for the supervisory authority.

The above findings are also relevant regardless of whether the issue is HF, automation or regulations. The experience of other industries such as the transport and aviation sectors has revealed the practical consequences of insufficiently understanding the drawbacks of pilot - automated system interaction, including through the regulations (during time-critical events); ref. the Air France 447 and Boeing 737 Max accidents.

7 Relevant Human Factors standards and guidelines

The purpose of this section is to identify important methods and best practice linked to the way in which human factors should be addressed in connection with the development, testing and implementation of automation, robotics and digitalisation. We want to highlight relevant HF standards and good practices which reduce costs and problems associated with their introduction, which in turn will help to reduce the risk of major accidents in, help to reduce HSE burdens on the environment and employees, and increase the sharing of good practice which improves HSE.

General arguments for referring to standards in the regulations are:
- to improve practice by using the regulations to establish minimum standards
- to make it easier to follow up those who are lagging behind with regard to best practice in the sector
- the need for regulatory requirements when the HSE consequences could be considerable

The interviews and data that has been collected indicate that the level of attention paid to human factors has diminished. The necessary knowledge has not been maintained and technology is the most important driver. Nevertheless, we have seen that higher levels of automation and user-centred development within the design community have led to increasing interest in HF. However, few professionals possess expertise relating to human factors/psychology in the industry (in both the supervisory authority and amongst key players.) The requisite standards have not been incorporated into the regulations. Attention to physical ergonomics (seating, light, temperature, air quality) has been taken care of, but little attention has been paid to essential cognitive standards and organisational HF. This gap becomes clearer and more challenging as the level of automation and digitalisation increases, without the prerequisites for the role of humans being clarified with regard to human limitations and opportunities.

We propose that the Framework Regulations and Management Regulations be updated and include references to recognised principles “Principles and Guidelines for Human Factors/Ergonomics (HF/E) Design and Management of Work Systems", as described in IEA/ILO (2020). User-centred design should be incorporated, together with the principle of meaningful human control. In order to support user understanding, key standards for interaction design (the ISO 9241 series) should be established, along with references to technical standards such as ISA 101.

The section comprises two parts – the first part relates to the standards for HF; this is followed by a brief list of specific standards linked to safety considerations associated with robotisation and digitalisation.

7.1 Standards and guidelines relating to human factors and autonomy

In the following section, we describe the existing application of standards established in the regulations, and go on to list some relevant standards that are lacking. We then present proposals for standards and guidelines for human factors which should be incorporated into the regulations.

The regulations and selected sections concerning human factors (ideally as part of the concept of MTO) are listed in Table 7.1. Here, we have added the HF standards that are referenced in the guidance.

Table 7.1 Regulations and sections which currently refer to human factors

Regulations Regulation	Sections which refer to human factors/MTO	HF themes referred to in the guidance
Framework	Section 13 Arrangements for employee participation Section 17 Duty to establish, follow up and further develop management systems	"workers and their union representatives shall participate in development work relating to the design and organisation of the work within the enterprise", but no approach or standard is cited
Management	Section 13 Work processes Section 18 Analysis of the working environment	Refers to MTO, but does not highlight design, cognitive or organisational factors. Does not mention any requirement for a knowledge of human factors. Refers to NORSOK S-002N and ISO 11064 Part 1.
Facility	Section 10 Installations, systems and equipment Section 20 Ergonomic design; Section 21 Human-machine interfaces and the presentation of information; Section 34a Control and monitoring systems	ISO 11064 to prevent human error Does not highlight cognitive/organisational factors, NORSOK S-002N and ISO 6385 NORSOK S-002N, EN 894 and NS-EN 614 EN 62682 and EEMUA 191
Activity	Section 33 Work arrangements Section 34 Ergonomic conditions Section 35 Psychosocial conditions	ISO 6385 NORSOK S-002N
Technical and operational	Section 7 Installations, systems and equipment Section 21 Human-machine interfaces and the presentation of information; Section 23 Ergonomic design Section 33a Control and monitoring systems	ISO 11064, avoiding human error NS-EN 614 and ISO 11064 ISO 6385 EN 62682 and EEMUA 191

This table gives an indication of the current status of the use of standards in the regulations. The provisions of the Management Regulations and Framework Regulations emphasise user participation, involvement and good work processes without actually referring to relevant standards. By highlighting greater substance in the guidance, this approach can be supported through good practice. The Norsok S002N standard is mentioned; this is a standard which covers physical ergonomics. Norsok-S002N was updated and published in a new version in 2018, albeit with some disagreement concerning content and some criticism linked to cognitive factors, organisation/distribution of responsibility, verification and validation. The criticism was not taken into account, and several members resigned from the working group as a result. When the standard is next revised, reference should be made to the principles of interaction design and the importance of consensus/involvement of those working with cognitive and organisational standards as a starting point.

ISO 11064 is a recognised standard which describes good practice for development, which can often be referred to as good practice for user-centred development which takes account of the MTO perspective.

EN 894 and NS-EN 614 are relatively detailed standards, and focus more on purely ergonomic factors rather than cognitive factors. The area for standardisation may be broad, but we have assumed that use of the standards in the regulations should provide a framework and context for the work based on a somewhat broader MTO structure, as described in IEA/ILO (2020), i.e. based on a development methodology which describes the stages involved in the development with a listing of standards for key areas, where EN 894 and NS-EN 614 can be included. We propose a subdivision into the following two areas:

- General principles and methods for development of relevance with regard to the Framework Regulations and the Management Regulations
- Key standards for interaction design and alarm management

7.2 General principles and methods

At an overarching level, linked to the Framework Regulations and the Management Regulations, we have standards which cover system approaches and user-centred design. Important principles at this level are referred to in IEA/ILO (2020):

These are principles that are based on good practice and can be incorporated into the regulations. The principles should be referenced in the guidelines. Examples include "User-centred design" and "meaningful human control". We have seen from specific projects that this allows the technology to receive solid user support more quickly and enables the quality of use and understanding of what is happening to be improved, which are general findings (Vredenburg, 2002), and it also enables the quality of the solution as regards HSE to be improved.

Relevant standards for development must describe the process of development and techniques that can support the various tasks that are described. An overall description that can be used for management systems generally is presented in ISO 11064 - Ergonomic design of control centres. The standard also presents a description of a phased method with an emphasis on strong user involvement and the iterative design of systems. The method provides a framework for the development of general control systems, and describes in detail elements in a control centre with interactive systems. The methodology is designed to improve both performance and HSE levels, rather than to simply "reduce the likelihood of human error", as noted in the regulations. The statement that ISO 11064 should be applied should be mentioned at an early stage, i.e. the Framework Regulations and the Management Regulations, aimed at design and used to bring about better performance, improved HSE levels and meaningful human control. It should be clarified that "human errors" are a consequence of poor design (Dekker, 2002).

7.3 Key standards for interaction design and alarm management

Key recognised standards linked to interaction design relating to control systems are set out in the ISO 9241 series:

- 200 series: "Human system interaction processes" and in particular ISO 9241:210 (2010) "Human-centred design for interactive systems", and

Key principles for human-centred automation are listed in Lee et al. (2017) "Designing for People", section 11.5 *Fifteen principles of Human-Centred Automation*. Similar principles are referred to by Endsley (2019), and in MITRE (McDermott et al. 2018). AI is already in use and is expected to be used even more extensively in the future (Bello et al., 2015; Kirschbaum, et al., 2020). The use of AI is under development and should be an issue for further work [V7]. An important principle for a higher degree of automation and AI is that the user must always be able to take over control of the systems, more precisely that meaningful human control must be possible.

ISA 101 Human-Machine Interfaces (specifically ISA 101.01) is published by the International Society of Automation. There is a relevant standard which focuses on important principles in the design of HMI, i.e. that interfaces with operators should be simple and based on a task analysis. ISA-TR101.02-2019, describes "HMI Usability and Performance".

Standards for interaction design must describe guidelines regarding the use of colour, structures for dialogue, support for alarm management, and the way in which an overview is ensured. It may be important to have several sources of information to ensure high-quality situational awareness and sensemaking. A useful reference regarding the design of monitors is the "High-performance HMI Handbook" (Hollifield et al., 2008). The standards are supported by ISO 9241 (e.g. 210) and ISA 101 Human-Machine Interfaces. An important principle for interaction design is to make the interaction simple and task-oriented. Task analysis is pivotal to all design work and task organisation, and should be carried out (Smith et al., 2020; Lee et al., 2017).

Relevant standards for alarm management are documented in EEMUA 191 and in standards developed under the auspices of PSA, including YA-711/710 which is openly available. Technically oriented standards include IEC 62682 Alarm Management.

7.4 Suggestions for key standards for attention to human factors

Based on the review of existing standards, findings from the interviews and findings from the investigations, we have listed gaps and proposals for principles and standards which should be established. The proposals are listed in the Table 7.2.

Table 7.2 Proposals for updated regulations and references relating to human factors

Regulations Regulation	Gap with proposed measures	HF perspectives and standards which should be incorporated into the guidance
Framework	Experience from the industry and the investigations strengthens the need for user-centred development and a focus on HF [T2]. Sections 13 and 17 lack more specific guidance regarding how workers should be involved in the development process. Based on good experience of user-centred development, principles from user-centred development should be mentioned.	Attention to user-centred design, which should be incorporated as a principle in connection with the introduction of automation and a higher level of digitalisation. IEA/ILO (2020) should be a key reference concerning the introduction of new technology such as automation and digitalisation
Management	Section 13 Work processes should highlight the user-centred design of systems which take account of cognitive and organisational factors. Should mention a requirement for a knowledge of human factors. The principle of meaningful human control should be incorporated. [T2]& [T3]. Section 18 Analysis of the working environment	Prioritisation of user-centred design, with a reference to IEA/ILO (2020); and the principles of the ISO 9241 series should be incorporated (particularly 210). Users must understand the systems if they are to intervene, i.e. "meaningful human control". Still NORSOK S-002N & ISO 11064 all parts (need not be limited)
Facility	For Section 10, the aims of ISO 11064 are to not only reduce human error, but also to support human performance, improve HSE – and support meaningful human control [T3]. In Section 20 and Section 21, greater attention is needed on cognitive/organisational factors, which are referred to in IEA/ILO (2020) and ISO 9241:210. [T2]& [T3]. In Section 34a, YA710 can be referred to – it is precise and identifies key aspects. This is freely available	Highlight IEA/ILO (2020), ISA 101 and ISO 9241:210 in Sections 10, 20 and 21 Continued reference to NORSOK S-002N and ISO 6385; EN 894 and EN 614 EEMUA 191 and YA710
Activity	Sections 33, 34 and 35 - attention to cognitive and organisational factors;	Highlight IEA/ILO (2020), ISA 101 and ISO 9241:210 ISO 6385, NORSOK S-002N
Technical and operational	In Section 7 Facilities, systems and equipment, the purpose of ISO 11064 is to not only reduce human errors, but also to optimise HSE and establish meaningful human control. Section 21 Human-machine interfaces and the presentation of information; Section 23 Ergonomic design	General: Highlight IEA/ILO (2020), ISA 101 and ISO 9241:210, still use ISO 11064 NS-EN 614 and ISO 11064 ISO 6385, ISO 9241:210,

	Section 33a Control and monitoring systems	EN 62682, EEMUA 191 and YA710

7.5 Standards and guidelines linked to technical development - automation

There is an ongoing trend involving a switch from automated systems operating in isolation from users with barriers and protection (such as isolated metro systems) to an arrangement where systems are integrated into operations close to the users, e.g. autonomous vehicles and drones used for air transport (Guiochet et al., 2017). Alternatively, operational functions may be relocated and centralised further away from the production process that is being controlled. The increasing introduction of automation and autonomous operations via robots will require appropriate procedures and standards during the development of solutions and appropriate procedures for risk assessments and operational procedures. We have therefore listed some guidelines relating to development, followed by a list of relevant standards and practice memos which describe a framework for risk assessments and standards for operational activities.

7.5.1 Standards for the development of solutions

The starting point for the development of standards is based on having a specification of requirements which describe the system as a whole, i.e. from a system perspective as described in Figure 1.1, with a description of the interface with users, necessary support from infrastructure, interfaces with other autonomous systems and interfaces with control systems (if necessary). Concept development can often entail radical innovation, but should address the interface/contact with users, as outlined above, e.g. via IEA/ILO (2020) or ISO 11064, to ensure that the principles of "Fitts list" (De Winter et al., 2014) are safeguarded, i.e. ensuring that human limitations and opportunities are addressed.

The development of software for automated systems and autonomous systems also requires methods and standards, ranging from "waterfall standards" to standards for agile development. Methods for the introduction of systems depend on whether readymade package solutions are to be used or whether programming and inhouse development are necessary. Standards, guidelines and development methods should be established in all development projects which include analysis, development, testing and the establishment of appropriate routines and procedures. For the development of critical systems and programming of automated systems, it is most important to point out that standards, guidelines and methods must be established. However, we believe that it is important to mention agile development as an important contribution to the rapid development of high-quality systems. This has become increasingly important in recent years, as systems have to be "patched" more rapidly and more frequently, partly as a result of security challenges.

Iterative and incremental software development which is an important part of agile development began back in the 1950s. Agile development was placed on the agenda in 2001 through the "agile manifesto" (Beck et al., 2001). Initially, agile development was only used in the development of general software and is now used worldwide. The methodology is so effective that it is also used in the development of instrumented safety systems in other industries.

In 2011, SINTEF and NTNU began the development of SafeScrum (Hanssen et al., 2018), which is used in the development of critical software and instrumented security systems. Both agile software development and SafeScrum involve the customer (operators, etc.) to a greater extent than is the case with normal software development. One of the principles of agile development establishes the following principle: "Our highest priority is to satisfy the customer through early and continuous deliveries of software which has value". SafeScrum and other similar approaches have become increasingly popular within all security domains. Agile methods are now being used by most suppliers to a greater or lesser extent. SINTEF sent an enquiry to all relevant certification bodies that the Norwegian supply industry uses regarding SafeScrum. These certification bodies responded that they accept SafeScrum as a development process. In most projects, aspects of the safety life-cycle (e.g. “Waterfall” and “V model”) are combined with SafeScrum or other similar approaches. In IEC 61508, the committee switched from being somewhat sceptical towards agile methods in 2014 to the view that agile methods are acceptable. Greater account of this is taken in the next version of the standard. SafeScrum is also permitted in relation to the current version of the IEC 61508 standard. It is of course necessary to satisfy all applicable requirements and perform all relevant analyses even when using agile methods. Documentation has long been a challenge both in general and within the petroleum industry in particular, not least when developing security-critical software. SINTEF and NTNU have therefore developed an agile approach to documentation by developing a methodology for "agile documentation" to confirm that products/systems are safe (Myklebust et al., 2018).

The most important requirement in connection with the development of automated and autonomous systems is that there is a standard method which defines requirements regarding how the development should take place, and how testing, documentation and procedures for use should be addressed. The need for certification, quality assurance and approval of the system should be clarified.

7.5.2 Standards for the risk assessment of automated systems (including robotisation)

The systematic risk assessment of equipment and new technology forms an integral part of the regulations, but it is still important to highlight existing and new standards that should be applied. Moreover, we also believe it is necessary to refer to good practice for the use of autonomous systems, and, in this context, refer to a standard for the use of autonomous systems in mining which lists the practice of risk assessments and operations (Bolsin, 2018; Department of Mines and Petroleum (2015).

Relevant standards for the risk assessment of automated/autonomous systems (and robots) must be based on the Machinery Regulation (the Regulation on Machinery) of 20 May 2009.
A hierarchy for safety standards which define the necessary guidelines (and good practice) for robotisation is listed below, from the general to the more specific:

Table 7.3 Hierarchical overview - safety standards and good practice for robotisation

Standard	Remarks
	Overarching standard – see also ISO/DTR 22100-5:2020 “Safety of machinery — Relationship with ISO 12100 — Part 5: Implications of embedded Artificial Intelligence-machine learning" (AI introduces greater uncertainty)
	Consider various "hazards", award scores, can they be prevented, discuss consequences, etc.

	Use of robots in industrial contexts— Part 1: Robots; — Part 2: Robot systems and integration
	The standard lists and discusses safety features that may be of relevance
Standards - security for safety	
NOROG -104 Recommended guidelines and requirements regarding information security levels in IT-based process control, security and support systems	Overarching guidelines for safety (and security), developed in cooperation in the petroleum sector, based on Johnsen et al (2008).
	Important for security for control systems and describes, amongst other things, certification schemes that should be implemented. (The standard is recommended for use in the petroleum sector in Norway).
	May be relevant, but does not discuss physical contact between equipment and user. The machine-specific variant is IEC 62061.

7.5.3 Summary of key standards that should be given more attention

Key recognised standards relating to interaction design for control systems that should be incorporated into the regulations are as follows:

- The ISO 9241 series: Alarm management is a vital prerequisite for managing complex operations, and best practice within alarm management should be followed up via EEMUA 191, for example.

Good practice for risk assessment and safety should be applied. The standards that address this area are:

The securing of infrastructure and systems should be addressed via the IEC 62443 standard and the certification schemes it recommends based on framework conditions provided by NOROG 104.

