Project description: Sensemaking in safety-critical situations – (SMACS)

PART 1 Knowledge needs

1. Knowledge needs

The ability to handle demanding maritime operations safely is increasingly dependent on ICT- based control systems (e.g. dynamic positioning and ballasting/stability). Such systems play a crucial role in the handling of critical situations, by presenting safety-critical information that allows operators to make sense of the situation. The growing dependence on such systems changes work processes, competence requirements, and above all – it introduces new opportunities and challenges related to the handling of risk in demanding maritime operations. This is the topic of this project.

We will study and improve the technical, human and organizational capabilities needed for effective sensemaking in safety-critical situations. The term sensemaking refers to the way actors combine the bits and pieces of information they have, and make decisions on this basis. Importantly, this process involves tight interaction between humans and technology that places high demands on the quality of technology, the experience of the operator, and the education and training of seamen and operators. Sensemaking depends on access to information about situation and surroundings, as well as on domain knowledge, analytical and cooperative skills to make sense of the information. We have identified the use of dynamic positioning and ballasting systems in critical situations as our key case. Anchor handling and rig move operations of drilling rigs in the high north is given particular attention. These are operations with huge amounts of energy involved, where situations may switch quickly from normal operations to critical situations, and where the consequences may be devastating. This makes such operations good cases for the study of demanding maritime operations. Furthermore, the number of demanding maritime operations in the Barents Sea is expected to increase due to the petroleum and aquaculture industries moving further north.

The objective of SMACS is to build and disseminate knowledge on how to enhance the technological, human and organizational (MTO) capabilities needed to be able to handle safety-critical situations. This requires closing the loop between design and operative experience. By improving the capabilities for sensemaking, we will improve the maritime industry's resilience in handling surprising situations, including emergencies. Resilience is here defined as the ability to handle surprises, or "the ability of a system or an organization to react to and recover from disturbances at an early stage, with minimal effect on the dynamic stability" (Hollnagel et al. 2006). The main problem to be addressed is the following: **How can the ability to deal with safety-critical situations be improved in demanding maritime operations?** The project targets MAROFF's thematic priority area number 2, "demanding, safe maritime operations". Within this area, we will address the following sub-priorities:

- Decision support for managing unanticipated situations, including emergencies.
- Human factors and risk management related to maritime operations;
- Management, cooperation and optimal planning and organization of operations;
- Use of simulators in education, as well as training and planning related to operations

The project team has broad industry backing and access to high-quality research networks.

Some cases further underline the need for addressing the issue of sensemaking in critical situations: In 2007, the anchor handling vessel Bourbon Dolphin capsized during a rig move northwest of Shetland. Eight people died in the accident. While the causes of the capsizing are complex, ballast systems are a key system for balancing the vessel and there have been speculation that the vessel was not properly ballasted.[1] Additionally, there have been incidents and accidents both related to loss of position on DP operated vessels[2], and related to the ballasting of cargo ships[3]. The same systems are also used on semi-submersible oil rigs. In 2012, the Scarabeo 8 semi-submersible drilling rig had an

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[1] http://www.vg.no/nyheter/innenriks/bourbon-dolphin-katastrofen/derfor-kantret-bourbon-dolphin/a/572180/
[2] See http://www.bsee.gov/uploadedFiles/BSEE/Regulations/Safety_Alerts/FINAL%20USCG-BSEE%20Joint%20DP%20Safety%20Alert.pdf
[3] For instance, the Stella Mare accident in the port of Albany where a ship rolled over in the harbour, killing three men.

unintended list of seven degrees during drilling. The triggering cause was a human error in the handling of the ballast system. The investigation report attributed the incident to insufficient training of control room personnel and weaknesses in the control room's human-machine interface (HMI). These examples illustrate two things: 1) that ICT-based control systems are key to controlling major accident risk both in the maritime and offshore industries, and 2) that operators' sensemaking based on information from these systems is a key factor in avoiding major accidents and enabling recovery in near misses.

