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Sizarta Sarshar

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Thesis for the Degree of
Philosophiae Doctor
Faculty of Engineering
Department of Mechanical and Industrial
Engineering

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Sizarta Sarshar

Management of Major Accident Risk through the Planning Process of Offshore Maintenance Activities

Contributions to the understanding of operational risk in the oil and gas industry

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Trondheim, February 2018

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Preface and Acknowledgements

This PhD research has been funded by the Center for Integrated Operations in the petroleum industry in Norway (IO CENTER) and has been carried out at the Department of Mechanical and Industrial Engineering at the Norwegian University of Science and Technology (NTNU). I would like to express my gratitude to Institute for Energy Technology (IFE) for providing me with a work environment close to home and thanks to NTNU for allowing me to study from IFE. This flexibility made the journey a lot more manageable. I want to acknowledge and convey my thanks to everyone who played a part in this work, and if I should have forgotten to mention you, please know that I am still very grateful.

I would like to express my gratitude to my supervisor Professor Stein Haugen from NTNU. We were introduced by colleague Dr. Bjørn Axel Gran who knew us both well. We had our initial talk at a seminar and within few weeks I was following my first PhD course which Stein held on major accident theories. This was even before the paperwork for the PhD was prepared and signed. Through the entire process Stein has provided me with the necessary guidance to address the topic of this thesis, to study how deep the rabbit hole goes and guide me back to Kansas. I thank you for your patience, motivation, and immense knowledge on the topic of this thesis. My sincerest thanks also go to Dr. Ann Britt Skjerve from IFE who accepted to be my co-supervisor. I especially thank her for providing valuable insights from the human factors perspective and teaching me to view things from different angles as I sometimes tend to look at things from an engineer's point of view only. I thank you both for inspiring discussions, your belief in me, your wisdom and understanding. I appreciate all your contributions, advice and feedback to the work. I specially thank you for your support during both difficult and joyful experiences in life while on this journey.

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I would like to thank my research group Risk and Dependability at IFE for enduring my nagging about this PhD over the years and supporting me when required. I appreciate our coffee meetings and inspiring discussions on all aspect of the universe. A special thanks to John Eidar Simensen, one of my best friends and colleagues, who has among other things played the role of the devil's advocate and did a *bad ass* review of the thesis. Thank you for valuable discussions and support throughout the years, both in life and work. When help and support is needed, you are always nearby. I would like to thank my colleague Grete Rindahl who lead the project in the IO CENTER which this PhD was part of and who contributed with her IO experience, literally 24/7. I would also like to thank my colleague Lars Hurlen for reviewing the work done with the last journal article, and my former and present colleagues at IFE who have shown great interest in the research.

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Sizarta Sarshar

Halden, October 2017

Summary

The overall objective of this thesis is to explore how major accident risk can be managed through the planning process of offshore activities. This objective was decomposed into three research questions. The relations between the planning process and major accidents were studied. Factors that can influence both planning and the plans were identified and presented to the industry. These were discussed with respect to challenges for managing major accident risk and for improving the planning process. Information and assessments required for decision support in critical steps of the planning process were explored, and a new concept for risk visualization was developed to enhance major accident risk understanding when planning offshore work.

Through the studies we identified that major accident risk can be better managed through the planning process by

- improving todays planning process to allow risks to be assessed earlier,
- improving how risk and barrier management is integrated within the planning process,
- using a common information carrier for the plans accessible to all personnel involved in both planning and execution of work
- enhancing risk communication through the planning process exemplified through the risk visualization concept developed.

The main contributions of the work include

- Identification of factors that can influence both the planning process and plans being made, with respect to major accidents.
- Documentation of industry challenges in managing major accident risk through the planning process and possibilities to address several of these challenges.
- Documentation of which risk-related information and assessments are required for decision support in several critical steps of the planning process to manage major accident risk.
- A new concept for risk visualization which integrates planning of work orders and work permits with risk and barrier management data to enhance understanding and communication of major accident risk related to the planned work to all personnel involved in both planning and execution of offshore work. The concept allows for better hazard identification than systems in use today.

The thesis illustrates that the planning process for offshore maintenance activities can better manage major accident risks through improving risk understanding and communication with use of new and innovative designed information systems.

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Overview of the Thesis

This dissertation consists of two parts. Part I presents the background, research objectives and questions, and methodology of the PhD research. The findings of the articles are summarized, the overall conclusions are discussed and possible future research is identified. Part II is a collection of articles that represent the main work of the research. Four journal articles and one conference paper have been published and prepared to answer the research questions during the research.

List of Publications

1. Sarshar, S., Skjerve, A.B., Haugen, S. (2013). Towards an understanding of information needed when planning offshore activities. *In Proc. of Risk, Reliability and Societal Safety, ESREL 2013*, September 29th – October 2nd, Amsterdam, Netherlands.
2. Sarshar, S., Haugen, S., Skjerve, A.B. (2015). Factors in offshore planning that affect the risk for major accidents. *Journal of Loss Prevention in the Process Industries*, vol. 33, 188-199.
3. Sarshar, S., Haugen, S., Skjerve, A.B. (2016). Challenges and proposals for managing major accident risk through the planning process. *Journal of Loss Prevention in the Process Industries*, vol. 39, 93-105.
4. Sarshar, S., Haugen, S., Skjerve, A.B. (2017). Major accident decisions made through the planning process for offshore activities. *Submitted to Journal of Loss Prevention in the Process Industries* (20.02.2017).
5. Sarshar, S. and Haugen, S. (2017). Visualizing risk related information through the planning process of offshore maintenance activities. *Safety Science*, vol. 101, 144-154.

For all publications, I was the main contributor and main author. My supervisors contributed with general advice and concrete suggestions for improvements in all phases of the work.

PART I: MAIN REPORT

Chapter 1

Introduction

Major accidents are characterized by a complex interaction of technical, human, organizational and environmental factors. These types of accidents have been given a lot of attention in the last 40-50 years, starting with Turner (1978) and followed by several different authors proposing different theories as to how these accidents occur and how they may be prevented (e.g. Perrow, 1984; Reason, 1997; La Porte and Consolini, 1991; Weick, 1995; Hollnagel et al., 2011). Much of the work has been focused on operation, "the sharp end", and has shifted the blame away from the operators by showing how the context, represented by the technology, the organizational structure, the culture etc. influences operations.

The Petroleum Safety Authority in Norway points out that the preparations for performing work activities offshore, i.e. the planning process, also can play a key role in major accidents: Inadequate planning, insufficient work descriptions, information that is not put forward during the planning process etc. are all factors that potentially can lead to unsafe performance of the work (PSAN, 2012). If a plan with reduced safety margins is implemented, it may lack needed robustness to prevent a major accident should anything fail during the task execution process. Thus, a plan with reduced safety margins may result in higher cost both with respect to human health, financial and reputational loss for the company. The planning process plays an important role in managing major accident risk.

In this work, the relations between the planning process and major accidents were studied. Factors that can influence both planning and the plans were identified and presented to the industry. These were discussed with respect to challenges for managing major accident risk and for improving the planning process. Information and assessments required for decision support in critical steps of the planning process were explored, and a new concept for risk visualization was developed to enhance major accident risk understanding when planning offshore work.

The project was motivated by the interests of the author, the industrial needs arising from the partners in and the research performed in the Center for Integrated Operations for the Norwegian petroleum industry (IO CENTER, 2017). I got to know the petroleum industry by visiting several operating companies through research within a program for “future collaboration environments” (Skjerve et al., 2011). This allowed me to interview employees in the organisations of several operating companies, study their work processes, visit offshore installations, observe meetings and execution of work and discuss with industry experts. The project consisted of studying how modern technology could enhance future collaboration through distributed teams and resulted in development of a prototype tool (Skjerve et al., 2011; Braseth and Sarshar, 2012) which also went through a usability study. I was involved in all steps of the project and gained valuable insights, which forms the basis for the work described in this thesis.

This thesis consists of two parts: Part I introduces the research background, how the research has been conducted, and presents the overall contributions of the thesis. Part II is a collection of five articles that represent the outcomes of the research.

The remainder of Part I is organized as follows: Chapter 2 describes the overall research objective and questions, the research tasks performed and the approach and methodologies applied in the thesis. Chapter 3 summarizes the state of knowledge on the planning process of offshore maintenance activities, on major accident theories and on related research. Main results are presented and discussed in Chapter 4. Chapter 5 presents overall conclusions and further work.

Chapter 2

Research

2.1 Objective and research questions

The objective of the research presented in this thesis is to contribute to understanding of how risk for major accidents can be better presented through the planning process of offshore maintenance activities within petroleum. The main research question is as follows:

> Can we improve information quality and availability to better support decision-making about major accident risk?

The research focuses on all aspects of the planning process, including man, technology and organizational aspects and is divided into three sub questions:

RQ1: What is the relation between planning and the potential for major accidents?

RQ2: How should the planning process be designed to better manage major accident risk?

RQ3: How can the underlying information technology support the improved planning process?

The assumption is that the planning process can be better supported by underlying technology to increase planning and plan quality to identify, assess, and communicate risk for major accidents through all phases of planning up to execution of the work. Necessary information is not always available at the right time or in the right format in the planning process today. There is a need for better information to improve planning to avoid major accidents for offshore activities.

2.2 Research tasks

The research process has been built step by step and has involved many thematic areas which have had to be studied in detail to address the research questions. For the three research questions, the explored thematic areas identified seven research tasks (T1-T7) that were carried out are listed below.

The relation between the research questions, their respective tasks and dissemination of results through published articles (A1-A5) is presented in Table 1. The first article was presented at a peer-reviewed international conference and published in the conference proceedings. The next four articles have been published in recognized international journals except for article 4 being under review.

RQ1: What is the relation between planning and the potential for major accidents?

> **T1**: Study and describe the planning process for offshore maintenance work
>
> **T2**: Study major accident theories and perspectives and relate these to the different steps of the planning process
>
> **T3**: Study hydrocarbon leak incidents and investigate if the cause or triggering factors can be linked to the planning process

RQ2: How should the planning process be designed to better manage major accident risk?

> **T4**: Explore industry challenges and propose improvements for the planning process to how these challenges may be addressed
>
> **T5**: Explore communication and information needs to identify what risk-related information is required as decision support

RQ3: How can the underlying information technology support the improved planning process?

> **T6**: Develop a concept for risk visualization using iterative design process with industry participation
>
> **T7**: Study and utilize design theory and visualization methods to enhance risk perception into the concept

2.3 Research approach and methodology

The research methodologies applied in this project include theoretical, empirical and analytical research, user stories and design method. The applicability of these for the respective research tasks are given with the research approach in the following. Figure 1 illustrates the studies performed and how these build on each other.

Table 1: Research dissemination

RQ1	T1	A1	Towards an understanding of information needed when planning offshore activities	Conference publication
	T2	A2	Factors in offshore planning that affect the risk for major accidents	Journal publication
	T3			
RQ2	T4	A3	Challenges and proposals for managing major accident risk through the planning process	Journal publication
	T5	A4	Major accident decisions made through the planning process for offshore activities	Journal (under review)
RQ3	T6	A5	Visualizing risk related information through the planning process of offshore maintenance activities	Journal publication
	T7			

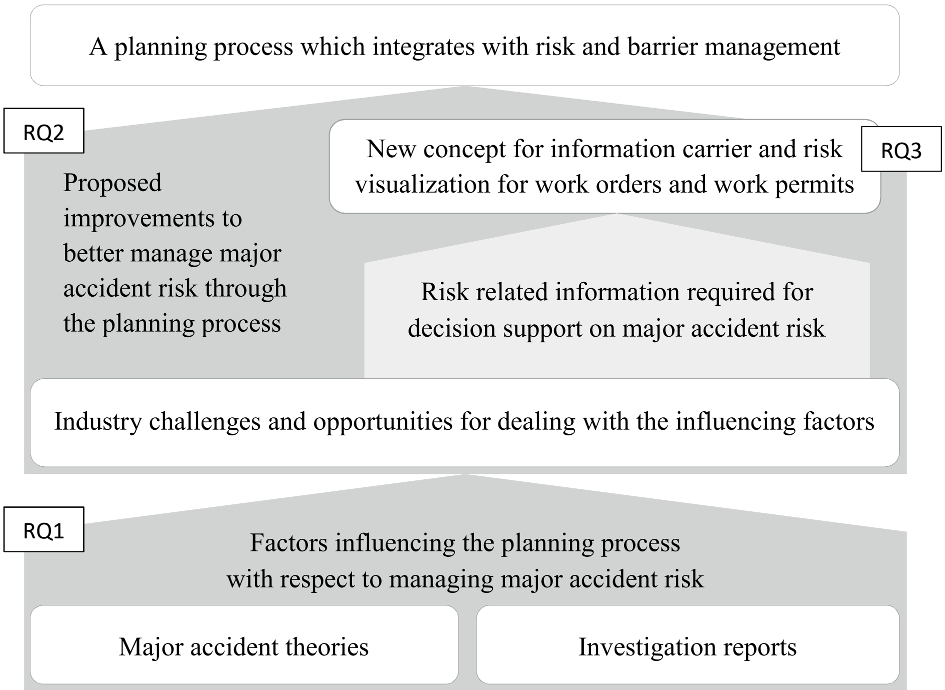

Figure 1: Studies performed to improve the planning process for better dealing with major accident risk.

The project starts by answering **research question one**, *What is the relation between planning and the potential for major accidents,* by studying the relation between major accidents and planning of offshore maintenance activities. The first three research tasks (T1-T3) are studies of the planning process, major accident theories and accident investigations.

The first task (T1) is studying the planning process for offshore maintenance work. The objective of T1 was to understand the process in detail to be able to later identify challenges but also possibilities with managing major accident risk and prevention through the planning process. The planning process for two companies operating on the Norwegian continental shelf were studied. Access was given to their work management systems. We performed a document review which, based on the recommendations of Witkin and Altschuld (1995), including work flows and management systems describing the steps in the processes, roles and purpose. In addition, interviews were conducted with offshore personnel and daily meetings were observed during a five day stay at an offshore facility. In total eight experts were interviewed. All interviewees had different roles during the planning process, and this is a strong contributor ensuring that the data sufficiently reflect the planning process and its challenges from multiple perspectives. The roles covered were offshore installation manager, maintenance and operation leader, deck and marine leader, health and working environment team leader and one technician from each of the four disciplines process, instrument, electrical and mechanical. The interviews were semi-structured and carried out individually, lasting 30-60 min. The data obtained was organized using codes (as for Grounded Theory; Strauss and Corbin, 1998) on the different aspects (established in the interview guide) that were discussed. The codes related to the research questions were selected for further detailing and included aspects related to meeting preparations, the meetings themselves, the results from the meetings, and aspects that could influence the plan or the planning process. The main results and learning from the offshore study is published in *article 1* (Sarshar et al., 2013).

In addition to the interviews of offshore personnel, interviews with onshore personnel working with risk management was performed to address research question two. Here, the interviewees included the HSE&Q manager, an onshore platform manager (on rotation), one from barrier management, and two persons working with the technical integrity of the facility.

For the second task (T2), major accident theories and perspectives were studied to identify what characterizes major accidents, how causation of accidents is explained and why some organisations do not encounter accidents. These were reviewed with regards to how their explanation of causes and contributing factors relate to plans and the planning processes. We reviewed the planning process from the perspective of each of the selected theories on major accidents to identify factors in the various steps of the planning process that may contribute to reduce the potential for major accidents associated with a completed plan. This forms the theoretical basis for the work.

For the third task (T3), we reviewed investigation reports (as for descriptive analysis; Zikmund, 1994) of hydrocarbon leakages for the period 2011-2013 from the Norwegian Continental Shelf. 24 reports were reviewed, from which 18 were found to potentially relate to the plan or planning processes. The review was performed in two iterations. In the first iteration, the analysis consisted of extracting aspects identified as causes from the reports. These aspects were then combined with the ones from the theoretical review (T2) and a selection of thirteen influencing factors was chosen for the empirical review (T3). In the second iteration of the analysis, aspects identified as causes were grouped as best could fit into the thirteen influencing factors. This provides empirical support for the theoretical basis in T2 to answer RQ1.

The result from these research tasks where thirteen factors that can influence major accident risk through the planning process. Results and learning from these steps is published in *article 2* (Sarshar et al., 2015) and answers research question one.

The project then addressed **research question two**, *How should the planning process be designed to better manage major accident risk,* by studying industry challenges and opportunities for managing major accident risk through the planning process through research task four (T4) and five (T5). Empirical data was gathered from interviews with onshore personnel involved in planning and from a workshop with industry experts on planning, risk and barrier management. The workshop objectives were to:

1. Identify the industry challenges for major accident risk related to planning
2. Identify how the contributing factors affect the planning process in practice
3. Identify if there are additional challenges that are not covered by the contributing factors

The workshop included ten experts on planning, risk management, general management and operation from the onshore organisation of one petroleum company. It was held at the operating company's location and lasted 4 hours.

The workshop was organised as follows: After an introduction of all participants, an overview of the study from *article 2* (Sarshar et al., 2015) was provided. Then, the planning phases and the purpose of the different activities during the planning process were discussed. Next, the major accident perspectives were introduced (Sarshar et al., 2015, p.190) and the thirteen influencing factors (Sarshar et al., 2015, p.195) were discussed using examples from the investigation reports on hydrocarbon leaks (Sarshar et al., 2015, p.197) as reference. All communication during the workshop was tape recorded. Data from the workshop were transcribed and made anonymous.

The results from the workshop were analysed with the findings from the interviews performed with both onshore and offshore personnel in the first research task (T1). The data sets resulting from the workshop and the interviews were initially treated separately, but following the exact same procedure. Data obtained from the workshop and from the interviews were compared to decide the extent to which onshore and offshore personnel's view on challenges would be similar. The process was as follows: The entire dataset was decomposed into groups where each group consisted of one type of challenge. The identified challenges were then associated with the phases in the planning process where they were reported to occur. Then the identified challenges were grouped in four main topics in order to identify the set of factors which is most critical for reducing the extent to which planning factors will contribute to major accident risk. The four challenges were exemplified through industry experiences gathered in the workshops and interviews, as well as from the findings from T3. Finally, proposals and suggestions for how to improve were then identified based on the workshop and interviews, as well as from the learnings from investigation reports (T3). The collected data set is limited in size and not adequate for statistical analysis. However, the data is nonetheless considered to be useful and relevant for identifying industry challenges. Main results and learning from this study (T4) is published in *article 3* (Sarshar et al., 2016).

The results of the project till this point were presented in workshops for both two operating companies participating in the project, separately and at their locations. Each workshop lasted for three hours and included nine and fourteen experts with onshore and offshore experience working with risk management, barrier management and planning of maintenance and modification activities for offshore installations, respectively. The objective of these workshops was to provide the knowledge gathered to the industry partners in order to discuss the findings with the experts. All communication during the workshops was tape recorded, transcribed and made anonymous.

Research task five (T5) further focused on studying what type of risk related information is needed for decision making in the various planning arenas through the planning process. This is a top down approach starting at the decision needs, which are broken down to assessments and information needs. This ensures selection of relevant and critical information that supports the decisions made through the planning process to manage major accident risk. The work was performed in three steps and builds on all research tasks carried out till this point and the additional two workshops. The process consisted of:

1. Describing the decisions that are made through the planning process. This was based on the work process documentation available from the two operating companies. The decisions made within the specific decision arenas were gathered from documents describing the work process which the specific decision arena is part of.
2. Identifying assessments necessary for supporting decisions made in the planning process. This was also based on the work process documentation and input from subject matter experts through interviews and workshops. The list of assessments provided were gathered from specific documents describing the work process where assessments needs to be made.
3. Describing what type of information is needed to support the assessments and decisions. This step was based on the planning data used by the two operating companies, logical reasoning and input from a subject matter expert.

In addition, step two and three builds on what should be assessed based on interviews and workshops with personnel involved in the planning process and observations of information flow between meetings from task one. Main results and learning from research task five is published in *article 4* (Sarshar et al., 2017).

The project then addressed **research question three**, *How can the underlying information technology support the improved planning process,* by studying the information technology used by the industry partners and proposing a new concept for information visualization based on the findings from research task five. Research task six (T6) and seven (T7) address the iterative concept development process and visualization methods applied to enhance risk perception into the concept.

First, what information is needed, and when, in the planning process is defined through studies with industry involvement. An iterative design process is then followed to develop design concepts for how to visualize the information. The design ideas and proposals are assessed in cooperation with industry partners through the design cycles in form of workshops. Based on the iterations a final visual design is specified.

1. Step one was to set the objectives and requirements. This was done through previous studies (T1 to T5).
2. Step two was to describe the users and their information needs through user stories (Cohn, 2004). This required identification of specific risk related information that is to support assessments and decisions to manage risk (based on task five).
3. Step three was rapid concept development with assessment and detailing in cooperation with industry partners through multiple design cycles in form of workshops. The first version of the concept built on lessons from previous projects with visual design of similar concepts (Skjerve et al., 2011; Braseth and Sarshar, 2012; Sarshar et al., 2014). Based on these lessons, a first visual design was developed to include the additional information on activities and system aspects. The concept development was done in cooperation with industry partners through three workshops.
4. Step four was to specify the final visual design.

Main results and learning from research task six (T6) and seven (T7) is published in *article 5* (Sarshar and Haugen, 2017).

The sum of all these research tasks contributes to answering the overall research question: *Can we improve information quality and availability to better support decision-making about major accident risk?* The results are presented and discussed in Chapter 4.

2.4 Scope and limitations

The scope of the research was limited to oil and gas companies operating on the Norwegian continental shelf where principles for integrated operations are known and applied.

Our focus has been on major accident potential related to maintenance activities on offshore installations. This can be categories within the defined hazard and accident condition (DFU) leaks of flammable gas or liquids, other DFU's such as major accidents related to well control incidents, fire/explosion, collisions and structural damage to facility or leaks from subsea production facilities with pipelines and associated equipment are not included in this research.

Planning within the oil and gas industry can be done at various levels including strategic, tactical and operational. The scope of the planning process studied focus on the *operational planning* spanning from three months' horizon to daily plans. Execution of the work that has been planned is not studied as such, although an important outcome of a good plan is its safe execution.

Two companies operating at the Norwegian continental shelf participated in the project. The empirical data set that has been collected is limited in size and not adequate for statistical analysis. However, the data are still considered to be useful and relevant for answering the research questions. Further, the planning process and decision arenas assessed were representative for the partner involved in the research, other companies may have different processes that safeguards some of the challenges highlighted throughout this research.

2.5 Quality assurance

The main quality assurance is via critical review by my supervisors, through peer reviewed articles in acknowledged international journals and through close industry collaboration. The work has been reviewed and discussed at different steps through three workshops with industry partners. The concept development has been iterative with industry involvement. Finally, the entire project has been presented and discussed in a separate workshop with the Petroleum Safety Authority in Norway.

Chapter 3

State of Knowledge

3.1 The planning process

To provide the operational context for this project a brief description of the planning processes is provided based on (Sarshar et al., 2013; 2015; 2016; 2017).

Production, operation and maintenance activities are carried out daily during offshore operation. The control room operators control the production as well as the initiation of maintenance activities, crane operations and helicopter and vessel operations. Safe operation and production is of key importance. Thus, the planning process for all offshore activities, the quality of the plans and the quality of their execution and end controls are important aspects which need to be managed (as described in Sarshar et al., 2013).

Activities must be assessed both individually and for concurrent execution with respect to Health, Safety and Environment (HSE). The planning process described here is a standardized process based on the operational concept Integrated Operation (IO). IO has been defined as "real time data onshore from offshore fields and new integrated work processes" (NOG, 2008) and was introduced with the purpose of achieving (NOG, 2005): increased recovery, accelerated and increased production, reduced operational cost, longer lifespan, and increased safety. IO may also be known as Intelligent Fields and has been gradually introduced by petroleum companies operating on the Norwegian continental shelf.

With respect to planning IO implies that several planning tasks (activities in the planning process) were moved from offshore to onshore, leading to an increased need to integrate offshore and onshore based personnel in the planning process and thus collaboration across geographical locations.