A gap between actual practice and HF standards was highlighted during the interviews. User-centred design and meaningful human control should be applied as principles in connection with the introduction of automation where the human still has an important role to play, and the framework surrounding this is described in

8 Workshop – automated systems and human factors

We held a workshop with 20 participants from PSA, SINTEF and the industry on 29 and 30 September, in order to validate and discuss findings (from the report – especially the literature review, interviews and investigations) and review the relevance of measures. Through this workshop, we wanted to both identify common attitudes and build a greater understanding of findings. We also wanted to identify proposals for measures that the stakeholders could agree on and where the findings can be implemented (i.e. a reality check that it is possible.)

In the following, we describe findings and measures relating to the areas that were discussed over the two days:
Day 1: **Human factors associated with development** in four areas: Balance between technological focus and human factors; Use of standards that address human factors; Fragmented structure for development; Updated regulations.
Day 2: **Human factors during investigations** in four areas: Breadth of investigation; Design assessments in investigation; Successful incidents; Near misses.

8.1 Human factors related to development/design

Table 8.1 lists topics and challenges identified during the group work.

Table 8.1: Overview of group themes and main challenges relating to design

Group theme	Main challenges
1 Balance between technology focus and human factors	• Cost reductions hamper the inclusion of HF in development • Lack of expertise concerning HF amongst many stakeholders [T1]
2 Application of standards that address human factors	• Need for better balance between technology and knowledge of HF • Use of recognised methods and standards, such as ISO 9241:210; [T2]
3 Fragmented structure of development	• Lack of client competence relating to HF [T1] • Clarity regarding the goals that will drive development – is it pure technology or user involvement [T2]
4 Updated regulations	• Are there adequate HF standards to support the regulations [T2] • Need to refer to good design principles [T2] • New and fragmented stakeholder group, with many subcontractors without a deep insight into the regulations [T3]

In the following, we present the key challenges and proposals for measures identified during the group work; details from the discussions can be found in Annex E.

8.1.1 Balance between technology focus and human factors

The theme for this group discussion was why an excessive focus on technology in relation to human factors can arise during development projects and how a better balance between the two factors can be achieved.

Key challenges and proposals for measures

- It is important that stakeholders throughout the industry, operators, developers, users and authorities facilitate the inclusion of human factors, and in order for this to be possible, there is a need for greater understanding and competence. Governments and others responsible

bodies, such as industry organisations, should raise awareness of human factors in the development of autonomous systems, e.g. through existing meeting arenas such as conferences and discussion meetings that they host [T1].
- Human factors should be included in investigations into incidents conducted by both authorities and in-house [T5]. In contracts, operators can clarify the responsibilities incumbent on all parties to ensure the early and continuous inclusion of human factors in development projects.

8.1.2 Application of standards that address human factors

The task for the group was to discuss the application of standards that address human factors, including a discussion of what is considered to be best practice, what methods and standards are applied in practice, and whether there is sufficient expertise relating to their application. The methods and standards that were mentioned by way of introduction were CRIOP, standards for "Design Thinking", ISO 9241:210, ISO 11064, IEA/ILO (2020) and alarm philosophies (YA-710, EEMUA 191).

Key challenges and proposals for measures
- The lack of expertise relating to HF should be remedied, i.e. the need to raise competence levels concerning Human Factors in the petroleum sector [T1].
- Technology focus that must be balanced against user-centred design (particularly as regards safety-critical tasks and non-conformity management) [T2].
- Failure to apply HF standards (good practice such as ISO 9241:210 must be specified.) [T3].

8.1.3 Fragmented structure of development

This group discussed the complexity of the stakeholder group and systems involved in development projects involving new technology.

Key challenges and proposals for measures
- It is important to do something about the inadequate level of competence amongst clients regarding HF, and to ensure greater clarity regarding the goals that will drive development forward, so that if users are affected/part of the picture, then HSE (including HF) must become part of the project [T1].

8.1.4 Updated regulations and supervision

The group discussed various issues relating to the possible need to update the regulations and revise future supervisory practices.

Key challenges and proposals for measures
- Are there adequate HF standards to support the regulations? Measures are about identifying good HF standards and incorporating them into guidance (normative references as such)
- The HF approach often competes against other factors as regards what is given emphasis internally within PSA. Measures could for example include the learning of lessons from the

airline industry as regards approval processes and the importance and value of focusing on HF.

- New stakeholders entering the Norwegian continental shelf do not necessarily have as much insight as traditional operators, including many stakeholders in complex systems. Measures could include the creation of arenas across stakeholders, including the establishment of dialogue (with system developers for example) to ensure a common understanding, even between all the stakeholders that they oversee and PSA, to ensure that everyone "speaks the same language".

8.2 Human factors during investigations

Table 8.2 lists topics and challenges identified during the group work.

Table 8.2: Overview of group themes and key challenges during investigations

Group theme	Main challenges
1 Breadth of investigations	• There is too little breadth in investigation teams, particularly with regard to competence relating to HF [T5]. • Increasing levels of automation increases the need for HF courses, both generally and in investigations [T1].
2 Design assessments in investigations	• Design is rarely considered in connection with investigations, but it can provide valuable insight into the root causes of accidents and incidents [T5].
3 Lessons from successful factors	• Too little attention is paid to the sharing of experiences from successful development processes [V5].
4 Near misses	• Near misses are not intercepted sufficiently by either public authorities or companies.

8.2.1 Breadth of investigations

The theme for this group was to reflect on the breadth of investigations as regards identifying the key underlying causes of incidents, and ensuring that investigations contribute to adequate learning and appropriate measures. In this context, 'breadth of investigations' means that it must be possible to facilitate the addressing of all MTO factors with the system during the investigation (from the design phase through to the operating phase inclusive). Emphasis must then be placed on ensuring the appropriate competence (breadth) in the investigation team (including HF), and the appropriate use of methods and organisation of the work.

Key challenges and proposals for measures

- Having an investigation team with sufficient breadth as regards competence was highlighted as a key challenge. It is important to ensure that competence relating to HF is included in investigation teams from the start (HF may then subsequently come to play a lesser role),
- One of the main challenges is that increasing levels of automation in many areas, such as drilling and wells, also entails a need to raise the level of competence relating to HF. It is therefore important to offer relevant HF courses, both in general and focused on investigations in particular.

8.2.2 Design assessments in investigations

The group's task was to discuss whether design was considered in connection with investigations, including questions such as: How is design evaluated in connection with investigations? What aspects of the design should be evaluated and how can the use of (design) methods and standards be evaluated in investigations? In connection with this task, it was emphasised that there was a desire in investigations to see whether the design process was based on good practice, and similarly whether the underlying causes were due to weaknesses in design. In the following, we have reviewed each theme, with a summary of proposed measures.

Key challenges and proposals for measures

- An important conclusion was that it is relevant to go back and check the design during an investigation, as poor design is relevant to understanding human error.
- The methodology used by Accident Investigation Board Norway is relevant to use in investigations, and Situational Awareness is particularly important in this regard. The investigations normally primarily focus on technical factors, so it is important to see whether the technology was designed to support tasks that are assigned to humans. The industry should focus more on what the stakeholders perceived, their understanding, and the support from across the MTO system.
- The petroleum sector should be able to refer to good examples of investigations which have included an assessment of design and situational awareness (SA), e.g. Accident Investigation Board Norway's report on Helge Ingstad and the Deepwater Horizon investigation by CSB, with seminars on these investigations.

8.2.3 Lessons from successful factors

This group discussed the fact that safety thinking has traditionally been concerned with what went wrong ("Safety I"), rather than what was successful ("Safety II").

Key challenges and proposals for measures

- There should be a stronger focus on sharing experiences from successful development *processes* (if it is difficult to share experiences about *products* which have been developed), i.e. set up forums such as "*Sharing to be better*".
- It is important to have clear responsibilities, e.g. only one supplier to relate to.

8.2.4 Near misses

The theme for this group discussion was near misses in autonomous systems and how these can be intercepted and reported for enhanced learning.

Key challenges and proposals for measures

- Near misses are not being sufficiently intercepted by authorities or companies, and both the authorities and the industry should jointly establish requirements regarding the data that must be logged concerning critical automated systems which can provide information on critical incidents.

8.3 Summary of findings and measures from the workshop

The workshop was an arena for discussing the various issues that were prioritised. The key findings and proposals for measures:

- **The inadequate level of HF competence should be remedied,** [T1] i.e. the need to raise the level of competence concerning HF within the petroleum sector, amongst stakeholders such as operators, clients, management, supervisory authorities and consultants/suppliers. This could be achieved through training based on research-based knowledge within HF or the use of experts. At the same time, the HF principles/methods in the regulations need to be updated. The need for a stronger focus on HF applies from the early phase of investigations. This is especially true in connection with a higher level of automation of safety-critical operations, where technology must be adapted to human capabilities and limitations.
- **Technology focus must be balanced against attention to user-centred design (particularly as regards safety-critical tasks, HMI, and non-conformity management**) [T2]; There is a strong impetus from the technology which must be balanced by a focus on user-centred design, with the consequence that systems must be adapted to meet user needs as soon as possible in the process, and efforts must be made to ensure that safety-critical features and non-conformities can be managed by users via thorough HF analyses.
- **Insufficient use of HF standards,** [T3]. HF standards become increasingly important when automating more and for more complex systems which an operator has to intervene when automation fails. There are many different standards and practices, but it is important to define a set of basic standards that can be used as a basis within the industry. It is therefore important that reference continues to be made to ISO 11064, and that more reference is made to standards such as ISO 9241:210. They should be mentioned in the regulations/guidelines and followed up within the petroleum sector. This follow-up could take place in a number of arenas between stakeholders with, for example, developers, where it is important to ensure a common understanding between the supervisory authorities and stakeholders. The verification and validation of solutions based on good practice should continue, with the involvement of HF experts.
- **Accident investigations have too strong a focus on technology and should cover HF/human experiences** and roles, in addition to organisational factors [T5]. All accident investigations should have HF experts as part of the investigation team from the outset. If appropriate, their involvement could subsequently be reviewed following an evaluation. The investigations should describe how the humans perceived the situation, e.g. with support in taxonomy from sensemaking or situational awareness. In order to illustrate best practice, the industry and supervisory authorities could select a number of good investigation reports which represent best practice and document the methods that were used. In this context, Accident Investigation Board Norway's report on the Helge Ingstad in 2019, or alternatively the CSB's report on the Deepwater Horizon (US-CSB, 2016), could be used as an example.
- **Investigations rarely consider design, but should consider the appropriateness of the design.**[T5]. Inappropriate design can be the root cause of many of the accidents, but is rarely considered by investigations. It is therefore proposed that design always be considered. Moreover, successful designs in connection with successful barriers/features should be highlighted more often.
- **Near misses should be identified and analysed to a greater extent.** There are currently no defined requirements regarding what must be logged concerning safety incidents involving automated systems in the oil and gas industry, or how such data should be handled in

connection with reporting and learning. Both the authorities and the industry should jointly establish requirements regarding the data that must be logged for safety-critical automated systems which can provide information on safety-critical incidents [T4].

- **Lessons from successful factors** [V5]. A higher priority may be given to the sharing of experiences of successful projects, particularly as regards good work processes. There are a number of collaboration forums and networks which could be used to share learning

9 Proposals for initiatives and further work

In the following, we propose measures and further work based on the project's findings. The findings and proposals are based on inductive analyses based on industry experience, combined with deductive analyses where we use theory from the area of human factors. The methodology used to draw up the proposals was based on the principles of action research, where practice and what the stakeholders actually do were examined (Guba et al., 1989).

A consistent finding by the project team was that there is a strong focus on technology without the necessary attention being paid to human strengths and limitations, a failing which could compromise HSE and hamper successful automation. Automation has generally been successful where it has been introduced in well-defined areas, gradually and in interaction with users. Automation can contribute to better utilisation of petroleum resources by enabling the drilling of challenging wells as well as drilling in formations where drilling has not previously been possible. Automation can lead to more efficient drilling and provide support for the earlier detection of failure events through the various technical solutions used in the drilling process. The positive user-centred development of automation should be continued based on lessons learned from pilot projects. It is necessary to apply the principles of meaningful human control when automating operations, partly in order to safeguard HSE.

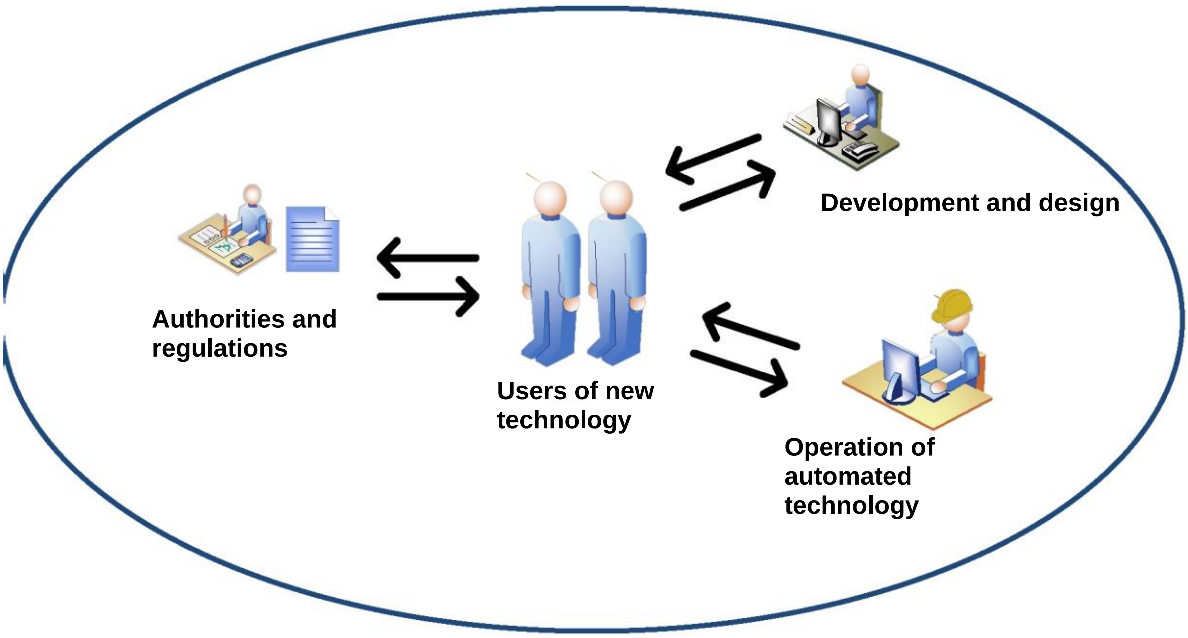

Figure 9.1 The human who uses a technology must be involved in communication with authorities, in the development and design of the technology and through continuous learning and updating of the technology through operation.

In the following, we summarise findings and proposals for measures, based on the results of the project activities (where the measures [Tx] can be traced). The measures are proposed from a lifecycle perspective based on standards such as ISO 11064. The order reflects the desire for cost reductions and efficiency by ensuring that good practice is incorporated at an early stage from delimitations, analyses and design; see Figure 9.1.

9.1 Strong technology focus and technology optimism

Both the literature review and the interviews indicated that there is a strong focus on technology and technology optimism in connection with automation. At the same time, findings in this study show that there is a lack of knowledge about human factors, especially with regard to cognitive and organisational factors. This can lead to design on the premises of technology which does not take account of human strengths or weaknesses. This in turn can lead to complex systems that are difficult for users to operate. The review of standards also indicated to us that the regulations require HF to be considered, but lack any reference to some important standards. Investigations into major accidents and incidents point to the poor handling of human factors as an important root cause. The focus on technology should be more strongly balanced by user-centred development and HF when systems are automated. The findings from the literature study, interviews and workshops are that industries and projects that prioritise HF achieve high levels of safety and efficient systems with a high utility value.

[T1] Improve knowledge and follow-up of human factors: In order to maintain meaningful human control when automation is introduced, it is necessary to consider HF (Lee et al., 2017).

Stakeholders must ensure that experts on human factors are involved in projects throughout the implementation phase, and user participation must be planned from the start. The industry and supervisory authorities should ensure that existing requirements in the regulations concerning HF (ref. Table 7.1) are followed up in projects. The Health and Safety Executive in the UK has analysed challenges relating to the gaining of acceptance of HR, and notes that requirements in regulations are important in ensuring that HF is used (HSE, 2015). Guidelines concerning the use of HF are set out in a number of standards, including NORSOK S002, and IOGP has drawn up proposals for the implementation of HF in projects (IOGP, 2020).

9.2 User-centred development has been successful and resulted in positive experiences

The literature review indicates that user-centring increases user satisfaction and leads to efficient systems with a high utility value. When we look at the experience gained in the aviation sector, they have succeeded in achieving an extremely high level of safety by focusing on user-centred design and gradual automation. The investigations indicate that users do not understand what is going on and that the systems may have been based on inadequate and fragmented designs which did not provide an overall understanding. The user-centring in the projects we have looked at has led to user engagement, a high level of acceptance of the solutions, and created a positive attitude amongst users. Other important positive factors include organisation with clear responsibilities, a single main supplier, attention from PSA and support from the management. At the same time, there has been a need to establish standards and methods in projects to ensure an adequate level of quality in the development. Good synergies and quality result from developers using common standards and methods.