PART 2 The knowledge-building project

2. Objectives

The primary objective of SMACS is to build and disseminate knowledge on how to enhance the technological, human and organizational capabilities needed to be able to handle safety-critical situations. This calls for a holistic perspective including understanding of technology, design, training and professional culture and seamanship. The secondary objectives are the following:

- to develop a state-of-the art literature review of sensemaking and resilience in safety-critical situations
- To review and evaluate current requirements regarding HMI and training related to safety critical systems
- to identify MTO characteristics that contribute to sensemaking and resilience
- to contribute to bridging the gap between new technology and old ideals of work in the maritime profession
- to develop and evaluate an MTO-based approach that can be used for HMI design related to sensemaking and resilience
- to develop an MTO-based approach for training and assessment of sensemaking skills

3. Frontiers of knowledge

Existing research has revealed a number of factors influencing the ability to deal with safety-critical situations. In the following, we will delineate three different strands of research, which forms the frontier of knowledge for SMACS:

- Design of safety-critical systems
- Sensemaking and resilience
- Learning and training

3.1 Design of safety-critical systems

Human-machine-interface (HMI) is a key factor shaping operator performance, via concepts like sensemaking and situation awareness (Endsley et al. 2003). This is true for most complex domains, such as aviation, military operations, process control, as well as for maritime and offshore activity. Importantly, the division of labour between man and machine is rapidly changing, making systems more autonomous. While this offers advantages, there are also challenges related to the human being left more "out of the loop". In response to a number of automation related accidents in recent years, effective human-automation collaboration has been the focus of considerable investigation, especially in the aviation domain. We expect the lessons learned from this work to be highly relevant also for the maritime sector.

Establishing the characteristics that make a system agile enough to adapt under pressure, rather than break in the face of unexpected events, has been another focus for the design of safety-critical systems where the consequences of highly unlikely situations might be critical (Hayes et al. 2003). Building flexibility and adaptability into the HMI has turned out to be easier said than done (Christoffersen & Woods 2002). In terms of design methodology, the ISO 11064 “user centered design” process as well as the NUREG 0700 (the US nuclear regulatory commission guidelines for HMI and control room design) is widely adopted by most safety-critical industries. These processes emphasize involvement of end users in all phases of the design and implementation, and they generally recommend iterative design, as well as some kind of performance-based evaluation/test. However, in most development projects there are often considerable economic, technological and/or organizational obstacles to operator involvement and in-depth MTO (man, technology and organization) work. These obstacles are likely to become more important under the current market situations in the maritime industry. Improved understanding of these obstacles will be an important part of the data gathering in SMACS. MTO is a systems-oriented approach. It is based on the assumption that to uphold safety in high-risk organizations it is necessary to focus on the relationship between human, technological and organizational factors. MTO conceives safety as a dynamic factor that is continuously created when human, technological and organizational factors adapt to and compensate for each other to ensure that performance is within the safety envelope. Thus, the MTO perspective differs from earlier safety philosophies where the individual was seen as the main factor for upholding system safety.

Despite good intentions, design solutions often turn out suboptimal from a safety perspective. In particular, the obstacles to design improvement are poorly understood and users are rarely sufficiently involved at an early stage of the design process. Therefore, we believe that it is fruitful to “revisit” some of the critical HMI solutions used in both the maritime and offshore industry, such as DP and ballasting. We will use the same overall design methodology, but with a broader MTO perspective, more focus on issues that affect safety, strong involvement of users and and strong commitment to exploring various design options to improve reliability and support resilience.

Here, the project intends to look to maritime actors involved in the project, such as The Norwegian Shipowners´ Association, Songa Offshore, Kongsberg SeaTex, The Norwegian Maritime Directorate, the Petroleum Safety Authority of Norway, as well as international actors working with high performance HMIs, e.g. the US User Centered Design Inc. and the US Humans and Autonomy Lab (HAL). A number of Norwegian actors are at the forefront of this development. SINTEF has led several projects related to human factors improvement and improvement of training, and has established the Human Factors network – HFC – Human Factors in Control with domestic and international researchers and practitioners. Institute for Energy Technology (IFE) has studied the effect of various HMI and automation visualization designs on operator performance, particularly in the petroleum and nuclear domain, and owns several patented design solutions that are being used by the industry.