Planning is performed with different time horizons in mind: a main plan has a span of several years, a yearly plan spans over one year, an operational plan spans for three months, a work order plan spans for one or two weeks and a work permit/day plan which covers the next 24 hours. Figure 2 illustrates the planning process ranging from operational plan (step A-H) to work order (step I-P) and work permit (step Q-T) to execution of work (step U) offshore. The no-helmet icons represent onshore personnel and those with helmets represent offshore personnel. Descriptions of each step and major accident analysis performed in these are given in Figure 2.

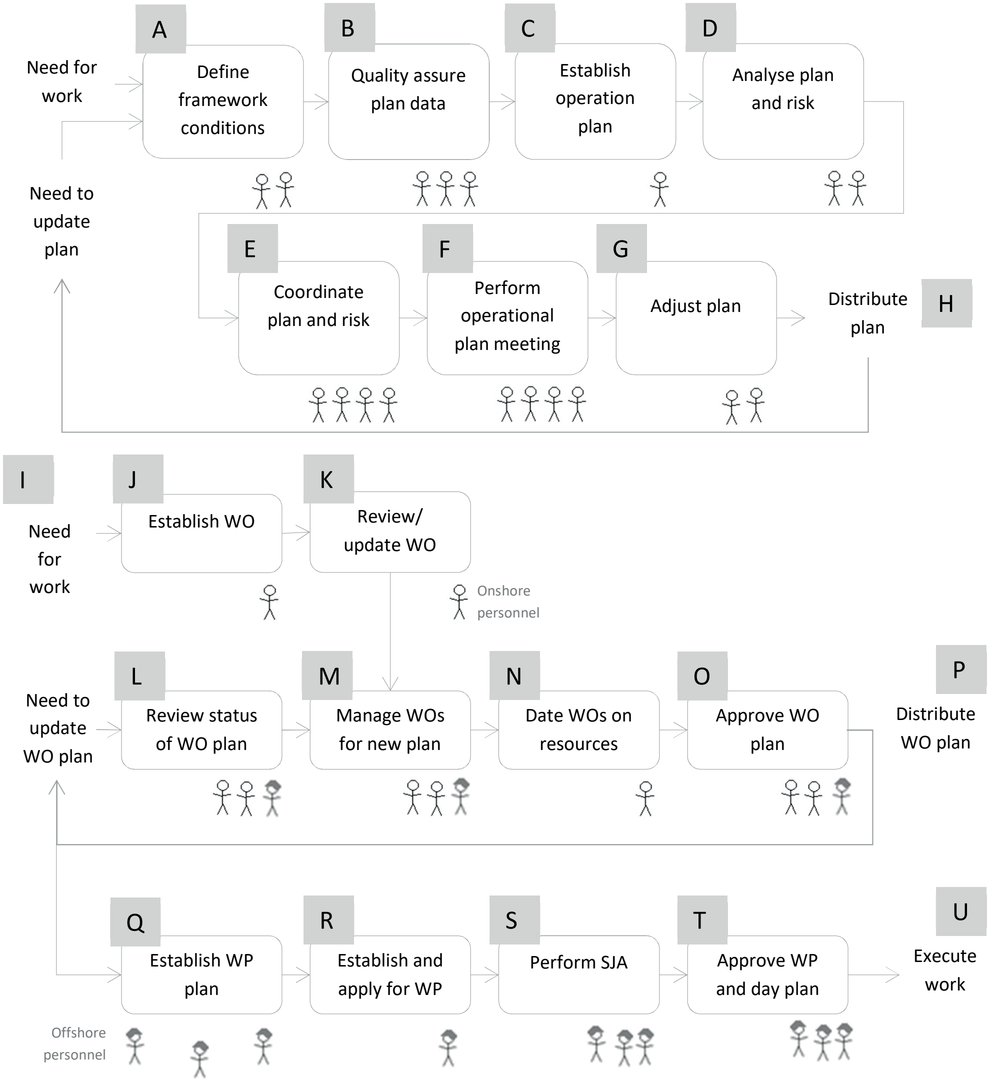

Figure 2: The planning process ranging from operational plan (step A-H) to work order (step I-P) and work permit (step Q-T) to execution of work (step U) offshore (Sarshar et. al., 2015).

Table 2: The planning process and major accident assessments (Sarshar et. al., 2015, Table 1 and Table 2).

Planning step	Description	Major accident assessment
Operational plan		
Define framework conditions	Communicate decisions and activities from the main plan and establish installation specific framework conditions (e.g. logistics, bed capacity). This is a collaboration activity.	Activity level being outside framework conditions, degraded technical integrity, higher risk for HSE incidents and wrong prioritization between activities.
Quality assure plan data	Risk that can affect the accomplishment of activities shall be identified and reported in relevant risk management tool. Examples include work on hydrocarbon carrying systems, disabling of safety critical systems/barriers, and critical/heavy lift operations. This is a collaboration activity.	In addition to the above; identify weakened technical, operational and organizational barriers and failure of equipment.
Establish plan	The planner establishes the operational plan based on the quality assured plan data. This is a proposed plan which will be adjusted and reviewed in the following steps.	Analysis from the above steps is considered at this step. This means that e.g. simultaneous tasks can be a risk due to co-ordination failures.
Analyse plan and risk	Analyse the plan and propose alternatives if deviations exist from framework conditions. This is a collaboration activity.	In addition to the above; insufficient overview of the risk picture.
Coordinate plan and risk	Preparation to plan meeting, establish alternatives and assess economy. This is a collaboration activity.	Analysis from the above steps is considered at this step.
Perform operational plan meeting	The main goal is to prioritize the activities on the plan, to decide on measures and approve plan. This is a collaboration activity.	Identify wrong prioritization.
Adjust plan	Adjust the plan based on the activity level and establish reference plan as basis to identify deviations in the operational plan. This is a collaboration activity.	Identify wrong prioritization, higher risk for HSE incidents and poor coordination between activities.
Distribute plan	Shall contain report from the planning (Gantt-diagram, manning, etc.) and decisions from the operational plan meeting.	Identify poor coordination between activities.
Work order plan		
Identify need for WO	When a need for work is identified, the criticality of the work is also assessed. The criticality is however focused on whether not doing this work (preventive maintenance, repair, modification) represents an increased risk for the operation of the plant (e.g. because a safety critical system is malfunctioning) or whether this may impair production from the plant.	A corrective WO requires considerations on criticality of the failure on safety and production. The priority and criticality considerations come from the morning meeting (notification/ event) that triggered the need for WO.
Establish WO	The work order is focused on describing what should be done and what equipment and resources are required. This would also include considerations of major accident risk since this may have an impact on resources required.	Major accident risk is considered and required risk controls are identified. Work specific aspects that can take out an existing barrier and compensating measures needed. Work operation type can present a major accident risk.
Review/update WO	Review the WO and change its status as e.g. material needs are met or dates get close to be ready for next plan	No or very limited focus is placed on major accident risk.
Review status for WO plan	Coordinate WOs which are not on plan and provide input to these WOs	
Manage WOs for new plan	Evaluate last active WO plan, the status of its WOs, coordinate these and provide status on active WO plan	
Date WOs on resource needs	Establishing the WO plan is typically focused on "piecing" together all WOs into a plan that can be completed within the available time and with available resources.	
Approve WO plan	Review, approve, quality assure plan and plan feasibility	

Planning step	Description	Major accident assessment
Work permits		
Establish day plan	The discipline leaders offshore make a WP plan for the next few days based on the WO plan for which activities to carry out when. Resource management for the discipline team.	
Establish and apply for WP	The WP serves two main purposes: To ensure that the work can be performed safely and (as part of that) to ensure that the work can be performed safely simultaneously with other activities (coordination).	Major accident risk is considered during the preparation of the WP. Work specific aspects that can take out an existing barrier, compensating measures needed. Work type can present a major accident risk, coordination needed. Comply with risk analysis from WO, need for safe job analysis or blinding list?
Perform SJA	Safe job analysis is a systematic and stepwise review of all risk factors prior to a given work activity or operation, so that steps can be taken to eliminate or control the identified risk factors during preparation and execution of the work activity or operation. Certain categories of work will always require SJA to be performed based on regulatory and company standards, others do not. However, any participant in any planned work task has the right to demand a SJA before work is undertaken.	Focus is too often on personal safety only and not on major accident risk (Leistad and Bradley, 2009).
Approve WP and day plan	The approval process takes care of both above purposes, including the coordination.	Major accident risk will be considered during the approval of the WP. Risks associated with the combination of jobs. Risks associated with simultaneous operations (drilling, helicopter, crane, boat). Area risk for specific jobs, weather conditions.

The operational plan contains the most valuable information about maintenance, operations and modifications which fall under the following categories:

- major tasks within HSE,
- production related tasks that require shut-down,
- tasks requiring external resources,
- tasks requiring additional bed capacity,
- tasks requiring coordinated actions (e.g. heavy lift operations), and
- tasks requiring monitoring.

Operational plan meetings are held every two weeks and include participants from onshore and offshore who evaluate simultaneous work activities and the total activity level with focus on risk and production. This meeting also facilitates the coordination of activities with the production and the well intervention plan.

The objective of the operational plan is to:

- Assure that decisions and activities from the main plan are performed.
- Set the framework for activities on underlying levels (top-down planning)
- Assure coordination to ensure the installations risk picture is acceptable with respect to major accident and production
- Assure coordination with respect to risk levels, prioritization and resource management within and across installations
- Assure that the activity level on the installation is implemented within framework conditions

External framework conditions, status on technical barriers and risk of activities must be analysed and evaluated together to ensure that the installation's risk picture is acceptable. External conditions can include infrastructure and dependencies between installations, and the risk of activities can include activity level, high-risk activities and simultaneous activities. The analysis shall provide an overview of simultaneous activities in each area, high-risk activities, consequences of high activity level, relevant dependencies that exist, and identified deviations from framework conditions.

The work order plan is based on the operational plan. In this phase, activities are prepared and planned in detail in coordination with logistics and contractors and involve both onshore and offshore staff. The risk evaluation in this step is performed with special attention to HSE and area/module specific risks (normally a printout of a simplified version of the quantitative risk analysis for a given module). Logistics and personnel-on-board planning are coordinated activities with the preparation of work order plans.

The objective of the work order plan is to plan for safe, effective and reliable execution of work on the installation in order to:

- Coordinate work to avoid lag in the maintenance of safety and production critical systems
- Assure coordination of work execution between different actors
- Plan for safe execution of simultaneous activities and operations
- Assure good resource utilization
- Minimise downtime on safety and production critical systems
- Collect work that is on the same system or part of the installation
- Avoid delay and waiting time for access to systems at the installation
- Coordinate access to equipment at the installation

A work order defines the need for work and is a formal request for the work that shall be done. It further describes a job package that normally can be divided into subtasks that can be carried out in sequence. Before any of these can be performed, the personnel that shall execute a task must apply for a work permit. A work permit is a permission to perform a specific work.

The work permit system was established to maintain control over which activities are to be carried out on the installation and to manage their risk. Activities that typically require a work permit are maintenance work on the process equipment, pipes or structure of the platform. There are two main categories; corrective (to correct failures that have occurred) or preventive (to prevent failures to occur) maintenance. Work permits are divided in two levels to differentiate between their impacts on risk. High-risk jobs which e.g. require welding are classified as level 1 while lower risk jobs are level 2, e.g. mounting personnel protection on a flange. Jobs that have been identified as no risk activities do not require a work permit and typically include jobs inside the living quarter, in office spaces or in workshops.

From the review of steps involved in the planning process and considerations made on risk for major accidents in these (Sarshar et al., 2015), we see that risks associated with the jobs are considered when establishing the work order and work permit; on the other hand, coordination and its associated risks are considered when approving work permits. Approving work permits is the last step in the planning process and has a critical role considering major accident risks.

3.2 Major accident theories

Major accidents can seldom be attributed to one factor, but result from the combination of factors such as: design factors, operational factors, maintenance factors, organisational factors, etc. We seek to contribute to major accident prevention in the petroleum industry by developing strategies to address the maintenance factor.

Based on accident investigations and the absence of accidents, major accident theories have arisen to explain the causation of occurred accidents as well as why some organizations do not encounter accidents. The most acknowledged theories include the energy and barrier perspective (Gibson, 1961; Haddon, 1980), conflicting objectives (Rasmussen, 1997), man-made disasters (Turner, 1978; Turner and Pidgeon, 1997), high reliability organisations (La Porte and Consolini, 1991) and resilience engineering (Hollnagel et al., 2011). Major accident theories can contribute in different ways to major accidents monitoring and prevention.

To identify in which steps in the planning processes there are barriers that reduce or control major accident risk, a systematic review of the planning process with respect to the major accident theories was performed in Sarshar et al. (2015). The main findings are provided in the following. The relevant contributions from the theories applied to the planning process are provided in Chapter 4.1. Refer to (ibid) for more details.

3.2.1 The energy and barrier perspective

The energy and barrier perspective provides an explicit view of the immediate causes of accidents (Gibson, 1961; Haddon, 1980). The perspective builds on defence in depth and barriers to prevent accidents in its safety design. The perspective has proven useful in hazard identification and as basis for identifying hazard control strategies. It is further the basis for analytical risk control. Safety management for both major and minor accidents is based on the energy and barrier perspective.

The notion of root causes for major accidents for this perspective is failure to establish and maintain adequate barrier functions and dependencies among barrier functions and the risk reduction strategies that should ensure that compensating measures are taken when barriers are unavailable (Rosness et al., 2010).

The energy and barrier principle is originally based on a physical understanding of the term "barrier", and with such an understanding it is hard to see how plans can be influenced by this principle. However, the understanding has been extended to cover a wide range of measures to control risk, including organizational issues (Reason, 1997). With an understanding like this, we may look at how plans and the planning process can contribute to introduce additional barriers that can prevent major accidents from occurring.

To identify in which steps in the processes there are barriers that reduce or control major accident risk, a systematic review of the planning process was performed (Sarshar et al., 2015). During the operational plan process, risk that can affect the accomplishment of activities shall be identified and reported in relevant risk management tool(s). Analysis is required on hazardous operations, simultaneous operations, barrier weaknesses and compensating measures. During the work order process, task specific aspects that can take out an existing barrier and necessary compensatory measures are identified. Work operation type can present a major accident risk.

3.2.2 Conflicting objectives

Organisational safety is influenced by regulatory and commercial interests, the working environment and management demands. The behaviour of those operating the systems, the roles and actors in the processes, is influenced by the conditions they work in and by the behaviours of others, particularly those in managerial positions (Flin et al., 2008).

Rasmussen (1997) suggests that we might think of the handling of conflicting objectives in terms of activities migrating towards the boundary of acceptable performance. Different boundaries that can affect decision making for different actors include: management pressure towards efficiency, gradient towards least effort and workload, boundary of locally and conditionally acceptable or unconditionally safe state of affairs. Actions within one activity might change the boundary of acceptable performance for another activity.

Causation of accidents may be the result of actors transcending the operational envelope of the systems they operate. Actors cross boundaries towards unacceptable risk to locally optimise behaviour. Organisational accidents in distributed systems typically involve several actors, each seeking local optimisation based on incomplete view of the system.

Major accidents thus tend to arise from situations where separated adaptation processes interact in a way that was not foreseen by the actors.

To apply the conflicting objectives perspective, a systematic review of the planning processes was performed (Sarshar et al., 2015) to identify in which steps

- one can expect considerations and discussions on safety vs cost and time and
- it is likely that risk is not considered or the focus is entirely on cost and time.

The steps which address potential conflicting objectives include:

- Perform operational plan meeting - Management's focus on efficiency (time and cost instead of safety) can put pressure or prefer production optimization operations ahead of maintenance operations (including maintenance on production critical equipment ahead of safety critical equipment).
- Steps for establishing and approving work orders and work permits - Management's focus on efficiency can put (time and cost) pressure (vs safety): not taking necessary time to prepare the work, not considering all aspects of the work (e.g. with respect to HSE, resources, or competence needed).
- Steps for establishing operational plan, work order plan and work permit plan - Risk is not considered in these steps, the focus is entirely on scheduling and date/time the work.

The conflicting objective perspective has focus on the processes and not on the product of the processes - the plans. However, the focus in the process will have impact on the plan. If the focus is more on cost and time than safety, this might result in a plan with reduced safety margins. When such a plan is implemented, it may lack needed robustness to prevent a major accident should anything fail during the task execution process. Thus, in the end a plan with reduced safety margins may result in higher cost both with respect of human health, financial expenses and in terms of reputation loss for the company.

3.2.3 Man-made disasters

The critical assumption in Turner's theory (1978; 1997) concerns the process leading up to a disaster, the onset. However, the man-made disaster model also includes stages after the actual disaster, including rescue and a final stage of full cultural readjustment to the surprise associated with the event. The starting point is a situation where matters are reasonably normal implying that a set of normative prescriptions, ranging from informal norms to laws and regulations are culturally accepted as being advisable and necessary precautions to keep the risks at an acceptable level. This is followed by the incubation period which is characterized by the accumulation of an unnoticed set of events, or events that are misunderstood, causing misperception of danger signals. A key factor here is the structure of communication networks, the boundaries where knowledge is not shared or where knowledge is simplified. The incubation period is brought to conclusion by a precipitating event, which is unpredictable for those sharing the culturally accepted beliefs about the system, a dramatic event such as an explosion.

Accidents and disasters develop through a chain of events leading back to root causes such as lack of information flow and misperception among individuals and groups. To control risk a key factor is to make efforts to collect and analyse information about hazards and what we do not know.

An important contribution of the information system perspective is Turners finding (Turner, 1978) that during the incubation period there is nearly always someone who is aware of the danger. This may be related to conflicting objectives in the previous section where e.g. time pressure can make one withdraw information, whether it is on purpose or not.

The theory explains causation of major accident with:

- Breakdown of information
  - For the planning process, this means that information does not flow between the activities in the process and between the roles and actors.
  - For the plan, it means that it does not contain all relevant information needed. The type of information important to share is e.g. hazardous operations and what makes them hazardous.
- Misperceptions - Many of the steps in the planning processes are collaboration activities and foster information sharing and discussions. Information must flow between the activities and between the roles and actors, and discussions should address misunderstandings.
- Lack of communication - For the planning process this means lack of communication channels or feedback channels between the activities in one process and between its roles and actors but also across processes: between the operational plan, work order and work permit processes.

Turner also saw managerial and administrative difficulties in handling information in complex situations that blurred signal with noise. This is sustained in high-reliability theory: Failure means that there was a lapse in detection. Someone somewhere did not anticipate what and how things could go wrong. Something was not caught as soon as it could have been caught (Weick and Sutcliffe, 2007).

To apply the man-made disaster perspective a review of the planning process was performed (Sarshar et al., 2015) to identify *what type of information shall be flowing through the process and to whom and what type of information shall the plans contain*?

The availability of information is important when establishing work order and work permit for covering all job aspects. The information flow between the planning activities and the mechanisms and channels must allow for information sharing and avoid misunderstandings and misperception. The information type and format must support the activity it is used in and for. Communication channels must be in place to allow easy access to necessary roles and actors in the processes. However, this is not sufficient alone; we also need to address the problem of promoting a safety culture that precedes having channels open. While one does spur the other, no one will use the channels unless safety is of a major concern to everyone involved. This again relates back to the previous section on conflicting objectives.

Further, useful information has some characteristics that should be in place as described by Westrum (2014):

- It provides answers to the questions that the receiver needs answered. The information should respond to the needs of the receiver, not the sender.
- It is timely. If not, it may lead to a wrong decision since information is used in decision making.
- It is presented in such a way that it can be effectively used by the receiver.

3.2.4 High reliability theory

The high reliability theory is not explicit regarding the nature of accident causation, but the implicit idea is that accidents are triggered by errors that have not been recovered in time. If one considers the slowness of bureaucracy and the incubation time from Turners theory, as described in the previous section, unrecovered errors could be due to wrong prioritization, misunderstandings or poor information flow.

The theory focuses more on why accidents do not happen than on causes for accidents (La Porte and Consolini, 1991; Rosness et al., 2010). Accidents can be prevented through good organisational design and management:

- Commitment to and consensus on production and safety as concomitant organizational goals
- Redundancy enhances safety - Build organisational redundancy to build fault tolerant organisations with overlapping tasks and competence
- Decentralised decision making is needed
- Monitor the structural and cultural preconditions for organisational redundancy
- Culture of reliability: Build cultures that combine requirement for fault-free performance with openness to the fact that errors do occur
- Learn from the daily operations and the normal procedure, but incidents/accidents may demonstrate the absence of the preconditions
- Downsizing may affect the preconditions for organisational redundancy

For the planning process (Sarshar et al., 2015):

- The bullet points above apply to all the planning process but is specially focused on in the operational plan meeting
- The steps in the processes which are collaboration activities works as organisational redundancy with overlapping tasks and competence, eye-to-eye contact and which easily communicate with each other
- The work permits approval and daily plan are managed offshore but their work order plans are approved in collaboration between onshore and offshore
- The evaluation and quality assurance of the work order plan is facilitated as a collaboration activity involving different key responsibilities/actors. This can make the work order plan approval process redundant in the way that more than one actor is involved. This, however, requires that involved personnel do not think in “silos”

but that they rather take responsibility to represent their domain and expertise. Some organisations include the offshore lead technicians in this step and hence include decentralised decision making.

- Learning from incidents/accidents is something all operating companies try to do. Depending on the severity of the incident, investigations and learning reports are made. How to operationalize findings from such reports is still a challenging task.

HR theory suggests organisations should take expertise seriously, listen to minority viewpoints and remain less concerned with strategy and more sensitive to daily operations.

3.2.5 Resilience engineering

Accidents, according to this perspective, are not the products of normal system malfunction or breakdown, but rather breakdowns in the adaptive capacity necessary to cope with the real world of complexity. Risk reduction is achieved by increasing coping ability rather than eliminating variability. Organizations should build and maintain the abilities to anticipate, attend, respond and learn. The purpose is to assess the preparedness of the system, not only to respond to unforeseen events, but also to manage known threats and pressures.

Resilience concepts (from various chapters in Hollnagel et al., 2006; referred to in Ferraira et al., 2011):

- Ability to adapt to changing conditions – the system must be flexible enough to respond to external changes and pressures
- Ability to cope with complexity – the system must be capable of maintaining normal operation whilst coping with changing conditions
- Ability to manage continuous stresses – the system must be capable of maintaining normal operation, even when submitted to extreme pressure
- Ability to respond to problems ahead of time – preparedness – the system must be able to react before problems cause any disruption to normal operation
- Learning culture – willingness to respond to events by reforming and adapting as opposed to denying the need for change
- Just culture – support in reporting of issues throughout the organisation avoiding behaviours of culpability attribution
- Ability to steer activities – the system must be able to control activities regardless of operating conditions
- Appropriate level of information about performance – awareness – the system must make available to its management appropriate levels of information regarding performance
- High enough devotion to safety – safety must be considered alongside other system goals
- Buffering capacity – the system must have available resources necessary to respond to arising problems and complex issues

A resilient system knows when to sacrifice acute production goals and prioritise chronic safety goals. If organisations are unable to support people when they back off from economic goals to invest in safety (the sacrifice), the organisation will be acting with higher risk than it realises or wants (Tjørhom and Aase, 2011).

A practice of resilience engineering requires that anticipation, monitoring, responding and learning are considered and addressed at all levels of the organization. The challenges in ensuring this, however, are many; Resilience assumes that one can foresee the changing shape of risk before failure or harm occurs. It requires monitoring key indicators to observe how close the organization is to the safety space boundary. The organization must then have the capability to respond by adapting or being flexible to the measured changes and opportunities. The loop is not complete until lessons learned are incorporated with regular revisions of performance standards.

The steps in the planning processes analyse and evaluate operations and prioritize those which require the ability to adapt to changing conditions, cope with complexity, respond to problems ahead of time, steer activities, and devote to safety.

3.3 Related research on maintenance and the planning process

This section provides related research on maintenance and the planning process in the context of major accidents.