[T2] Stronger focus on user-centred development (As described by ILO/IEA (2020), ISO 11064, ISO 9241 and ISA 101.)
An important principle is to involve key users in a project, and to ensure that the tasks of users are understood based on generally accepted analysis methods and techniques. The use of established development methods, with short iterations and the implementation of feedback from users constitutes good practice. Iterations should test whether users understand the system and whether

the system meets the applicable needs and requirements. A system also includes procedures, trained users and interaction with other stakeholders. This means that changes are made when it is most cost-effective during the design phase. Users must set aside time to specify requirements, assist during the innovation process and have time for testing, trials and documentation of procedures concerning use of the systems. An approximate distribution of time spent on a project should be drawn up based on a code/scope of procedures/organisational changes, but is normally approximately one third spent on technology & programming, one third on testing and one third on establishing the distribution of responsibility/clear procedures (Nelson, 2007; NavalCenter, 2008; Johnsen, 2008). Safety and human factors must explicitly be part of the development process in the methods used to ensure that HSE is safeguarded. Standards, principles and methods referred to in ILO/IEA (2020), ISO 11064, ISO 9241, ISA 101 and Lee et al. (2017) should be used as a starting point and be minimum requirements.

9.3 Need for stronger focus on meaningful human control

Both the literature review and experience indicate that the interaction between man and machine becomes increasingly critical as the level of automation increases. Clear lines of responsibility become particularly important when the unexpected happens. Clear and transparent systems, appropriate alarms and training concerning critical operations are all essential. The investigations point to the same conclusions, with the systems often not having any provision for meaningful human control because the information was fragmented. During the incidents, there were often many alarms which were difficult to understand. The interviews also pointed to concern about the lack of overview and poor understanding of what the systems are actually doing. Automation often leads to more multifaceted and complex systems, and users do not always understand what is going on in the systems, which is challenging when systems fail when the unexpected happens and humans have to take over. It is therefore vital to establish the principle of meaningful human control.

[T3] Ensure that new technology is designed to support "meaningful human control":
Meaningful human control means that those who will have to take over have the prerequisites to do so. Situational awareness and sensemaking must then be part of the analysis which forms the basis for development of the systems (Lee et al. 2017; Endsley 2019).

During the design phase, a safety-critical task analysis (Smith et al, 2020) should be carried out, e.g. using guidelines from High performance HMI from Hollifield et al. (2008). Alarm design must be planned at an early stage based on standards such as YA710 and EEMUA191, rather than as an issue that must be resolved retrospectively. A life-cycle perspective is therefore important in the development of automated systems and processes. The systems must be tested using recognised standards. Testing prior to commissioning should include the use of procedures and the delegation of responsibilities, to ensure that they are clear/understandable and avoid the possibility of human error. Alarms must be few in number and easy to understand. Training concerning critical scenarios must be conducted and maintained.

Need to delimit the area for automation
The literature review and investigations into accidents with autonomous systems indicate that positive experiences of automation are often based on good delimitation with respect to the surroundings.

Within the field of drilling, it has been important to clearly define and delimit the operating area for high safety, e.g. partial robotisation of drill floor and partially automated control systems.

[T3a] Delimitations and infrastructure support:
Analyses of automation must be based on a knowledge of the distribution of tasks between man and machine that addresses safety (DSA Roadmap 2019). Delimitation of the operating area must be based on a risk assessment, and build on principles of meaningful human control combined with proactive and reactive barriers. It has often been shown that there is a need for more infrastructure support in connection with automation, such as monitoring systems which enable the automation and operators to gain a better understanding of what is going on.

Need for robust solutions and utilisation of principles from Resilience Engineering
The literature review and experiences from other industries indicate that the robustness and quality of sensors that provide the automated system with information are important. The investigations that have been reviewed lead to the same conclusion, i.e. many reports on accidents involving automated systems point to a lack of robustness, such as faults on individual sensors or the failure of sensors to detect non-conformities because their operating area was too narrow. Automated systems where there is potential for major accidents should be robust as regards data collection, i.e. they should have a number of independent sensors and systems which provide information. The systems must be capable of providing an overview of the status with respect to the limit values for the operating area. The systems must be sufficiently flexible, so that critical tasks can be performed even in the event of individual faults. Autonomous systems must be capable of switching to a safe state in the event of failure or if the unexpected happens ("Both safe and secure"). Planned robustness (*resilience*) is therefore an important attribute.

[T3b] Principles from the regulations and "Resilience Engineering" should be applied in the design of critical systems, to ensure that they are robust and capable of switching to a safe state and rapidly returning to operational condition in the event of failure:
Robust solutions that include MTO form a natural part of assessments that should be carried out in connection with analysis and design of automation. Known principles are redundancy in sensors and systems to ensure that the operator can obtain a more complete overview of the system's status (an example is gas sensors which detect temperature deviations, gas detection, as well as visual inspection via CCTV). Flexibility could be the ability to perform tasks in a number of alternative ways if part of the system fails. Control and overview of margins could be forecasts and overviews of dynamic parameters in normal ranges and guidelines that monitor workload, so that the operator limits themselves to a certain number of simultaneous critical operations.

Need for the handling of organisational and technical silos
As the level of automation increases, this allows for several different systems to be controlled either by a person or via a network. The investigations showed that fragmented systems in themselves represent a risk. Poor integration of systems and cooperation between a number of stakeholders based at different locations have been identified as the cause of a number of accidents and incidents. Measures that have been implemented to address this have included both organisational measures and the clarification of responsibility. Technical measures have been implemented in the form of systems that provide a better overview. There is also a need for better interaction via the training of groups that will work together. Principles from Crew Resource Management (CRM) have been seen as best practice in this area.

[T3c] Measures: The integration of critical systems must be analysed from an MTO perspective. Need for common interfaces, coordinated alarms and joint training (CRM) must be established:
When several systems have to be monitored, the interfaces must be coordinated. This could be achieved via integrated systems, such as Unified Bridge (Danielsen et al. 2019) or by creating standards for interfaces, such as OpenBridge (Nordby et al. 2019). The integration of critical systems must not only form an integral part of the design and development process, but also be considered in connection with supervision or verification and validation. With regard to training, other sectors (aviation, maritime) with a need to ensure high levels of safety across a number of dispersed stakeholders (either geographically or organisationally) have had good experiences of applying the principles of CRM. Amongst other things, systematic CRM training has led a reduction in the number of incidents and lower insurance premiums (Flin et al., 2002). In the oil industry, a number of stakeholders have adopted this approach, and IOGP has recommended the introduction of CRM training (IOGP, 2014).

9.4 Poor learning between accidents and incidents, investigations and development/design/supervisory practices concerning human factors

The literature review indicated that data collection from automated systems is inadequate. It has been assumed that little is happening and data collection has been insufficient, not only at operator level, but also at overarching authority level. The need for detailed reporting and the collation of historical data when something happens is not often the subject of sufficient planning/consideration. This can lead to a lack of data and experiences from near misses, leading to a lack of important information for use as a basis in risk-based supervision. From investigations, we have seen that detailed data collection at operator level provides a good basis for understanding and analysing what happened. (Some companies such as Tesla have even introduced ongoing data collection to bring about continuous improvements to automated systems.) It is therefore important to address this at both operational level and authority level. An example of requirements regarding data collection from automated systems comes from the Civil Aviation Authority Norway relating to the use of drones.

[T4] Data reporting and analyses for strengthening risk-based development in order to provide a basis for the systematic improvement of automation. Data collection should include a single rich set of data. This should be carried out by the stakeholders in the industry, in much the same way as has been required by other authorities such as the Civil Aviation Authority in connection with the use of drones.

Investigations lack an HF perspective
The literature review indicated that, although HF is covered in investigations to varying degrees, current investigation methods tend to focus on the role of the human (CIEHF, 2020). Moreover, the investigations have often not included any assessment of design factors. In investigations, we have seen that technical factors, certain organisational factors and, to a lesser extent, human factors, have been assessed. This can result in both the investigation becoming too technically focussed and a failure to learn lessons concerning the contribution of human factors. In turn, this can lead to a poor learning loop. Findings made during investigations can also be misleading with regard to HF, e.g. when explaining accidents or incidents by referring to *human error*, or poor compliance as being the root cause, instead of asking "Why was compliance poor?". Critical reviews of investigation

reports often find root causes that can be traced back to design. However, design was rarely covered in the investigations that were reviewed for this report, which can lead to poor learning back to the design phase.

[T5] Investigations should include HF and design decisions. Methods and perspectives that analyse human factors should be used, such as HFACS (CIEHF, 2020). The investigation team should possess expertise concerning HF, organisational factors and corporate governance on an equal basis with technical expertise. In an accident, the operators' perceptions during the unfolding sequence of events should be documented. What situational awareness did they have and what was the process of sensemaking like? The industry should have examples of good practice for investigation methods that include HF, e.g. the Helge Ingstad investigation (AIBN, 2019). The industry could also collate a set of good investigation reports and have references to recommended investigation methods. In the case of major incidents or analyses of relationships, there should be cooperation with an independent investigation group which has a knowledge of HF (e.g. Accident Investigation Board Norway).

9.5 The measures must be implemented at as early a stage as possible for the best possible effect

We have described a set of measures above which could help to improve HSE levels in connection with automation. In order for the measures to be as cost-effective as possible and result in appropriate systems that are user-friendly, the measures must be implemented in the correct sequence. The measures have therefore been placed in sequence in the figure below, starting with delimitation, via analysis and through to design development. It all starts with gaining a good understanding of HF methods, after which principles such as user-centring should be the determining factor. Meaningful human control is important as a principle. Data reporting must be carried out in order to secure the risk-based development of the regulations. The learning of lessons from investigations presupposes that HF is included, and that design is assessed during the investigation, so that we can establish a good learning loop.

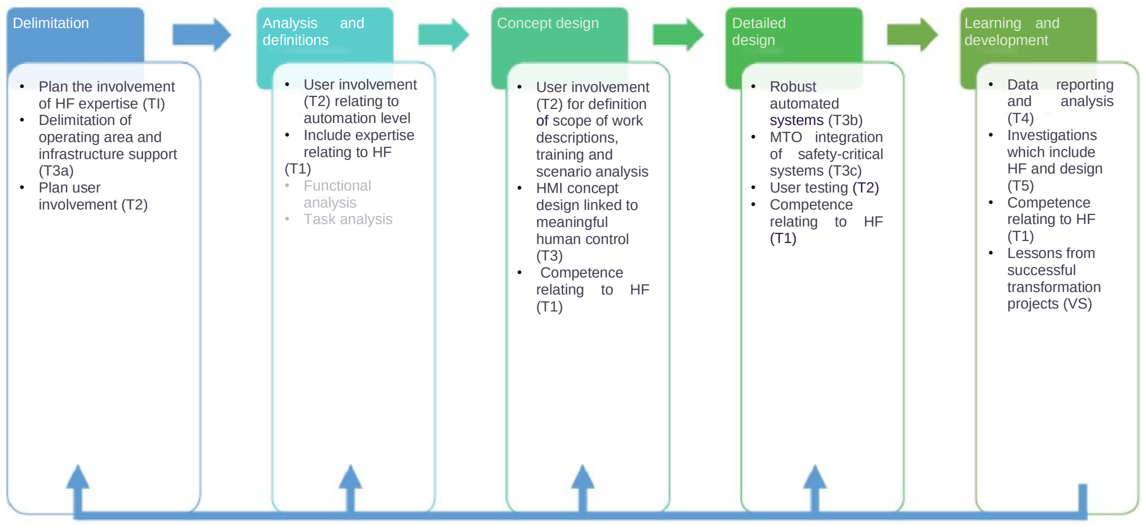

Figure 9.2 Measures proposed from a life-cycle perspective

Through the project, we have seen that automation has generally been successful where it has been introduced in well-defined areas, gradually and in interaction with users. In the petroleum sector, automated systems can contribute to better utilisation and more efficient drilling, and provide support for the earlier detection of failure events via automation of the drilling process. The positive user-centred development of automation should be continued based on lessons learned from pilot projects. It is recommended that references to standards as outlined in the report be updated. In order to address HSE, the principles of meaningful human control should be applied.

9.6 Proposals for further work

In the following, we present a number of proposals for further work which did not form part of the project, but which has emerged from discussions during the project. The proposals comprise the following proposed tasks which must be considered by PSA as the client, as detailed in the appendix:

- When reviewing investigations, we have seen that there are possible gaps and repetitive findings that may be due to the fact that the fundamental root causes were not identified, particularly when investigations have not used experts within the discipline of human factors. We therefore suggest that the following measure be assessed: [V1] - Review of possible gaps and repetitive findings from accident investigations.
- In connection with the review of automation generally and automation in drilling and wells in particular, we have noted that no broad-ranging investigation (NOU) has been carried out concerning industrial automation. This should have been carried out on an equal footing with the maritime area, transport and drones – our proposal is therefore that an initiative be established: [V2] - Investigations concerning strategy for robotisation and automation generally which include drilling and wells at national level.
- Within the field of drilling and wells, there are many systems, silo systems and other systems which contain proprietary information which is owned by the subcontractors. There is an increasing need for coordination, standardisation and centralisation of this type of information, as well as a need to overcome the challenges associated with remote control. It is therefore proposed that an assessment be carried out to identify positive experiences, challenges and essential measures: [V3] - Review of the need for prioritisation of holistic MTO in connection with integration and remote control of critical systems.
- There is no systematic collation of incidents and near misses relating to automated/autonomous systems. A preliminary study should be carried out in collaboration with PSA to determine whether it is possible/appropiate to analyse incidents and near misses involving autonomous systems: [V4] - In-depth study from RNNP, analyse incidents involving autonomous systems.
- Many aspects of the projects we have examined have had a positive impact on safety levels, efficiency and quality in connection with the introduction and development of technologies. This is for example linked to early user participation, the follow-up of training, delimitations linked to having a single responsible supplier, and the management prioritising and supporting the project. The industry should give greater priority than it does at present to identifying factors for success and processes that other stakeholders and projects can learn from, e.g. from the perspective of learning from what went well. [V5] - Learning from successful transformation projects (digitalisation/automation).
- Questions have been raised about whether projects and supervision focus sufficiently on human factors. This has been identified via interviews, workshops, and discussions of standards. By carrying out a series of supervisions during the early phases of projects, it is possible to identify recurring weaknesses and potential for improvement with regard to delimitations, user-centring and attention to human factors. This should be done at as early a stage as possible in order to reduce costs and enhance the effect. This approach could put projects on the right track as early as possible. [V6] - Supervisory series linked to the use of HF in connection with automation/digitalisation.
- The completed project followed a broad approach, but it may be useful to look in more detail at the complete automation of drilling and well operations, with the detailing of challenges associated with the use of AI and further automation. It must cover technical, human and

organisational factors. Such a project could look at important risks and the need for high-performance interfaces, and discuss the opportunities for adaptive automation. [V7] - Detailed analysis of the development of automated drilling operations.

10 References

- Aas, A. L., & Skramstad, T. (2010). A case study of ISO 11064 in control centre design in the Norwegian petroleum industry. Applied ergonomics, 42(1), 62-70.
- AIBN (2019) – Sub-report 1 on the collision between the frigate KNM Helge Ingstad and the tanker Sola TS off the Sture terminal in Hjeltefjorden, Hordaland, 8 November 2018 – (https://havarikommisjonen.no/Sjofart/Avgitte-rapporter/2019-08).
- Altawy, R., & Youssef, A. M. (2017). Security, privacy, and safety aspects of civilian drones: A survey. ACM Transactions on Cyber-Physical Systems, 1(2), 7.
- Antonovsky, A., Pollock, C., & Straker, L. (2014). Identification of the human factors contributing to maintenance failures in a petroleum operation. Human factors, 56(2), 306-321
- Aricò, P., Borghini, G., Di Flumeri, G., Colosimo, A., Bonelli, S., Golfetti, A., Pozzi, S., Imbert, J. P., Granger, G., Benhacene, R., & Babiloni, F. (2016). Adaptive Automation Triggered by EEG-Based Mental Workload Index: A Passive Brain-Computer Interface Application in Realistic Air Traffic Control Environment. Frontiers in human neuroscience, 10, 539. https://doi.org/10.3389/fnhum.2016.00539
- Autonomous ships (2019), see https://www.regjeringen.no/no/tema/naringsliv/maritime-naringer/ny-temaside/forste-kolonne/markedsadgang-og-regelverk/id2589230/, Date: 20.07.2018
- Bakken, T., Holmstrøm, S., Johnsen, S.O., Merz, M., Grøtli, I.G., Transeth, A., Risholm, P., Storvold, R., (2019) Use of drones in the High North, HSE factors relating to the use of drones in petroleum operations in the High North. SINTEF report 2019:001284
- Bainbridge, L. (1983). Ironies of automation. In Analysis, design and evaluation of man–machine systems (pp. 129-135). Pergamon.
- Beck, K., Beedle, M., Bennekum, A. v., Cockburn, A., Cunningham, W., Fowler, M., . . . Thomas, D. (2001). Manifesto for Agile Software Development
- Bello, O., Holzmann, J., Yaqoob, T., & Teodoriu, C. (2015). Application of artificial intelligence methods in drilling system design and operations: a review of the state of the art. Journal of Artificial Intelligence and Soft Computing Research, 5(2), 121-139.
- Berman (2019) "The key to autonomous vehicle safety is ODD» www.sae.org/news/2019/11/odds-for-av-testing
- Beuscart-Zéphir, M. C., Elkin, P., Pelayo, S., & Beuscart, R. (2007). The human factors engineering approach to biomedical informatics projects: state of the art, results, benefits and challenges. *Yearbook of medical informatics*, *16*(01), 109-127.
- Blankesteijn, M., Jong, F. D., & Bossink, B. (2019). Closed-open innovation strategy for autonomous vehicle development. International Journal of Automotive Technology and Management, 19(1-2), 74-103.
- Borst, C., Mulder, M. & Van Paassen, M. M. (2010). A review of Cognitive Systems Engineering in aviation. IFAC Proceedings Volumes (IFAC-PapersOnline), 11, PART 1.
- Bolsin, N. (2018). Designing national guidelines for automated vehicle trials in Australia. Transport and the City, 177
- Buckingham, M., & Goodall, A. (2019). The feedback fallacy. *Harvard Business Review*, *97*(2), 92-101.
- Chmela, B., Kern, S., Quarles, T., Bhaduri, S., Goll, R., Van, C., (2020). Directional drilling automation: Human factors and automated decision-making. Presented at the SPE/IADC Drilling Conference, Proceedings.