3.2 Sensemaking and resilience

Sensemaking has been approached within different theoretical frameworks. In the framework of psychological/organizational research, sensemaking refers to the processes involved when people seek to make sense of something, i.e., when they are trying to figure out what is going on in a given situation (Weick 1995, Weick et al. 2005). People are believed to engage in sensemaking when they experience uncertainty and/or ambiguity: Uncertainty implies that one is unable to make sense of an occurrence, while ambiguity means that there are more opportunities for interpretation available. Sensemaking is usually conceived as a distributed, social process. When engaging in sensemaking, people share the information they each possess, and they negotiate and contest the information available together to reach a shared understanding of how to make sense of their environment. The process of ascribing meaning to an event or situation is present both in normal operations and in a safety-critical context. Sensemaking is particularly important when one is facing unforeseen or even unprecedented situations where individuals and teams are forced to act within a limited time frame. This is where standardized responses have clear limitations and where the need for situational adaptation and improvisation increases (Antonsen et al. 2012). In such situations, sensemaking is a key part of resilience, in that it enables a person or a crew to "bounce back" when put under pressure. For this reason, the decisions made during a sensemaking process need not be fully justified, but may rather be considered as current plausible solutions. Still, when the solutions are implemented (e.g. as ways of thinking about a situation) it will change the environment, and come to constrain what solutions that may be decided on further on in the sensemaking process. This constitutes what Weick refers to as *enactment*.

Sensemaking has also been approached within the framework of ethnomethodology. In this framework, sensemaking is broadly considered as a discursive act (e.g. Garfinkel 1967). Research addresses the discursive processes that are involved in the construction of meaning, as well as different ways in which sensemaking may proceed. Gephart (1993), e.g., reported how interpretation of texts may provide insights into how an organization makes sense of risk and blame. The various types of instruments that may help mediate discursive processes, such as, e.g., figures and graphs, constitute an important research topic. The research area computer supported cooperative work (CSCW) specifically addresses how tools may be used to support sensemaking processes (e.g., Ravid et al. 2008; Knight et al. 2013).

Sensemaking has also been addressed within the framework of Naturalistic Decision Making (NDM). NDM aims at understanding how domain experts (like DP and ballasting operators), make decisions in demanding real-life situations. Klein, Moon, and Hoffman, thus, defined sensemaking as "a motivated, continuous effort to understand connections (which can be among people, places and events) in order to anticipate their trajectories and act effectively" (Klein et al. 2006, 71).

According to Weick (1995), sensemaking is retrospective in the way that we make sense of our actions and experience *after* they have happened. The idea that sensemaking processes also involve looking at the future is sometimes implied, but rarely discussed explicitly in the research literature. Nevertheless, by introducing the notion of prospective sensemaking (Rosness et al. 2016), the argument is that sensemaking processes must explicitly entail the ability to look ahead and make sense of what will happen in the short and long term. "Instead of waiting for things to happen and making sense of them in retrospect the operating team members constructed plausible projections of what might happen and how they might handle such plausible futures" (Rosness et al. 2016, 53).

All of the above approaches to sensemaking will be further explored in the project. The aim of a sensemaking process in an organization will be to provide meaning to an event or situation in a given context. In such situations, sensemaking can be a source of resilience, in that it enables a person or a crew to "bounce back" when put under pressure. In safety-critical situations, sensemaking may thus be a matter of life and death, as illustrated by Weick's (1993) study of the Mann Gulch disaster. The concept of sensemaking shed light on how people manage safety-critical contexts in such a manner that the process supports resilience; i.e. such that the situation can be controlled within the context of safety.

Resilience should be a property to be designed in the whole system (i.e. MTO). Resilience principles should be used to handle surprises such as when the system has gone to an exceptional state due to a failure or that the result of a user's action does not match the presumed responses or interactions. When designing interfaces in a complex environment with high risks the concept of High Performance HMI (Hollifield et al. 2008) has been used as a "best practice" guideline. The method used to establish High Performance HMI consists of guidelines describing: principles of hierarchy, how to reduce cognitive processing, principles of interactions to identify exceptions or deviations (based on use of colours, patterns and prognostics) and how to integrate decision systems (normal development and alarms) in the design. These principles have been used in the design of ship bridges, and have been an area of focus for the project and project participants (Lurås & Nordby 2014).

3.3 Learning and training

Learning and training are key topics for promoting an operator's ability to make sense of a situation at hand. For instance, the task of an operator engaged in dynamic positioning (DP) operation may be decomposed into three main phases: 1) monitoring to identify need for interventions to prevent a safety threat; 2) making sense of the potentially critical situation at hand and deciding on how to intervene; and 3) implementing actions. The system operator will spend most of his or her time on the monitoring activity. When the need for intervention arises, the time available for making sense of the situation and deciding how to proceed may be short (Maybe as short as 30 seconds.)