Based on research from the Center for Integrated Operations for the Norwegian petroleum industry (IO CENTER, 2017), features that may have effects on teamwork and risk perception were identified in two explorative observational studies of IO collaboration, field visits, and surveys in six different organizations (Skjerve et. al. 2009, Kaarstad et. al. 2009, Rindahl et. al. 2009). This formed the basis for developing a software test bed, called the Maintenance and modification Planner (IO-MAP) for a series of explorative studies on whether and how technology characteristics may improve risk identification in maintenance and modification planning for oil and gas installations in future IO work practices (Skjerve et al., 2011). The focus was on work orders and work permits on a plan and how associated hazards of these items on a plan could be visualized to the planner. IO-MAP was used to study how risk identification can improve by using a digital graphic work surface and a set of agreed symbols and logics to illustrate factors that affect the safe and effective execution of the work tasks undergoing planning. The visual concept of the prototype is reported in (Braseth and Sarshar, 2012; Sarshar et al., 2010). Lessons learned from this study was used when developing the first visual concept reported on in article 5 (Sarshar and Haugen, 2017).

A first usability evaluation of the IO-MAP was performed and is reported in (Skjerve et al., 2011). The main conclusions from the study on effectiveness of identifying risk include challenges related to the planners' ability to identify safety hazards early in the planning process. This task was hypothesized to be of key importance for planning in future IO settings. Earlier risk identification is important to manage uncertainty in plans and is addressed in article 3 (Sarshar et al., 2016; 2016b). Skjerve et al. (2011) reports that for "The planners participating in the first usability evaluation (onshore planners), identification of risk was not a part of their daily tasks. During the study, it was clear that onshore planners, with no offshore experience, currently lack this competency. It was, however, also clear that planners with extensive offshore experience were far better suited to identify risk in the early parts of the planning process. As implementation of IO has led to offshore planners being relocated onshore, it is reasonable to assume that improvement of tools, in addition to adequate collaboration and information flow, is required to improve or even maintain safety through this change".

This research was further expanded to address different aspect of integrated operations with focus on: The planning levels from annual to work permits (Sarshar and Sand, 2010), Quality aspects in planning based on the evaluation of plans made by the tool (Sarshar et al., 2011), and How leaders can use technology to enhance risk perception and communication (Taylor et al., 2014). The authors state that risk visualization tools are not sufficient in themselves for risk management; an overall risk communication strategy is needed to ensure effective communication targeted to the needs of the different teams of personnel in planning and execution.

Another conclusion from the studies highlight future research needs (Sarshar et al., 2011): "The findings, moreover, contribute to the basis for assessment of maintenance and modification plans. They point to overall issues that should be taken into consideration when plans are assessed. Further work is needed to identify which concrete characteristics that should be addressed when plans are assessed, e.g.: Which 'safety related matters' should be into consideration in the planning process? In addition, more work is needed to determine how the characteristics of the plans identified should be prioritized vis-à-vis each other: Are the aspects equally important - under all conditions?" These are some of the issues related to major accident risk which are addressed through this thesis.

There are many ways in which the planning process can influence the occurrence of major accidents. A key conclusion made by Smith and Harris (1992) was that prior to major accidents, there is often a lack of detailed safety objectives and long-term safety control. In the absence of a tight safety and reliability control and consequent corrective actions, a mismatch can develop between the management's perception and the actual condition of the plant. The study further revealed that the lack of an internal department, responsible for reviewing plant safety matters, and independent of production pressures can have a serious detrimental effect on plant safety. Further, Mize (2016) explains that deviations from established practices and procedures can be introduced due to failure to e.g. adequately identify and acknowledge change, due to resource constraints (e.g. limits on availability of experienced personnel), ageing equipment and infrastructure and institutional knowledge. Mize emphasizes that adherence to operational discipline over the long term remain the best defence against deviations becoming normal. Both studies relate well to the conflicting objective (see chapter 3.2.2) were safety goals may be jeopardized by production pressure and were Mize exemplifies how the organisation may encounter drifts towards unsafe operational boundaries. Article 2 of our project (Sarshar et al., 2015) addresses these issues and provides examples of how deviations can contribute to hydrocarbon leaks.

Loss of technological knowledge is another crucial factor contributing to why a major accident may occur. Silva (2015) studied three major accidents and identified that the technological knowledge can be lost due to (1) new technology (e.g. Macondo, Gulf of

Mexico); (2) loss of knowledge due to inadequate training, procedures, and information (e.g. Three Mile Island); and (3) the failure to incorporate new knowledge such as the lessons learned (e.g. Fukushima, Japan). Technology refers here not only to manufacturing processes, but includes the management system in place to handle the hazardous processes.

Kongsvik et al. (2015) suggest several principles for improving decision support for major accident prevention in industries. While many decisions today are based on a high degree of uncertain information, they see a need to deploy more factual information to make the risk picture more relevant for both operational and instantaneous decisions. A basic premise for improvements in the decision process is the need to be conscious regarding the type of decision that is to be made. They suggest three decision types to address: whether it is a strategic, operational or instantaneous decision. Yang and Haugen (2015) add a fourth decision type to this list, emergency decisions, and group the four decision types in planning which includes strategic and operational decisions and execution which includes instantaneous and emergency decisions. These decision types all use information about risk as input, although it is not necessarily the same information.

For operational decisions, Almklov et al. (2016) propose a model for instantaneous risk. Their concluding remarks include two aspects closely related to our work: (1) strengthening the work order meeting to focus on major accident risk. This is also a finding from our studies reported on in article 2 (Sarshar et al., 2015); (2) include more formal risk considerations of preparation and resetting task related to maintenance. This issue is also highlighted by Skjerve et al. (2011) and article 3 (Sarshar et al., 2016). The conceptual design for work orders and work permits developed and reported on in article 5 (Sarshar and Haugen, 2017) addresses this issue through risk visualization.

Okoh and Haugen (2013) present a classification scheme for causes of maintenance related major accidents. The scheme is based on a combination of accident process and work process classification where the process based classification is further divided in active and latent failures. Many of the causes for latent failures correlate with the contributing factors identified through our project (article 2, Sarshar et al., 2015). Further, the authors agree with our views that major accidents are not caused by one causation factor alone, it is the combination of "lack of maintenance" or "lack of maintenance error" with "new hazard" or "initiating event" or other non-maintenance related causes that can cause major accidents (Okoh and Haugen, 2013, p.1064).

For petroleum facilities, prevention of hydrocarbon leaks is significant as they may lead to major accidents if ignited. Vinnem et al. (2016) study preventive maintenance of pressure safety valves and demonstrate how such activities are a significant source of loss of containment (a barrier function) related risk due to operator errors during isolation. Their added insight is that planning of preventive maintenance of such valves should be extended to cover the leak potential of the work in addition to the focus on trade-off between maintenance intervals and failure probability. For work on hydrocarbon carrying systems the isolation and reinstatement of the system are critical tasks that require verification of correct performance (NOG, 2012; 2013). The case applied in our project (article 5, Sarshar and Haugen, 2017) is a work order on such a valve requiring isolation, blinding and depressurization, execution of replace or repair work, and reinstatement.

The Risk OMT project (Risk Modelling - Integration of Organisational, Human and Technical factors) (Gran et al., 2012; Vinnem et al., 2012) models the risk of hydrocarbon leakages using event trees to explain the relationship between planning and performance tasks, and the risk of leakages. Sarshar et al. (2012) study visualization of safety hazards, such as hydrocarbon leakage, on a geographical map of an installation and how this can contribute to raised awareness of potential hazard in a given situation.

Fyffe et al. (2016) has gone through accident reports from CSB (The United States Chemical Safety Board) to develop lessons learned to improve safety and operations at chemical industry facilities. In their study of "Key Issues" reported by investigators of the accidents, they sorted the accidents thematically to capture insights. Several of the themes are related to the scope of our project (article 2, Sarshar et al., 2015) including process hazard analysis, hazard recognition, operating procedures, maintenance, management of change, management oversight.

Sanders (2005) studied several maintenance-induced accidents and process piping problems within the process industry and concluded as Wallace and Merrit (2003) that fundamentals of good practices for safe maintenance are:

1. Proper preparation for maintenance begins during the mechanical design of the process
2. The operating staff must properly prepare for maintenance
3. Identify potential hazards and plan well in advance
4. Good communication is critical

Related to these practices, Akalezi (2004) highlighted that it is the duty of personnel at different levels of the organisation to manage risks pertaining to their specific activity and to the activities of their teams. This duty should be an integral part of operational management. This aspect is discussed for permit to work systems, safety meetings and job preparations. In our work, we address this aspect in article 1 (Sarshar et al., 2013).

Andersen and Mostue (2012) found that risk analysis methods are mostly used in design and modification projects and not during daily operation. Based on their surveys, safe job analysis was the most commonly used method for work in daily operation. Hazard identification (HAZID) and hazard and operability studies (HAZOP) were performed sometimes for difficult or special activities. The main reason for not using many formal risk assessment methods in operation was their limited ability to give valuable safety information for operational tasks. This was especially valid for extensive quantitative methods like quantitative risk assessment (QRA). The generation of risk knowledge in operation was instead mainly based on three approaches that were identified (ibid): (1) formal procedures and governing documentation, (2) plant specific competence and common sense, and (3) the planning processes.

Traditionally risk is measured in terms of an expected loss which is calculated by multiplying probability and consequence. Haugen and Edwin (2016) describe that this is a useful measure for strategic decisions since it can be used to minimize expected loss over an extended period. For operational decisions focusing on short-term activities this is not necessarily the best criterion for managing risks.

Haugen et al. (2016) study activity based risk analysis. The modelling is based on the barrier functions and the activity characteristics are reviewed to identify if the activities may directly or indirectly cause an impairment or deviation in the barrier. Based on planned activities and other conditions affecting the barrier status, the risk can then be calculated on a daily basis.

Several of the approaches for modelling activity related risk can provide underlying input to the concept developed for risk visualization in article 5 (Sarshar and Haugen, 2017).

Many of the research studies address different aspect of planning and occurrence of major accidents. However, there are no thorough studies which systematically break down the planning process with respect to managing major accident risk and which try to address these issues in an operational context. By addressing these issues, this thesis contributes to increase the understanding of operational risk in the oil and gas industry.

Chapter 4

Main Results and Discussions

The planning process shall deliver a sound plan which has been assessed for major accident risk to ensure safe and efficient execution of work at the installation. The main research question addresses this issue by studying RQ1 – RQ3. The results from these studies are presented, discussed and related to the main research question in this chapter.

4.1 The relation between planning and the potential for major accidents

The purpose of the first study was to understand the planning process and the offshore execution of work. Article 1 (Sarshar et al., 2013) presents the results from study performed at an offshore installation at the NCS. The focus was on information needed for evaluation and assessment of maintenance and operational activities. Our assumption was that low-quality planning processes lead to low-quality plans, which in turn increases the risk of major accidents.

The study suggests that the following attributes must be fulfilled to obtain a high-quality plan:

- The plan is robust
- The description of task execution includes the contribution of all disciplines and other parties
- All safety issues have been resolved
- The plan is comprehensive to its users

The theoretical study, in article 2 (Sarshar et al., 2015), identified factors which can influence the processes with respect to major accidents. These include:

- Energy and barrier: Risk assessment, barrier control, hazardous operations, simultaneous activities
- Conflicting objectives: Goal conflict, pressure towards efficiency, workload, practice
- Man-made disasters: Information flow, communication, misunderstandings, plan quality, overview of activities,
- High reliability theory: Commitment, redundancy, learning culture
- Resilience engineering: Preparedness, learning culture, ability to steer activities, awareness, goal conflict, buffering capacity, anticipation, monitoring, responding

The energy and barrier, conflicting objectives and man-made disaster perspectives can be related to the plans established and their content as summarized in Table 3 (ibid). High reliability theory and the resilience engineering perspective apply more to the organisational level rather than the plans directly.

Table 3: Relation of the energy and barrier, conflicting objectives and man-made disaster perspective to *plans* and their content (Sarshar et al., 2015).

Plans	**Energy and barrier**	**Conflicting objectives**	**Man-made disasters**
Operational plan	Risk that can affect the accomplishment of activities shall be identified and reported in relevant risk management tool. Analysis required on hazardous operations, simultaneous operations, barrier weaknesses and compensating measures.	Potential conflicts at the organisational level in which there is incompatibility between safety and production goals, but also at group level when the informal norms of a work group are incompatible with the safety goals of the organisation.	
Operations			Contains information on whether the operations repeal safety critical systems or barriers. For the plan, it means that it does not contain all relevant information needed.
Work order plan	Major accident risk should be considered and required risk controls identified.	As above (operational plan)	
Work orders	Work specific aspects that can take out an existing barrier and needed compensating measures are identified. Work operation type can present a major accident risk.		The work order may not contain all relevant information needed to communicate hazards and risk.
Work permit /Daily plan	Analysis required on hazardous activities, simultaneous activities, barrier weaknesses and compensating measures.	Potential conflict at the group goal conflicts, when the informal norms of a work group are incompatible with the safety goals of the organisation, but also at the individual goal conflicts caused by preoccupation or group specific concerns.	
Work permits	Major accident risk will be considered during the preparation of the WP. Work specific aspects that can take out an existing barrier and needed compensating measures are identified. Work type can present a major accident risk, coordination needed.		As above for work order

Relevant contributions from the energy and barrier, conflicting objectives, man-made disaster, and high reliability theory perspectives can be related to the planning processes as summarized in Table 4 (ibid). In addition, the resilience engineering perspective is applicable to all processes since the steps for analysing and evaluating work, and its prioritization require the ability to adapt to changing conditions, cope with complexity, respond to problems ahead of time, steer activities, and devote to safety. The tables pinpoint possible risks in each stage by each theory.

Table 4: Relation of the energy and barrier, conflicting objectives, man-made disaster and high reliability organizations perspective to the planning processes (Sarshar et al., 2015).

Planning steps	**Energy and barrier**	**Conflicting objectives**	**Man-made disasters**	**HRO**
Operational plan				
Need for work		Major accident risk is considered and required risk controls are identified. Management's focus on efficiency can put (time and cost) pressure (vs safety) or favour production optimization operations ahead of maintenance operations.	Information must flow between the activities and between the roles and actors, and discussions should address misunderstandings. Type of information important to share is e.g. hazardous operations and what makes them hazardous. Communication channels and feedback loops with the WO and WP process is necessary.	
Define conditions	These steps present organisational barriers since major accident risk is considered and required risk controls are identified.			These steps are foremost collaboration activities which works as organisational redundancy with overlapping tasks and competence, eye-to-eye contact and which easily communicate with each other.
Quality assure plan				
Establish plan				
Analyse				
Coordinate				
Operational plan meeting				
Work order plan				
Establish WO	An organisational barrier is present in this stage, since major accident risk is considered and required risk controls are identified.	Major accident risk is considered and required risk controls are identified. In this step, management's focus on efficiency can put (time and cost) pressure (vs safety): not taking necessary time to prepare the work: not considering all aspects of the work (e.g. with respect to HSE, resources).	Major accident risk is considered and required risk controls are identified. The WO may not contain all relevant information needed to communicate hazards and risk. For the planning process, this means that information may not flow between the activities in the processes, between the roles and actors.	There are at least two persons with overlapping competence and with access to necessary/required information present in this activity
Approve WO plan	No or very limited focus is placed on major accident risk. No barriers.	No or very limited focus is placed on major accident risk. Management's focus on production and efficiency will determine the prioritization of WOs which make it to the plan.	No or very limited focus is placed on major accident risk. When establishing the WO plan, misunderstanding and misperception of information or between actors and roles in the planning processes can generate low quality plans.	The evaluation and quality assurance of the WO plan is facilitated as a collaboration activity involving different key responsibilities making the approval process redundant. Some include the offshore lead technicians in this step and hence include decentralised decision making.

Planning steps	Energy and barrier	Conflicting objectives	Man-made disasters	HRO
Work permit/Daily plan				
Establish and apply for WP	Major accident risk will be considered during the preparation of the WP and this is therefore also an organizational barrier. Consideration in this step is to ensure that the work can be performed safely.	Management's focus on efficiency can put time and cost pressure: not taking necessary time to prepare the work: not considering all aspects of the work (e.g. with respect to HSE, resources, or competence needed). One might also choose deliberately not to perform such assessment and take the necessary time for preparations or cut on safety measures because one considers these unnecessary.	Major accident risk will be considered during the preparation of the WP. As for establishing WO, the WP may not contain all relevant information needed. This can be directly related to poorly established WO. For the planning process, this means that information doesn't flow between the activities in the (WO and WP) processes and between the roles and actors.	As above for establish WO
Approve WPs and day plan	The approval process ensures that the work can be performed safely and (as part of that) ensure that the work can be performed safely simultaneously with other activities (coordination). This would therefore be an org. barrier.		Misunderstandings and misperception of information or between actors and roles in the planning processes can cause that WPs are approved based on inadequate basis.	The maintenance and operation leader approves WPs at level 2 while the platform manager approves WPs at level 1.

Based on the theoretical study and the review of incident reports thirteen factors were identified that influence the planning process or plans with respect to major accidents. These include:

- Information flow – When information is missing, inadequate or not passed from one step to another in or across planning phases
- Communication – When communication channels is missing or is inadequate between roles and actors
- Misunderstandings/misperception – When assumptions and misperceptions influence the quality of the work
- Documentation – When documentation is missing or not reflecting the real system
- Procedures – Missing, not available or not precise procedures
- Planning quality – The planning processes should manage the quality of plans
- Plan quality – Weakness in plans should be managed during assessment steps
- Competence – When required competence is not present
- Overview/situation awareness – Relates to overview of activities, their relations and complexity
- Work practice – Poor work practices may exist that deviate from procedures or defined processes

- Workload – Assumed caused by e.g. time pressure
- Risk assessment – Inadequate analysis or actions or measures not followed up
- Learning – Assumed that one should consider learning from similar type of work when assessing it

In the second iteration of the analysis, aspects identified as causes in the investigation reports which could be related to planning or plans were grouped as best could fit into the thirteen influencing factors. The result is presented in Table 5 where columns represent the planning processes and their steps (grouped in establish, assess and coordinate and approve) and the rows represent the influencing factors. The content of the table illustrates the number of incidents that had an influence on these steps. There were 18 incidents which could be related to the planning processes in one way or another. These are identified from **A** to **R** in the table. Some of the incidents, e.g. **G**, contribute more frequently (14 times) to the occurrences in the table while some contribute few times. The explanation of this can be that some incidents are examined more thoroughly than others, hence causes are described in more detail, while other reports are short and only describing the incident without any in depth study of causation. Examples of the influencing factors from the incidents for the work order and work permit plan are provided in Table 6.

Table 5: Incidents identified from A to R and their relation to the planning processes (Sarshar et al., 2015).

Influencing factors	**Entire process**	**Operational plan**			**Work order plan**			**Work permit plan**		
		Est.	Assess	C&A	Est.	Assess	C&A	Est.	Assess	C&A
Information flow	K, M, N, P									
Communication	A								C	D
Misunderstandings	I		A					K	O	D
Documentation	G, H, J, M, O								A	R
Procedures	B, C, R							G	E	
Planning quality	H, P				D, M		A, I, M	G		D
Plan quality					D, G			G	C	
Competence						G	G		D, N	G
Overview of activities							G			C, G, Q
Work practice	M									E, M, R
Work load										G
Risk assessment	F, G, I									N
Learning						A, C, D, G, N			A, C, D, G, N	

Based on these studies we conclude that there are theoretical contributions from the major accident theories that can be related to the planning processes. The empirical study further illustrates the relations between reported incidents with major accident potential and the planning processes.

Table 6: Exemplified influencing factors for the work order and work permit planning phases from the incident reports. The examples applicable to the work order process are also valid for the work permit process. (Sarshar et al., 2015).

Contributing factors	Work order process	Work permit process
Information flow	**M:** Information and history when a need for work and work permit was established was not included in the further process	
	N: General risk measures identified earlier in the process was not signed by involved personnel before the operation started	
Communication		**C:** Procedure was not known to all process operators
		D: Lack of communication
Misunderstandings/ misperception	**A:** Misperception around the criticality of the work	
		D: Work performed was not the work described in the WP
		K: Operation was seen as routine operation and safe job analysis was not performed and work permit not established
		O: Technicians assumed the equipment/system was a barrier and considered this to be sufficient
Documentation	**M:** Inadequate documentation and drawing of the valve	
		A: Inconsistent torque table
Procedures	**G:** Not precise procedures (which manual valves that should be opened and in which order)	
Planning quality	**D:** Missing need for work for a general agreed work of replacing parts of a HC-system when these systems were down	
	L: Failure in prioritization of work order with respect to consequence	
	A: Material needs not coordinated with prioritization	
	M: Lack of original parts when planning to execute the job	
	M: A new work order or operation not established to replace the reused parts	
		G: The operation did not have a work permit
		D: Work permit modified after approval
Plan quality	**G:** The work description did not fit the criticality and importance of safety of the work	
	D: Not precise description of a new activity added to an already assessed work order	
		C: Failure in preparation of correctly establishing a barrier
Competence	**G:** Plant specific competence was not present during decision making	
	N: There is a procedure for the work which was not known and used	
		D: Decision made based on inadequate knowledge and competence on the process system by mechanical team
		G: Shift of personnel which was not part of the preparations before execution of work, new personnel had no experience or competence on the system
Overview of activities/ situation awareness	**G:** Onshore had no overview of activities offshore when plans were changed to include test on ESDV (emergency shutdown valve), no assessment of plan	
		C: Bleed to unsafe area was not coordinated with other activities
		G, Q: (Very) high activity level at the installation
Work practice	**M:** "Silent deviation" on bleed to unsafe area	
		M: Blinding list verified to be correct when it deviated from procedure
		R: Work permit approved and considered routine operation without any additional requirements
		R: The type of maintenance not always documented by offshore organisation
		E: Blinding list not established
		E: Work permit signed before job preparation
Work load		**G:** High workload on operation and maintenance leader
Risk assessment	**G:** The segment contained large amount of gas which was not identified or considered during planning	
		N: The risk for the incident was not included in detail procedure or handover between teams
Learning	**A, C, D, G, O:** Similar incident not considered during preparation of work	
		G: Earlier studies of similar incidents were not known to the personnel

The distribution of influencing factors for each of the planning phases is illustrated in Figure 3. Besides the factors affecting the overall process, the work order and work permit phases have the highest occurrences of the factors with "learning" and "planning quality" as the highest. The factor "learning" occurs five times in both the latest phases of planning. The examples from the incidents on this factor relate to "similar incident not considered during preparation of work" and that "earlier studies of similar incidents were not known to the personnel". We assumed in our study that one should consider learning from similar type of work when assessing it, and this assessment is done in the work order and work permit phases which explains the need for learning from incidents in these steps.

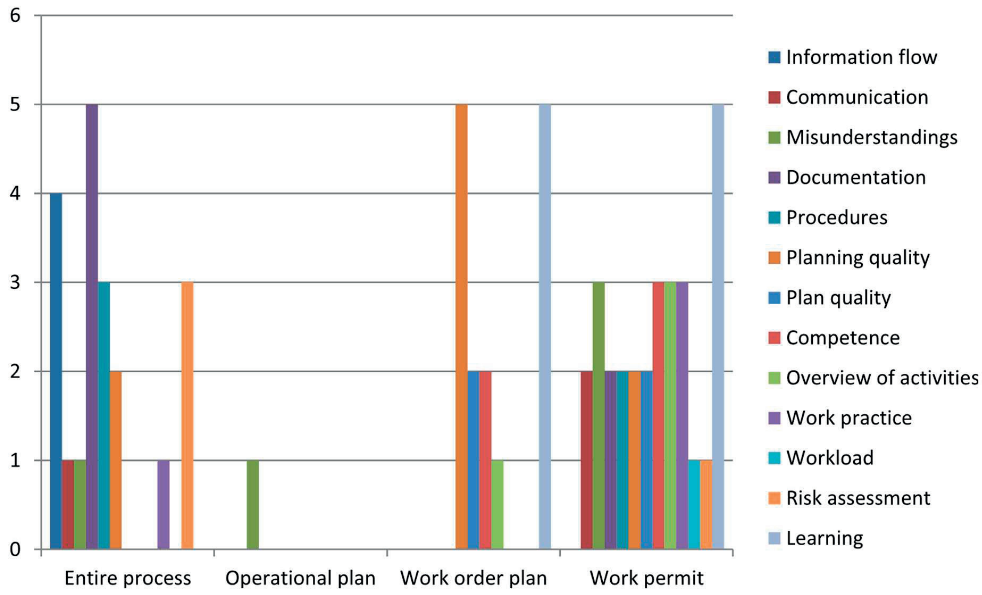

Figure 3: Distribution of the influencing factors for each of the planning phases (Sarshar et al., 2015).