- Ciavarelli, A. (2016). Integration of Human Factors into Safety and Environmental Management Systems. Paper presented at the Offshore Technology Conference. Offshore Technology Conference
- CIEHF (2020) White Paper "Learning from Adverse Events" retrieved from https://www.ergonomics.org.uk/Public/Resources/Publications/Learning_from_Adverse_Events/Learning_from_Adverse_Events.aspx
- CNBC (2019) - https://www.cnbc.com/2019/07/29/experts-say-its-at-least-a-decade-before-you-can-buy-a-self-driving-car.html
- Corbato, C. H., Bharatheesha, M., Van Egmond, J., Ju, J., & Wisse, M. (2018). Integrating different levels of automation: Lessons from winning the amazon robotics challenge 2016. *IEEE Transactions on Industrial Informatics*, *14*(11), 4916-4926.
- CRIOP (2011) from www.criop.sintef.no
- Danielsen, B. E., Bjørneseth, F. B., & Vik, B. - 2019 -Chasing the end-user perspective in bridge design
- Dashevskiy, D., Macpherson, J., Mieting, R., Wassermann, I., (2020). Advisory system for drilling: Automatic Procedures Acting on Real-time Data. Presented at the SPE/IADC Drilling Conference, Proceedings.
- Data Safety Guidance Version 3.2,(2020) The Data Safety Initiative Working Group (DSIWG).
- Dehais, F., Peysakhovich, V., Scannella, S., Fongue, J. & Gateau, T. (2015). Automation surprise in aviation: Real-time solutions. Conference on Human Factors in Computing Systems - Proceedings, 2015.
- Dekker, S. (2002). Reconstructing the human contribution to accidents: The new view of human error and performance. Journal of Safety Research
- Dekker, S. (2004). "Ten questions about human error: A new view of human factors and system safety". CRC Press.
- Dekker, S. (2019). *Foundations of safety science: A century of understanding accidents and disasters*. Routledge.
- de Wardt, J.P., Sheridan, T.B., Di Fiore, A., (2016). Human systems integration: Key enabler for improved driller performance and successful automation application. Presented at the SPE/IADC Drilling Conference, Proceedings.
- De Winter, J. C., & Dodou, D. (2014). Why the Fitts list has persisted throughout the history of function allocation. *Cognition, Technology & Work*, *16*(1), 1-11.
- Design Council (2007) "Eleven lessons: managing design in eleven global companies - Desk research report" from www.designcouncil.org.uk/
- Department of Mines and Petroleum (2015) «Safe Mobile Autonomous Mining in Western Australia Code of Practice» - from http://www.dmp.wa.gov.au/Documents/Safety/MSH_COP_SafeMobileAutonomousMiningWA.pdf
- DNV-GL (2018) DNVGL-CG-0264 Autonomous and remotely operated ships
- DNV-GL (2020) "Safemass - Study of the risks and regulatory issues of-specific cases of MASS" Report; retrieved from http://www.emsa.europa.eu/implementation-tasks/ship-safety-standards/item/3892-safemass-study-of-the-risks-and-regulatory-issues-of-specific-cases-of-mass.html
- DNV-GL (2020b) "Well control expertise - Mapping of well control expertise in the drilling and well industry" from Petroleum Safety Authority Norway, www.ptil.no

- DSA Roadmap (2019) Drilling Systems Automation Roadmap Report https://dsaroadmap.org/drilling-systems-automation/dsa-r-report
- ECAA (2019) Aircraft Accident Investigation Preliminary Report Ethiopian Airlines Group B737-8 (MAX) Registered ET-AVJ 28 NM South East of Addis Ababa, Bole International Airport March 10, 2019 (https://leehamnews.com/wp-content/uploads/2019/04/Preliminary-Report-B737-800MAX-ET-AVJ.pdf)
- EN-894 (2008) Safety of machinery - Ergonomic requirements for the design of displays and actuators (Three parts)
- Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. Human Factors (37) 32–64.
- Endsley, M. R. (1996). Automation and situation awareness. *Automation and human performance: Theory and applications*, *20*, 163-181.
- Endsley, M.R., (2012). Designing for Situation Awareness: An Approach to User-Centered Design, CRC press.
- Endsley, M. R. (2015). Autonomous Horizons: System Autonomy in the Air Force-A Path to the Future. *United States Air Force Office of the Chief Scientist, AF/ST TR*, 15-01.
- Endsley, M. R. (2017). From here to autonomy: lessons learned from human–automation research. *Human factors*, *59*(1), 5-27.
- Endsley, M. R. (2018). Level of automation forms a key aspect of autonomy design. *Journal of Cognitive Engineering and Decision Making*, *12*(1), 29-34.
- Endsley, M.R., 2019. Human Factors & Aviation Safety, Testimony to the United States House of Representatives Hearing on Boeing 737-Max8 Crashes — December 11, 2019
- Edwards, T., Homola, J., Mercer, J., Claudatos, L. (2017). Multifactor interactions and the air traffic controller: the interaction of situation awareness and workload in association with automation. Cognition, Technology and Work 19 (4).
- Eriksson, A., & Stanton, N. A. (2017). Takeover time in highly automated vehicles: noncritical transitions to and from manual control. Human factors, 59(4), 689-705.
- Equinor (2018) - https://www.offshore-mag.com/drilling-completion/article/16803487/equinor-steps-up-use-of-wired-drill-pipes
- Equinor (2019) Investigation report – Collision between the supply vessel Sjoborg and Statfjord A (of 13.09.2019)
- Equinor (2019a) Learning after platform supply vessel collision with Statfjord A Presentation HFC forum October 2019. (www.sintef.no/projectweb/hfc/moetereferat/)
- ESReDA (2015) "Barriers to learning from incidents and accidents" Published 2015 at the ESReDA website: http://www.esreda.org/
- Evjemo, Tor Erik (2018) Safety and autonomy in Norwegian aviation – challenges and opportunities. SINTEF report 2018:01451
- Flaspöler, E., Hauke, A., Pappachan, P., Reinert, D., Bleyer, T., Henke, N., & Beeck, R. (2009). The human machine interface as an emerging risk. EU-OSHA (European Agency for Safety and Health at Work). Luxembourg.
- Flemisch, F., Heesen, M., Hesse, T., Kelsch, J., Schieben, A., & Beller, J. (2012). Towards a dynamic balance between humans and automation: authority, ability, responsibility and control in shared and cooperative control situations. Cognition, Technology & Work, 14(1), 3-18.

- Florence, F., & Iversen, F. P. (2010, January). Real-time models for drilling process automation: Equations and applications. In *IADC/SPE Drilling Conference and Exhibition*. Society of Petroleum Engineers.
- Flin, R., O'Connor, P., & Mearns, K. (2002). Crew resource management: improving team work in high reliability industries. Team performance management: an international journal
- Regulations concerning Machinery (the Machinery Regulations) of 2009 – taken from https://lovdata.no/dokument/SF/forskrift/2009-05-20-544
- Gatwick (2018) Gatwick Airport drone incident Wikipedia 2018 https://en.wikipedia.org/wiki/Gatwick_Airport_drone_incident
- Gard (2020). Jan-Hugo Marthinsen, Vice President, Head of Offshore Energy Claims "Lessons Learnt After Offshore Claims And Accident Investigations" HFC Webinar 21 October 2020, at https://www.sintef.no/projectweb/hfc/moetereferat/
- Godhavn, J.M., Pavlov, A., Kaasa, G.O. og Rolland, N.L., "Drilling seeking automatic control solutions" i Preprints of the 18th IFAC World Congress, Milano, 2011.
- Guiochet, J., Machin, M., & Waeselynck, H. (2017). Safety-critical advanced robots: A survey. Robotics and Autonomous Systems, 94, 43-52.
- Gunnerod, J., Serra, S., Palacios-Ticas, M., & Kvarne, O. (2009). Highly automated drilling fluids system improves HSE and efficiency, reduces personnel needs. *Drilling Contractor Magazine*.
- Guba, E. G., & Lincoln, Y. S. (1989). Fourth generation evaluation. Sage.
- Hanssen G. K., Stålhane T. and Myklebust T.. SafeScrum – Agile Development of Safety-Critical Software. ISBN 9783319993348.Springer. December 2018.
- Hareide (2019); ref. https://www.sintef.no/globalassets/project/hfc/documents/02-hfc-forum-oct-2019-presentation-osh.pdf
- Hollifield, B., Habibi, E., Nimmo, I., & Oliver, D. (2008). The high performance HMI handbook: A comprehensive guide to designing, implementing and maintaining effective HMIs for industrial plant operations. Plant Automation Services.
- Hollnagel, E., Woods, D.D., Leveson, N., 2006. Resilience Engineering : Concepts and Precepts. Ashgate Publishing Limited, Aldersot.
- Hollnagel, E. (2008). Risk+ barriers= safety?. Safety science, 46(2), 221-229
- Hollnagel, E. (2016). Barriers and accident prevention. Routledge.
- Hollnagel, E., (2017). FRAM: The Functional Resonance Analysis Method, first ed. FRAM: The Functional Resonance Analysis Method. Ashgate, Farnham. UK.
- HSE (2015) Literature review: Barriers to the application of Ergonomics/Human Factors in engineering design
- IEA (2000) https://iea.cc/what-is-ergonomics/
- IEA/ILO (2020) Principles and Guidelines for Human Factors/Ergonomics (HF/E) Design and Management of Work Systems
- IEC 61508 - Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems
- Facilities Regulations (2019) Regulations relating to the design and outfitting of facilities, etc. in the petroleum activities
- IOGP (2014) International Association of Oil & Gas Producers (IOGP). Crew resource management for well operations teams. Report No. 501. April 2014, London.
- IOGP (2020) International Association of Oil & Gas Producers (IOGP). Human Factors Engineering in Projects. Report No. 454. June 2020, London.

- IRIS (2018) Digitalisation in the petroleum industry Development trends, knowledge and proposed measures
- ISA-101.01 (2015), Human Machine Interfaces for Process Automation Systems
- ISO series 11064:2000 – Ergonomic design of control centres at https://www.iso.org
- ISO series 9241– Ergonomics of human-system interaction at https://www.iso.org
- ISO 9241-210 (2010) Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems
- ISO/TR 9241-810 (2020) Ergonomics of human-system interaction — Part 810: Robotic, intelligent and autonomous systems
- ISO 26800 "Ergonomics – General approach, principles and concepts"
- Iversen, F., Gressgård, L. J., Thorogood, J. L., Bcilov. M. K. & Hepsø, V. (2013). Drilling automation: Potential for human error. SPE Drilling and Completion, 28 (1): 45-59.
- Johnsen, S (2008) "IT technology in logistics and transport" Vett &Viten, ISBN 82-412-0412-4.
- Johnsen S., Ask R., Roisli R. (2008) Reducing Risk in Oil and Gas Production Operations. In: Goetz E., Shenoi S. (eds) Critical Infrastructure Protection. ICCIP 2007. IFIP International Federation for Information Processing, vol 253. Springer, Boston, MA. https://doi.org/10.1007/978-0-387-75462-8_7
- Johnsen S & Håbrekke S (2009) Can organisational learning improve safety and resilience during changes Safety, Reliability and Risk Analysis: Theory, Methods and Applications, 805-815.
- Johnsen et al (2013) Team dynamics in critical situations – Crew Resource Management (CRM) and other approaches; (HFC forum, April 2013) – Report SINTEF A24687.
- Johnsen, S. O., & Stålhane, T. (2017). Safety, security and resilience of critical software ecosystems. Safety and Reliability–Theory and Applications.
- Johnsen, S. O., Kilskar, S. S., & Fossum, K. R. (2017). Missing focus on Human Factors–organizational and cognitive ergonomics–in the safety management for the petroleum industry. Proceedings of the Institution of Mechanical Engineers, Part O: Journal of risk and reliability, 231(4), 400-410.
- Johnsen, S. O., Kilskar, S. S., & Danielsen, B. E. (2019). Improvements in rules and regulations to support sensemaking in safety-critical maritime operations. In Proceedings of the 29th European Safety and Reliability Conference (ESREL). 22–26 September 2019 Hannover, Germany. ESREL 2019.
- Johnsen, S.O., Evjemo T.E. (2019): "State of the art of unmanned aircraft transport systems in industry related to risks, vulnerabilities and improvement of safety". ESREL 2019 - 29th International European Safety and Reliability Conference September 22 - 26, 2019, Leibniz Universität Hannover, Germany
- Johnsen S.O.,Kilskar S. S. (2020) "A Review of Resilience in Autonomous Transport to Improve Safety and Security" ESREL 2020.
- Johnsen S. O., T. Bakken, A. A. Transeth, S. Holmstrøm, M. Merz, E. I. Grøtli, S. R. Jacobsen - R. Storvold: "Safety and Security of Drones in the Oil and Gas Industry". Proceedings of the 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference, Edited by Piero Baraldi, Francesco Di Maio and Enrico Zio, ESREL2020-PSAM15. Published by Research Publishing, Singapore.

- Kaber, D. B., & Endsley, M. R. (1998). Team situation awareness for process control safety and performance. Process Safety Progress, 17(1), 43-48.
- Kaber, D. B. (2018). Issues in human–automation interaction modeling: Presumptive aspects of frameworks of types and levels of automation. *Journal of Cognitive Engineering and Decision Making, 12*(1), 7-24.
- Karwowski, W (2012). The discipline of human factors and ergonomics. In: Salvendy, G (ed.) Handbook of human factors and ergonomics. Hoboken, NJ: John Wiley & Sons, pp.3–37.
- Kilskar, S.S, Danielsen, B.E, Johnsen, S.O. (2019). Sensemaking and resilience in safety-critical situations: a literature review. Safety and Reliability – Safe Societies in a Changing World Proceedings of CRC, ESREL 2018. CRC Press
- Kirkpatrick, D. L. (1979). Techniques for evaluating training programs. Training and development journal.
- Kinnersley, S. and A. Roelen (2007). The contribution of design to accidents. Safety Science 45(1-2), 31-60.
- Kirschbaum, L., Roman, D., Singh, G., Bruns, J., Robu, V., & Flynn, D. (2020). AI-Driven Maintenance Support for Downhole Tools and Electronics Operated in Dynamic Drilling Environments. IEEE Access, 8, 78683-78701.
- Kyllingstad, Aa., Nessjoen, P. J. (2010), "Hardware-in-the Loop Simulations Used as a Cost-Efficient Tool for Developing an Advanced Stick-Slip Prevention System", SPE128223.
- Lee, J. D., Wickens, C. D., Liu, Y., & Boyle, L. N. (2017). Designing for people: An introduction to human factors engineering. CreateSpace.
- Leveson, N. (2004). A new accident model for engineering safer systems. Safety science, 42(4), 237-270.
- Leveson, N. (2011). Engineering a safer World, Systems Thinking applied to Safety. MIT Press, Cambridge, Massachusetts.
- Leveson, N. (2016). CAST Analysis of the Shell Moerdijk Accident ref http://sunnyday.mit.edu/STAMP-publications-sorted-new.pdf
- Leveson, N. (2019). CAST HANDBOOK: How to Learn More from Incidents and Accidents, from http://sunnyday.mit.edu/CAST-Handbook.pdf
- Act on ports and territorial waters: Government Bill 86 L (2018-2019) /www.regjeringen.no/contentassets/bcd204c187a54039984d552138663e4f/no/pdfs/prp201820190086000dddpdfs.pdf
- National Security Act (*sikkerhetsloven*) – entered into force on 1 January 2019 https://lovdata.no/dokument/NL/lov/2018-06-01-24/
- Lovdata (2015) Regulations on pilotless aircraft, etc (updated April 2019) from https://lovdata.no/dokument/SF/forskrift/2015-11-30-1404;BSL A 7-1
- Lund, J., and Aarø, L. E. (2004). Accident prevention. Presentation of a model placing emphasis on human, structural and cultural factors. Safety Science, 42(4), 271-324
- Lundberg, J., Rollenhagen, C., & Hollnagel, E. (2009). What-You-Look-For-Is-What-You-Find–The consequences of underlying accident models in eight accident investigation manuals. Safety science, 47(10), 1297-1311
- Lundberg, J & Josefsson, B. (2018) A pragmatic approach to uncover blind spots in accident investigation in ultra-safe organizations - a Case Study from Air Traffic Management. In

proceedings of 9th International Conference on Applied Human Factors and Ergonomics (AHFE 2018). 21-25 July. Orlando, FL.