Today, theories on learning (Raw & Gurr 2013) and training (Smith et al. 1997) increasingly focus on how to promote sensemaking and adaptability. A training approach that is often used to develop this type of competencies is Crew Resource Management (CRM) training. CRM training addresses non-technical skills, i.e. "…cognitive, social and personal resource skills that complement technical skills" (Flin et al. 2008). The overall purpose of CRM training is to contribute to safe and efficient task performance by minimizing, trapping and mitigating errors. Non-technical skills are of key importance for promoting sensemaking; they enable crew members to jointly make sense of a situation in ways which benefit from their shared competencies and perspectives.

Still, a system operator will not always have crewmembers present to support his or her sensemaking processes. For this reason, it is of key importance that each operator has the competencies needed to make sense of a situation on his/her own. The unpredictability of the ‘emergency mode’, its low frequency and its complexity can be a challenge to the best training program. The research in resilience engineering has given us more insight into how to handle surprises in an MTO context. This is will be explored in this project. HMI design should take into consideration challenges that training programs cannot effectively solve, making HMI better support the mode-switching between passive monitoring and active response/intervention. Adaptive expertise theory (Hatano & Inagaki 1986) offers a promising basis for development of training programs to achieve this.

Adaptive expertise presupposes and integrates routine expertise. Routine expertise is manifest when a person is able to perform standard tasks using well-learned procedures or routines with high efficiency and accuracy. Routine expertise is developed using traditional training principles, such as feedback addressing procedure compliance, repetition, and overlearning. Adaptive expertise, on the other hand, is developed using different training principles. These include critical thinking, experimentation, and exploration. Training aimed at developing adaptive expertise will not be focused at preventing errors, but at building a capacity for sensemaking by promoting detailed conceptual and practical insights into how the technical system works in its environment.

In the SMACS project, we will seek to develop basic principles for training to promote sensemaking which combines principles from CRM training, resilience engineering and adaptive expertise training. The goal is to promote operators’ sensemaking processes regardless of whether they work as part of a team or on their own. As part of this work a measure for assessing the level of sense making in individuals and teams in the maritime profession will be adapted from existing measures (e.g., Duffy et al. 2013; Wilson & Wilson 2013) and/or developed.

4. Research tasks and scientific methods

As indicated, the primary objective of SMACS is to build and disseminate knowledge on how to enhance the technological, human and organizational capabilities needed to be able to handle safety-critical situations. This is an ambitious goal that demands a holistic perspective including the technical systems, via concepts for training and education, to the more general professional cultures into which new technology and new training concepts are introduced. Figure 4.1 illustrates the focus of our proposed project.

Figure 4.1: Areas of focus to support sensemaking of safety-critical situations

The figure illustrates that the project places at the center the sensemaking that goes on in safety-critical situations (RQ1). While sensemaking is present in normal, everyday operations, it is particularly important in critical situations where time-pressure may be high, information low and the stress-level extreme. In order to understand and improve the handling of such situations, there is a need to address both the design of safety-critical systems (RQ3) and the training that is to enable operators to deal with the unexpected (RQ4). None of these processes, however, can be understood in isolation from the more general human, technological and organizational context of which they are part (RQ2). This model, and the research tasks involved, draws on expertise from psychology, engineering, pedagogics, as well as sociology and anthropology. A key part of our approach is the strong involvement of both operative personnel and designers, and the combination of a wide variety of scientific methods.

Table 1 gives an overview of the study's research questions and the tasks that have been designed to answer these questions.