The factor "planning quality" occurs five times in the work order phase, an example from the steps for coordination and approval of work orders include "failure in prioritization of work order with respect to consequence". This factor also occurs two times in the work permit phase exemplified with work permit being modified after approval and that an operation did not have a work permit.

Many of the occurrences of the influencing factors are in the late phases of planning. It might be that the more contributing factors have been identified closer to the sharp end as these typically are easier to find as they are closer to the incident. The "entire process" may be plan-related organisational aspects which indirectly can contribute to an incident. The occurrences of these are also high and can be exemplified through the incident reports as "bolt degradation not detected", "weakness of valve had been reported earlier but was probably not assessed to cause mechanical rupture", "operating company had no quality assurance process for the activity" and "results of tests performed by vendor was not requested or shared with the operating company". These examples provide empirical evidence that inspection programs, risk analysis, procedures, work processes and communication between involved parties can be inadequate.

Further, the different planning phases has different focus, so it is unreasonable to expect all the influencing factors to apply to the steps in each phase. The factors can have dissimilar weighting for the different phases. The factor "workload" for instance may be more important in the work permit process compared to the operational plan phase. In fact, only one occurrence was traced to the operational phase of the studied investigation reports. This occurrence concerned a work activity which was not followed up due to a misunderstanding in the plan assessment step.

Aspects from major accident theories related to planning can include communication, information and data sharing which are necessary for all involved parties to have an adequately shared understanding of the thoughts behind plan activities. Since the plan is made over several phases, traceability of decisions and underlying information must be in place to better aid those who need to re-plan a task due to new circumstances. Assumptions made in earlier planning phases must now be known so they can be verified before new decisions are made.

To summarize, the relation found between the planning (process), and the potential for major accidents is mediated by the influence of a set of contributing factors (Sarshar et al., 2015). When these factors are in non-optimal states, the risk that major accidents have not been properly addressed increases. Using the influencing factor "communication" as an example; when communication is lacking or when procedures are not known to all involved, the risk that the plan, resulting from the planning process, will not adequately address major accident risk increases.

4.2 A planning process designed to better manage major accident risk

With basis in the theoretical and empirical studies performed, further interviews where performed with onshore personnel involved in planning and risk management for one operating company. This was followed up by gathering industry experts in a workshop to present and discuss the findings from the studies in order to identify industry challenges and opportunities with managing major accident risk through the planning process. This forms the basis for proposing measures to address research question 2.

Based on the results from the workshop, interviews, accident reports and theoretical work, the challenges identified have been grouped in the following four main topics: inadequate plan, inadequate planning, inadequate shared overview and understanding, and late risk identification. This is reported in article 3 (Sarshar et al., 2016) with a summary provided in the following.

An inadequate plan may create latent conditions, which contribute to the risk of major accidents. These conditions can be summarized as follows:

- The quality of the work orders does not meet the requirements from the offshore organisation. Issues include: inadequate work descriptions, inadequate resource allocation, side activities not foreseen or planned.
- The workload and time-pressure for offshore personnel increase. Time and cost pressure can result in staff not taking the time to prepare the work, not considering

all aspect of the work (e.g. with respect to HSE, resources, or competence needed) and the focus being on scheduling and date/time for the work.

Inadequate planning and change handling can contribute to the risk for major accidents. The challenges can be summarized as follows:

- Inadequate planning quality: short preparation time, offshore expertise not present
- The impact of changing the plan is not (re)assessed: the personnel may not have qualification to assess the quality of a revised plan from a safety perspective – locally and globally; are there enough resources to perform the necessary reassessment?
- In the morning meetings, one may add additional work that is not planned for in a work order.
- When unplanned events occur, the plans seem to be put aside and the event gets all the attention and focus even if it is not a critical event.
- Capture impacts which the work causes (can be new activities).

Inadequate shared overview and understanding may contribute to the risk for major accidents. The challenges can be summarized as follows:

- Inadequate overview of: simultaneous activities, area risk, barrier status and conditions, process status.
- Inadequate information flow and communication
- Poor ICT tools and poor technology literacy

The challenges of late risk identification in the planning process may contribute to the risk for major accidents and can be summarized as follows:

- The work order plan is not assessed for simultaneous operations before approval. Risk assessment is performed when establishing individual work orders, but the ones in the plan are not assessed all together. This is first done at the work permit level.

Though many of the challenges highlighted can be addressed by e.g. robust procedures, competence systems, HSE management systems, management of change and compliance with governing documentation and standards – incidents and accidents do occur. The findings point to areas where systems can be improved, while we also should acknowledge that it is unrealistic to assume that systems that are introduced always work perfectly. There is in some cases a gap between what is intended to be good practice versus what is the current practice.

Proposals for some of these challenges that was discussed in the workshop are presented in Table 7. We stress that the intention has not been to address all challenges that were identified above. The improvements are grouped in the following three categories:

improvements to the planning process, improvements for risk structuring and ICT tools to provide shared overview. Table 7 links the challenges to the proposed improvements.

Table 7: Identified challenges and proposed improvements (Sarshar et al., 2016).

Identified challenges	
Plan quality	Inadequate work descriptions, resource needs and side activities not foreseen or planned
	Increased workload and time-pressure offshore
Planning quality	Short preparation time
	Offshore expertise or installation specific competence not present
	Impact of changing the plan is not (re)assessed
	Capture changes which the work causes
Shared overview and understanding	Inadequate overview of activities
	Inadequate information flow and communication
	Poor ICT tools
Late risk identification	Work order plan not assessed before approval

Proposed improvements	
Risk characteristics for the job should be identified when establishing the work order	**Planning process**
Perform a SJA preparation step onshore	
Assess work order plan with respect to major accident risk before approval	
Use separate notification on additional jobs	
Include installation specific competence and experience more often in job preparation and risk assessment	
Structure risk information from operational plan to work order plan and to work permits	**Risk structuring**
Make results from risk assessments visible	
Visualise simultaneous activities, area risk and potential hazards	**ICT tool**
Make information available for all involved in the planning and execution process	

Further, the study reported implies that the IO concept is not fully implemented with respect to e.g. information sharing, and through fast access to expert advice from global support centres (IO CENTER, 2017). The challenges related to information flow illustrates that the potential of information sharing is not obtained and the challenges related to having installation specific competence easily available illustrates that fast access to expert advice is not present in the organisation in the study.

The outcome of the present study has some potential biases. The empirical part of the study is based on investigation reports, a workshop with one operating company, and interviews of offshore personnel from another company. The challenges and proposals gathered from these sources represent what the expert participants involved have experienced and do not necessarily represent all industry challenges and opportunities. Further, the findings are limited to the challenges and recommendations identified by Sarshar et al. (2015) based on 24 investigation reports analysed. Many of the recommendations from these investigations are incident specific and we would expect that they have already been implemented. Very few were generic recommendations that can be related to the planning process. The most common practice was to go through the incident with all shifts for learning and improvement.

The challenges identified can be related to some key aspect of the resilience engineering perspective. The practice of resilience engineering (Hollnagel et al., 2011) requires that anticipation, monitoring, responding and learning are considered and addressed at all levels of the organization. For instance, key performance indicators related to work orders or work permits are important indicators of an effective process safety management system (iChemE, 2015). Examples can include KPI on plan efficiency, plan periodic achievement and plan productivity. Some aspects from the resilience engineering perspective which may affect the planning process:

- Preparedness - ability to respond to problems ahead of time is challenging when the plans and their activities are inadequately prepared. This would require adequate installation specific competence in the onshore organisation.
- The ability to adapt to changing conditions is challenging when decision makers do not have necessary information and overview to manage change in plans. This can be the result of inadequate planning (preparedness), inadequate communication of plans and/or inadequate information on ongoing activities.
- Buffering capacity - having available resources necessary to respond to arising problems and complex issues is challenging if the organisation already is under pressure (time and cost) due to inadequate plans and planning. Time and cost pressure has two effects in this case: Inadequate time for the planners will lead to low-quality plans which in term may lead to time pressure to those performing the work because the work is not sufficiently planned.

The proposals on extending and adding new activities in the planning process may demand more time spent in preparing the work orders and the work order plan. As these activities are performed onshore, this should not conflict with the principle of spending time mainly on execution offshore, rather than on administrative work. An important aspect to consider is how these proposals can be implemented without increasing workload, having in mind the conflicting objectives of efficiency versus safety.

Regarding the SJA preparation step onshore, a potential consequence is that the SJA itself (performed offshore) may assume that all risk has been identified in the preparation step onshore. The idea is, however, that the first step prepares and includes technical integrity in the SJA process. The SJA offshore should still include all executing personnel offshore as is required today. An aspect worth studying can be if offshore personnel's risk understanding decreases over time if they are less involved in risk assessments (preparation of the SJA) in practice. Another aspect is whether this may affect knowledge transfer between offshore personnel; if offshore personnel are contractors, will they base their work on the assumption that all risk has been identified earlier and will they be sufficiently familiar with the platform to identify all risks?

The latter two proposal categories concern information, risk structuring and ICT tools for managing and visualizing these. These proposals require introduction of new technologies for risk management. A challenge when introducing ICT tools and new technology solutions is technology literacy. Sarshar and Rindahl (2014, p.6) explain how collaboration and decision arenas may fail in effective communication and in obtaining good shared understanding due to poor technology literacy: "Rolling out new technology or ways of working can be difficult when people are busy with their daily tasks and skilled in their old ways of doing them. Leaders can assist with this introduction to new concepts by using the collaboration technology regularly themselves, demonstrating how it works, and systematically encouraging team members. ... Technology shall support and enable a desired work practice, and not the other way around and it is recommended to train as you work."

The next step was studying what type of risk related information is needed for decision making, in the various planning arenas through the planning process. Gaining insight into these decision-making arenas is important for the understanding and management of activities that have potential for major accidents. This has been addressed using a top-down approach where major accident decisions are described, which assessments and analyses these are based on and what risk related information they need. The study has highlighted what information is needed, and when in the planning process it is needed, to manage major accident risk with focus on activity, technical and some organisational factors. This is reported in article 4 (Sarshar et al., 2017) and summarized in the following.

Within the planning phases there are decision arenas such as meetings in which work activities and plans are discussed and approved (illustrated in Figure 4). Daily meetings are highlighted with grey background while less frequent meetings have dashed outlines. Activities and actions occurring between these meetings are shown with a white background. While there are many decision arenas through the planning process, the four most important regarding the managing of major accident risk include the operational plan meeting, work order plan meeting, work permit meeting and morning meetings (highlighted in the figure). Important decisions with respect to managing risk are also made in other meetings and arenas, but these four represent the most important decisions arenas through the planning process and are emphasized in our study.

Operational plan meetings occur every two weeks and looks three months ahead. The operational plan contains information about the activities on the installation with respect to drilling, operations, maintenance, inspection and modifications. Its goal is to maintain the installation's total risk picture with respect to major accidents, production and development. The plan focuses on risk levels, priorities and resources within and across installations. It is to make sure that the activity levels are regulated in order to stay within the framework conditions. The objective is to assess activities for HSE issues, their influence on area risk, their criticality and the technical integrity.

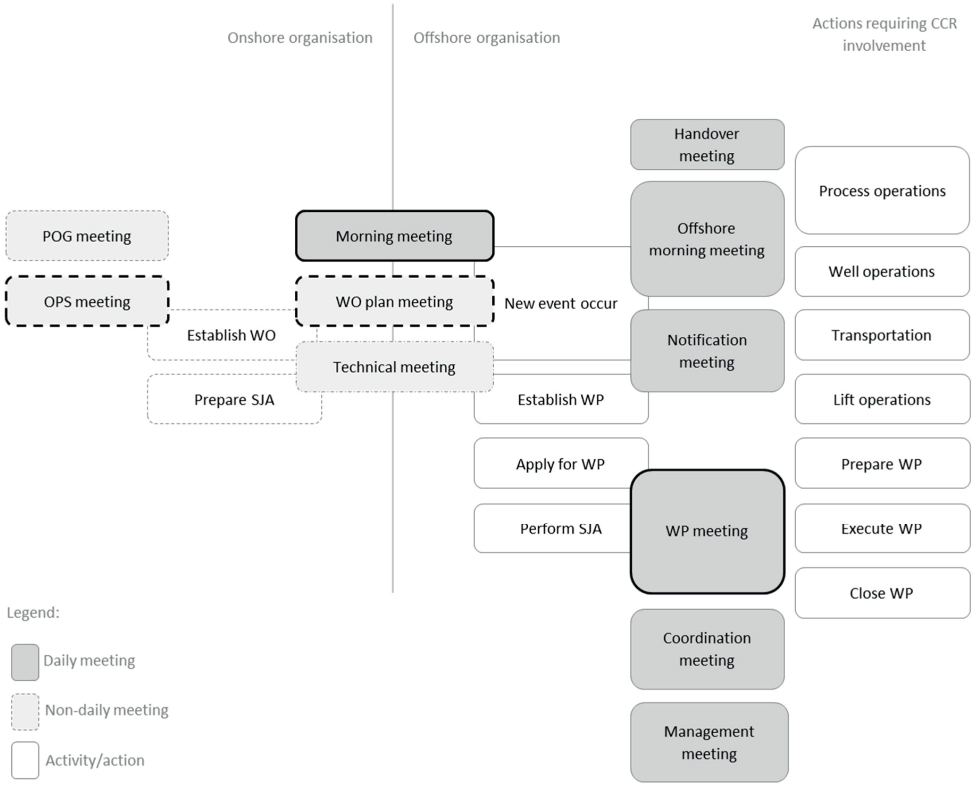

Figure 4: Meetings and activities/actions close to execution of offshore maintenance and operations (Sarshar et al., 2017).

Work order plan meetings occur on a weekly basis and look two weeks ahead. The objective is to plan for safe, efficient and sustainable execution of work on the installation. The main activity is to schedule and coordinate activities on plan according to resource needs.

Work permit meetings occur every day and focus on the following days activities. The objective is to assess work permits, coordinate and assess them for simultaneous execution.

Morning meetings occur daily and focus on today's activities. The objective is to emphasize required preparations and coordination for execution of the work.

The planning phases (on which we have had special focus) contain several steps: identifying the need for performing the work, establishing and assessing the activities, coordinating them on a plan and approval of the plan. While these are the steps primarily for the operational plan and work order plan, the work permit system focus on correct execution of the planned work offshore. For the operational and work order plan, there are several assessment and coordination activities prior to the *operational plan meeting* and *work order plan meeting* respectively. In these meetings, the plan is discussed and approved. Offshore, the *work permit meeting* addresses the work permits and their approval while the *morning* *meeting* focus on approval of today's activities. In our study, we focus on the decisions made in these meetings, the assessments and analysis needs (performed in the steps prior to the meetings) and their risk-related information needs.

The results are summarized in Table 8. The four meetings emphasized are listed in each row with the columns describing their objectives, decisions, major accident assessment and analysis needs, and risk-related information needs.

The assessments and risk related information contributes to coordinate and approve activities and the different plans. Where possible, the risk related information needs are grouped in activity, technical and organisational related information. While the activity and technical aspects have been discussed, the organisational aspect can e.g. relate to correct performance of human critical tasks. The focus is on people as a barrier rather than as a source of errors. During operation, it can be to verify that an isolation plan is correctly set. For work on hydrocarbon carrying systems the isolation and reinstatement of the system are critical tasks that require verification of correct performance (NOG, 2012; 2013). For planning it can be that critical expertise or personnel input is required in assessment of the plan and its activities.

The results illustrate what should be addressed, assessed and made available through the different planning phases and their respective decision arenas and is based on our previous and current studies on the topic (observation of the different planning meetings; interviews with planners, personnel working with technical integrity, platform managers and technicians offshore; and by studying different planning and work order and permit management tools). It should be noted that in practice, the described decisions and assessments are not necessarily performed by the operating companies (contractors may be involved) and some aspects may be performed only to a limited extent. Similarly, the information needs do not represent what is available of information through the planning process.

The results (decisions, assessments and information needs) from this study has been assessed by a subject matter expert.

To summarize, the planning process can be better designed to deal with and manage major accident risk by e.g. assessing and identifying risk related to the activities being planned earlier, assess work order plan with respect to major accident risk before approval, and make risk related information available to decision makers. Many of these measures are to enable personnel involved in the planning process to identify and assess work and plans earlier and better than is done today.

Table 8: Overview of main decision arenas in the different planning phases, their main decisions for managing major accident risk, their assessment and information needs (Sarshar et al., 2017).

Decision arenas	Objective	Decisions	Major accident assessments and analysis needs	Risk-related information needs
Operational plan meeting *Occurs every second week and looks three months ahead*	Assess activities for HSE issues, their influence on area risk, their criticality, and the technical integrity	Approve operational plan	- Assessment of planned activities in the context of the framework conditions with respect to e.g. POB, high risk activities (such as heavy lift over process area, hot work or work on hydrocarbon carrying systems). - Are there weakened technical, operational and organisational barriers? - Risk analysis of how activities or absence of activities can degrade the technical integrity. - Risk analysis of how activity may influence or be influenced by area risk. - Assessment of activities with respect to priority and criticality. - Simultaneous operations analysis	Activity related information: - Description, priority, criticality - Work type Technical related information: - Status of barriers for the installation - Weaknesses and degradations and their status - Deviations and their status - Area risk, FAR/QRA data
Work Order plan meeting *Occurs every week and looks two weeks ahead*	Schedule and coordinate activities according to resource needs	Approve work order plan	*In addition to the above:* - Activity hazard and risk analysis - Can some activities introduce latent hazards? - Are activities that take out or depend on barriers identified? - Are adequate compensating measures identified and planned for? - Are all resource needs identified? - Is new risk assessment performed when changes occur in the work order plan? - Are there critical human aspects of the work execution? - Need for preparing SJA?	*In addition to the above:* Activity related information: - Responsible technicians - Description of equipment: functional hierarchy, documentation, maintenance history - Applicable procedures - Tools required - Space required - Resource needs: expertise or other technicians, scaffolding, material movement on site, crane operation - Hazards and risks Technical related information: - Status of barriers for the installation - Weaknesses and degradations and their status - Deviations and their status - Area specific risk - Process and instrumentation diagrams - Maintenance history Organisational related information: - HRA data on critical activities
Work Permit meeting *Occurs daily and focus on the following day*	Assess work permits, coordinate and assess for simultaneous execution	Approve work permits	- Are the activities coordinated correctly? - Is safe job analysis required and performed? - Is isolation plan required and prepared? - Are activities coordinated with respect to simultaneous execution? - Is the weather within framework conditions? - Are required personnel available for the job? - Which activities require isolation plan? - Which activities require crane lift over process area? - Which activities depend of specific barriers, take out or degrade barriers? - Which areas have potential for diffuse leaks, hydrocarbon leaks and ignition? - Should activities be limited in execution time due to e.g. noise/vibration limitations?	*In addition to the above:* Activity related information: - Work type Technical related information: - Overview of installation decks and modules, and location of planned activities - Hazardous area classifications - Noise classification - Crane reach - Escape routes and emergency equipment - Master P&ID
Morning meeting *Occurs daily and focus on today's activities*	Preparations for and coordination during execution	Approve execution of today's activities	*In addition to the above:* - Is HSE focus maintained? - Are all coordination issues solved? - Do technicians know what to do in case of an event with the planned activities? - Are required personnel prepared and ready for the job?	

4.3 Information technology to support the improved planning process

Most companies make use of separate tools and systems to manage various aspects of maintenance planning. Some operating companies have different software tools to manage the work activities in the different planning phases; different tools for managing barrier management, process and instrumentations diagrams, hazard analysis etc. These different systems often use tabular and textual formats to present information. Using these tools do not necessarily mean that all necessary information is made available and is used in the different stages of the planning process.

On the work order level, the attention is traditionally on scheduling and activity performance and little attention is given to their risk impact. While the intention of the planning process is to detail and deal with uncertainties as one plan towards execution at the sharp end, it seems like there is a continuity break in the information flow from the operational plan to the work order plan (Sarshar et al, 2016). It is not until the work permit level that risk assessments are performed again.

In Sarshar et al. (2017) it was identified areas where information systems can be improved to manage information through all planning phases to:

- assure transparency and flow of risk-related information between the planning steps,
- make information available at the planning step it is needed and in the context of the assessments it needs to support,
- visualize and present the information in an intuitive way for the users to understand and interact with, and
- support the plan and its risks to support decision making.

The objective of our visual design is to support the personnel involved in establishing and managing work orders and work permits in identifying potential hazards related to the activities planned. The intention is to present information in a way that supports the raising of relevant questions concerning the activities and the plans for discussion (alternatively; one could aim at developing a concept which provided a solution automatically). This requires mapping of the information to the decisions.

Trough the development of the design concept we have strived for a more thorough overview of activities and their hazards where the plan should be seen as a whole whenever possible and not divided in separated parts. This means that when e.g. a work order is established and assessed, its sub-activities should be viewed in the same context as the work order. Such sub activities often require a work permit to execute and form the basis for these. The challenge is that they normally are viewed as a separate activity and when assessed, they are not assessed in the context of the work order. The result is that information and hazards identified at the work order is not seemingly included when establishing and assessing the work permit.

An overview of the concept development, main evaluation aspects and proposed improvements from the iterative design workshops are provided in Table 9.

Table 9: Concept description, evaluation and improvements of the design iterations (Sarshar and Haugen, 2017).

Iteration	Concept development	Evaluation	Improvements
1	Present valuable information to support establishment of work orders, link the activity to the equipment and include list of hazards and affected barriers. To support hazard identification and providing a visual representation of the work, the activities and hazards are visualized in a P&ID, area map and a barrier overview.	Many of the information aspects presented are normally not used at the work order level, identifying the presented aspects earlier is very good. By visualizing this way several persons with less domain expertise can also contribute as it allows the user to easily relate to the work and the system the work applies to. *Evaluation by leader for operational plans and work orders.*	Add information of known incidents to the system. Add reference to other planned work orders or events on the same system. Add temporary degradations and dispensations to the technical integrity on the visual representation of the map area.
2a	The equipment's maintenance history, incidents history and other planned work for are visualized using a timeline with the different events rather than listed textually.	It is very visual and effective to see all the events, history and planned work, for the equipment we plan work for. Brings to attention to dig into earlier events and check for coordination aspects for other planned work. All information presented is good and necessary to support risk identification. The operational degradation causing diffuse discharges are good. To avoid many of the incidents we have experienced we need good tools to help us manage these (presented) data through such tools. *Evaluation by a platform manager.*	Highlight if there are planned (other) work on the blinds or valves involved in the isolation plan. Add technical degradations on the system, but also on other related systems nearby as is done for the firewall, e.g. corroded pipes or degraded shutdown function for parts of the system. Add safe job analysis as part of the hazard table.
2b		The inclusion of barrier information and the link between planning and barrier management is very interesting. *Evaluation by a process engineer.*	The historical timeline has a system/equipment perspective, one could also add activity aspects making us able to analyse what we went through; such as when it was notified about need for work, planned, assessed, executed etc.
3	Modified the timeline to also include activity history.		

Eppler and Aeschimann (2008, p.26-27) present a set of guidelines to be followed when attempting to visualize risks. These guidelines relate to the proper context of risk visualization, and the correct and user friendly visual rendering of risks. In Table 10 the guidelines are discussed in relation to our concept study. These, and the design principles by Schneiderman (1983; 2010), Kraak et al. (1996), Ware (2008), Roth (2012), have been applied to the developed concept.

Table 10: Risk visualization guideline used in the concept development process (Sarshar and Haugen, 2017).