- Manikas, K., & Hansen, K. M. (2013). Software ecosystems–A systematic literature review. Journal of Systems and Software, 86(5), 1294-1306.
- Matheus, J., & Naganathan, S. (2010, January). Automation of Directional Drilling--Novel Trajectory Control Algorithms for RSS. In IADC/SPE Drilling Conference and Exhibition. Society of Petroleum Engineers.
- McDermott, P., Dominguez, C., Kasdaglis, N., Ryan, M., Trhan, I., & Nelson, A. (2018). Human-Machine Teaming Systems Engineering Guide. MITRE CORP BEDFORD MA BEDFORD United States.
- Moura, R., Beer, M., Patelli, E., Lewis, J., & Knoll, F. (2016). Learning from major accidents to improve system design. Safety science, 84, 37-45.
- Milch, V. & Laumann, K. (2016) Interorganizational complexity and organizational accident risk: A literature review. Safety Science, 82, 9-17.
- Myklebust T. and Stålhane T. (2018) The Agile Safety Case. ISBN 9783319702643. Springer International Publishing. February 2018.
- Mærsk Drilling (2015) - Investigation report, " MÆRSK GALLANT" 02.06.2015
- NASA (2012) - Shafto, M., Conroy, M., Doyle, R., Glaessgen, E., Kemp, C., LeMoigne, J., & Wang, L. (2012). Modeling, simulation, information technology & processing roadmap. *National Aeronautics and Space Administration*.
- NavalCenter (2008) Naval Center for Cost Analysis Air Force Cost Analysis Agency - Software Development Cost Estimating Handbook Volume I, Developed by the Software Technology Support Center 2008.
- Nelson, R. R. (2007). IT project management: Infamous failures, classic mistakes, and best practices. MIS Quarterly executive, 6(2).
- Norwegian Design Council (2020) https://doga.no/verktoy/designdrevet-innovasjon/guide-for-designdrevet-innovasjon/
- Nordby, K., Gernez, E., & Mallam, S. (2019). OpenBridge: designing for consistency across user interfaces in multi-vendor ship bridges. Ergoship 2019.
- NTSB Price (2019) "What Accident Investigation Has Taught Us (And Continues to Teach Us) About Human Factors in Automated Transportation" J. Price /NTSB at HFC meeting https://www.sintef.no/projectweb/hfc/moetereferat/
- NTSB (2017) Highway Accident Report "Collision between a car Operating With Automated Vehicle Control Systems and a tractor-Semitrailer Truck" Fra https://www.ntsb.gov/investigations/AccidentReports/Pages/HWY16FH018-preliminary.aspx
- NTSB (2019) ASR-19-01 Safety Recommendation Report: "Assumptions Used in the Safety Assessment Process and the Effects of Multiple Alerts and Indications on Pilot Performance" https://ntsb.gov/investigations/AccidentReports/Pages/ASR1901.aspx
- NTSC (2019) Final report published 25/10 2019 - FINAL KNKT.18.10.35.04 Aircraft Accident Investigation Report PT. Lion Mentari Airlines Boeing 737-8 (MAX); PK-LQP Tanjung Karawang, West Java Republic of Indonesia 29 October 2018 (http://knkt.dephub.go.id/knkt/ntsc_home/ntsc.htm)
- National Transport Plan 2018-2029 Government White Paper No. 33 www.regjeringen.no/no/dokumenter/meld.-st.-33-20162017/id2546287/

- Nilsen, E.T., Li, J., Johnsen, S. O., & Glomsrud, J. A. (2018). Empirical studies of methods for safety and security co-analysis of autonomous boat. Safety and Reliability-Safe Societies in a Changing World.
- Norwegian Drone Strategy (2018) from https://www.regjeringen.no/no/dokumenter/norges-dronestrategi/id2594965/
- NOROG 104 - Norwegian Oil and Gas recommended guidelines on information security baseline requirements for process control, safety and support ICT systems, 2016, Rev. 6
- NORSOK S-002 N (2018) Working environment. Edition 5
- NORSOK U-102 (2003) - Remotely operated vehicle (ROV) services
- NORSOK I-005 (2005); System Control Diagram (SCD)
- Norman, D. (2013). “The design of everyday things: Revised and expanded edition”. Basic books.
- NS-EN 614 (2008) Machine Safety - Ergonomic principles of design (two parts)
- NS 5814 (2008): Risk assessment requirements. Norwegian Standard, see https://www.standard.no
- NS 5830 (2012). Societal security - Prevention of intentional undesirable actions - Terminology. Norwegian Standard NS 5830:2012. e https://www.standard.no
- Nystad, M., Pavlov, A (2020). Micro-testing while drilling for rate of penetration optimization. International Conference on Offshore Mechanics and Arctic Engineering.
- Onnasch, L., Wickens, C. D., Li, H., & Manzey, D. (2014). Human performance consequences of stages and levels of automation: An integrated meta-analysis. Human factors, 56(3), 476-488.
- OESI (2016) "Human Factors and Ergonomics in Offshore Drilling and Production: The Implications for Drilling Safety", Ocean Energy Safety Institute, Texas, USA. http://oesi.tamu.edu
- Oliver, N., Calvard, T., & Potočnik, K. (2017). Cognition, technology and organizational limits: Lessons from the Air France 447 disaster. Organization Studies 28(4): 729-743.
- Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. Human factors, 39(2), 230-253.
- Pęciłło, M. (2016). The concept of resilience in OSH management: a review of approaches. International Journal of Occupational Safety and Ergonomics, 22(2), 291-300.
- Petritoli, E., Leccese, F., & Ciani, L. (2017). Reliability assessment of UAV systems. In 2017 IEEE International Workshop on Metrology for AeroSpace (MetroAeroSpace) (pp. 266-270). IEEE.
- PSA (2015) Investigation of hydrocarbon leak at Kårstø, 18 February 2015
- PSA (2017) Principles for barrier management in the petroleum industry Barrier memo 2017 from https://www.ptil.no/fagstoff/utforsk-fagstoff/fagartikler/2017/barrierenotat/
- PSA (2019) Investigation of the incident in well 7132/2-1, unintentional disconnection of the lower marine riser package (LMRP) on *West Hercules*, 16 January 2019 – at https://www.ptil.no/en/supervision/investigation-reports/2019/Seadrill-West-Hercules-investigation-lmrp/
- PSA (2019b) Requirements concerning digitalisation from https://www.ptil.no/fagstoff/utforsk-fagstoff/fagartikler/2019/klare-krav-til-digitalisering/
- PSA (2019c) Report following supervision - Alarm load and HF in control room - Oseberg A, published 27.5.2019

- PSA (2020) "Report following supervision of planned reconstruction, digitalisation and robotisation of the drilling facility at Valhall IP - Performinator project" from https://www.ptil.no
- QCS-Quality Control Systems Corp (2019) NHTSA's Implausible Safety Claim for Tesla's Autosteer Driver Assistance System February 8, 2019 from www.quality-control.us
- Framework Regulations of 1 January 2011; Regulation relating to health, environment and safety in the petroleum activities (the Framework Regulations) https://lovdata.no/dokument/SF/forskrift/2010-02-12-158
- The Norwegian Government's AI Strategy - National Strategy for Artificial Intelligence – (2020) https://www.regjeringen.no/no/dokumenter/nasjonal-strategi-for-kunstig-intelligens/id2685594/?ch=4
- The Norwegian Government's Marine Strategy (2017) New growth, proud history. https://www.regjeringen.no/no/dokumenter/ny-vekst-stolt-historie/id2552578
- Roberts, R., Flin, R., Cleland, J., 2015. "Everything was fine"*: An analysis of the drill crew's situation awareness on Deepwater Horizon. J. Loss Prev. Process Ind. 38, 87–100. https://doi.org/10.1016/j.jlp.2015.08.008
- Rosness, R., Grøtan, T.O., Guttormsen, G., Herrera, I.A., Steiro, T., Størseth, F., Tinmannsvik, R.K., Wærø, I., 2010. Organisational Accidents and Resilient Organisations: Six Perspectives. Revision 2 (No. SINTEF A17034). SINTEF Technology and Society.
- Rommetveit, R., Bjorkevoll, K. S., Cerasi, P. R., Havardstein, S. T., Fjeldheim, M., Helset, H. M., ... & Nordstrand, C. (2010, January). Real time integration of ECD, temperature, well stability and geo/pore pressure simulations during drilling a challenging HPHT well. In *SPE Intelligent Energy Conference and Exhibition*. Society of Petroleum Engineers.
- Rosen, R., Von Wichert, G., Lo, G., & Bettenhausen, K. D. (2015). About the importance of autonomy and digital twins for the future of manufacturing. *IFAC-PapersOnLine*, *48*(3), 567-572.
- SAE (2018). SAE International standard "J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems." Revised: 15.06.2018
- SaudiArabia (2019) - https://www.digitaltrends.com/news/saudi-arabia-oil-drone-attack-commercial-uavs/
- Samset, K. (2001) "Project assessment during the early phase", Tapir Akademiske forlag, Trondheim, 2001. Page 39 - Figure 4.2 .
- Sethi, M. (2008, January). LIP Control & Protective System Upgrade-proving a case for consideration of human factors in design. In *International Petroleum Technology Conference*. International Petroleum Technology Conference.
- Safety Forum (2019) Learning after incidents, Report by the Safety Forum
- Singh, M. (2019) Hybrid Tactics Come of Age: Implications of the Aramco Attack. CLAWS journal, 12(2), 144-149.
- SMACS (2020), Sensemaking in safety-critical situations https://www.sintef.no/projectweb/hfc/smacs/ .
- Smith, E., & Roels, R. (2020). Guidance on human factors safety critical task analysis. Energy Institute, London, UK.
- Sdir (2020) - Norwegian Maritime Administration, circular RSV 12-2020 "Guidelines in connection with the construction or installation of automated functionality, with the aim of carrying out unmanned or partially unmanned operations" www.sdir.no/sjofart/regelverk/rundskriv/foringer-i-forbindelse-med-bygging-eller-

SINTEF

installering-av-automatisert-funksjonalitet-med-hensikt-a-kunne-utfore-ubemannet-eller-delvis-ubemannet-drift/

- Sneddon, A., Mearns, K., & Flin, R. H. (2013). Stress, fatigue, situation awareness and safety in offshore drilling crews. Safety Science, 56, 80 –88.
- Management Regulations of 1 January 2011. Regulation relating to management in the petroleum activities and on certain onshore installations (the Management Regulations) https://lovdata.no/dokument/SF/forskrift/2010-04-29-611
- Sugiura, J., Samuel, R., Oppelt, J., Ostermeyer, G. P., Hedengren, J., & Pastusek, P. (2015, March). Drilling modeling and simulation: Current state and future goals. In *SPE/IADC Drilling Conference and Exhibition*. Society of Petroleum Engineers.
- Sætren GB, Laumann K (2014) Effects of trust in high-risk organizations during technological changes. Cognition, Technology & Work 17:131–144
- Sætren, G.B., Hogenboom, S., Laumann, K., 2016. A study of a technological development process: Human factors—the forgotten factors? Cognition, Technology & Work 18, 595–611.
- Teoh, E. R., & Kidd, D. G. (2017). Rage against the machine? Google's self-driving cars versus human drivers. Journal of Safety Research, 63, 57-60
- Thorogood, J.L., Florence, F., Iversen, F.P., Aldred, W.D., (2009). Drilling Automation: Technologies, Terminology and Parallels With Other Industries. Presented at the SPE/IADC Drilling Conference and Exhibition, Society of Petroleum Engineers.
- Tinmannsvik, R. K., Albrechtsen, E., Bråtveit, M., Carlsen, I. M., Fylling, I. M., Hauge, S., ... & Okstad, E. (2011). The Deepwater Horizon accident: Causes, lessons and improvement measures for the Norwegian continental shelf. SINTEF report A, 19148.
- Torkildson, E. N., Li, J., & Johnsen, S. O. (2019, September). Improving Security and Safety Co-analysis of STPA. In Proceedings of the 29th European Safety and Reliability Conference (ESREL). 22–26 September 2019 Hannover, Germany. Research Publishing Services.
- Technical and Operational Regulations (2019) Regulations on technical and operational conditions at onshore facilities in the petroleum activities, etc. (TOF)
- Unified Bridge (2018) at Kongsberg/Rolls Royce. (https://eggsdesign.com/work/case/unified-bridge-sets-a-new-standard-at-sea#;)
- US-CSB (2016) U.S Chemical Safety and Hazard Investigation Board. Drilling rig explosion and fire at the Macondo well. Investigation report volume 3, Report no. 2010-10-I-OS, 20 April 2016. Washington, DC
- US-CSB (2019) U.S Chemical Safety and Hazard Investigation Board, Gas Well Blowout and Fire at Pryor Trust Well 1H-9 (Final Report), 2019. Washington, DC
- Vagia, M., Transeth, A. A., & Fjerdingen, S. A. (2016). A literature review on the levels of automation during the years. What are the different taxonomies that have been proposed?. Applied ergonomics, 53, 190-202.
- Valente, J., & Cardenas, A. A. (2017). Understanding security threats in consumer drones through the lens of the discovery quadcopter family. In Proceedings of the 2017 Workshop on Internet of Things Security and Privacy (pp. 31-36). ACM.
- Vredenburg, K., Mao, J. Y., Smith, P. W., & Carey, T. (2002, April). A survey of user-centered design practice. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 471-478).

- Waraich, Q. R., Mazzuchi, T. A., Sarkani, S., & Rico, D. F. (2013). Minimizing human factors mishaps in unmanned aircraft systems. ergonomics in design, 21(1), 25-32
- Weick, K.E. (2001). Making sense of the organization. Blackwell publishing.
- WHO (2018) - 2018 World Health Organization Global Status Report on Road Safety https://www.who.int/publications/i/item/9789241565684
- Wiegmann, D.A., Shappell, S.A. (2001) Applying the Human Factors Analysis and Classification System (HFACS) to the analysis of commercial aviation accident data. Presented at the 11th International Symposium on Aviation Psychology. Columbus, OH: The Ohio State University.
- Wróbel K Montewka J & Kujala P (2017) Towards the assessment of potential impact of unmanned vessels on maritime transportation safety Reliability Eng. & Systems 155-169
- Wylie, R., McClard, K., De Wardt, J., 2018. Automating directional drilling: Technology adoption staircase mapping levels of human interaction. Presented at the Proceedings - SPE Annual Technical Conference and Exhibition.

A. Abbreviations and terms used in the report

In the following, we have alphabetically listed some abbreviations and terms used in the report.