RQ no.	Research Question	Task	Supports
RQ1	What are the characteristics of sensemaking and resilience in safety-critical situations?	**Task 1: Literature review of sensemaking and resilience in safety-critical situations**	**RQ2 RQ3 RQ4**
RQ2	What are the needed human, technological and organizational factors to support sensemaking and resilience in safety-critical situations in the maritime profession?	**Task 2: Review and evaluate current requirements regarding HMI and training related to safety-critical systems** **Task 3: Identify MTO characteristics that contribute to sensemaking and resilience in an organization** **Task 4: How to bridge the gap between new technology and old ideals of work in the maritime profession**	**RQ3 RQ4**
RQ3	What are the characteristics of an HMI that facilitates sensemaking and resilience in safety-critical situations in the maritime domain?	**Task 5: Develop and evaluate an MTO-based approach that can be used for HMI design aiming to contribute to sensemaking and resilience**	**RQ4**
RQ4	What are the characteristics of training methods that promote the development of sensemaking in the future maritime profession?	**Task 6: Develop an MTO-based approach for training and assessment of sensemaking, aimed at situations where trainees use new technology designed to support sensemaking and resilience**	**RQ3**

Table 1 Research questions and tasks

Case design: All tasks of the project are designed to shed light on different parts of the chain between design and operation of safety-critical systems. The design work of Rolls-Royce Marine provides an entry point to the blunt end of this chain, while access to the operative world of Songa's rigs and Bourbon's service vessels allows us to view the system through the eyes of the users. Importantly, the combination of these two angles allows for closing the loop between design intentions and operative experience. This is considered a key to both the generation of sound scientific knowledge, but also to be able to improve the design of safety-critical systems.

Task 1: Literature review of sensemaking and resilience in safety-critical situations

In recent years, research has been done on how to increase sensemaking and resilience in general. We will focus our analysis on sensemaking and resilience in safety-critical situations more generally, but with a particular emphasis on accident/incident investigation reports and peer-reviewed scientific publications that specifically addresses HMI, training, and procedures that have been shown to increase sensemaking and resilience. If there is not enough literature that specifically describes how HMI, training, and procedures increase sensemaking and resilience, we will derive characteristics that support sensemaking and resilience from the general literature. This first task addresses main research questions RQ1. To solve this task we will also host meetings with national and international experts to discuss these characteristics. The literature studies and workshops will result in one peer reviewed scientific publication. These meetings will be held at international conferences.

Task 2: Review and evaluate current requirements regarding HMI and training related to safety-critical systems

Regulatory requirements and standards play an important part for the design of safety-critical systems and the training performed to be able to use these systems. In this work package, current requirements regarding HMI and training for ballasting and DP systems will be reviewed. This is planned in two phases: First, as a qualitative assessment of the involved authorities' perceptions of the quality of existing requirements. Second, after having conducted interviews, observation and anthropologically inspired fieldwork in task 4, we will also perform an evaluation of the effectiveness of existing regulations. The results will be used as input to identify improvement areas for how HMI is currently followed up by rules and requirements on the NCS. This task addresses and builds on main research question 2. The project aims to write one peer-reviewed scientific publication based on this task.

Task 3: Identify MTO characteristics that contribute to sensemaking and resilience
The purpose of this task is to identify key performance shaping factors (PSFs) governing successful operations in an MTO perspective. An MTO perspective is a holistic approach that takes into account human, technological and organizational aspects of safety, and the interaction between these factors. The MTO analysis will focus on establishing the overall factors that enable operators to execute their task in a safe and efficient manner when working with a particular HMI. This task addresses main research question 2 and will explore questions such as:

- What is the importance of sensemaking and resilience in safety-critical situations?
- How are operators supported in making sense of information provided by the HMI, including information showing the status of barriers and current safety margins?
- What factors, other than the HMI, need to be present?
- How are operators supported in making decisions?
- What role does the HMI play in collaboration across geographical location?
- How are operators supported in implementing decisions accurately and timely?

The MTO analysis will be performed by means of semi-structured interviews, observations and a workshop. The interviews and observations will be performed on board ships and rigs and based on the perspective of the system users. The workshops will include personnel with subject matter expertise, operational experience, and knowledge in HMI design and human factors. After the workshop, the map outlining the MTO relationships for the different systems will be validated by the workshop participants. The outcome of the MTO analysis will be input to HMI design, as well as other MTO components, such as training, work practices, and operating procedures. The aim of the activity is to contribute to closing the loop between design activities and operational experience. The outcome will form the basis for a peer-reviewed scientific publication.