Guideline	Concept study
Don't precipitate the use of risk visualization. *Visualizations reify thoughts or opinions: Once something has been represented in an image, it is difficult to view it in another way. Thus, carefully time the use of a graphic risk representation, as simple risk conversations can be more flexible than fixing them to an image too quickly.*	In some cases, one might want to wait to show a risk overview, and first collect individual opinions. In our concept, the known technical hazards are visualized to help the user to identify how the work order may affect or be affected by these. The hazards represented are not to provide complete list of risks, rather to support risk identification.
Consider the application context and its constraints. *It is not always possible to make productive use of visualizations in risk management contexts because of lacking time, tools, or space. Thus, consider the time, resource and know-how constraints in a given situation and whether your audience would react positively to visualization or not. Visualizations may also detract attention from a presenter in a verbal communication setting. In addition, in inter-cultural risk committees the use of visuals may cause confusion because of differing expectations and conventions.*	The concept, being a support tool to identify and manage hazards related to work order and work permits, is based on feedback from the workshops a way to present factual information and gathers experts to discuss potential hazards.
Make sure that the risk visualization respects the basic rules of visualization and perception. - *Items that are bigger should conceptually be more important or significant (as they attract more attention).* - *Items that are more centrally placed in a graphic are perceived to be more important than those at the periphery of a diagram.* - *Items that are placed close to one another are perceived to be similar or to be part of one group.* - *Visualize the same things with the same symbols and colours and different things differently. Use a consistent representation style.* - *Don't overload a diagram. Eliminate unnecessary elements whenever possible.* - *Time is usually mapped from left to right.* - *Provide a clear informative title for each diagram or map that indicates the so-what or key message it contains.*	The concept developed tries to follow these basic laws of visual perception and the conventions of graphic design. As examples, the visual representation of the work order is the same symbol used in the timeline, P&ID and area view. The diagrams are simplified to avoid unnecessary elements.
Avoid decorative visualization without added benefit. *You should always check whether your risk visualizations add value, for example by making a risk easier to understand or assess, by communicating risk related information quicker or by being more memorable than text alone. You should also try to avoid unessential elements in a visualization, such as shading, borders, too many colours, animation effects, etc.*	The hazards are both presented in table form (textual) and visual in the P&ID and are mapped when possible (given that they have a space or process relation that fits the diagrams).
Think visualizing, not visualization. *The power of visualization lies in its potential to surface implicit assumptions, capture different perspectives, and reveal night insights. This is especially true if visualization is used interactively by a group of managers and risk analysts. The process of creating and modifying a risk visualization is as important (if not more) as the result.*	Through all workshops and iterations with the design, the work has been presented as preliminary work in progress that invites for changes and modifications, rather than as a polished final product. The visualization has therefore been improved through the knowledge of the workshop participants.
Pre-test the risk visualization. *Have somebody who was not involved in the creation of the visualization give you spontaneous feedback on its comprehensibility.*	The different iterations were discussed with colleagues not involved in the concept development process before they were used in the workshops with industry partners.

The concept developed in our study is a visual concept (static) with no real user interaction as it is not a prototype. We apply the design principles described as best fits our purpose. The principle we aim for is to increase users' risk understanding through the visual representation of a work order and its context. The final design of the concept for work order visualization and interaction is presented in Figure 5. The screen consists of a part which contains information and descriptions about the work (left part) and a visual part which present the work and its sub activities in process and instrumentation, plot and barrier diagrams (right part). The information provided is carefully selected to support risk identification and risk management through the planning of the work order activities. Refer to Sarshar and Haugen (2017) for detailed description of the concept. The main new features of the concept include:

- Integrate the planning process with barrier management by presenting merged plan and risk related information.
- Visualise the work planned in the process and instrumentation diagram and area view simultaneously as all work descriptions, work operations and hazards are present.
- Present information about technical factors such as weaknesses and barrier status using visual clues in the process and instrumentation diagram and area view.
- Allow work operations (including work permits) to be assed in the context of the entire work package as work operations are expanded and managed in the same view as for the work order.
- Allow for evaluating not only the specific equipment the work order applies to, but also e.g. equipment being part of the isolation plan (barriers) and their associated hazards and weaknesses.

The final design has been presented to three different companies operating at the NCS with the following feedback summed up:

- The concept illustrates that it is possible to present a lot of valuable data in a single screen and in an understandable way.
- The concept provides good overview of work orders and their sub activities.
- The concept should allow for better hazard identification than systems in use today.
- Some operators have most of the data available, but in different systems and in other formats than presented here.

To summarize, new and innovative information technology solutions are needed to address the challenge of operationalizing and enhancing understanding of major accident risk related to activities and operations. As a response to this a new concept for managing work orders, their operations and work permits has been developed as case with industry involvement. The intention was to illustrate that risk related information gathered from many different systems and processes can be designed into a visual surface to support personnel involved in planning to better identify hazards that may evolve into major accidents than systems in use today.

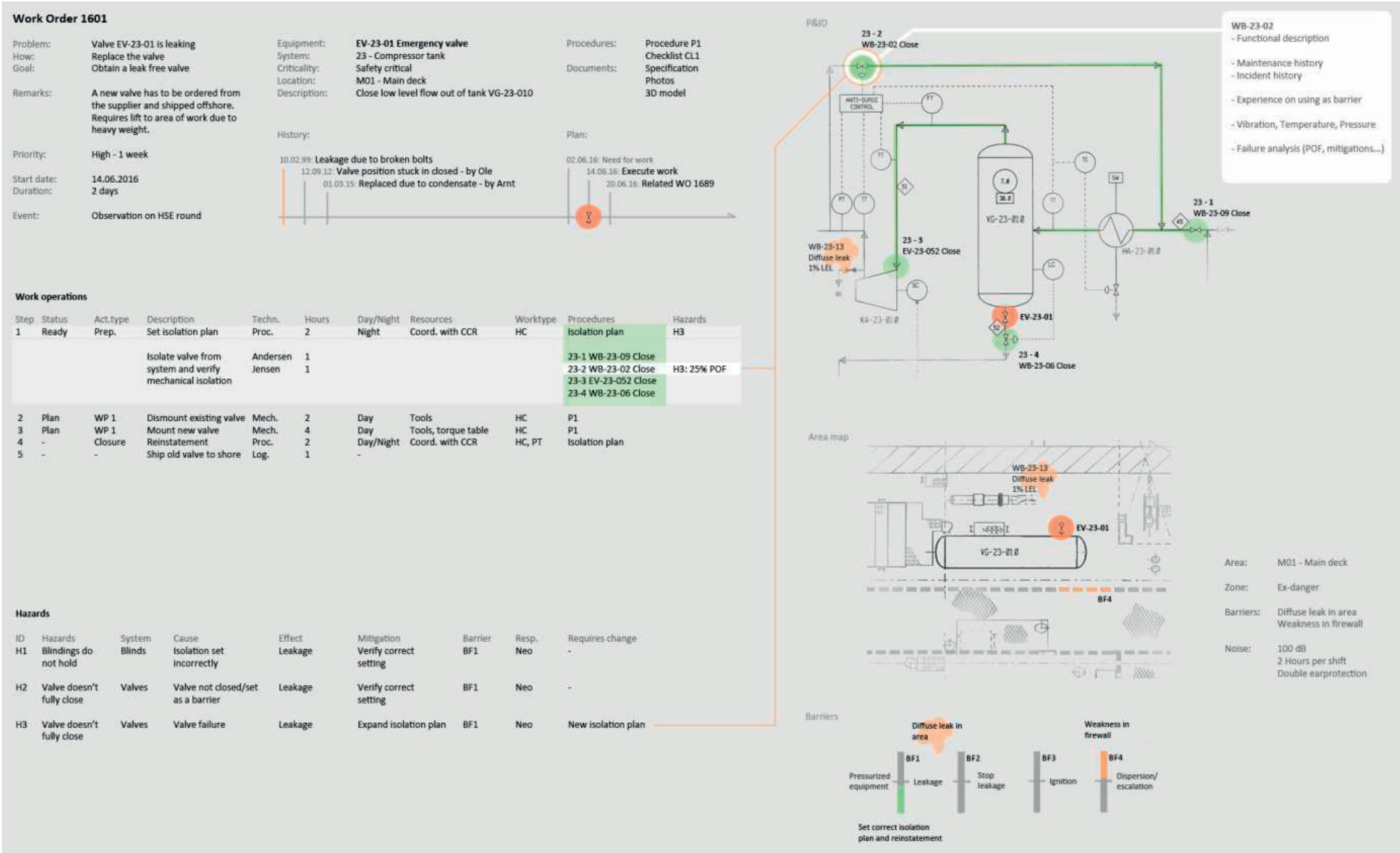

Figure 5: Concept for establishing and managing a work order with its respective operations and work permits required (Sarshar and Haugen, 2017).

4.4 Management of major accident risk through the planning process

The planning process shall deliver a sound plan which has been assessed for major accident risk to ensure safe and efficient execution of the work at the installation. Today, there is a risk that the potential for major accidents has not been sufficiently addressed in these plans. The main research question addresses how major accident risk can be managed better than today through the planning process of offshore activities. Through the three research questions addressed in this chapter we have explored:

- Factors that can influence the planning process and e.g. result in poor-quality plans being made, poor risk communication through the planning process and poor risk and situation understanding of how specific work activities can evolve into incidents with major accident potential.
- Industry challenges of dealing with major accident risk in operation where e.g. underlying information technology is developed to manage data and not to communicate risk, and that the work order plan is not assessed for major accident risk.
- Proposed improvements for how risk related information should be utilized in decision support to better manage major accident risk through assessment of the work processes applied in the industry, and through development of a new concept for a planning tool that integrates risk and barrier management.

The quality of the planning process impacts the extent to which the potential for major accidents has been addressed in the resulting plan. Poor-quality plans with poor work descriptions, assessment and coordination is more prone to introduce incidents, either latent or during execution. The quality of the plans may be addressed through the planning process which develops the work descriptions, performs the assessments and assures coordination of the activities in a plan. A good planning process is essential to produce high quality plans.

The successful management of major accident risk through the planning process requires more than good plans. The steps involved in planning, from operational plans to work orders and work permits, all require risk assessment of the work in certain arenas. In these arenas, competence on risk inducing factors for specific work on defined process equipment is critical to assure thorough assessments. When getting close to execution of the work, barrier status of necessary equipment to be part of e.g. an isolation plan is required. Coordination between all planned simultaneous activities is vital to identify risk and communicate it to everyone for shared risk and situation awareness. E.g. weather conditions may jeopardise the planned activity. These are some examples of factors that may influence safe execution of planned work daily at an installation. Hence, the planning process must allow for different personnel and staff to be able to understand the work being planned, its assumptions for safe execution, and they should be able to identify changes in conditions that may affect the prior made assessments, or that may introduce new hazards.

A thorough overview of risks in plans is also required. Such an overview should include the activities, the technical and external factors. This requires aggregation of risk related information from different software systems into an overview to support the decisions needed to be treated in the different decision arenas.

In practice, it is the personnel involved in the various phases of the planning process that must understand the risk involved in the plans and make the final decisions. Establishing a thorough overview of risks in plans also involves collaboration between the onshore support centres and the offshore organisation to understand and identify how the system risk can e.g. affect the planned activities and their framework conditions. The subject matter expert involved in our study highlighted that there is a gap between our analysis of what should be assessed and how personnel involved in the planning process can be enabled to perform the assessments. A skilled worker can traditionally assess her own activity, but the aim is to also assess how it may influence other activities and technical factors, as well as how other activities and technical factors can influence her activity. The latter is supported to a limited extent today.

On the work order level, the attention is traditionally on scheduling and activity performance and little attention is given to their risk impact. While the intention of the planning process is to detail and deal with uncertainties as one plan towards execution at the sharp end, it seems like there is a break in continuity in the information flow from the operational plan to the work order plan (Sarshar et al, 2016). It is not until the work permit level that risk assessment is performed again.

As mentioned above, uncertainty is an important aspect of managing risk through the planning process. PSAN (2014) defines risk as the consequences of an activity with an associated uncertainty. Early in the planning process, there is significant uncertainty in various aspects of the work being planned. As illustrated in Table 8 the assessments and information needs becomes more detailed as the plan goes from operational to work order to the execution phase. This is a way to cope with the uncertainties through the planning process. The assessment of a plan for simultaneous activities is e.g. performed in all planning phases. At the operational plan, the uncertainty is higher. E.g. at this level the activities are coordinated based on their criticality and POB (people on board). At the work order level, the focus is more on scheduling as one has information about resources and constraints. At the work permit level coordination regards work types that should not be executed simultaneously due to increased risk. Here one is more certain about the activity steps and operations. If uncertainty is seen as lack of information, a systematic process to information collection must be applied to reduce this uncertainty (Almklov et al., 2017).

Information management is, as argued in the previous section, of key importance to assure transparency and flow of risk related information between the planning phases, mainly from the operational plan to the execution of the planned activities. Such an information carrier together with information collection and information visualization plays a key role in supporting the planning process. The role of such an information carrier would be to manage and present the relevant information in the planning steps where they are to be used (to support assessments and decisions).

Based on our study it is possible to review current work processes and practices for maintenance planning in a petroleum company to assess the extent to which the information needed to make decisions that address the risk for major accidents during planning are present.

By monitoring when risk related information is added to the information carrier over time one can possibly trend when different types of considerations are made, which can support in identifying where effort and focus is needed e.g. to identify risk earlier. Is for instance the activity's influence on the facility identified in the operational plan, when establishing the work order, when the work order plan is assessed or is it identified in several steps but detailed and made more precise as one move towards the sharp end? Late risk identification leads to a range of inadequacies in planning, e.g. insufficient work descriptions, as well as relevant information which remains unaddressed during the planning process. These are factors that can lead to unsafe and less effective task execution. A planning process allowing for earlier risk identification may increase the plan quality in several ways (Sarshar et al., 2016b):

- Descriptions of identified risks are included as part of the work description through several steps of the planning process, and hence the probability of identifying important aspects increases as risk is iteratively assessed.
- Proper documentation of risks early reduces the probability of aspects identified are forgotten in later phases.
- Changes late in the process, but before the job is to be executed, are avoided. In practice, the later in the process changes are made, the pressure to proceed with a plan where safety is not fully ensured is likely to increase.

The planning process is a framework meant to assure high quality plans and safe execution of the work being planned. This framework is today supported by several different underlying information systems that manage plan data, risk analysis, technical integrity and barrier management, competence on personnel, POB planning etc. The concept developed in this project focused on enabling the personnel involved in establishing and managing work orders to identify and manage hazards for major accidents by integrating data from different systems into one. Based on feedback from the participants during design iterations the concept is easy to understand and present very valuable information that is not normally available to them in their existing systems.

The final design of the concept study is based on the iterations with expert evaluations that was possible to perform during this study and is not meant to be a final product of any sort. It demonstrates how information can be aggregated from different sources (work order systems, barrier management systems, hazard and risk analysis, safe job analysis, etc.) and presented in a way that supports hazard identification and decision-making processes related to managing work orders. Ideally, we would have run many more iterations with personnel involved in establishing and assessing both work orders and work permits to get an even better evaluated concept. However, the workshop iterations have highlighted the potential and needs for studying risk visualisation further.

The results were also presented to the Petroleum Safety Authority in Norway (PSAN) which shared their concerns on:

- Ongoing organisational changes and adaptations made by the industry in response to the reduced oil price. This applies to operators, vendors and suppliers in parallel, causing a complex process of change.
- Some companies reduce their manning where there previously has been a challenge to keep up with critical maintenance on equipment even if operational experience disfavour such reduction.
- More are reporting on potential major accident risk. Earlier the focus was more on work environment.
- There are concerns around technical integrity of systems and equipment and maintenance related to these.
- There is less maintenance work carried out and there are several recent incidents were maintenance is a central contributing factor to the development of the incidents. Some contributing factors identified when studying eight incidents in 2016 included poor planning, inadequate risk understanding and competence, technical aspects with degradations and leadership.

A factor not addressed in our studies is cost. Damnjanovic and Røed (2016) argue that improved operational safety can be achieved concurrently with increased operational efficiency. Their approach focuses on planning as a means to managing systems' response uncertainty and consequently reducing both major accident risk and the cost of operations. When the process (planning or execution) is interrupted, the result is a delay, a non-productive time and a new "on-the-ground" situation that often brings new safety risks. The more certain we are about the systems' response, the more efficient the operations become, and the lower the chances are for a major accident. However, there is a limit to how much planning can reduce the uncertainty at an early planning phase. Another point is being aware of the uncertainty based on the type and amount of information available.

Chapter 5

Conclusions and Further Work

The overall objective of this thesis was to explore how major accident risk can be managed through the planning process of offshore activities. This objective was decomposed into three research questions. Through the studies performed we identified that major accident risk can be better managed through the planning process by

- improving the planning process applied today to assess risk earlier,
- better integrate risk and barrier management within the planning process,
- use a common information carrier for the plans accessible to all personnel involved in both planning and execution of work, and
- enhance risk communication through the planning process exemplified through the risk visualization concept developed.

The main contributions of the thesis include

- Identification of factors that can influence both the planning process and plans being made with respect to major accidents.
- Documentation of industry challenges with managing major accident risk through the planning process and possibilities to address several of these challenges.
- Documentation of what risk-related information and assessments are required for decision support in several critical steps of the planning process to manage major accident risk.
- New concept for risk visualization which integrates planning of work orders and work permits with risk and barrier management data to enhance understanding and

communication of major accident risk related to the planned work to all personnel involved in both planning and execution of offshore work. The concept allows for better hazard identification than systems in use today.

The results from this thesis has been presented to the two companies participating in the studies. Both show great interest in the work and are considering utilizing the results in their operations. As the work implies that current practices should be improved to address many of the challenges highlighted through this work, the utilities may face strategical choices with respect to redesigning their processes.

Developing the visual concept is another aspect discussed with the industry. As the concept address work orders and work permits as case, there is remaining work on the further development of the concept to include the operational plan, work order plans and daily plan.

The reported studies performed in this thesis is targeted at addressing major accident potential from the planning perspective. These studies alone are not sufficient to prevent major accidents. Our aim has been to contribute to the understanding of operational risk in the industry. A follow up study could be to explore the effects of implementing the concept, redesigning the planning process and/or supporting it with a visual tool for risk management. Can major accident risk be better managed through the planning process of offshore activities?

Abbreviations

DFU	Defined hazard and accident conditions
FAR	Fatal Accident Rate
HAZID	Hazard Identification study
HAZOP	Hazard and Operability study
HSE	Health, Safety and Environment
HSE&Q	Health, Safety, Environment and Quality
ICT	Information and Communication Technology
IFE	Institute for Energy Technology
IO	Integrated Operations
KPI	Key Performance Indicator
NCS	Norwegian Continental Shelf
NOG	Norwegian Oil and Gas
NRC	Norwegian Research Council
NTNU	Norwegian University of Science and Technology
POB	People on Board
PSAN	Petroleum Safety Authority in Norway
QRA	Quantitative Risk Assessment
RNNP	Trends in Risk Level
SJA	Safe Job Analysis
WO	Work Order
WP	Work Permit

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PART II: PAPERS

Article 1

Sarshar, S., Skjerve, A.B., Haugen, S. (2013). Towards an understanding of information needed when planning offshore activities. *In Proc. of Risk, Reliability and Societal Safety*, ESREL 2013, September 29th – October 2nd, Amsterdam, Netherlands.

Towards an understanding of information needed when planning offshore activities

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ABSTRACT: Performance of maintenance activities on an offshore installation is necessary to maintain safe and efficient operations. Maintenance activities are carried out with reference to plans for performance of maintenance tasks. To prevent that the performance of maintenance tasks will contribute to incidents or accidents, Health, Safety and Environment (HSE) should be a key concern throughout the planning and task execution process. This study contributes to the understanding of what attributes maintenance plans should have to prevent major accidents offshore and how the planning process should be organized to promote that the plans will come to have these attributes. The focus in this paper is on information needed for evaluation and assessment of maintenance and operational activities. The study reported here is based on interviews of offshore personnel working on one of the oil and gas producing installations on the Norwegian continental shelf and is limited to the offshore staff's involvement in assessment of offshore activities.

1 INTRODUCTION

The process of producing oil and gas can be described as follows: After drilling, oil and gas is transported from the reservoir to the surface and the installation through wells. On the installation, oil, water and gas are separated before the final products, oil and gas, are transported to shore, often through pipelines. Our scope is limited to management of the process and activities on the offshore installation.

Production, operation and maintenance activities are carried out daily during operation. The control room operators control the production as well as the initiation of maintenance activities, crane operations and helicopter and vessel transportation. Safe operation and production is of key importance. Thus, the planning process for all offshore activities, the quality of the plans and the quality of their execution and end controls are important aspects which need to be managed. Activities must be assessed individually and for concurrent execution with respect to Health, Safety and Environment (HSE). Risk management and HSE aspects are important for major accident prevention.

The Petroleum Safety Authority in Norway has through several years of audits, reporting of accidents and near misses, investigations of major accidents and research and development activities identified four concrete event categories with high potential for major accidents [5]. These include hydrocarbon leaks, serious well incidents, damage to load-bearing structures and maritime systems, and ships on collision course. Hydrocarbon leak followed by ignition is one the major accident scenarios that is closely related to maintenance activities.

In our study, we explore the relation between high quality plans for offshore maintenance and operational activities and major accident prevention.

Our assumption is that *low quality planning processes lead to low quality plans, which in turn increase the risk for major accidents.* Based on these assumptions two research questions were defined: *(1) What are attributes of high-quality plans vis-à-vis preventing major accidents? (2) How should the planning process be organized to promote development of high-quality plans?* This paper highlight findings from an initial field study to help us better understand and answer these questions.

The research questions can be addressed in different ways, either analytically or empirically. The approach taken in this work so far has been empirical. The results are based on observations and interviews from a field study on one of the offshore oil and gas installation operating on the Norwegian continental shelf. The study was performed with observation of meeting activities and with interviews of key personnel with focus on their involvement in planning and execution of maintenance and operation activities. The information type and flow needed to support assessment of plans and activities was addressed specifically.

The planning process is described in section 2, the method used in the study is described in section 3, the results are discussed with our assumption and research questions in section 4, and conclusions and further work are presented in section 5.

2 THE PROCESS OF PLANNING OFFSHORE ACTIVITIES

The planning process described here is a standardized process based on the operational concept Integrated Operation (IO). IO has been defined as “real time data onshore from offshore fields and new integrated work processes” [2] and was introduced with the purpose of achieving [3]: increased recovery, accelerated and increased production, reduced operational cost, longer lifespan, and increased safety. IO may also be known as Intelligent Fields and has been gradually introduced by petroleum companies operating on the Norwegian continental shelf.

2.1 *The planning process onshore*

The onshore organization is responsible for *yearly plans*, *operational plans* which have a horizon of three months and *work order plans* which have a horizon of one week. These three plans are briefly presented in the following based on [7] and [8].

The *production manager onshore* is responsible for the yearly plan. The level of detail in this plan corresponds to high-level description of activities and personnel on board.

The operational plan contains the most important information about maintenance, operations and modifications which fall under the following categories: major tasks within HSE, production related tasks that require shut-down, tasks requiring external resources, tasks requiring additional bed capacity, tasks requiring coordinated actions (e.g. heavy lift operations), and tasks requiring monitoring. Operational plan meetings are held every two weeks and include participants from onshore and offshore who evaluate simultaneous activities and the total activity level with focus on risk and production. This meeting also facilitates the coordination of activities with the production and intervention plan.

The work order plan is based on the operational plan. In this phase activities are prepared and planned in detail in coordination with logistics and contractors and involve both onshore and offshore staff. The risk evaluation in this step includes special attention to HSE and area/module specific risks (normally a printout of QRA, Quantitative Risk Analysis, for a given module). Logistics and personnel-on-board planning are coordinated activities with the preparation of work order plans.

2.2 *The planning process offshore and the work permit system*

A work order plan is sent from the onshore planning team to offshore once a week. This plan contains work descriptions for the activities that are planned to be carried out. Figure 1 and Figure 2 illustrates the work flow offshore which is described in the following.

There are several technical disciplines offshore including process technicians, instrumentation technicians, electrical technicians and mechanical technicians. Each discipline goes through the work orders which they are responsible for and divide the task through the week with respect to their priority and available resources.