Table A.1: Abbreviations and terms

Abbreviation	Description
ADC	Automated Drilling Control
AGV Automated Guided Vehicle	Terrestrial vessels that can operate autonomously/automatically.
AI Artificial Intelligence	In ideal terms, AI/Artificial Intelligence systems are something "that can learn, reason and act on their own initiative. They can make their own decisions when encountering new situations in the same way that humans and animals can". A description of the current status is "a system's ability to correctly interpret external data, to learn from such data, and to apply this knowledge to achieve specific goals and tasks through flexible adaptation".
AUV Autonomous Underwater Vehicle	Autonomous underwater drone.
BOP	Blow Out Preventer
CRM	Crew Resource Management – training arrangements recommended by NTSB following a number of aviation accidents, which include communication, situational awareness, problem-solving, decision – focused on reducing risk in connection with interaction in distributed groups during the performance of safety-critical operations.
DGD Dual gradient drilling	DGD is a subset of MPD, which means "two or more pressure gradients within selected well sections to manage the well pressure profile".
DoS Denial of Service	Data attacks consisting of overloading, causing the computer to fail or stop
DP	Dynamic Positioning - technique for keeping ships and semi-submersible platforms in the same position above the seabed using the vessel's own propellers, rather than anchors.
Drones	In this report, the word "drones" is used collectively to refer to everything from manually controlled, remotely controlled to autonomous systems that can be used in the air, on the surface of the sea or underwater.
Digital twin	A digital twin is an integrated multiphysics, multiscale simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin
EASA	European Union Aviation Safety Agency
EDS	Emergency Disconnect System
GDPR	General Data Protection Regulation, personal data protection that applies within the EU

GNSS Global Navigation Satellite System, e.g. GPS	GNSS stands for Global Navigation Satellite System, a collective term for satellite navigation systems such as the US GPS (Global Positioning System), the Russian GLONASS, the Chinese BeiDou and the European Galileo system.
GPS Global Positioning System	Developed by the US armed forces, GPS is a satellite-based positioning and navigation system which provides accurate location determination in three dimensions.
HAZID - HAZard Identification	HAZID is a systematic method for assessing and identifying risks associated with a system or activity. The word is an acronym for HAZard IDentification
HCD	HCD Human-centred design is an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance. ISO 9241-210:2019(E)
HFACS	Human Factors Analysis and Classification System
HMI Human Machine Interface	The interface between man and machine
HF Human Factors	A scientifically based definition of the slightly broader term 'human factors', by which we mean from the IEA (2000) - International Ergonomics Association: "Human Factors (or Ergonomics) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance".
HSE	Abbreviation for health, safety and the environment and described by PSA as follows: ... *includes safety, working environment, health, external environment and economic values (including production and transport regularity)...*
IMU Inertial Measurement Unit	Sensor for measuring acceleration, angular velocity and, in some cases, orientation
IATA	International Air Transport Association (IATA), comprises 290 airlines in 120 countries
IADC	International Association of Drilling Contractors
IOGP	International Association of Oil & Gas Producers
IT	Information technology
IR Infra Red	An IR camera "sees" thermal radiation (infrared)
ISA	International Society of Automation

Cognitive	'Cognitive' means what is associated with perception and thinking; the term is, amongst other things, used to specify cognitive systems, such as screen displays or interaction with information systems.
LBL (Long Baseline Localisation)	Acoustic positioning
LiDAR Light Detection And Ranging	Sensor type based on light signals
LOA	Levels of Autonomy – automation level
Model-based solutions	By 'model-based solutions', we mean solutions where models and data are included in order to describe all or certain aspects of the equipment and process. They can be used offline for testing equipment and processes, for planning or for training purposes prior to an operation or the next step in an operation. The models can also be used in real-time during an operation with a direct link to the control systems that are controlling the drilling operation.
HTO	Human – Technology – Organisation
Human factors	In the report, the term 'human factors' is used as a slightly broader term than the term "human factors" as defined by the IEA
Human-centred design	Human-centred design is the process of designing solutions based on general natural characteristics and idiosyncrasies of human psychology and perception, taking into account human strengths and weaknesses. This means that solutions based on human-centred design will not only be adapted to the tasks, but also functionally in accordance with psychological characteristics and functions typical of large groups of users. (See also HCD).
MDP – Managed Pressure Drilling	MPD provides a closed-loop circulation system in which pore pressure, formation fracture pressure, and bottomhole pressure are balanced and managed at surface. Drilling fluid is supplemented by surface backpressure, which can be adjusted much faster in response to downhole conditions compared with changing mud weights conventionally.
MTBF	Mean Time Between Failures
NTSB	National Transportation Safety Board
OT	Operational Technology (Mechanically related in relation to IT)
OIM Offshore Installation Manager	Platform Manager
ODD Operational Design Domain	Operational area or operational envelope, description of where, who and what for an operational area for automated solutions
PSA	Petroleum Safety Authority Norway
RCD	Rotating Control Device
ROP Rate of penetration	The speed at which the drill bit can break the rock under it and thus deepen the wellbore. Speed can be reported in units of meters per hour.
ROV	Remotely Operated Vehicle
RPAS	Remotely Piloted Aircraft System

Risk	'Risk' means the consequences of an activity and associated uncertainty; ref. the Framework Regulations (2019), Section 11 Principles of risk reduction – guidance.
SA – Situational Awareness	Situational awareness is defined as the ability to: 1) perceive information from the surroundings, 2) understand this information, and 3) anticipate future developments.
Safety I	Safety-I is used to describe freedom from unacceptable risk, with the prioritisation of accidents and what goes wrong.
Safety II	Safety-II has been used to describe the ability to operate safely under different conditions, and focuses both on what goes well and on what goes wrong.
Sensemaking	Sensemaking is the description of the process for achieving situational awareness. This process can be affected by the working environment, training/knowledge, support systems and other factors
Safety-critical equipment, functions, activities, work and operations	By "safety-critical", we mean that when a system fails we can perceive critical HSE incidents (such as critical injuries to humans and damage to equipment and the environment). Safety-critical equipment, functions, activities and operations in the petroleum sector cover a broad span, and are described variously using terms such as safety-critical pipes, safety-critical expertise, safety-critical personnel, safety-critical work and safety-critical equipment. One type of safety-critical system comprises instrumented safety systems, emergency shutdown systems (ESD/NAS), production shutdown systems (PSD/PAS), fire and gas systems (F&G/B&G), and overpressure protection (HIPPS, OPS). When referring to such systems, we will use the term "instrumented safety systems".
SJA	Safe Job Analysis
Threat	A possible unwanted action which could trigger a negative consequence for an entity's security
UAS Unmanned Aircraft System	UAS includes the drone/UAV and the ground system, as well as the communication between the two
UAV Unmanned Aerial Vehicle	UAV is often used in the same way as airborne drone
UPR	Upper Pipe Ram
VPR	Variable Pipe Ram
UID Underwater Intervention Drone	Typically includes underwater drones which can operate without cables and which are able to perform interventions.
US-CSB	The U.S. Chemical Safety and Hazard Investigation Board
USV Unmanned Surface Vehicle	Autonomous systems that can be used on the surface of the sea
UUV Unmanned Underwater Vehicle	Encompasses all underwater drones: ROV, AUV, UID, etc.
WOB Weight on bit	WOB is the amount of downward force exerted by a drill bit during drilling operations

Terms linked to risk and vulnerability assessments

The perspectives in the vulnerability and risk assessments are based on Lund and Aarø (2004), where improvements to safety levels depend on broad-ranging measures which include technical, human and organisational factors, such as designs that reduce technical errors, provision for meaningful human actions, regulations and good practice. The term 'risk' is often used as an expression of the combination of probability and consequences of an undesirable event (Norwegian Standard NS 5814). This definition has been used in some scientific articles on autonomous solutions. The Petroleum Safety Authority Norway defines risk as "Risks are the consequences of the activities and associated uncertainty"; ref. Guidance to the Framework Regulations (2019) in Section 11 Principles for risk reduction. Consequence is a collective term for all consequences, i.e. injury to or loss of human life and health, environment and material values, as well as conditions and events that could cause or lead to these types of consequences. In this context, "associated uncertainty" means uncertainty relating to what the consequences of the activity could be. Given the description of the consequences above, the uncertainty relates to what events could occur, how often they will occur, and what damage to or loss of human life and health, the environment and material values the various events could give rise to.

A threat is defined as a possible unwanted action that could result in negative consequences for an entity's safety or security, NS 5830 (2012). The term "entity" is used as a simplistic collective term. An entity could for example be a physical object, an individual, an organisation, a state, a grouping, a business, or some other entity that appropriately fits into the context concerned.

B. Implementation of project activities and method use

The project was initiated by a start-up meeting with the PSA on 21 April, and ended in a meeting on 3 December. The project had defined clarification meetings with PSA on 21 April, 15 May, 18 June, 13 August, 23 September, 5 November and 3 December, during which the start-up of the activities was discussed, in addition to findings and conclusions.

The project was carried out with clearly defined activities, where the SINTEF project team held regular weekly project meetings/reflection meetings during the project period, supplemented by thematic meetings within the project to discuss and agree on findings and conclusions from the project's activities.

Table A.2: The project's activities

Activities (period carried out) –	Discussed with PSA
Start-up and organisation - (April)	21/4
Literature review - (April...June)	15/5, 18/6
Review of investigation reports - (May...August)	15/5, 13/8
Collection of information from industry - (April... August)	21/4, 13/8
Review of standards and guidelines - (May...August)	15/5, 23/9
Workshop - (29 & 30 September)	18/6, 23/9, 5/11
Analysis of supervision and regulations (August... October)	13/8, 5/11

Analysis and reporting (ongoing discussion with PSA)	5/11, 27/11, 10/12
Project management and QA (ongoing)	Ongoing

In the following, we briefly describe the approach and methodology used for the activities: Literature Review, Review of investigation reports, Collection of information from industry, Review of standards and guidelines and Workshop held on 29 and 30 September 29.

Literature review

Certain sections of the report are based on literature studies where we used search strings in Scopus; see Table B.1,. Scopus is a scientific database which contains summaries and citation references to published material, primarily research-based articles in various research journals. A total of 85 hits were found through this search in Scopus, 50 of which were considered to be relevant to the theme of this study. References to scientific sources from the results in Scopus have also been used. In addition, some key reports and references in these reports have been used as a basis in the literature study:

- Bakken, T., Holmstrøm, S., Johnsen, S.O., Merz, M., Grøtli, I.G., Transeth, A., Risholm, P., Storvold, R., (2019) Use of drones in the High North, HSE factors relating to the use of drones in petroleum operations in the High North. SINTEF report 2019:001284
- Evjemo, Tor Erik (2018) Safety and autonomy in Norwegian aviation – challenges and opportunities. SINTEF report 2018:01451
- IRIS (2018) Digitalisation in the petroleum industry Development trends, knowledge and proposed measures
- OESI (2016) "Human Factors and Ergonomics in Offshore Drilling and Production: The Implications for Drilling Safety", Ocean Energy Safety Institute Droner

Table A.2 Search strings used in literature search

Database	Search string	Number of relevant documents
Scopus		50

Review of investigation reports

In consultation with PSA, nine investigation reports were selected which were then analysed by a team at SINTIF with a variety of professional experience from previous investigations, including the petroleum sector, safety, and human factors.
Of the nine investigation reports, five were reviewed with a particular focus on autonomy and HF, along with four reports from the petroleum sector (drilling and wells) and HF.
We focused on the investigative methods and the learning of lessons linked to the way in which the investigations were conducted.

Interviews – implementation and analysis

As part of the work relating to the collection of information from industry (Chapter 4), interviews of various players in the petroleum industry were conducted. A total of 10 interviews with 27 respondents were conducted, all digitally (via Microsoft Teams). The distribution of respondents was as follows:

- Two operators, with six respondents
- One rig owner, with three respondents
- Five system suppliers, with 14 respondents
- Two independent HF experts (i.e. two respondents)

The interviews that were conducted were semi-structured interviews. In other words, an interview guide was prepared, but the discussions were not limited to the pre-defined set of questions. The interviews consisted of a combination of individual interviews and group interviews, and were conducted via the Microsoft Teams platform. All the interviews were minuted. Following each interview, a written summary was prepared.

The analysis process in this activity consisted of a simplified thematic analysis. This involved all participants in the interviews doing their own work regarding the thematic key findings that they considered to be important. The collated key findings were then reviewed during a joint working meeting, with the findings being nuanced and analysed. The results of this working meeting essentially form the thematic section of the section presented in the “Collated experiences” section. For more information about the interview process, see the “Collated experiences” section.

Review of standards and guidelines

Standards and guidelines were identified and discussed via interviews with industry players and consultants with extensive experience of projects in the petroleum sector. In addition, relevant standards were discussed with participants in standardisation groups (ISO/IEC/Norwegian Standard), with expert groups from universities and HF groups working on autonomous solutions and with PSA.

Workshop (29 & 30 September)

We held a workshop with 20 participants from PSA, SINTEF and the industry on 29 and 30 September in order to validate and discuss findings and the relevance of measures. The workshop consisted of meetings in plenary and group work in four groups split over two days with rotation of the participants in order to take advantage of the breadth of expertise amongst the participants.

The theme for the first day was Human Factors in connection with development, and was framed by three lectures:

- M. Green/HCD : "A personal view of HF issues in the Norwegian Sector"
- T. Myklebust/SINTEF: "Agile Development"
- M. Endsley/HFES: "Situation Awareness & Automation In Oil Drilling Operations"

Group work was then carried out **(1) Human factors in connection with development**

- Four areas were considered: Balance between technological focus and human factors; Use of standards that address human factors; Fragmented structure for development; Updated regulations.

The theme for the second day was human factors during investigations, and was framed by two lectures:

- Organisational psychologist Jan Thore Mellem/Accident Investigation Board Norway: "Why are Human Factors an important part of Accident Investigation Board Norway's investigations?"
- J. Price/NTSB : "Lessons Learned from Investigations of Crashes Involving Automated Vehicles"

Group work was then carried out **(2) Human factors during investigations**

- Four areas were considered: Breadth of investigation; Design assessments in investigations; Focus on successful incidents; Near misses.

C. Suggested further activities for discussion and priorities.

Findings and measures [V1] Review of possible gaps and recurrent findings from accident investigations. It is well-known that investigations are often characterised by the accident models that are used in the investigation (Lundberg et al., 2009). The barrier perspective is well-adapted to the process industry and is an easily understandable perspective that is very useful. However, it can lead to the prioritisation of technical factors, where human and organisational factors can be subjected to less thorough analysis, (Hollnagel, 2008, 2016). There may also be a reactive perspective. Challenges associated with advanced programmed control systems may also require new methods and approaches, as outlined by Leveson (2019). Consideration should be given to the need to identify the most common gaps in investigations, e.g. using complementary methods such as "The human factors analysis and classification system - HFACS" (Shapell et al., 2000). There is an HF method that is referred to in CIEHF (2020) and elsewhere. Support for finding gaps in investigations is described in "Systematic Safety Analysis for Investigators and Aviation Safety Assessors – SYSAN" (Lundberg et al., 2018). It is proposed that the sector review certain investigations with the involvement of HF experts in order to assess and identify gaps in the investigations. Particularly with regard to why there are recurrent findings relating to a lack of HF focus or designs which are adapted to human strengths and weaknesses. Also investigate why there are recurrent problems (e.g. with compliance). This may be due to poor analysis models or poor strategies for development, or poor learning. At the same time, an assessment could be carried out of new inputs, such as that the investigation process is more regulated and formalised amongst the companies than the action and learning process, and that regulatory knowledge/systematics are lacking amongst smaller subcontractors in a supply chain.

Findings and measures [V2] Investigations concerning strategy for robotics and automation generally which include drilling and wells. NOUs and strategies have been prepared concerning initiatives relating to autonomous ships and drone strategy (for the increased use of automated airborne drones). This has led to considerable concern about automation in shipping, where Norway is considered to be a leading player. The strategy for airborne drones has also led to a high level of innovation and development in this field. However, no national studies have been carried out at the same level concerning the use of robots or the automation of production processes or operations in drilling and wells. Similarly, no studies have been carried out concerning automated/autonomous metro systems or automated trains (although the operational experience gained from closed, highly automated routes is very positive). Consideration should therefore be given as to whether or not an investigation should be launched, an NOU concerning a strategic initiative relating to robots in the field of drilling and wells, possibly as part of a broader investigation into the use of robotisation and automation in industrial production and rail transport.

Findings and measures [V3]Review of the need for a stronger focus on MTO in connection with integration and remote control of critical systems. A greater degree of digitalisation and integration of systems means that more and more information will become available to improve efficiency and HSE during operation. At the same time, there are some significant challenges to be faced with regard to digitalisation and automation in the petroleum sector, as there are many silo-oriented systems that have not been integrated, as well as situations where data is owned by different supplier companies. This presents major challenges as regards data sharing, and makes it more difficult to give operators a general overview and control over safety-critical processes. Automation means that there is an expectation that fewer personnel will be needed and that operators must be capable of operating more systems from central installations. At the same time, the requirements regarding training increase, with the result that there may be more players involved who need to share identical information or that there will be technical requirements which require the systems to collate different information in a single management system. This requires both provision for strategic control from many levels, as well as the development of standards to achieve the type of interaction e.g. from an eco-system perspective (Manikas et al., 2013; Johnsen et al., 2017) or the prioritisation of open innovation (Blankesteijn, et al (2019). There is a need for MTO measures, i.e. both integrated system design and expertise relating to interaction between distributed players / organisations. It is proposed that the sector identify needs regarding integration, possible benefits and challenges (technical and organisational obstacles) in order to identify opportunities when integrating a number of safety-critical systems. At the same time, experience gained concerning remote control should be systematised and structured. This is an area which over the past 30 years has seen the increasingly centralised control of complex processing facilities from larger centres, which often cut across national borders (with improved safety and efficiency and cost reductions as a result).

Findings and measures [V4] In-depth study from RNNP, analyse events involving autonomous systems. There is no systematic collation of incidents and near misses relating to automated/autonomous systems. A preliminary study should be carried out in collaboration with PSA to determine whether it would be possible/appropriate to analyse incidents and near misses from autonomous systems. This could help to clarify the framework conditions needed to carry out such a study, and possibly the need to develop defined hazards and accidents involving automated/autonomous systems.

Findings and measures [V5] Lessons learned from successful transformation projects (digitalisation/automation)
Many aspects of the projects we have examined have had a positive impact on safety levels, efficiency and quality in connection with the introduction and development of technologies. This is for example linked to early user participation, the follow-up of training, delimitations linked to having a single responsible supplier, and the management prioritising and supporting the project. The industry should give greater priority than it does at present to identifying successful factors and processes that other players and projects can learn from, e.g. with a perspective aimed at learning from proved to be successful (Buckingham et al., 2019).
This appears to be difficult to share across suppliers and operators, e.g. as a result of commercial considerations such as competition. From a safety perspective, there should be good mechanisms in place for sharing best practice between the stakeholders involved. We propose placing a spotlight on the development *process* rather than specific *products* that have been developed. What can we learn from each other's processes in order to develop systems that address human and organisational factors?
The stakeholders and PSA could develop a form of best practice meeting series or initiatives in this area. Similar work has been carried out in the field of well control incidents through "*Sharing to be better*". The aim here could be to initiate a period of maturation during which PSA makes the industry aware of the issue, which in turn could lead to specific measures being implemented by various stakeholders over time.