Task 4: How to bridge the gap between new technology and old ideals of work
Efforts involving changes in the way work is to be performed will always meet a set of existing ideals of work. Every profession develops a set of norms, values and attitudes that, together with knowledge and experience, influence the actual work practice. This can be referred to as professional culture, found in every profession and discussed for example by Helmreich and Merrit (1998) in aviation and medicine, and by Lamvik et.al. (2010) in the maritime industry. Also the similar term "seamanship", discussed by Antonsen (2009a, 2009b) Knudsen (2009), Antonsen & Kongsvik (2015) fits into this picture. This refers to the informal ideals of work that specifies what a job is really about. The use of new technological systems may or may not resonate with these informal ideals. In order to understand the way technology is used, it must be seen in close relation to this social context. The gap between formal and informal routines and between technology-as-designed and technology-in-use, needs to be addressed and bridged (see Antonsen et al. 2008 and Lamvik et al. 2010 for further discussions on this topic). While the bridging of these gaps may have different solutions, it seems inevitable that tomorrow's operator should be more familiar with IT practices. This activity will be performed by means of interviews, observation and anthropologically inspired fieldwork. The results will provide important input to all other tasks. Also, SINTEF will submit an IPN application to the MAROFF program aiming to develop new onboard computer-based training technology. The knowledge generated about the users' needs, competence and work situation will provide invaluable input also to this project. The activity will be documented by a peer reviewed scientific publication.

Task 5: Develop and evaluate an MTO-based approach that can be used for HMI design aiming to contribute to sensemaking and resilience
The goal of this task is to translate the results from the MTO analysis and assessment of HMI as a PSF into principles for design solutions for operations and design processes that support sensemaking and

resilience. Our fundamental starting point is that the match between humans and technology is best attended to by adapting technology to humans, and not vice versa.

The guideline can be used in the development of new HMIs with the goals of increasing sensemaking and resilience. The guideline will describe characteristics of the HMI, method to evaluate the HMI, training and procedures in the development process. Activities are:

- Developing a design philosophy, including key design goals, based on results from MTO analysis and the assessment of HMI as a PSF.
- Developing a guideline describing a user-centred, participatory, design process that includes understanding the risk context, and how the design solution can enhance safety and resilience.

These guidelines and principles are intended for use by design teams. They will be developed in cooperation with the project members that have a background in design and engineering. This task addresses main research question 3.

In order to evaluate the quality of the HMI, existing methods will first be investigated. Then, based on task 1 (the literature study), we will explore if and how these methods could be changed to also include evaluations of sensemaking and resilience. Workshops will be held with national and international experts to establish a new HMI evaluation method that includes sensemaking and resilience. This task addresses main research question 3. The project aims at writing two peer-reviewed scientific publications based on this task and producing an edited scientific book in collaboration with leading international scholars.

Task 6: Develop an MTO-based approach for training and assessment of sensemaking, aimed at situations where trainees use new technology designed to support sensemaking and resilience

The purpose of this activity is to provide generic guidance on assessment and training of sensemaking in the maritime profession, focusing on situations where personnel work with new technology specifically designed to support sensemaking. Simulator training and other forms of computer-supported training are likely to be important building blocks of this approach. This task will be carried out based on the MTO analysis performed in Task 3. The guidance material on training and assessment will be developed in an iterative process with the design and testing of the HMI to ensure that user/trainee feedback on training needs are continuously obtained, in addition to information on potential adjustments needed in the HMI design, work practices, etc., to establish the best possible conditions for sensemaking and resilience in operations.

1) The guidance material aims a supporting identification of sensemaking that need to be trained, as well as principles and training approaches for promoting sensemaking. The training principles and approaches will be based on Adaptive Expertise theory to enhance trainees' ability to handle unforeseen events, and on Crew Resource Management training (i.e. BRM – Bridge Management training) to promote teamwork in sensemaking processes and reduce the risk for human errors. In particular simulator training and exercises are perceived to be highly suitable for sensemaking training. These training approaches allow a variety of realistic cues and noises to be introduced. They, thus, provide trainees the opportunity for practicing and refining their ability to identify and make sense of patterns in the environment to improve their potential for making fast and sound decisions when problems arise. Training elements or modules for promoting sensemaking will be developed. The elements or modules may be integrated into existing company training programs.

2) In order to be able to assess if training aimed at sensemaking has achieved its goal, it is necessary to have a measure that allows assessment of the trainees' "level of sensemaking" prior to and following training sessions. The sensemaking measure should work both at the individual and at the team level. The suitability of existing sensemaking measures will be assessed vis-à-vis sensemaking focusing on situations where personnel work with new technology designed to support sensemaking. Based on the findings, an existing sensemaking measure may be used or adapted to the characteristics in the maritime domain, or a new measure may be developed.