A work order describes a job package and can normally be divided in sub tasks that can be carried out in sequence. Before any of these can be executed, the personnel that shall execute a task must apply for a *work permit*. The work permit system is established to ensure scrutiny of factors related to HSE before job execution. The work permit for each task is discussed between representatives from the vari-

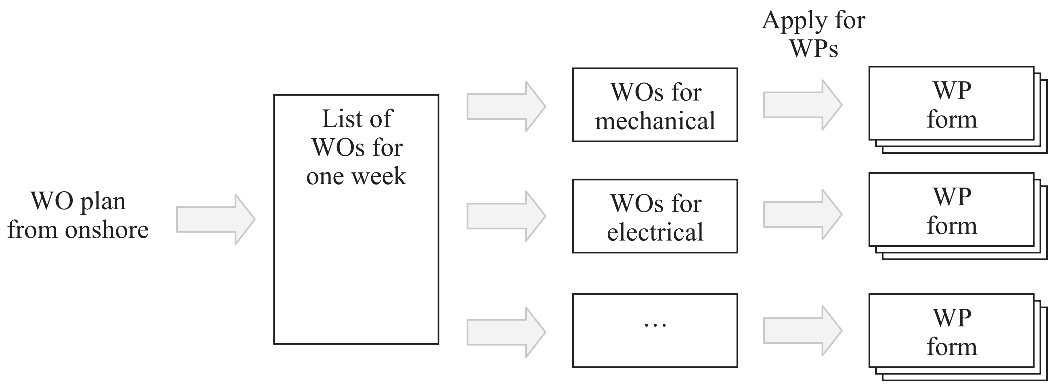

Figure 1: The work order (WO) plan is divided for each technical department and WPs are applied for based on their respective WOs.

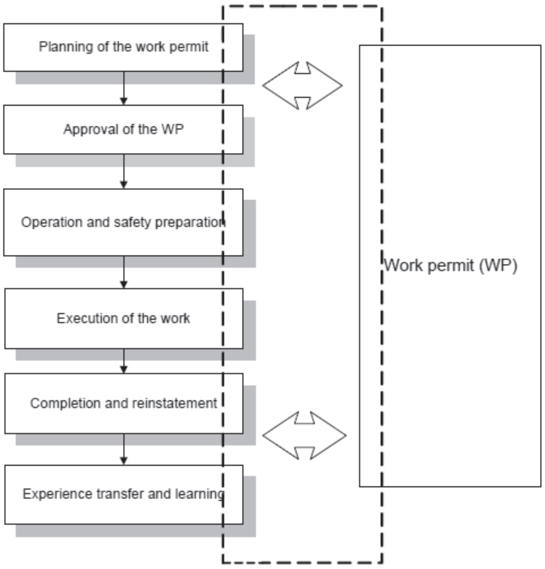

Figure 2: Flow diagram of planning and execution of work permits [4].

ous disciplines in plenum and the job description and related safety measures are evaluated. Examples of such are safety equipment needed to perform the job safely. A general work permit flow as described in [4] is illustrated in Figure 2. After job execution, the job responsible logs feedback from the execution and closes the job in the maintenance management system.

The work flow offshore is implemented through several meetings with specific agendas. In addition to the daily meetings, specific meetings are set up when required. E.g., if an activity is evaluated to be critical or not described in the procedures, a *safe job analysis* is carried out.

From a *risk perspective*, some risk elements are addressed and controlled through procedures and others through work permits. If some risk elements still exist, these are to be managed by safe job analysis. This is the intention of the work permit system and works well to identify and manage risk related to HSE. This process of risk management has clear lines to the energy and barrier perspective [1], where procedures, work permits and safe job analysis are steps in mitigating risk elements.

During the interviews performed in this study, the preparations to, the execution and the results from the work permit meeting, the coordination meeting and the management meeting and the information flow between these were discussed to get an understanding of the work flow, the plans and job preparations. The results are presented and discussed in section 4.

3 METHOD

This chapter briefly describes the data collection, observations of meetings, interviews performed and the analysis approach used in this study.

The empirical data that forms the basis for this study was gathered from observations of meetings and interviews with offshore personnel working at an oil and gas installation at the Norwegian continental shelf.

3.1 *Observations*

Observations were carried out offshore to gain a better understanding of the domain and the offshore work processes. The observations involved handover meetings in the control room, meetings with the onshore organization, work permit meetings, coordination meetings and management meetings.

3.2 *Interviews*

A semi-structured interview guide was established and used to interview eight individuals in different positions. These were the Offshore Installation Manager (OIM), Maintenance and Operation (M&O) leader, Deck and Marine (D&M) leader, Health and Work Environment (HWE) team leader, and one from each of the four disciplines process technician, instrumentation technician, electrical technician and mechanical technician.

The OIM is responsible for all activities and operations on the installation, both during normal operations and in emergencies. The M&O leader owns the process equipment for production and is responsible for all maintenance activities on these. Similarly, the D&M leader is responsible for crane operations, vessel traffic near the installation and helicopter flights. He is normally responsible for the helicopter deck, the cranes and the laydown areas. The HWE team leader is responsible for the living quarter and the hospital. HSE is the line management's responsibility. The different technicians are responsible for maintaining the process equipment and have expertise on their respective fields.

The interviews were semi-structured and carried out individually lasting 30-60 minutes. The main focus was on how information availability and information flow influence quality of the plans. We focused on information flow between formal meetings and informal talks and discussions they participate in during daily operations. The attention was not only on the information and data used in meetings, but also during preparations and in between meetings.

3.3 *Analytical approach*

The data obtained from the interviews were organized using codes (as for Grounded Theory [12]) on the different aspects (established in the interview guide) that were discussed. The codes related to our research questions were selected for further detailing and included aspects related to meeting preparations, the meetings themselves, the results from the meetings, and aspects that could influence the plan or the planning process. The report is based on these.

4 RESULT AND DISCUSSION

The observations and interviews have given a better understanding of the planning process offshore. We first present the result from the observations and interviews and discuss some of the planning activities (in section 4.1 and 4.2), because these insights constitute the basis for addressing the research questions from section 1; second we discuss the quality of plans and the planning process (section 4.3 and 4.4).

4.1 *Observation of main meetings related to assessment of work permits*

A general planning process and work permit system offshore was presented in chapter 2.2. The result from the observations of some of the activities in this process and interviews of participating personnel is presented here. The meeting activities include the *work permit meeting*, the *coordination meeting* and the *management meeting*. There are different practices for these types of meetings; the ones described here do not necessarily reflect the practices from other sites. The information flow between these meetings is discussed afterwards.

4.1.1 *The work permit meeting*

New work permits created in the work permit management system are evaluated in the work permit meeting against process parameters and discussed.

Preparations are done by the M&O leader which logs into the system and lists the new work permits that are to be discussed and evaluated. The D&M leader has an overview of activities and operations for his staff with him in the form of notes. The other participants have no specific preparation other than bringing in their experience and process knowledge.

In the meeting, the list of work permits are displayed to all participants on a large screen and each work permit is opened and talked through. Potential issues for simultaneous activities (e.g. opening of a hydrocarbon carrying system and hot work) are written in the work permits and the need for SJA is discussed. When the different aspects have been checked, the work permit can be approved. Some engineering disciplines discuss the work with one of the process engineers or the M&O leader before the work permit is created, such pre-discussions are normally referred to during the work permit meeting and help clarify potential misunderstandings.

The result from this meeting is that the new work permits have been evaluated and those which qualify are approved. In some cases, the work permit will be approved after the meeting, when clarifications need to be done with personnel not participating in the meeting.

4.1.2 *The coordination meeting*

The work permit plan which is scheduled to be executed the following day is discussed inter-disciplinary at the coordination meeting. The M&O leader is also responsible for this meeting.

Preparations are done by all participants. The M&O and D&M leader looks at the status of the day's work permits and activities in the management system and brings notebooks into the meeting. The discipline responsible have a quick discussion within their group on status of activities and the plans for the next day which is written down in a notebook and brought to the meeting.

In the meeting, the status of performed activities and the plans for the next day are shared around the table by the discipline responsible. The M&O and D&M leaders write down these statuses and plans in their notebooks during the meeting. Discussions on potential simultaneous issues are raised when needed to support coordination of the planned work permits and operations.

The result from this meeting is that all participants have an overview of the plan for the next day. Actions and comments are written in the participants notebooks.

4.1.3 *The management meeting*

The maintenance and operation activities of the day and the next day are discussed at a higher level in the management meeting. The focus is on HSE and simultaneous activities. The OIM is responsible and the leader of this meeting.

Preparations are done by all participants. The OIM goes through the work permits from the work permit meeting, evaluates and approves those which needs his approval (work permits are divided in two levels were level one has higher risk than level two due to the work type). Similarly, the HWE team leader goes through the work permits that have special aspects related to health and work environment (e.g. work permits which require use of chemicals). The M&O and D&M leader come directly from the coordination meeting. Their notes from that meeting are used as input in this meeting. The provision leader has a quick discussion with his staff on special issues as preparation.

In the meeting, potential HSE issues are discussed before the maintenance and operation activities of the day and the next day are talked through. This is done by the M&O and D&M leaders which read from their notebook the planned activities they noted from the previous meeting. A potential coordination issue that was raised in the previous meeting is decided on in this meeting. The M&O and D&M leaders also inform about operations not related to maintenance (e.g. heavy lift operations). Other management issues are also discussed in this meeting, but are not focused on in this study.

The result from this meeting is that all participants have an overview of the plan for the next day. Actions and comments are written in the participants notebooks.

4.1.4 *Information within and between meetings*

The information flow between the three meetings consists mainly of notes written in participants notebooks and information gathered from computer systems during preparations.

The computer systems used during daily operation related to maintenance and operation activities includes tools and systems for:

- Work order and work permit management
- Procedures
- Process and instrumentation diagrams
- Logistic management
- Weather data
- Communication (video conferencing, email and phone calls)

These are normally used by the individual staff from his or her desktop computer. As seen from the observations, these systems are used in preparation for some of the meetings. While the work permit management system was used in the work permit meeting, the following two meetings observed did not use any computerized tools. The information used was from notebooks.

Several informal meetings and discussions occur between the meeting activities. These can be between offshore staff and with the onshore support center. The need for such discussions can be due to clarifications and misunderstandings.

One of the interviewees highlighted some possibilities regarding information sharing in meetings and out of meetings by providing printouts into meeting that the participants could bring with them afterwards. One cannot require that one can remember all that has been said through the different meetings based on notes. This and other issues regarding information management and sharing during preparation, during the meeting, and after the meeting with use of computerized solutions are discussed in [9].

4.2 *Interviews on the quality of plans and the planning process*

The interviewees raised some possibilities and challenges related to the planning process and the offshore work flow. Those related to plan quality and the planning process quality are presented and discussed next.

The insights provided by the respondents were summarized on the following topics to help us better understand the research questions:

Which circumstances can affect the planning process?

Aspects that can affect the planning process highlighted during the interviews were on external factors and disturbances. Information needed on such factors can include concurrent jobs in an area, e.g. work on hydrocarbon carrying systems and hot work. Such assessment is normally done in the work permit meeting. Another example of external factors is if a critical safety system fails, requiring immediate response. Disturbances and incidents that occur can change the plan. For the HWE team leader, all emerging personnel health cases can disturb planned activities, but handling of this is part of the operational philosophy.

Are there aspects of a plan that should have been dealt with in an earlier planning phase?

The majority of the responses to this question were related to what the offshore personnel expected from onshore organization regarding the quality of the work order plan. The work orders form the basis for applying for a work permit. Thus, if the work order has insufficient descriptions, has weak risk assessments or other shortcomings, this will cause problems and delays in the work flow for applying and assessing a work permit. One example is a work order that requires a contractor to perform the job and material to be shipped offshore; it often happens that the contractor arrives before the material he needs. A follow up to the same example is that the job would normally require support from one or more of the technicians offshore and the need for such resources are often not part of the plan. A lot of the planned jobs require assistance from the different technicians offshore.

If critical equipment or systems is out of function and the repair of it is given high priority, this can generate a big amount of work orders to be sent offshore in a short period of time. In such periods, the quality of the work orders decrease due to little preparation time from the onshore organization.

These examples may be interpreted as minor issues, but even such small issues cause the need for changes in the plans which can increase the backlog. However, the most important impact low quality plan has on the offshore staff is that they sometimes *end up doing the preparations or assessment that they expected would have been in place during preparations* of the work orders. In other cases larger projects and jobs are sent back for better planning with comments on what to include and improve. Things that are not captured onshore are supposedly identified offshore and the plans can go through iterations and improvements. Some of the interviewees propose that onshore staff should take a trip offshore when planning larger projects and jobs to better understand the surroundings and size of the activities.

One interviewee focused more on the work flow offshore regarding whether plans could have been prepared better in earlier phases. His comment was that technicians who prepare a work permit form often discuss the job with the M&O leader, the central control room or with the process technicians who know the process equipment before they apply for the work permit. This way, clarifications are made prior to the work permit meeting. This meeting functions as one barrier to clarify HSE aspects related to each work permit, another barrier is the operators in the control room which activate the work permit for execution. It could be other aspects that are important to evaluate at that time, and involving them early in the work permit process is beneficial for increasing their understanding of the work permits.

Are there aspects around the planning process that are not fully supported?

There is a gap in common/shared understanding of what is needed to perform a job between onshore and offshore. Thus, paramount planning is done onshore while detail planning is done offshore. One interviewee commented that *requirements for a good plan that has great value for offshore staff is not known or is misunderstood by onshore staff.* This was explained to be caused by the lack of offshore competence available onshore. The onshore staff without offshore experience has "no way" to identify or imagine the challenges that may arise related to a job that is to be carried out offshore. It was stated that improvements has been made and onshore personnel involved in planning are making trips offshore to get experience.

Have you experienced challenges with information flow?

The information flow between onshore and offshore was again raised as challenging: *"The quality of the documentation we get is not satisfactory; the documentation they assume is good enough onshore is not good enough for us offshore. Activities have been postponed due to unsatisfactory descriptions and quality"*.

Another example is the other way around, if there is some critical parts or equipment that are urgent to repair, they are shipped to land with the vendor as addressee, but it can get stuck at the base for several weeks without it being sent to the vendor. A partly explanation for this is communication and the systems they use. Even if the delivery is marked as an urgent delivery, this may not be understood by those onshore when they use the system. A possible solution the interviewee proposed was that they could be better at making a phone call to communicate that this delivery is urgent to the base.

A different aspect that was highlighted was that there are a lot of clarifications that are needed, this takes time and some takes several meetings. Hence, *there is confusion and vagueness due to the need of clarifications*.

How is the relationship between how a task is planned to be executed versus how it is actually executed?

There can be circumstances that make it difficult to execute a planned job as described. If for example a work order is applied for by the mechanical technician who is responsible to carry out the job, the work order may not describe that an electrical technician have to disconnect power etc. and that a process technician have to prepare for shutdown of this equipment and so on.

This creates side activities to support the main activity. These side activities are not always foreseen and planned. Some of the disciplines are involved in a lot of such side activities though it is not in their original plans.

A different example concerns a mismatch between the hours planned for a task versus hours actually spent. This can be due to lack of knowledge of the activity size when planning it. A different reason can be that the area where the activity is to be carried out has a high noise level and the technician cannot work more than a limited time in that area. This is a factor that is often not taken into consideration during estimation of the work. Though the total amount of hours planned can be the same as spent in this case, it will extend in time.

Is there risk related to the planning process?

The main impression on this was as one interviewee stated that *"the major risk is that we do not have a common or shared understanding between onshore and offshore on the different activities. Activities are planned onshore and they perform risk assessment, but that is sometimes not satisfactory from the line management's point of view, or from operational point of view or from the technician's point of view"*. Thus, additional rounds of assessment are performed offshore to get a satisfactory quality. However, that is part of the operation, to perform risk assessment if it is not satisfactory.

To have an overview of simultaneous activities and operations was another issue highlighted concerning risk related to the offshore process.

Which criteria are used to assess and evaluate a work permit?

Regarding evaluation of work permits, the following criteria were discussed: competence and experience required to execute the job, materials and tools, need for resources, and the need for scaffolding. These criteria are preferably identified when the work order is described onshore, but this is not always the case due to the differences in experience. The offshore assessment and evaluation of work permits include these in addition to other aspects related to HSE and the criteria that are already in place in the work permit forms. Simultaneous activities and work on pressurized systems, especially on hydrocarbon carrying systems were the potential for explosion is high, was also highlighted as a focus area. Other aspects include potential for incidents, injuries to personnel and damage to equipment.

Do you have an overall risk picture and how is the relation between the risk picture and the activity level?

The line management indicated that they had an overall risk picture.

An interviewee said that it is easier to have a total overview when the activity level was low compared to high. During high activity periods it requires more effort to get an overview; more people are needed in the right positions and that the planning from onshore is done properly (have enough resources, material, and personnel).

A different interviewee said that there is potential risk as long as personnel are on the installation and the process equipment is pressurized. When the activity level is low, personnel can tend to find the time to "complain" a little bit compared to when the activity level is high and they are occupied.

4.3 *What are attributes of high-quality plans vis-à-vis preventing major accident?*

Based on the data obtained from the interviews the following attributes were suggested to characterize high-quality plans:

***The plan is robust*:**

All or most planned tasks *can* be performed as intended: All foreseeable factors have been taken into account and realistic time frames have been allocated for performance of the tasks.

If a plan is robust, a low (as possible) number of tasks will be sent back to onshore for re-planning. This implies that the size of the back-log will be kept to a minimum and that the number of *latent errors* [6] associated with maintenance issues will also be as low as possible.

The study indicates that effort is needed to clarify the needs and expectations around the work order plan so it can better support the work permit system offshore.

The description of task execution includes the contributions of all disciplines and other parties:

The work descriptions should reflect how the task is going to be executed. All factors related to sub activities and their preparations, with technician requirement and material needs must be assessed.

The study indicates more detailed knowledge about job execution should be available when describing work orders and planning resources.

All safety issues have been resolved:

Performance of the tasks planned does not imply a *direct* risk for other people/HSE. Tasks, which may negatively impact each other from a safety perspective, are not performed at the same time within the predefined safety zones; Personnel who perform daily non safety-critical routine tasks on the platform, are not at risk due the performance of maintenance tasks, etc.

This attribute will generally imply that all safety standards and rules of the oil and gas company have been followed. And further, that the people involved in the planning process – jointly – have a high level of domain understanding and the ability to make sound judgments.

The detail risk assessment for the jobs individually and for concurrent operations are performed offshore. The study indicates that parts of the assessments for individual jobs could be prepared and performed in earlier phases.

The plan is comprehensible to its users:

The plan provides all key information about a task (e.g., responsible unit, pre-conditions, post-conditions, dependability, etc.) and is written in a language all parties involved in the planning process understand.

If all parties involved in the planning process understand the elements of the plan, this will increase the possibilities for identifying unwarranted interrelationships between the tasks prior to executions – and reduce the risk for misunderstandings.

4.4 *How should the planning process be organized to promote development of high-quality plans?*

The organization of the planning process to promote development of high quality plans can be addressed by:

- Time: When engaged in planning activities, the staff members should be able to work without being disturbed and without being under unreasonable time pressure. Planning is a complex activity. Disturbances increase the risk that not all aspects of the jobs will be addressed. The same is true, if planners work under unduly time pressure.

- Competence: Onshore planners should be able to understand offshore hazards. This is needed, e.g., to ensure that work orders will satisfactorily come to address all issues of importance for performance of a job. This issue has also been addressed in earlier studies (e.g., [10] and [11]).
- Involvement of relevant disciplines: To the extent staff members involved in planning do not *currently* possess all relevant competencies to fulfill their role(s) satisfactorily, the planning process must *temporarily* be adjusted to ensure that staff members with the needed competence are included to assist (and educate) the staff members that currently lack competence.
- Communication: To promote that all the staff members involved in planning will be able to build a suitable level of shared situation understanding, a common *language* should be established. As of today, the need for a common language seems most pronounced across onshore planners and offshore staff members.
- In general, the planning-execution process should contain a feedback loop, which promotes continuous development and adjustments of the planning process based on lessons learned.

5 CONCLUSION AND FURTHER WORK

The results reported on in this paper are based on observations of meetings and interviews with eight key personnel offshore. The results may be biased as all interviewees were all from the same shift and from the same installation.

The purpose of this study was to get a better understanding of the offshore process when it comes to understanding and answering the two research questions *(1) What are attributes of high-quality plans vis-à-vis preventing major accidents? (2) How should the planning process be organized to promote development of high-quality plans?*

Based on this field study, the plans that are retrieved from onshore can be improved to better satisfy the offshore needs and requirements. Some of the aspects related to this issue are that there might be different understanding of needs, but also lack of offshore experience available onshore.

Further work includes studying similar aspect from the onshore organization, both for this company and others. An analytical and theoretical approach can also be applied to answer the research questions.

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Article 2

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Factors in offshore planning that affect the risk for major accidents

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ABSTRACT

The purpose of this paper is to systematically analyse a typical planning process in the offshore industry from the perspective of causes of major accidents, with the ultimate aim of identifying factors that affect the risk for major accidents occurring. We first study and describe a typical planning process for offshore oil and gas operations in Norway. Then we analyse a number of theories of major accidents, to see how the different theories and their explanations of causes and contributing factors can be of relevance for future plans and planning processes. Finally, we review accident investigations to search for evidence of how weaknesses in planning processes can contribute to major accidents through the above identified factors. Also, we try to identify any additional factors that have not been recognised through the theoretical review. This provides empirical support for the theoretical basis. Thirteen factors which directly or indirectly can influence the planning process causing a major accident potential are identified. These are exemplified through a review of investigation reports. The paper suggests that planning process should focus more on increasing quality in the plans at an early phase, with examples from incidents, and illustrate the relation between planning quality and potential for major accidents.

1. Introduction

Major accidents are characterized by a complex interaction of technical, human, organizational and environmental factors. These types of accidents have been given a lot of attention in the last 20–30 years, starting with Turner (1978) and are being followed by a number of different authors proposing different theories about how these accidents occur and how they may be prevented (e.g. Perrow, 1984; Reason, 1997; La Porte and Consolini, 1991; Weick, 1995; Hollnagel et al., 2011). Much of the work has been focused on operation, "the sharp end", but has shifted the blame away from the operators by showing how the context, represented by the technology, the organizational structure, the culture etc. influences operations.

The Petroleum Safety Authority in Norway point out that the preparations for performing work activities offshore, i.e. the planning process, also can play an important role in major accidents: Inadequate planning, insufficient work descriptions, information that is not put forward during the planning process etc. are all factors that potentially can lead to unsafe performance of the work (PSA, 2012). The purpose of this study is to explore the relationship between planning of offshore activities and the potential for major accidents. In this paper, we describe a typical planning process in the offshore industry, from the perspective of causes of major accidents with the ultimate aim to identify factors that affect the risk for major accidents.

1.1. Scope and limitations

The scope of this paper is limited to the planning processes for operational, work order and work permit planning. Execution of the work that has been planned is not studied as such, although an important outcome of a good plan is its safe execution.

The rest of the paper is structured as follows. In Section 2, the research methodology applied in this study is described, followed by a brief description of a typical planning process in Section 3. Sections 4 and 5 present the main results from the research, covering theoretical analysis and empirical evidence respectively. Section 6 provides discussion, followed by conclusions in Section 7.