Findings and measures [V6] Supervisory series linked to the use of HF in connection with automation/digitalisation. Given the lack of attention being paid to HF in some projects, PSA could carry out a series of supervisions in cooperation with specialist HF groups in order to review compliance with regulations, look at relevant knowledge concerning the use of HF (e.g. in drilling and wells, process control) and evaluate the effects of projects that have been carried out both with and without input from the specialist community which has a knowledge of HF. As mentioned previously, the definition and prioritisation of such a series of supervisions should be formulated in cooperation with stakeholders with experience of using HF and the challenges that are faced within the industry in complying with the current requirements. It is therefore proposed that knowledge concerning HF be drawn in not only from the stakeholders and the groups that work with human factors and safety amongst the companies, but also consultants with a high level of expertise relating to HF (e.g. from design groups which have a broad multidisciplinary industry knowledge). The aim should be to document the status in relation to the regulations, influence projects that are in their early phase, and disseminate knowledge concerning the effects of using HF.

Findings and measures [V7] Detailed analysis of the development of automated drilling operations.

In this report, we have discussed developments and described example projects, which illustrate the work that is under way relating to remote control and automation of aspects of the drilling process. A detailed analysis of whether fully automated drilling operations are possible from a technical, safety and economic perspective was outside the scope of this report. There are no specific technical obstacles to achieving this, but increasing complexity and vulnerability will present challenges that require good analysis, good interaction design, good processes for user involvement and good testing and ongoing learning. We therefore propose that a somewhat more detailed investigation be carried out which exclusively focusses on analyses of more fully automated drilling operations, with a review of relevant automation levels (including analyses of adaptive automation), analyses of safety-critical operations, the design of interaction design, the establishment of HMI for high performance and other relevant issues. An evaluation of AI should form part of such a project, via a "state of the art assessment". AI can be utilised very effectively in many areas (Bello et al., 2015; Kirschbaum, et al., 2020). At https://www.ai-safety.org, there are discussions concerning the framework for the use of AI. It is not only models that can be discussed, but also the surrounding framework; see Figure V7.1.

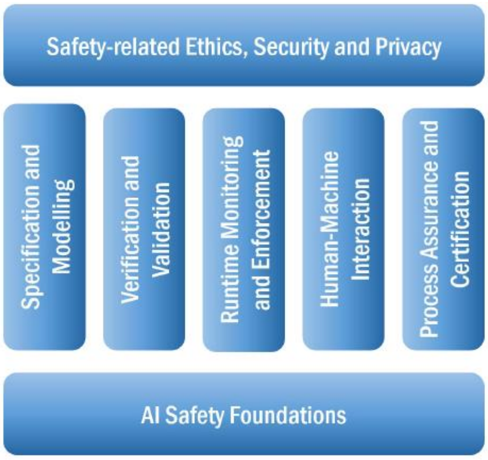

Figure V7.1 Theme for AI – see https://www.ai-safety.org

On the basis of the specific use of methods within HF, the contributions that HF has made concerning design could be reviewed and documented with regard to highlighting the interaction between automation and humans. One could discuss the principles for interaction design with "High

Performance HMI", practice for alarms, the interaction between stakeholders and the responsibilities involved in drilling and wells. Here, one should carefully review key aspects of the distribution of responsibilities between operator, contractor and supplier, i.e. who does what with what equipment in order to detect and manage a well control incident? How does automation alter work processes and the distribution of responsibilities based on different strategies for automation (e.g. adaptive automation and AI solutions)? What specific methods are used to identify potential risk as part of projects, and what are considered to be the key risk elements?

D. Table from accident investigations DP

Table C.1 DP accidents and their root causes, non-conformities and missing barriers, results from MTO analysis, after Dong et al. (2017)

Accident	Direct causes	Underlying	Non-conformities - procedures etc.	Missing barriers
DP operator wanted to alter the position of Shuttle Tanker during tandem loading from the Floating Storage Unit. When the change of direction was initiated, the Shuttle Tanker (ST) began to accelerate forwards.	Incorrect estimation of thruster values resulted in changes for the main propeller.	The software manual for tandem loading was not available on board. Insufficient parameterisation of DP software.	Insufficient information to the operating teams following installation of new system. Abnormal settings for main propeller.	- Training should be carried out after new installations. - Support manuals should be available on board following new installations. - Failure to test system integrity after new installation.
Captain changed DP mode in connection with a position change of 50 metres to correct ST relative to FPSO. DP compensates input by setting full speed ahead. Captain does not detect forward movement indicated on screen until 55 seconds later	- DP logic initiated full speed ahead based on the change of mode and command given by the captain. - Inadequate human-machine interface, important information provided on different screens. - Poor alarm design.	Inadequacy of DP design (Poor design) Inadequate ergonomic design with regard to the provision of appropriate alarms.	Insufficient information for software design teams.	Clear requirements should be established regarding how position and course adjustments of ST should be made in DP operations. Sea tests should be carried out in accordance with an FMEA. A procedure for ST testing should be prepared in accordance with an FMEA.
ST suffered a blackout due to fuel shortage and the auxiliary battery was dead. There was also a connection error in the wiring for the power distribution board. DP system unable to maintain position.	Manual control was taken over too late.	Inadequate ergonomic design with regard to appropriate alarms. Massive alarm load from various devices on the bridge.		
All position reference systems were lost. The DP system accepted incorrect input from Gyro. Without position reference system and correct input from gyro, the DP system was unable to hold the ship in the correct position.	Reception interference led to GPS failure. Incorrect gyro direction due to errors in the gyro's latitude and speed compensation. Error in position reference system due to incorrect input to DP system and incorrect gyro direction	Poor design of gyro and DP system.		Lack of barrier in gyro to reject incorrect latitude and speed compensation. Inadequate requirements in design standards and guidelines. The DP system's barriers for calculating deviations between measured and calculated direction are too wide.
After observing a discrepancy of 5m between the position control system and the DP system and noticing stress in the hawser, the operator altered an output parameter in the DP system in order to reduce the stress. When this did not work, "position drop out" was performed in order to calibrate the system. The reference station that was selected for the reference point gave the wrong signal, and the DP system activated the main propeller for full speed ahead.	The discrepancy of 5 m may have been caused by an incorrect DP offset related to the position reference system and gyro which deviates from true north. Risk of "position drop out" not identified. Incorrectly configured measurement station and DP processor overloaded.	Lack of training.	After two verifications, the reference system was configured to "continuous" mode for telegram updates.	The mode for the frequency of updating should have been checked after verification.

E. Results from Workshop

Balance between technology focus and human factors

The theme for this group discussion was why an excessive focus on technology in relation to human factors can arise during development projects and how a better balance between the two factors can be achieved.

Focus on reduced costs complicates inclusion of HF in development

In the oil industry, there is often a focus on cost-cutting in projects, which leads to areas that are considered to be “less important" being downgraded in priority. For example, methods and expertise relating to human factors could be considered to be cost-drivers if the benefits of including them are overlooked. Iterative development which includes experiences from users in stages is considered to be an expensive method, and user involvement itself is considered to be a substantial cost. However, all the theory, experiences and practices that were shared during the group work suggest that it would actually be cost-saving to include users and apply methods that address human factors both at an early stage and throughout the development process, as this approach would enable expensive changes costing 100-10,000 times more to be avoided. The challenge seems to be linked to a knowledge of good practice for project implementation.

Another aspect that could explain why human factors are not sufficiently taken into account in development projects concerning autonomous systems is that the business models and contracts that are used consider such projects to be products. This means that the challenges associated with the systems that become apparent after the projects have been concluded are not included in the project costs. The companies developing the systems may therefore have limited access to further development and learning from the use of the systems. In addition, suppliers will generally not suffer any financial consequences as a result of systems not working optimally or causing accidents or other incidents.

Lack of expertise concerning HF amongst all stakeholders

Many players involved in development projects today lack expertise relating to HF. Expertise concerning human factors is currently "a long way down the hierarchy", and operators who order autonomous systems often believe that addressing human factors is the responsibility of the suppliers. There is also a lack of awareness that provision must be made to ensure that developers have good access to users for experience transfer and testing of the systems that are being developed. One possible reason why there may be insufficient focus on human factors is that the field is considered to be challenging, with few solutions available to overcome the challenges, and a strong belief in the ability of humans to adapt to technical systems. Amongst developers, there may also be a lack of understanding of the importance of including human factors at an early stage, even before a working system has been produced, e.g. as part of prototype development. It may also be that managers in companies that are involved in the development of autonomous systems do not sufficiently understand when, how or why human factors should be included in system development, with consequences for the way in which the projects are planned.

Improvement points relating to cost reductions in projects and lack of expertise concerning human factors

It is important that stakeholders throughout the industry, operators, developers, users and authorities facilitate the inclusion of human factors, and in order for this to be possible, there is a need for greater understanding and competence. Public authorities and others responsible bodies, such as industry organisations, should increase the focus on human factors in the development of autonomous systems, e.g. through existing meeting arenas such as conferences and discussion meetings that they host. An explicit focus should also be placed on human factors in investigations into incidents, both amongst authorities and within companies in order to highlight the need to include the HF perspective in development. In contracts, operators could facilitate the clarification of the responsibilities incumbent on all parties to ensure the early and continuous inclusion of human factors in development projects.

Application of standards that address human factors

The task for the group was to discuss the application of standards that address human factors, including a discussion of what is considered to be best practice, what methods and standards are applied in practice, and whether there is sufficient expertise relating to their application. The methods and standards that were mentioned by way of introduction were CRIOP, standards for "Design Thinking", ISO 9241:210, ISO 11064, IEA/ILO (2020) and alarm philosophies (YA-710, EEMUA 191).

Need for better balance between technology and knowledge of HF – i.e. better knowledge of HF and user-centred introduction of technology

Developments are largely driven by technology, where a competence gap is apparent in relation to the use of HF at many levels, with the result that HF factors and considerations regarding human performance and limitations are taken into account at a late stage in connection with the introduction of new technology/automation.

A general lack of expertise relating to HF was apparent, while it was also apparent that there is increasing interest in HF and positive experiences of user-centred design in connection with the introduction of new technology. To ensure that new autonomous solutions reduce risks, there is a need for:

- A higher level of expertise amongst companies acting as clients, strengthening of the ability to perform the role - competence concerning regulatory requirements in connection with orders – as well as company requirements and an understanding of what HF methods/perspective can contribute in the development process
- Greater use of hired expertise concerning human-centred design development/automation, knowledge of choosing and applying appropriate recognised methods (and how they are linked together/build on each other) and relevant knowledge of major accident risks in the industry.

The general conclusion was that the introduction of technology should be based on a principle of user-centred design and user-centred introduction, so that critical tasks are created based on appropriate analyses which ensure that the right information is presented (e.g. via HMI) at the right time, and that the user understands what is happening in the system, so that the right action can be taken.

The safe use of automation requires the use of recognised methods and standards, such as ISO 9241:210 – Human-centred design for interactive systems

The supervision is carried out within a function-based regulatory framework which supports the use of recognised methods. HF methods and standards are perceived as being more important going forward due to the introduction of more automation and more complex and multifaceted systems which often depend on interaction with users who need to be prepared to take over control of parts of the system. It is therefore important that systems take into account human factors and the fact that "people are people" with all their associated strengths and weaknesses, particularly in connection with safety-critical operations. There is a wealth of normative standards that are cited, and these are not always available in the latest version for all stakeholders in the supply chain (the standards cost money), so checks should be made to determine whether all standards are available in the latest version amongst the projects that are being reviewed and establish who purchases such expensive standards. There are many standards, and relevant standards are followed to some extent. Standards are important in ensuring good systematic risk management, where risks are identified and managed during the project using recognised methods:

With the current strong focus on technology, it would be useful if a principle of user-centred development (where users are affected/involved) were to be followed up in the petroleum sector. The principle of user-centred development is well-established and in line with both the recommendations issued by the IEA/ILO (2020) and the intentions of existing regulations. Requirements regarding regulations and standards which ensure human-centred design should be an important foundation in the petroleum sector and communicated clearly from all levels.

- There is a need to update the guidelines in order to provide references to established standards, such as the ISO 9241 series (particularly Interaction Design:210) - Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems
- It must be clarified between the client and the contractor who is responsible for obtaining the standards that are to be applied to the project
- Verification and validation should be carried out to ensure that best practices (methods/standards) are followed from the earliest stages of the project and through the introduction of new technology, i.e. from the Plan for Development and Operation, concept reviews, clarification, analyses/detailed design and implementation

A summary of challenges and proposed measures from the group work is presented below:
- **Lack of competence relating to HF which should be remedied**, i.e. the need to improve competence levels concerning Human Factors in the petroleum sector [T1].
- **Technology focus that must be balanced with a focus on user-centred design** (particularly for safety-critical tasks and non-conformity management) [T2].
- **Failure to apply HF standards** (good practice such as ISO 9241:210 must be specified) [T3].

Fragmented structure of development

This group discussed the complexity of the stakeholder group and systems involved in development projects involving new technology.

Need to raise the level of competence concerning HF amongst clients

An underlying, basic theme is client expertise relating to HF. How should operators, authorities and suppliers know which HF requirements should be imposed on stakeholders in connection with development and investigations? In order to raise the level of competence amongst clients, this can be targeted at a number of areas within the industry. For example, one starting point would be to address key issues relating to human-machine interaction when new technology is introduced. For example, the introduction of new technology could be discussed in established collaborative structures, such as the Safety Forum. Another possible measure is for PSA to ask questions about user involvement and HF expertise to a greater extent than it has in the past in connection with the early phases of development projects, where each discipline is both integrated and given specific attention. This requires sufficient expertise relating to HF and good multidisciplinary cooperation with PSA. Internal competence development and competence-building within PSA is another possible measure going forward

Clarity regarding the goals that will drive development forward
Is it better safety, cost reductions or technological advances that are the goals and drivers behind development projects? This should be clarified at an earlier stage. If the *goal* of the new technology is improved HSE or a reduction in the risk of major accidents (starting from the work processes of users and seeing how the technology can overcome the challenges), this would trigger more of the processes and analyses that should be carried out in order to safeguard meaningful human control than if projects were to be initiated on the basis of cost reductions/efficiency targets or impressive technology ("here's some new technology – what can we do with it?"). In order to establish a good process, the stakeholders involved should be clear about the goals behind the introduction of technology at as early a stage as possible, and check whether the technology requires changes in how users perform tasks (i.e. where HSE and user-centring become important), or whether it is a purely infrastructure-/technology-driven change that does not require involvement.

The basic conclusion from this group was that it is important to do something about the inadequate level of competence amongst clients regarding HF, and to ensure greater clarity regarding the goals that will drive the development, so that if users are affected/part of the picture, then HSE (including HF) must become part of the project.

Updated regulations and supervision

The group discussed various issues relating to the possible need to update the regulations and revise future supervisory practices. The starting point for the discussion was formed by the points that had been prepared in advance by the project linked to the following questions:

- What aspects of the regulations address the development of autonomous systems?
- How can standards be applied in guidance to the regulations?
- How can the desire for more authority contact amongst system suppliers be addressed?
- How/To what extent is the implementation of new technology addressed in consents, Declarations of Conformity (DOC) and Plans for Development and Operation (PDO)?

Key words for the discussions were provided in advance in the form of: Learning from incidents (accidents and positives), the “see to it” responsibility, user involvement, certifications, competence concerning HF/psychology amongst authorities. However, the group chose to reformulate the first question above because the current regulations cover a wide variety of aspects, but are not necessarily up-to-date. The group chose to specifically discuss the following questions: *"Do current regulations adequately address the development of autonomous/automated systems?"*.

By way of introduction, PSA recapitulated the types of regulations that must be followed in the industry in the form of functionally based regulations, which is of course intended to increase the number of degrees of freedom for the stakeholders, but which will actually lead to a somewhat cumbersome exercise if one envisages changing this to a more descriptive approach, including specific requirements laid down in the regulations. There were also deliberations regarding what the regulations should primarily protect us against, which means that one must ask what is actually good enough – what is the lowest level of safety that society will accept? This is defined by the parties involved and could be affected by input concerning change. However, it is important to consider the mechanisms that collectively help to reduce risk, as regards not only major accidents, but also working environment-related accidents. For example, the focus on barrier management has not altered significantly as a result of the stronger focus on HF. Given the stronger anchoring of HF as a perspective for applied use internally within PSA, it was argued that one must be able to demonstrate that HF design processes, for example, constitute relevant tools for reducing the risks associated with accidents, as different perspectives compete for attention internally, including the fact that any changes in regulations must also have a socio-economic perspective.