A workshop will be performed with training departments in the maritime profession to evaluate the usefulness of various training principles and approaches. The project will publish two peer-reviewed scientific publications based on this task.

5. Organization and project plan

Table 2 shows an overview of the main activities.

#	Main activity, objectives and deliverables
1	Literature review of sensemaking and resilience in safety-critical situations
2	Review and evaluate current requirements regarding HMI and training related to safety-critical systems
3	Identify MTO characteristics that contribute to sensemaking and resilience in an organization
4	How to bridge the gap between new technology and old ideals in the maritime profession
5	Develop and evaluate an MTO-based approach that can be used for HMI design aiming to contribute to sensemaking and resilience
6	Develop an MTO-based approach for training and assessment of sensemaking, aimed at situations where trainees use new technology designed to support sensemaking and resilience
7	Dissemination – articles and web of knowledge (Part of task1-6)
8	Project management

Table 2. Activities

The project will be managed by research director Stian Antonsen (Phd) at the department of Safety research at SINTEF Technology and society. Antonsen is the author of two books related to safety management and maritime safety, as well as numerous scientific publications on the topics of seamanship, maritime safety culture, and maritime safety regulation. Antonsen will lead the project in close collaboration with senior researcher Stig O. Johnsen, one of Norway's leading human factors professionals.

Institute for Energy Technology (IFE) is the core partner in the project. IFE is an independent international research foundation for energy and nuclear technology. The objective of the Industrial Psychology department at IFE is to improve the safety of dynamic and complex production systems, focusing on human performance and organizational factors. The department performs research on human potentials and limitations in the operational environment, focusing both on human interaction and human-machine interaction. The results are used within design, evaluation and safety assessment of complex production system.

6. Important milestones

The project is planned to start at 1/1-2017 and continue in a period of 4 years, being finished at 31/12-2020. The time schedule of the different tasks are as suggested in table 3:

Tasks	**2017**		**2018**		**2019**		**2020**	
	H1	**H2**	**H1**	**H2**	**H1**	**H2**	**H1**	**H2**
1: Literature review								
2: Review/evaluate requirements								
3: Identify MTO characteristics								
4: Bridge the gap								
5: Method/evaluation, HMI design								
6: Approach for training								
7: Dissemination	Continuous							
8: Project management	Continuous							

Table 3: Project plan and milestones

9. Other collaboration

Songa Offshore owns and operates a modern, safe and reliable fleet of mobile drilling units. Their goal is provide a cost efficient operation and meet the market and regulatory demands. Songa Offshore is going to be a case where we are exploring HMI design and operational and collaboration-related challenges in connection with rig moves.

Bourbon Offshore Norway has agreed to take part in the project[4]. The Bourbon group is a leading player within offshore shipping providing shipborne supplies to oil and oil- related companies all over the world. The anchor handling vessel "Bourbon Arctic" is a newly designed vessel with new DP and ballast systems which is involved in complex maritime operations (rig moves) in the Barents sea. The vessel will form an important part of our case study of demanding maritime operations in the high North.

Kongsberg SeaTex is a leading international marine electronics manufacturer specializing in the development and production of precision positioning and motion sensing systems. The commitment is to provide quality products and solutions for safe navigation and operations at sea in the commercial offshore, maritime, hydrographics and defence industries. We are going to explore the use and design of DP systems together with SeaTex.

Rolls-Royce Marine has put long-lasting efforts into a user-centred design approach, show-cased by the Rolls-Royce Unified Bridge. The concept concerns the ship bridge environment utilizing a user-centred design process from the very beginning to the end-product, where users/operators are constantly involved to provide input for the next versions based on feedback from operators onboard vessels sailing with the Unified Bridge concept on board.

Participation from the Norwegian Authorities – The Petroleum Safety Authority (PSA) and the Norwegian Maritime Authority (NMA). The Petroleum Safety Authority has accepted to be a part of a reference group of the project, since they find the project of academic / professional interest. (Ref e-mail from the PSA at 25/8-2016). The Norwegian Maritime Authority has accepted to be a part of a reference group for the project (Ref e-mail from the NMD at 25/8-2016).