2. Method

The method that has been applied is as follows:

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1. Study and describe a typical planning process for offshore oil and gas operations in Norway. The planning process described is a typical process based on the concept of Integrated Operations which is used on the Norwegian Continental Shelf. This is based on a document review (Witkin and Altschuld, 1995) including work flows and management systems at several operating companies, and these documents described the steps in the processes, roles and purpose. Interviews of personnel involved in the planning processes at two operating companies were also conducted, with both onshore (six interviews) and offshore (eight interviews) personnel; and the first author also attended meetings in the planning processes onshore and offshore to get a better understanding of the planning processes. The data obtained from the interviews were organized using codes (as for Grounded Theory: Strauss and Corbin, 1998) on the different aspects related to meeting preparations, the meetings themselves, the results from the meetings, and aspects that could influence the plan or the planning process. The findings from the interviews of offshore personnel are reported in (Sarshar et al., 2013). The result of step one of our method is described in Section 3.
2. Analyse a number of theories of major accidents, to see how the different theories and their explanations of causes and contributing factors can be of relevance for plans and planning processes. The hypothesis is that these factors influence the quality of plans and planning processes from the perspective of managing major accident risk, and that by controlling these factors we can also control how planning influences major accident risk. This then forms the theoretical basis for the work. Factors that the different theories focus on regarding accident causation and explanation or factors that contribute to why accidents do *not* occur is studied and described in Section 4. We review the planning process from the perspective of each of the selected theories on major accidents to identify factors in the various steps of the planning process that may contribute to reduce the potential for major accidents associated with a completed plan.
3. Review accident investigations (as for descriptive analysis: Zikmund, 1994) to search for evidence of how weaknesses in planning processes can contribute to major accidents through the above identified factors and also to identify any additional factors that have not been identified through the theoretical review. This provides empirical support for the theoretical basis. We reviewed investigation reports of hydrocarbon leakages for the period 2011–2013 from the Norwegian Continental Shelf. 24 reports were reviewed whereof 18 were found to have potential relations to the plan or planning processes. The review was performed in two iterations. In the first iteration the analysis consisted of extracting from the reports aspects identified as direct and indirect causes. These aspects were then combined with the ones from the theoretical review and a selection of thirteen influencing factors was chosen (based on their applicability on the incident reports) for the empirical review. In the second iteration of the analysis, aspects identified as direct and indirect causes in the investigation reports which could be related to planning or plans were grouped as best could fit into the thirteen influencing factors. This step is described in Section 5.

The study of incidents in Step 3 focuses on hydrocarbon leakage incidents. A leakage in the process equipment on an offshore installation which contains large quantities of hydrocarbons under pressure has a potential to become a major accident. A causal analysis from the Norwegian continental shelf has shown that a significant proportion of hydrocarbon leaks relate to human and operational errors when planning work on process equipment, executing this work and reinstating the equipment in order to restart the process plant (Norwegian Oil and Gas, 2012, 2013).

3. The planning process

Production, operation and maintenance activities are carried out daily during offshore operation. The control room operators control the production as well as the initiation of maintenance activities, crane operations and helicopter and vessel transportation. Safe operation and production is of key importance. Thus, the planning process for all offshore activities, the quality of the plans and the quality of their execution and end controls are important aspects which need to be managed (as described in Sarshar et al., 2013). Activities must be assessed individually and for concurrent execution with respect to Health, Safety and Environment (HSE).

The planning process described here is a standardized process based on the operational concept Integrated Operation (IO). IO has been defined as “real time data onshore from offshore fields and new integrated work processes” (NOG, 2008) and was introduced with the purpose of achieving (NOG, 2005): increased recovery, accelerated and increased production, reduced operational cost, longer lifespan, and increased safety. IO may also be known as Intelligent Fields and has been gradually introduced by petroleum companies operating on the Norwegian continental shelf.

With respect to planning IO implies that several planning tasks were moved from offshore to onshore, and an increased need to integrate offshore and onshore based personnel in the planning process and thus collaboration across geographical locations.

Planning is performed with different time horizons in mind and our focus will be on the latter three:

- a main plan has a span of several years,
- a yearly plan spans for one year,
- an operational plan spans for three months,
- a work order plan spans for one or two weeks and
- a work permit/day plan which covers the next 24 h.

The operational plan contains the most important information about maintenance, operations and modifications which fall under the following categories:

- major tasks within HSE,
- production related tasks that require shut-down,
- tasks requiring external resources,
- tasks requiring additional bed capacity,[1]
- tasks requiring coordinated actions (e.g. heavy lift operations), and
- tasks requiring monitoring.

Operational plan meetings are held every two weeks and include participants from onshore and offshore who evaluate simultaneous activities and the total activity level with focus on risk and production. This meeting also facilitates the coordination of activities with the production and well intervention plan.

The objective of the operational plan is to:

- Assure that decisions and activities from the main plan are performed

[1] Bed capacity: An important constraint for performing work offshore is the capacity of the offshore installation to accommodate people. “Bed capacity” is therefore and important issue in offshore operations.

- Set the framework for activities on underlying levels (top-down planning)
- Assure coordination to ensure the installations risk picture is acceptable with respect to major accident and production
- Assure coordination with respect to risk levels, prioritization and resource management within and across installations
- Assure that the activity level on the installation is implemented within framework conditions

External framework conditions, status on technical barriers and risk of activities must be analysed and seen together to ensure that the installation's risk picture is acceptable. External conditions can include infrastructure and dependencies between installations and risk of activities can include activity level, high risk activities and simultaneous activities. The analysis shall provide an overview of simultaneous activities in each area, high risk activities that limit accomplishment of the tasks, consequences of high activity level, relevant dependencies that exist, and identified deviations from framework conditions.

The work flow process for updating the operational plan is illustrated in Fig. 1 while Table 1 describes these briefly and whether major accident risk is considered in these activities. The highlighted steps in the figure represent steps which consider and manage major accidents to some extent.

The work order plan is based on the operational plan. In this phase activities are prepared and planned in detail in coordination with logistics and contractors and involve both onshore and offshore staff. The risk evaluation in this step includes special attention to HSE and area/module specific risks (normally a printout of a simplified version of the quantitative risk analysis for a given module). Logistics and personnel-on-board planning are coordinated activities with the preparation of work order plans.

The objective of the work order plan is to plan for safe, effective and reliable execution of work on the installation:

- Coordinate work to avoid lag in the maintenance of safety and production critical systems
- Assure coordination of work execution between different actors
- Plan for safe execution of simultaneous activities and operations
- Assure good resource utilization
- Minimise downtime on safety and production critical systems
- Collect work that is on the same system or part of the installation
- Avoid delay and waiting time for access to systems at the installation
- Coordinate access to equipment at the installation

A work order defines the need for work and is a formal request for the work that shall be done. A work order describes a job package and can normally be divided into subtasks that can be carried out in sequence. Before any of these can be performed, the personnel that shall execute a task must apply for a work permit. A work permit is a permission to perform a specific work.

The work permit system was established to maintain control over which activities are to be carried out on the installation and to manage their risk. Activities that typically require a work permit are maintenance work on the process equipment, pipes or structure of the platform. There are two main categories; corrective (to correct failures that have occurred) or preventive (to prevent failures to occur) maintenance. Work permits are divided in two levels to differentiate between their impacts on risk. High-risk jobs which e.g. require welding are classified as level 1 while lower risk jobs are level 2, e.g. mounting personnel protection on a flange. Jobs that have been identified as no risk activities do not require a work permit and typically include jobs inside the living quarter, in office spaces or in workshops.

The work flow process for updating the work order and work permit plan is illustrated in Fig. 2 and Table 2 describes these in brief and whether major accident risk is considered in these activities. The highlighted steps in the figure represent steps which consider and manage major accident to some extent.

From the review of steps involved in the planning process and considerations made on risk for major accidents in these, we see that risks associated with the jobs tasks are considered when establishing the work order and work permit; on the other hand, coordination and its associated risks are considered when approving work permits. Approving work permits is the last step in the planning process and has a critical role considering major accident risks.

4. Theoretical basis

Major accidents are seldom born from one factor, but from a combination of factors: design factors, operational factors, maintenance factors, organisational factors etc. We seek to contribute to major accident prevention in the petroleum industry by developing strategies to address the maintenance factor.

Based on accident investigations and the absence of accidents, major accident theories have arisen to explain the causation of the accidents occurred and why some organizations do not encounter accidents. The most acknowledged theories which form the theoretical basis of our work include the energy and barrier perspective (Gibson, 1961; Haddon, 1980), conflicting objectives (Rasmussen,

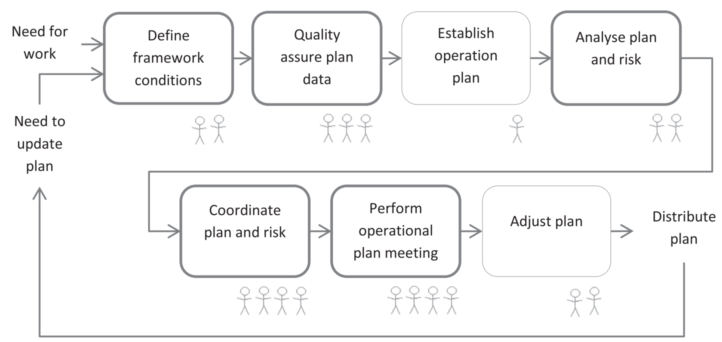

Fig. 1. The work flow process for updating the operational plan.

Table 1
Description of the steps for updating the operational plan and major accident analysis performed in these activities.

Step in the process	Description	Major accident analysis
Define framework conditions	Communicate decisions and activities from the main plan and establish installation specific framework conditions (e.g. logistics, bed capacity). This is a collaboration activity.	Activity level being outside framework conditions, degraded technical integrity, higher risk for HSE incidents and wrong prioritization between activities.[a]
Quality assure plan data	Risk that can affect the accomplishment of activities shall be identified and reported in relevant risk management tool. Examples include work on hydrocarbon carrying systems, disabling of safety critical systems/barriers, and critical/heavy lift operations. This is a collaboration activity.	In addition to the above; identify weakened technical, operational and organizational barriers and failure of equipment.
Establish plan	The planner establishes the operational plan based on the quality assured plan data. This is a proposed plan which will be adjusted and reviewed in the following steps.	Analysis from the above steps is considered at this step. This means that e.g. simultaneous tasks can be a risk due to co-ordination failures.
Analyse plan and risk	Analyse the plan and propose alternatives if deviations exist from framework conditions. This is a collaboration activity.	In addition to the above; insufficient overview of the risk picture.
Coordinate plan and risk	Preparation to plan meeting, establish alternatives and assess economy. This is a collaboration activity.	Analysis from the above steps is considered at this step.
Perform operational plan meeting	The main goal is to prioritize the activities on the plan, to decide on measures and approve plan. This is a collaboration activity.	Identify wrong prioritization.
Adjust plan	Adjust the plan based on the activity level and establish reference plan as basis to identify deviations in the operational plan. This is a collaboration activity.	Identify wrong prioritization, higher risk for HSE incidents and poor coordination between activities.
Distribute plan	Shall contain report from the planning (Gantt-diagram, manning, etc.) and decisions from the operational plan meeting.	Identify poor coordination between activities.

[a] We will exemplify the relevance of work prioritization and major accident risk in Section 5 when reviewing incident investigation reports.

1997), man-made disasters (Turner, 1978; Turner and Pidgeon, 1997), high reliability organisations (La Porte and Consolini, 1991) and resilience engineering (Hollnagel et al., 2011).

The theoretical study of relating the major accident theories to the planning processes performed in this section highlight some factors which can influence the processes with respect to major accidents. These include:

- Energy and barrier: Risk assessment, barrier control, hazardous operations, simultaneous activities
- Conflicting objectives: Goal conflict, pressure towards efficiency, workload, work practice
- Man-made disasters: Information flow, communication, misunderstandings, plan quality, overview of activities,
- High reliability theory: Commitment, redundancy, learning culture
- Resilience engineering: Preparedness, learning culture, ability to steer activities, awareness, goal conflict, buffering capacity, anticipation, monitoring, responding

In Section 5, a selection of these factors will be used to group and relate the studied incidents to the planning phases. The following sub sections review these theories to see how their explanations of causes and contributing factors can be of relevance for plans and planning processes. These are then analysed together, and a summary of relevant contributions is given in the last subchapter.

4.1. *The energy and barrier perspective*

The energy and barrier perspective provides an explicit view of the immediate causes of accidents (Gibson, 1961; Haddon, 1980). The perspective builds on defence in depth and barriers to prevent accidents in its safety design. The perspective has proven useful in hazard identification and as basis for identifying hazard control strategies. It is further the basis for analytical risk control. Safety management for both major and minor accidents is based on the energy and barrier perspective.

The notion of root causes for major accidents for this perspective is failure to establish and maintain adequate barrier functions and dependencies among barrier functions and the risk reduction strategies should ensure that compensating measures are taken when barriers are unavailable (Rosness et al., 2010).

The energy and barrier principle is originally based on a physical understanding of the term “barrier”, and with such an understanding it is hard to see how plans can be influenced by this principle. However, the understanding has been extended to cover a wide range of measures to control risk, including organizational issues (Reason, 1997). With an understanding like this, we may look at how plans and the planning process can contribute to introduce additional barriers that can prevent major accidents from occurring.

To identify *in which steps in the processes there are barriers that reduce or control major accident risk*, a systematic review of the planning process from Tables 1 and 2 is performed. During the operational plan process risk that can affect the accomplishment of activities shall be identified and reported in relevant risk management tool. Analysis is required on hazardous operations, simultaneous operations, barrier weaknesses and compensating measures. During the work order process, task specific aspects that can take out an existing barrier and necessary compensatory measures are identified. Work operation type can present a major accident risk.

4.2. *Conflicting objectives*

Organisational safety is influenced by regulatory and commercial pressures, the working environment and management demands. The behaviour of those operating the systems, the roles and actors in the processes, is influenced by the conditions they work in and by the behaviours of others, particularly those in managerial positions (Flin et al., 2008).

Rasmussen (1997) suggests that we might think of the handling of conflicting objectives in terms of activities migrating towards the boundary of acceptable performance. Different boundaries that can affect decision making for different actors include: management pressure towards efficiency, gradient towards least effort and

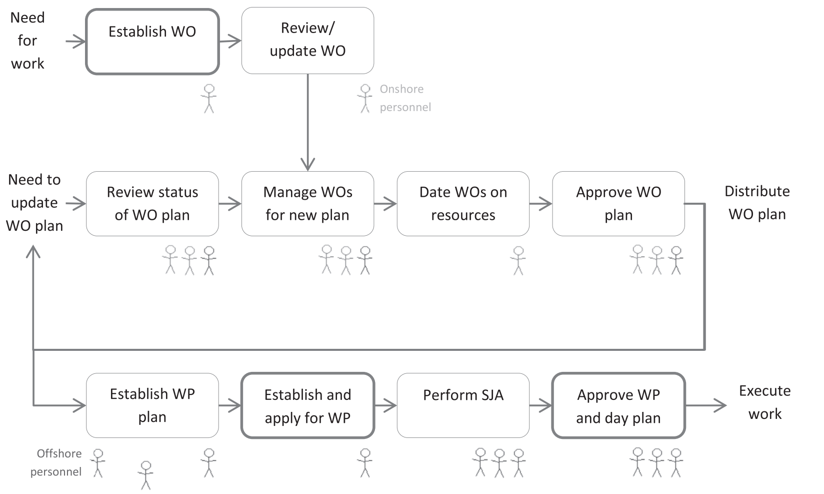

Fig. 2. The work flow process for updating the work order and work permit plan.

workload, boundary of locally and conditionally acceptable or unconditionally safe state of affairs. Actions within one activity might change the boundary of acceptable performance for another activity.

Causation of accidents may be seen as the result of actors transcending the operational envelope of the systems they operate. Actors cross boundaries towards unacceptable risk in an effort to locally optimise behaviour. Organisational accidents in distributed systems typically involve several actors, each seeking local optimisation based on incomplete view of the system. Major accidents thus tend to arise from situations where separated adaptation processes interact in a way that was not foreseen by the actors.

To apply the conflicting objectives perspective a systematic review of the planning processes is performed to identify

- *in which steps one can expect considerations and discussions on safety vs cost and time* and
- *in which steps it is likely that risk is not considered or the focus is entirely on cost and time.*

The steps from Tables 1 and 2 which address potential conflicting objectives include:

- Perform operational plan meeting – Management's focus on efficiency can put (time and cost) pressure (vs safety) or prefer production optimization operations ahead of maintenance operations (including maintenance on production critical equipment ahead of safety critical equipment).
- Steps for establishing and approving work orders and work permits – Management's focus on efficiency can put (time and cost) pressure (vs safety): not taking necessary time to prepare the work, not considering all aspects of the work (e.g. with respect to HSE, resources, or competence needed).
- Steps for establishing operational plan, work order plan and work permit plan – Risk is not considered in these steps, the focus is entirely on scheduling and date/time the work.

The conflicting objective perspective has focus on the processes and not on the product of the processes – the plans. However, if the focus in the process is more on cost and time than safety that will clearly also have an impact on the plan: It may result in a plan with reduced safety margins. When such a plan is implemented, it may lack needed robustness to prevent a major accident should anything fail during the task execution process. Thus, in the end a plan with reduced safety margins may result in higher cost both with respect of human health, financial expenses and in terms of reputation loss for the company.

4.3. Man-made disasters

The critical assumption in Turner's theory (1978; 1997) concerns the process leading up to a disaster, the onset. However, the man-made disaster model also includes stages after the actual disaster, including rescue and a final stage of full cultural readjustment to the surprise associated with the event. The starting point is a situation where matters are reasonably normal implying that a set of normative prescriptions, ranging from informal norms to laws and regulations are culturally accepted as being advisable and necessary precautions to keep the risks at an acceptable level. This is followed by the incubation period which is characterized by the accumulation of an unnoticed set of events or events that are misunderstood causing misperception of danger signals. An important factor here is the structure of communication networks, in particular the boundaries where knowledge is not shared or where it is simplified. The incubation period is brought to conclusion by a precipitating event, which is by definition unpredictable for those sharing the culturally accepted beliefs about the system, a dramatic event such as an explosion.

Accidents and disasters develop through a long chain of events leading back to root causes such as lack of information flow and misperception among individuals and groups. To control risk a key factor is to make intensive efforts to collect and analyse information about hazards and what we do not know.

An important contribution of the information system perspective is Turners finding (Turner, 1978) that during the incubation period; there is nearly always someone who is aware of the danger. This may be related to conflicting objectives in the previous section were e.g. time pressure can make one withdraw information, whether it is on purpose or not.

The theory explains causation of major accident with:

Table 2
Description of the steps for updating the work order and work permit plan and major accident analysis performed in these activities.

Step in the process	Description	Major accident consideration
Identify need for WO	When a need for performing work is identified, the criticality of the work is also assessed. The criticality is however focused on whether not doing this work (preventive maintenance, repair, modification) represents an increased risk for the operation of the plant (e.g. because a safety critical system is malfunctioning) or whether this may impair production from the plant.	No consideration of the risk associated with performing the work is done at this stage. A corrective WO requires considerations on criticality of the failure on safety and production. The priority and criticality considerations come from the morning meeting (notification/event) that triggered the need for WO.
Establish WO	The work order is focused on describing what should be done and what equipment and resources are required. This would also include considerations of major accident risk since this may have an impact on resources required.	Major accident risk is considered and required risk controls are identified. Work specific aspects that can take out an existing barrier and compensating measures needed. Work operation type can present a major accident risk. Risk analysis needed?
Review/ update WO	Review the WO and change its status as e.g. material needs are met or dates get close to be ready for next plan	No or very limited focus is placed on major accident risk.
Review status for WO plan	Coordinate WOs which are not on plan and provide input to these WOs	
Manage WOs for new plan	Evaluate last active WO plan, the status of its WOs, coordinate these and provide status on active WO plan	
Date WOs on	resources needs	
	Establishing the WO plan is typically focused on "piecing" together all WOs into a plan that can be completed within the available time and with available resources.	
Approve WO plan	Review, approve, quality assure plan and plan feasibility	
Establish WP plan	The discipline leaders offshore make a WP plan for the next few days based on the WO plan for which activities to carry out when. Resource management for the discipline team.	
Establish and apply for WP	The WP serves two main purposes: To ensure that the work can be performed safely and (as part of that) to ensure that the work can be performed safely simultaneously with other activities (coordination).	Major accident risk will be considered during the preparation of the WP. Work specific aspects that can take out an existing barrier, compensating measures needed. Work type can present a major accident risk, coordination needed. Comply with risk analysis from WO, need for safe job analysis or blinding list?
Perform SJA	Safe job analysis is a systematic and stepwise review of all risk factors prior to a given work activity or operation, so that steps can be taken to eliminate or control the identified risk factors during preparation and execution of the work activity or operation. Certain categories of work will always require SJA to be performed based on regulatory and company standards, others do not. However, any participant in any planned work task has the right to demand a SJA before work is undertaken.	Focus is too often on personal safety only and not on major accident risk (Leistad and Bradley, 2009).
Approve WP and day plan	The approval process takes care of both of the above purposes, including the coordination.	Major accident risk will be considered during the approval of the WP Risks associated with the combination of jobs Risks associated with simultaneous operations (drilling, helicopter, crane, boat) Area risk for specific jobs, weather conditions

- Breakdown of information
  - For the planning process this means that information do not flow between the activities in the process and between the roles and actors.
  - For the plan it means that it does not contain all relevant information needed. The type of information important to share is e.g. hazardous operations and what makes them hazardous.
- Misperceptions – Many of the steps in the planning processes are collaboration activities and foster information sharing and discussions. Information must flow between the activities and between the roles and actors, and discussions should address misunderstandings.
- Lack of communication – For the planning process this means lack of communication channels or feedback channels between the activities in one process and between its roles and actors but also across processes: between the operational plan, work order and work permit processes.

Turner also saw managerial and administrative difficulties in handling information in complex situations that blurred signal with noise. This is sustained in high-reliability theory: Failure means that there was a lapse in detection. Someone somewhere did not anticipate what and how things could go wrong. Something was not caught as soon as it could have been caught (Weick and Sutcliffe, 2007).

To apply the man-made disaster perspective a review of the planning process is performed to identify *what type of information shall be flowing through the process and to whom* and *what type of information shall the plans contain?*

The information availability when establishing work order and work permit is important to cover all aspects of the job. The information flow between the planning activities and the mechanisms and channels for this must allow for information sharing and avoid misunderstandings and misperception. The information type and format must support the activity it is used in and for. Communication channels must be in place to allow easy access to necessary roles and actors in the processes. However, this is not sufficient alone; we are not also tackling the problem of promoting a safety culture that precedes having channels open. While one does spur the other, no one will use the channels unless safety is of a major concern to everyone involved. This again relates back to the previous section on conflicting objectives.

Further, good information has some characteristics that should be in place as described by Westrum (2014):

- It provides answers to the questions that the receiver needs answered. The information should respond to the needs of the receiver, not the sender.
- It is timely. If not it may lead to a wrong decisions since information is used in decision making.
- It is presented in such a way that it can be effectively used by the receiver.

4.4. High reliability theory

The high reliability theory says little explicitly about the nature of accident causation, but their implicit idea is that accidents are triggered by errors that have not been recovered in time. If one considers the slowness of bureaucracy and the incubation time from Turners theory as described in the previous section, unrecovered errors could be due to wrong prioritization, misunderstandings or poor information flow.

HR theory focus more on why accidents do not happen rather than on causes of accidents. Accidents can be prevented through good organisational design and management:

- Commitment to and consensus on production and safety as concomitant organizational goals
- Redundancy enhances safety – Build organisational redundancy as a means to build fault tolerant organisations with overlapping tasks and competence
- Decentralised decision making is needed
- Monitor the structural and cultural preconditions for organisational redundancy
- Culture of reliability: Build cultures that combine requirement for fault-free performance with openness to the fact that errors do occur
- Learn from the daily operations and the normal procedure, but incidents/accidents may demonstrate the absence of the preconditions
- Downsizing may affect the preconditions for organisational redundancy

For the planning process:

- The bullet points above applies to all the planning process but is specially focused on in the operational plan meeting
- The steps in the processes which are collaboration activities works as organisational redundancy with overlapping tasks and competence, eye-to-eye contact and which easily communicate with each other
- The work permits approval and daily plan are managed offshore but their work order plans are approved in collaboration between onshore and offshore
- The evaluation and quality assurance of the work order plan is facilitated as a collaboration activity involving different key responsibilities/actors. This can make the work order plan approval process redundant in the way that more than one actor is involved. This, however, requires that involved personnel do not think in "silos" but that they rather take responsibility to represent their domain and expertise. Some organisations include the offshore lead technicians in this step and hence include decentralised decision making.

HR theory suggests organisations should take expertise seriously, listen to minority viewpoints and remain less concerned with strategy and more sensitive to daily operations.

4.5. Resilience engineering

Accidents, according to this perspective, are not the product of normal system malfunction or breakdown, but rather a breakdown in the adaptive capacity necessary to cope with the real world of complexity. Risk reduction is achieved by increasing coping ability rather than eliminating variability. Organizations should build and maintain the abilities to anticipate, attend, respond and learn. The purpose is to assess the preparedness of the system, not only to respond to unforeseen events, but also to manage known threats and pressures.