The group also discussed challenges relating to the way in which regulations can keep up with technological development, which has been substantial since the 1990s, a development which is, for example, characterised by the fact that everything should now be controlled from a chair where the operator initiates a process and everything proceeds automatically – there is nothing in the regulations that takes this into account. Such development, which is very rapid at times, also requires the supervisory authorities to possess expertise relating to the technology itself. It will in any case be challenging to stay ahead as a regulator as technology develops rapidly. It is also the case that technological developments usually occur amongst suppliers, rather than oil companies, which in turn becomes challenging as the "see to it" responsibility becomes difficult to address. This is considered in the context of the fact that regulations consist of functional requirements, while technology is delivered according to standards.

It was also noted how the complexity of drilling and wells has increased in recent years, and there is currently no satisfactory overview of the entire industry – things are moving faster than before, new areas with new processes. It is therefore very important to clarify what the current requirements entail for the industry. There are also many new players who do not necessarily have the same level of insight into the current regulations as traditional petroleum players, and in this regard more normative references in the form of standards should be available. The question raised by the group was whether adequate and recognised standards are available? However, it is important to take into account the fact that one cannot come up with standards that turn the current standards upside down. As a supervisory authority, one must be able to argue that it is certain requirements that are not being met, but then in most cases by referring to (intended) standards.

As of today, there are few references in the regulations regarding HF-related standards. One question the group is left with is the extent to which adequate standards are available for use as a starting point for designs specific to new systems. For example, there are currently few standards available concerning the interface between human and machine, and those that do exist are vague to some extent, and when one draws in aspects associated with automation, there are no standards which are being applied. Standards are also important for the reason that they are tools for assessing the quality of new solutions by offering good normative references, including guidance in connection with supervision. At the same time, it was argued that it is not necessarily always the regulations that are the challenge per se, but that different players may also lack both insight and an understanding of the content and purpose of regulations.

Another topic which was discussed was the possibility of being able to draw lessons from other industries as regards how different processes should be implemented, especially from the aviation industry and safety approval programs in particular. In this context, it was pointed out that approval mechanisms are used to a greater extent in the USA, for example, compared with Norway, where responsibilities are often assigned to the operator.

Summary of key challenges and proposals for associated measures:

- Are there adequate HF standards to support the regulations? Measures are about identifying good HF standards and incorporating them into guidance (normative references as such)
- There is a need to be able to refer to good design processes with regard to reducing the risks relating to HF. The HF approach often competes with other factors as regards what is given emphasis internally within PSA. Measures could for example include learning from the airline industry as regards approval processes and the importance and value of focusing on HF.
- New stakeholders entering the Norwegian continental shelf do not necessarily have as much insight as traditional operators, including many stakeholders in complex systems. Measures could include the creation of arenas across stakeholders, including the establishment of dialogue (with system developers for example) to ensure a common understanding, even between all the stakeholders that they oversee and PSA, to ensure that everyone “speaks the same language”.

Breadth of investigations

The theme for this group was to reflect on the breadth of investigations as regards identifying the key underlying causes of incidents, and ensuring that investigations contribute to adequate learning and appropriate measures. In this context, ‘breadth of investigations’ means that it must be possible to facilitate the addressing of all MTO factors with the system during the investigation (from the design phase through to the operating phase inclusive). Emphasis must then be placed on ensuring the appropriate competence (breadth) in the investigation team (including HF), and the appropriate use of methods and organisation of the work. Two (main) issues were selected for the discussion in the group related to breadth:

a) Why are some investigations not sufficiently broad, and how can sufficient breadth be ensured?
b) If the theme is HF in the design of automated systems, how can this be addressed in investigations (better than it is at present)?

a) Why is there not sufficient breadth, and how can breadth be ensured in investigations?
Experience suggests that 88% of all accidents are linked to human factors. It is therefore striking to observe how little HF expertise has been involved, and how little HF is considered, in investigations at all. Having an investigation team with sufficient breadth as regards competence was highlighted as a key challenge. The problem may be due to a lack of strategic anchoring and general knowledge amongst the companies concerned regarding the importance of human factors in incidents. As a next step, it may help to establish the premises for the mandate when a decision is made to initiate

an investigation into an incident. This is based on how the investigations are organised with regard to the use of resources and the composition of expertise in the investigation team.

In the petroleum sector (and other areas as well), it is important to involve HF expertise from the beginning in more investigations than is the case at present. It then becomes important to have personnel with "proper" expertise relating to HF within the organisation. Part of the essence is being able to ask the question: Why did it make sense to act as they did? The actions taken can then be explained and used to learn lessons, rather than just look for what they did wrong (ref. deviations from norms/procedures). In addition to expertise relating to HF, a general knowledge of HF is important within the organisation (up to decision-makers/management) in order to ensure that the importance of HF is understood. This is essential in order to highlight the topic and balance it correctly against other requirements and criteria in the investigation. As an example where other requirements have gained such a position, preparedness is included as a theme in “all” investigations – so why not HF?

b) If the theme is HF in the design of automated systems, how can this be addressed in investigations?
One of the main challenges stems from the fact that the increasing levels of automation being introduced in many areas, such as drilling and wells, also entail a need to raise the level of expertise relating to HF. A clear signal from other industries that have introduced more automation is a "Loss of control" - incidents linked to automation, a phenomenon which has been experienced in numerous aviation accidents (ref. the Air France accident in the Pacific Ocean and the Boeing 737 Max accidents).

There are currently no formalised requirements regarding HF competence in investigations, in either investigations conducted by the authorities or those conducted by companies. At the same time, there is a very limited recruitment of personnel with HF expertise taking place amongst the organisations, reflecting the lack of influence and use of HF expertise in the industry generally. A contributory cause is of course prioritisation, but the incorrect use of such expertise, or difficulties in communicating well with other specialist groups or the rest of the organisation, may also be a factor. Part of the explanation may lie in the lack of adapted courses (modules/semesters) for the further education of HF personnel, particularly aimed at HF in the design of automated systems, "*user experience*". HF personnel must develop an "ability" to look at technology and understand the systems sufficiently in order to contribute. It is also difficult to find "accurate" information/literature concerning such industry-oriented HF knowledge. One possible measure is to pick out more specifically the most relevant accidents in order to learn more about the importance of HF in incidents. A better framework should also be established which, to a greater extent than today, governs what (HF-related) aspects should be requested in investigations; ref. breadth in perspectives and holistic MTO. Furthermore, one should look at what other nations are doing (e.g. Sweden, et al.) as regards the formalising of requirements regarding HF expertise in investigations.

As regards opportunities for further education, tailored courses should be arranged for workers who are not full-time students. The courses must combine an HF/psychology background with a good system understanding relating to the design and use of automated systems in drilling and wells.

To summarise – it is important to ensure that HF expertise is included in investigations from the outset (HF may then come to play a smaller role later on). It is also important to offer relevant HF courses, both in general and focused on investigations in particular.

Design assessments in investigations

The task for the group was to discuss whether design was considered in connection with investigations, with themes such as:
a) How is design evaluated in connection with investigations? (Including, for example, looking at underlying causes of poor design, e.g. appropriate distribution of tasks between human and machine; was user-centred design/iterative design used, has workload been assessed?).
b) What aspects of the design should be evaluated? (Physical design versus cognitive elements or being able to provide the right information at the right time?)
c) How can the use of (design) methods and standards be evaluated in investigations (Themes such as: prerequisites for investigation teams, including basic knowledge of HF and design)

In connection with this task, it was emphasised that there was a desire in investigations to see whether the design process was based on good practice, and similarly whether the underlying causes were due to weaknesses in design. In the following, we have reviewed each theme, with a summary of proposed measures.

a) How is design evaluated in connection with the investigations?
Design is not generally examined in individual incidents (although it may become apparent later that design should have been scrutinised), e.g. well incidents were mentioned where there is interaction (between the operator, suppliers and driller) with recent changes in human-machine interfaces, e.g. a higher level of automation – where it subsequently became apparent that the incidents were due to inadequate/poor HMI interfaces, rather than "*Human Error*". It is therefore considered to be beneficial to evaluate design in investigations. However, this can also be done retrospectively in the case of many incidents. Some investigations conducted by PSA have involved design, e.g. Gudrun (PSA, 2015), where a design with insufficient robustness was highlighted.

As regards the root causes of incidents, the problems can often be due to poor design, i.e. inadequate task analysis (or no analysis at all carried out) and failure to carry out a workload analysis. A review of the quality of design processes should be a theme for the supervision and operators, and should be carried out sufficiently early to enable adjustments to be made.

Designs are often produced by other parties when companies buy in a standard product, where it is too late to make changes, but there is then a specification of requirements against which any incidents can be evaluated. Amongst specific factors in standard products, there are usually opportunities to adapt alarms (in terms of number, priority and adaptations to existing alarm strategies).

It is important that design is carried out on the basis of a good operational knowledge and systematic risk assessments, and this must be budgeted for and planned into projects. There may be people other than the users who have a broad understanding of risk, so it must be analysed in cooperation with a number of stakeholders. It is important to set aside time in projects for input from experienced users (The budget for user input should be on a par with the input/budget for creating/developing the system from the technical side/programming).

Key aspects are:

- **Design is rarely considered in connection with investigations**, but it can provide valuable insight into the root causes of accidents and incidents, e.g. inadequate task analysis, inadequate HMI. A more systematic approach to the assessment of design should be established

b) What aspects of a design should be evaluated? (Physical design versus cognitive elements.)
Technical factors are always covered thoroughly, but the entire MTO aspect is important, and for human elements, cognitive elements in particular are important to investigate. It is important that the industry maps the various stakeholders and their roles in connection with an investigation, and assesses both the physical design and the design of control systems in order to support the users' understanding of the operation (via the systems). It is important to consider elements that support situational awareness such as HMI.

Accident Investigation Norway's investigations were mentioned as an example of the use of methods which assess important elements from design. Accident Investigation Board Norway bases its investigations on a detailed overview of the stakeholders' actions documented in a STEP diagram. Situational awareness was then analysed (based on theory from M. Endsley (2012) and an MTO analysis. PSA follows the MTO approach (but does not normally use STEP) and has not used analysis methods for SA – situational awareness, or any other explicit methods. The mapping of SA from those "at the sharp end" can improve investigations, not only in order to identify design weaknesses, but also to identify challenges linked to automation. It is important to check the quality of user experiences. In MTO investigations in the petroleum sector generally, technical factors are usually thoroughly evaluated, while human factors are not given adequate consideration.

Cognitive factors were highlighted as key elements. Examples mentioned included checklists and evaluations based on the use of Performance Influencing Factors (PIFs) as a possible approach to determining the quality of a design, where a set of PIFs such as good HMI can be put together. These elements are also reviewed in CRIOP analyses. The design quality of the barrier element should be considered, not just the technical aspects, but also aspects linked to human and organisational factors. Existing research-based knowledge concerning human performance should be utilised in connection with barrier supervision and require access to competence or specialist expertise.

Key aspects are: Designs that support situational awareness become more important in connection with higher levels of automation. Methods that analyse SA, such as that used by Accident Investigation Board Norway, could be used as a starting point to strengthen the focus on cognitive elements (SA and HMI).

c) How can the use of (design) methods and standards be evaluated?
Expertise relating to HF should be included in all teams that investigate incidents, with a minimum knowledge of task analysis and how SA is established. A multidisciplinary perspective across the board is an important measure in both design and investigations. Key methods are based on a task analysis of the totality – so a check should be made to determine whether a task analysis of the

system has been performed, and whether all interfaces have been evaluated. During the analysis, it is important to understand the context and major accident potential, to examine how the system is used both during normal operation and in fault situations.

Good examples that evaluate design can be highlighted. SINTEF has participated in early evaluations of new technology/new systems (e.g. remote control systems five years prior to commissioning), focussing on drawing in strong user representation at an early stage during the concept phase, in order to produce combined technology with user needs and users' knowledge of possible accidents and incidents at as early a stage as possible. Methods such as CRIOP using scenario analyses have been used to assess the quality of use, HMI and have worked in practice. Key aspects are:

- Systematic evaluations (verification and validations) should be carried out on an ongoing basis and as early as possible based on good practice. (Methods such as CRIOP and HFAM have been developed in collaboration with the industry and are available – and should be used.) Verification and validation should be used in connection with investigations.

Summary of measures - linked to design assessments in investigations
An important conclusion was that it is relevant to go back and check the design during investigations - there are many lessons to be learned in connection with investigations into the quality of design as part of the investigation - poor design is relevant to understanding human error. (Checks should be made to determine whether there are verification and validation reports available linked to systems which failed, which could contribute to the analysis of designs).

The methodology used by Accident Investigation Board Norway is relevant for use in investigations (can be used to help understand the patterns of action of the stakeholders), and SA in particular is an important factor. The investigations normally primarily focus on technical factors, so it is important to see whether the technology was designed to support tasks that are assigned to humans. The industry should focus more on what the stakeholders perceived, their understanding, and the support from the entire MTO system, consisting of human, technical and organisational elements.

The petroleum sector should be able to refer to good examples of investigations which have included an assessment of design and situational awareness (SA), e.g. Accident Investigation Board Norway's report on Helge Ingstad and the Deepwater Horizon investigation by CSB, with seminars on these investigations.

Lessons from successful factors

This group discussed the fact that safety thinking has traditionally been concerned with what went wrong ("Safety I"), rather than focussing on what was successful ("Safety II").

The industry should share and learn more from successful processes, systems and technologies
The fact that good systems (e.g. in order to ensure situational awareness) will be proprietary and difficult to share between operators may appear to represent a challenge, which would not support the goal of adopting best practice and ensuring that Norway is a leader in HSE on the continental shelf. It is difficult to share across suppliers and operators, e.g. for commercial reasons and due to the importance of “keeping one’s cards close to one’s chest” for competitive reasons. From a safety

perspective, there should be good mechanisms in place for sharing best practice between the stakeholders involved. In general, it will be the industry itself that possesses the best underlying experience for sharing across the board. One possible measure would be to place a spotlight on the development *process* rather than specific *products* that have been developed. What can we learn from each other's processes in order to develop systems that address human and organisational factors?

With many different stakeholders and players, it also became apparent that a vital factor for success was to only have one supplier to relate to, which simplified the entire system integration process. Here, there are a number of possible measures to bring about improvements where the industry and PSA could make use of arenas which already exist in order to put the issue on the agenda. This can encourage the industry to share its experiences. It could be that the Norwegian Oil and Gas Association is developing a form of best practice (e.g. standards/methods/guidelines or process tools adapted to the industry) with a focus on the MTO aspect in the introduction of new technology. Similar work has been carried out in the field of well control incidents through "*Sharing to be better*". The aim here could be to initiate a period of maturation during which PSA makes the industry aware of the issue, which in turn could lead to specific measures being implemented by various stakeholders over time.

In order to summarise the discussion - There should be a stronger focus on sharing experiences from successful development *processes* (if it is difficult to share experiences about *products* which have been developed), i.e. set up forums such as "*Sharing to be better*". Moreover, it was important to have clear responsibilities with, for example, only one supplier to relate to.

Near misses

The theme for this group discussion was near misses in autonomous systems and how these can be intercepted and reported for enhanced learning.

Near misses are not intercepted sufficiently by either public authorities or companies.
There are currently no defined requirements regarding what should be logged as regards critical automated systems in the oil and gas industry, or how such data should be handled in connection with reporting and learning. In automated and autonomous systems, unexpected incidents can occur which cannot be easily resolved on site. For these cases, sufficient data should be available to enable the incident to be analysed retrospectively, so that one is able to stay ahead with regard to measures aimed at preventing future incidents. It is also uncertain whether users of autonomous drilling systems today have enough experience to determine the types of incidents that should be reported as expressions of concern, or whether such systems are used adequately. There is also no systematic collection of less critical near misses on the part of the authorities. It is uncertain whether these incidents are being sufficiently intercepted through the reporting of Defined Situations of Hazard and Accident or other reporting points to RNNP.

Improvement points relating to near misses
A general raising of the level of competence with regard to near misses involving critical parts of autonomous drilling systems should be carried out, and seminars organised by PSA could be used

for this purpose. Meetings requested by the industry are another opportunity for PSA to obtain information about experiences with near misses. PSA should also consider the need to obtain information about minor near misses involving critical autonomous systems through other systems, such as RNNP. Both the authorities and the industry itself should jointly establish requirements regarding the data that should be logged in the case of critical automated systems which can enable lessons to be learned and improvements implemented in relation to critical incidents. This data should be collected and systematised by the industry itself. Within both the autonomous road transport sector and the aviation sector, there are systems for logging various types of sensor data, such as Flight Data Monitoring (FDM) with its associated warning and analysis procedures which also address privacy considerations. These could be considered in order to develop requirements for logging from autonomous drilling systems. These systems should be developed so that sufficient data is logged which can enable lessons to be learned with regard to hardware, algorithms and human factors such as situational awareness. Infrastructure which handles this data, so that the necessary lessons can be learned from the data that is collected, is also needed. Provision should also be made to ensure that users of autonomous systems can report unexpected situations involving autonomous systems, and training must be provided concerning the types of incidents that should be reported, e.g. expressions of concern.

The general conclusion from this group work was that near misses are not being given sufficient attention by either authorities or companies, and both the authorities and the industry should jointly establish requirements regarding the data that must be logged concerning critical automated systems which can provide information on critical incidents.

SINTEF

Technology for a better society

www.sintef.no