Participation from local and international experts involved in HMI design

We have agreement from Norwegian design firms that vill participate in workshops and collaboration with the project to combine high performance HMI design with sensemaking and resilience. We are going to collaborate with Ian Nimmo at User Centered Design Services that has been a central resource in establishing "The High Performance HMI Handbook" (Hollifield et al. 2008) that has been used in recent design projects. In addition we have established contact through the HFC forum to prior speakers that are positive to return and collaborate such as:

- Greg Jamieson (Associate Professor, University of Toronto)
- US Humans and Autonomy Lab (HAL) now at Duke University (Prof. M. Cummings).

These informal trelationships can be formalized through agreements if needed.

PART 3 Project impact

10. Importance for national knowledge base

Design of maritime control systems have traditionally been technology-focused in the sense that the cognitive strengths and limitations of the user has been taken into account at a late stage of the technology development process. Moreover, the role of the more contextual factors like team properties, training and education are rarely taken into account when considering the ability to use safety-critical systems in a way that increases the ability to deal with particularly demanding situations.

The research partners posits highly complementary knowledge and their internal strategies focus on different aspects of the ability to deal with demanding situations. This ranges from competence related to layout and design of ship bridges and control rooms, via design of human-machine-interface, to experience with team properties, training, education and learning. The combination of these fields of expertise will build new research networks that will be able to approach the problem of sensemaking in complex situations in a more holistic manner. This will give the Norwegian maritime and offshore industry a competitive edge in creating improved technical systems, for instance related to dynamic positioning and ballasting. It will provide the industries with new knowledge on how to better include user experience in technological innovation processes. The project will improve current training

[4] Subject to final agreement with company management.

methods related to the role of ICT-based systems in dealing with demanding situations. In sum, this will contribute to lasting improvements in our ability to handle the risks of major accidents and prepare the next generation of seamen and operators for new forms of work.

The project has also established a national competence-building group. Key stakeholders of the Norwegian maritime industry will receive results from the project continuously, as well as providing input to the project's empirical work. The belief is that this group will create an ownership among key stakeholders that can enable the industry to take a qualitative leap in the way safety-critical systems are designed and the training methods that forms the basis of sensemaking in safety-critical situations. For further information, see dissemination plan.

11. Relevance for Norwegian industry

The participating companies will develop expertise and knowledge that will make them better able to perform demanding maritime operations in a safe manner, create safer technological systems and improve their competitive positions as ship-owners and technology developers. By integrating the project with the HFC forum, the project will also have a targeted way of making the results available for other relevant stakeholders.

Norwegian industry at large is facing a transition period. Parts of the Norwegian maritime industry is in the early stages of a restructuring period as a response to declining oil prices. This involves both a challenge and an opportunity, as it forces us to look for new areas of innovation. The proposed project aims to prepare the grounds for innovation and value-creation as an extension of Norway's core competence in the sectors of maritime transport, offshore activities and technology development sectors.

The knowledge from SMACS (particularly tasks 4 and 6) will also form input to a planned innovation project (IPN) developing new tools for computer-based training. The proposal for this project will be submitted to MAROFF in October 2016.

PART 4 Other aspects

12. Other socio-economic benefits

The project can be expected to improve training methods in maritime and offshore education. The link to the innovation project also means that the knowledge generated can form the basis of commercialization of training concepts and simulators further down the value chain. This may form the basis of new business opportunities related to the Norwegian maritime industry. The ability to handle demanding maritime operations is a competitive advantage for the Norwegian maritime industry. With the increasing need and ambition to exploit the resources of the ocean space, this competitive advantage can have a potential for further growth within aquaculture and offshore wind energy.

13. Dissemination and communication of results

The project has an ambitious dissemination plan. We will publish eight scientific publications, as well as a book (edited volume). As the attached CVs illustrate, the project team has shown the ability to publish through a wide variety of channels. The results from the project will also be disseminated systematically in the HFC forum's workshops, of which the project will take a leading responsibility in the project period. As already indicated, we have established a competence-building group which will receive regular presentation of results. Conferences for maritime safety (e.g. "Sjøsikkerhetskonferansen") will also be used as a way of making the results available for a larger audience within the maritime sector. The members of the project team also hold positions at NTNU which serve as channels for diffusing project results to students within safety management and human factors.

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