Resilience concepts (from various chapters in Hollnagel et al., 2006; referred to in Ferraira et al., 2011):

- Ability to adapt to changing conditions – the system has to be flexible enough to respond to external changes and pressures
- Ability to cope with complexity – the system must be capable of maintaining normal operation whilst coping with changing conditions
- Ability to manage continuous stresses – the system must be capable of maintaining normal operation, even when submitted to extreme pressure
- Ability to respond to problems ahead of time – preparedness – the system must be able to react before problems cause any disruption to normal operation
- Learning culture – willingness to respond to events by reforming and adapting as opposed to denying the need for change
- Just culture – support in reporting of issues throughout the organisation avoiding behaviours of culpability attribution
- Ability to steer activities – the system must be able to control activities regardless of operating conditions
- Appropriate level of information about performance – awareness – the system must make available to its management appropriate levels of information regarding performance
- High enough devotion to safety – safety must be considered alongside other system goals
- Buffering capacity – the system must have available resources necessary to respond to arising problems and complex issues

A resilient system knows when to sacrifice acute production goals and prioritise chronic safety goals. If organisations are unable to support people when they back off from economic goals in order to invest in safety (the sacrifice), the organisation will be acting with higher risk than it realises or wants (Tjørhom and Aase, 2011).

A practice of resilience engineering requires that anticipation, monitoring, responding and learning are considered and addressed at all levels of the organization. The challenges in ensuring this, however, are many. Resilience assumes that one can foresee the changing shape of risk before failure or harm occurs. It requires monitoring key indicators to observe how close the organization is to the safety space boundary. The organization must then have the capability to respond by adapting or being flexible to the measured changes and opportunities. The loop is not complete until lessons learned are incorporated with regular revisions of performance standards.

The steps in the planning processes analyse and evaluate operations and prioritize those which require the ability to adapt to changing conditions, cope with complexity, respond to problems ahead of time, steer activities, and devote to safety.

4.6. Relevant contributions from the theories

Major accident theories can contribute in different ways to major accidents monitoring and prevention. By applying different perspectives, we can view the problem from different angles and thereby possibly learn something new, which can help us manage the risk.

Table 3
Relation of the energy and barrier, conflicting objectives and man-made disaster perspective to plans and their content.

Plans	Energy and barrier	Conflicting objectives	Man-made disasters
Operational plan	Risk that can affect the accomplishment of activities shall be identified and reported in relevant risk management tool. Analysis required on hazardous operations, simultaneous operations, barrier weaknesses and compensating measures.	Potential conflicts at the organisational level in which there is incompatibility between safety and production goals, but also at group level when the informal norms of a work group are incompatible with the safety goals of the organisation.	
Plan	operations	Contains information on whether the operations repeal safety critical systems or barriers.	
For the plan it means that it does not contain all relevant	information needed.		
Work order plan	Major accident risk is considered and required risk controls are identified.	As above (operational plan)	
Work order	Work specific aspects that can take out an existing barrier and needed compensating measures are identified. Work operation type can present a major accident risk.		The work order may not contain all relevant information needed to communicate hazards and risk.
Work permit plan	Analysis required on hazardous activities, simultaneous activities, barrier weaknesses and compensating measures.	Potential conflict at the group goal conflicts, when the informal norms of a work group are incompatible with the safety goals of the organisation, but also at the individual goal conflicts caused by preoccupation or group specific concerns.	
Work permit	Major accident risk will be considered during the preparation of the WP. Work specific aspects that can take out an existing barrier and needed compensating measures are identified. Work type can present a major accident risk, coordination needed.		The work permit may not contain all relevant information needed to communicate hazards and risk.

The energy and barrier, conflicting objectives and man-made disaster perspectives can be related to the plans established and their content as summarized in Table 3. High reliability and the resilience engineering perspective apply more to the organisational level rather than the plans directly.

Relevant contributions from the energy and barrier, conflicting objectives, man-made disaster, and high reliability organisation perspectives can be related to the planning processes as summarized in Table 4. In addition, the resilience engineering perspective is applicable to all processes since the steps for analysing and evaluating work, and its prioritization require the ability to adapt to changing conditions, cope with complexity, respond to problems ahead of time, steer activities, and devote to safety. The tables pinpoint possible risks in each stage by each theory.

5. Empirical evidence

The theoretical study of relating the major accident theories to the planning processes performed in Section 4 identified factors which can influence the processes with respect to major accidents. This section describes the result from a review of accident investigations to search for evidence of how weaknesses in planning processes can contribute to major accidents.

A systematic review of the incident reports on direct and indirect causes of hydrocarbon leakages related to the planning processes was performed in two iterations. In the first iteration the analysis consisted of extracting from the reports aspects identified as direct and indirect causes. These aspects were then combined with the ones from the theoretical review and a selection of thirteen influencing factors was chosen (based on their applicability on the incident reports) for the empirical review. These include:

- Information flow – When information is missing, inadequate or not passed from one step to another in or across planning phases
- Communication – When communication channels is missing or is inadequate between roles and actors
- Misunderstandings/misperception – When assumptions and misperceptions influence the quality of the work
- Documentation – When documentation is missing or not reflecting the real system
- Procedures – Missing, not available or not precise procedures
- Planning quality – Assumed that planning processes should manage the quality of plans
- Plan quality – Assumed that weakness in plans should be managed during assessment steps
- Competence – When required competence is not present
- Overview/situation awareness – Relates to overview of activities, their relations and complexity
- Work practice – Assumed that poor work practices may exist that deviate from procedures or defined processes
- Workload – Assumed caused by e.g. time pressure
- Risk assessment – Inadequate analysis or actions or measures not followed up
- Learning – Assume that one should consider learning from similar type of work when assessing it

In the second iteration of the analysis, aspects identified as direct and indirect causes in the investigation reports which could be related to planning or plans were grouped as best could fit into the thirteen influencing factors. The result is presented in Table 5 where columns represent the planning processes and their steps (grouped in establish, assess and coordinate and approve) and the rows represent the influencing factors. The content of the table illustrates the number of incidents that had a direct or indirect

Table 4
Relation of the energy and barrier, conflicting objectives, man-made disaster and high reliability organisations perspective to the planning processes.

	Step in the process	Energy and barrier	Conflicting objectives	Man-made disasters	HRO
Operational plan	Need for work Define conditions Quality assure Establish plan Analyse Coordinate Perform operational plan meeting	No barriers in the present planning process. These steps present organisational barriers since major accident risk is considered and required risk controls are identified.	Major accident risk is considered and required risk controls are identified. In this step, management's focus on efficiency can put (time and cost) pressure (vs safety) or favour production optimization operations ahead of maintenance operations.	Information must flow between the activities and between the roles and actors, and discussions should address misunderstandings. The type of information important to share is e.g. hazardous operations and what makes them hazardous. Communication channels and feedback loops not only within this process but also with the WO and WP process are necessary.	These steps are foremost collaboration activities which works as organisational redundancy with overlapping tasks and competence, eye-to-eye contact and which easily communicate with each other.
Work order plan	Establish WO	An organisational barrier is present in this stage, since major accident risk is considered and required risk controls are identified.	Major accident risk is considered and required risk controls are identified. In this step, management's focus on efficiency can put (time and cost) pressure (vs safety): not taking necessary time to prepare the work: not considering all aspects of the work (e.g. with respect to HSE, resources, or competence needed).	Major accident risk is considered and required risk controls are identified. The WO may not contain all relevant information needed to communicate hazards and risk. For the planning process this means that information may not flow between the activities in the (onshore and offshore) processes and between the roles and actors.	There are at least two persons with overlapping competence and with access to necessary/required information present in this activity
	Approve WO plan	No or very limited focus is placed on major accident risk. No barriers.	No or very limited focus is placed on major accident risk. Management's focus on production and efficiency will determine the prioritization of WOs which make it to the plan.	No or very limited focus is placed on major accident risk. When establishing the WO plan, misunderstanding and misperception of information or between actors and roles in the planning processes can generate low quality plans.	The evaluation and quality assurance of the WO plan is facilitated as a collaboration activity involving different key responsibilities making the approval process redundant. Some organisations include the offshore lead technicians in this step and hence include decentralised decision making.
Work order	Establish and apply for WP	Major accident risk will be considered during the preparation of the WP and this is therefore also an organizational barrier. Consideration in this step is to ensure that the work can be performed safely.	Management's focus on efficiency can put time and cost pressure: not taking necessary time to prepare the work: not considering all aspects of the work (e.g. with respect to HSE, resources, or competence needed). One might also chose deliberately not to perform such assessment and take the necessary time for preparations or cut on safety measures because one considers these unnecessary.	Major accident risk will be considered during the preparation of the WP. As for establishing WO, the WP may not contain all relevant information needed. This can be directly related to poorly established WO. For the planning process this means that information don't flow between the activities in the (WO and WP) processes and between the roles and actors.	As above (establish WO)
	Approve WPs and day plan	The approval process ensures that the work can be performed safely and (as part of that) ensure that the work can be performed safely simultaneously with other activities (coordination). This would therefore be an org. barrier.		Misunderstandings and misperception of information or between actors and roles in the planning processes can cause that WPs are approved based on inadequate basis.	The maintenance and operation leader approves WPs at level 2 while the platform manager approves WPs at level 1.

influence on these steps. There were 18 incidents which could be related to the planning processes in one way or another. These are identified from **A** to **R** in the table. Some of the incidents, e.g. **G**, contribute more frequently (14 times) to the occurrences in the table while some contribute few times. The explanation of this can be that some incidents are examined more thoroughly than others, hence direct and indirect causes are described in more detail, while other reports are short and only describe the incident without any in depth study of causation. Examples of the influencing factors from the incidents for the work order and work permit plan are provided in Table 6.

6. Discussion

As described in Tables 3 and 4, there are learnings from major accident theories that can be related to the planning processes described in Section 2. The empirical study described in Section 5 (Tables 5 and 6) further illustrates the relations between reported incidents with major accident potential and the planning processes. In this section, some of these relations are discussed.

The distribution of influencing factors for each of the planning phases is illustrated in Fig. 3. Besides the factors affecting the overall process, the work order and work permit phases has the highest occurrences of the factors with “learning” and “planning quality” as the highest. The factor “learning” occur five times in

Table 5
Incidents identified from A to R and their relation to the planning processes.

Influencing factors	Entire process	Operation plan			Work order plan			Work permit plan		
		Est.	Assess	C&A	Est.	Assess	C&A	Est.	Assess	C&A
Information flow	K, M, N, P									
Communication	A								C	D
Misunderstandings	I		A					K	O	D
Documentation	G, H, J, M, O								A	R
Procedures	B, C, R							G	E	
Planning quality	H, P				D, M		A, L, M	G		D
Plan quality					D, G			G	C	
Competence						G	G		D, N	G
Overview of activities							G			C, G, Q
Work practice	M									E, M, R
Workload										G
Risk assessment	F, G, I									N
Learning						A, C, D, G, N			A, C, D, G, N	

both the latest phases of planning, and all occur in steps of assessment in the planning processes. The examples from the incidents on this factor relate to "similar incident not considered during preparation of work" and that "earlier studies of similar incidents were not known to the personnel". We assumed in our study that one should consider learning from similar type of work when assessing it, and this assessment is done in the work order and work permit phases which explains the need for learning from incidents in these steps.

The factor "planning quality" occurs five times in the work order

Table 6
Exemplified contributing factors for the work order and work permit planning phases from the incident reports. The examples applicable to the work order process are also valid for the work permit process.

Contributing factors	Work order process	Work permit process
Information flow	**M**: Information and history when a need for work and work permit was established was not included in the further process	
	N: General risk measures identified earlier in the process was not signed by involved personnel before the operation started	
Communication		**C**: Procedure was not known to all process operators
		D: Lack of communication
Misunderstandings/ misperception	**A**: Misperception around the criticality of the work	
		D: Work performed was not the work described in the WP
		K: Operation was seen as routine operation and safe job analysis was not performed and work permit not established
		O: Technicians assumed the equipment/system was a barrier and considered this to be sufficient
Documentation	**M**: Inadequate documentation and drawings of the valve	
		A: Inconsistent torque table existed
Procedures	**G**: Not precise procedures (which manual valves that should be opened and in which order)	
Planning quality	**D**: Missing need for work for a general agreed work of replacing parts of a HC[a]-system when these systems were down	
	L: Failure in prioritization of work order with respect to consequence	
	A: Material needs not coordinated with prioritization	
	M: Lack of original parts when planning the job	
	M: A new work order not established to replace the reused parts	
		G: The operation did not have a work permit
		D: Work permit modified after approval
Plan quality	**G**: The work description did not fit the criticality and importance of safety of the work	
	D: Not precise description of new activity added to an already assessed work order	
		C: Failure in preparation of correctly establishing a barrier
Competence	**G**: Plant specific competence was not present during decision making	
	N: There is a procedure for the work which was not known and used	
		D: Decision made based on inadequate knowledge and competence on the process system by mechanical team
		G: Shift of personnel which was not part of the preparations before execution, new personnel had no experience or competence on the system
Overview of activities/situation awareness	**G**: Onshore had no overview of activities offshore when plans were changed to include test on ESDV[b], no new assessment of plan	
		C: Bleed to unsafe areas was not coordinated with other activities
		G, **Q**: (Very) high activity level at the installation
Work practice	**M**: "Silent deviation" on bleed to unsafe area	
		M: Blinding list verified to be correct when it deviated from procedure
		R: Work permit approved and considered routine operation without any additional requirements
		R: The type of maintenance not always documented by offshore organisation
		E: Blinding list not established
		E: Work permit signed before job prepared
Workload		**G**: High workload on operation and maintenance leader
Risk assessment	**G**: The segment contained large amount of gas which was not identified or considered during planning	
		N: The risk for the incident was not included in detailed procedure or handover between teams
Learning	**A**, **C**, **D**, **G**, **O**: Similar incident not considered during preparation of work	
		G: Earlier studies of similar incidents were not known to the personnel

[a] HC: hydrocarbon carrying.
[b] ESDV: emergency shutdown valve.

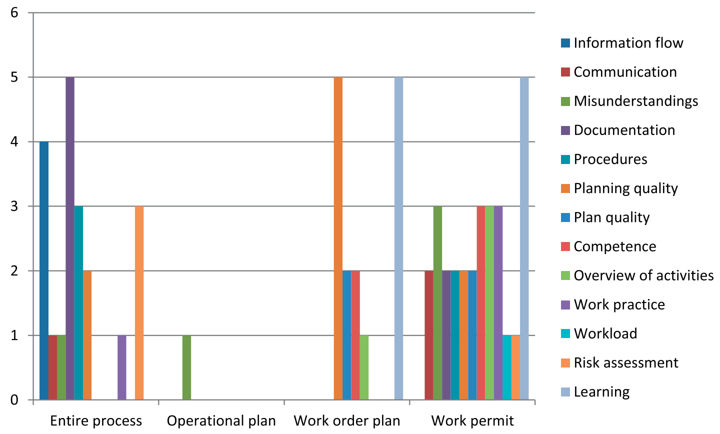

Fig. 3. Distribution of the influencing factors for each of the planning phases.

phase, an example from the steps for coordination and approval of work orders include "failure in prioritization of work order with respect to consequence". This factor also occurs two times in the work permit phase exemplified with work permit being modified after approval and that an operation did not have a work permit.

Many of the occurrences for the influencing factors are in the late phases of planning. This can show that the incident reports have identified more contributing factors closer to the sharp end, close to the incident, and fewer at the blunt end. The "entire process" may be seen as plan-related organisational aspects which indirectly can contribute to an incident. The occurrences of these are also high and can be exemplified through the incident reports as "bolt degradation not detected", "weakness of valve had been reported earlier but was probably not assessed to cause mechanical rupture", "operating company had no quality assurance process for the activity" and "results of tests performed by vendor was not

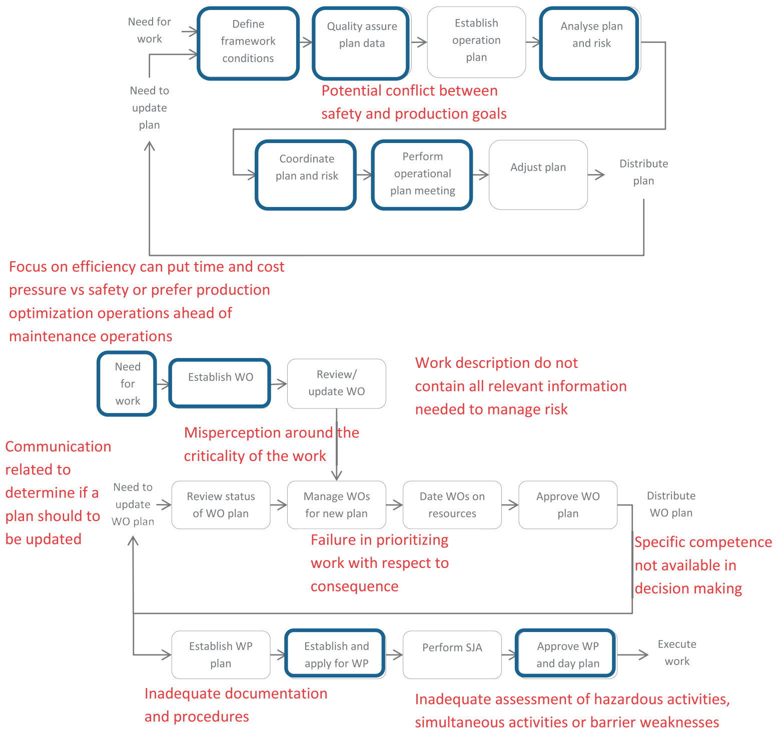

Fig. 4. Exemplifies how the steps in the planning processes potentially can relate to major accidents.

requested or shared with the operating company". These examples provide empirical evidence that inspection programs, risk analysis, procedures, work processes and communication between involved parties can be inadequate.

Further, the different planning phases focus differently, so one cannot expect all the influencing factors to apply to the steps in each phase. The factors can have dissimilar weighting for the different phases. The factor "workload" for instance may be more important in the work permit process compared to the operational plan phase. In fact, only one occurrence was traced to the operational phase of the studied investigation reports. This occurrence concerned that a work activity was not followed up caused by misunderstanding in the plan assessment step.

Fig. 4 illustrates the steps in the planning processes and exemplifies how they potentially can relate to major accidents based on the theoretical and empirical study performed in Sections 3 and 4. The highlighted steps in the figure represent steps which consider and manage major accident to some extent based on the study performed in Section 3 on the planning processes.

As seen from Section 3, aspects from major accident theories related to planning can include communication, information and data sharing so that all involved parties have an adequate shared understanding of the thoughts behind the activities in a plan. Since the plan is made over several phases, traceability of decisions and underlying information must be in place in order to better aid those who need to re-plan a task due to some new circumstances. Assumptions made in earlier planning phases must now be known so they are verified before new decisions are made.

Example. Considering the influencing factor "documentation" which can be exemplified from the incidents in our study as e.g. "P&ID[2] not reflecting the real system", NOG (2013) clearly states how crucial an accurate P&ID is when preparing work on hydrocarbon carrying systems: "[…] should this contain errors, no steps later in the work process will pick them up. […] – They assume that the latter [master P&ID] is correct. This means that routines for amending the master P&ID, and for ensuring that work on an isolation plan is actually based on the master P&ID, are critical for preventing major accidents".

7. Conclusions and further work

The aim of the study was to describe a typical planning process in the offshore industry, from the perspective of causes of major accidents (from theories and incident reports) with the ultimate aim to identify factors that affect the risk for major accidents through the planning process. The study was conducted in three steps. (1) The planning process, its phases and steps where studied. (2) Major accident theories where examined and related to the planning process. (3) Investigations reports with major accident potential were reviewed to gather empirical evidence and examples of the relations between planning and major accidents. Through this study, thirteen aspects influencing the planning process are identified as aspects that need to be addressed and focused on: information flow, communication, misunderstandings/misperception, documentation, procedures, planning quality, plan quality, competence, overview/situation awareness, work practice, workload, risk assessment and learning. Further work includes proposing improvements within the mentioned aspects to better manage major accident risk through the planning processes.

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[2] P&ID: Prosess and Instrumentation Diagram.

Article 3

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Challenges and proposals for managing major accident risk through the planning process

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ABSTRACT

Major accidents are characterized by complex causal patterns with many factors influencing the occurrence of such accidents. The causes can be found not just in the execution of the work, but also in the preparations and planning before performing the work. In this paper, we have identified a set of challenges related to planning that may influence major accident risk. The basis is theoretical and partly empirical. The theoretical part is from a study of major accident theories. The empirical part includes studies of investigation reports, interviews and a workshop. The challenges identified can be grouped into four main topics including *inadequate plan, inadequate planning, inadequate shared overview and understanding* and *late risk identification*. The challenges have subsequently been addressed through a set of proposed improvements, which are aimed at improving the planning process *to better manage major accident risk*.

1. Introduction

The Petroleum Safety Authority (PSA) in Norway has a strong focus on major accidents when following up the Norwegian oil and gas industry. Their definition of a major accident is *"an acute incident, such as a major discharge/emission or a fire/explosion, which immediately or subsequently causes several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets"* (PSA, 2015). Major accidents are characterized by complex causal patterns and many factors influencing the occurrence of such accidents, and PSA (2012) has pointed out that preparations for performing work activities offshore can play an important role in major accidents. Among the factors that are related to the preparations for performing work are planning. Other factors may be insufficient work descriptions, information transfer during the performance of the preparatory activities, etc. Weaknesses in the preparations can lead to unsafe performance of the work.

The purpose of this study is to propose improvements in the planning process to better manage major accident risk through the planning processes. Risk is defined as "combination of the probability of occurrence of harm and the severity of that harm" (NORSOK Z-013, 2001).

The present study is based on the work reported by Sarshar et al. (2015), which aimed at describing a typical planning process in the Norwegian offshore industry and relate this to major accident causation factors. This study was conducted in three steps: First, the planning process was studied and described. This part of the study was based on information from the industry and represents a typical process as applied in the Norwegian offshore industry. Second, major accident theories were examined to understand their implications as seen from the perspective of planning processes. Finally, investigation reports from offshore accidents and incidents with major accident potential were reviewed, to gather empirical evidence and examples of planning-related factors being contributing causes to major accidents. This study identified thirteen factors that are related to the planning process and that would contribute to increase or reduce risk. These were: information flow, communication, misunderstandings/misperception, documentation, procedures, planning quality, plan quality, competence, overview/situation awareness, work practice, workload, risk assessment and learning.

In the present paper, the above results are combined with more empirical results. The empirical study included a workshop with a major operating company on the Norwegian continental shelf. Ten experts in planning, risk management, management and operation

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participated. Challenges and opportunities for improvements in managing major accident risk within the planning process were identified using the thirteen influencing factors as a reference. Further, eight offshore personnel were interviewed (Sarshar et al., 2013).

The scope of this paper is limited to planning. Emerging tasks, e.g. critical corrective maintenance work that is carried out without being part of the plan, is not addressed. Execution of the planned work is also not addressed as such, although an important outcome of a good plan is its safe execution.

The paper is structured as follows: Section 2 provides background. In Section 3, the research methodology applied in this study is described. Section 4 and 5 present the main results from the research, covering the main challenges identified (Section 4) and opportunities (Section 5) for improved management of major accident risk through the planning process. Section 6 provides discussions and Section 7 conclusions and further work.

In Section 4 and 5 references are made to contributing factors identified through investigation reports. The investigations studied (Sarshar et al., 2015) are hydrocarbon leakage incidents on the Norwegian continental shelf and represent many operating companies. The investigations are therefore not specific to the operating companies participating in the interviews and the workshop, but are more generic.

2. Background

Smith and Harris (1992) analysed the causes of several major accidents with the aim of understanding how the maintenance function was involved. A key conclusion was that prior to major accidents, there is often a lack of detailed safety objectives and long-term safety control. In the absence of a tight safety and reliability control and consequent corrective actions, a mismatch can develop between the management's perception and the actual condition of the plant. The study further revealed that the lack of an internal department, responsible for reviewing plant safety matters, and independent of production pressures can have a serious detrimental effect on plant safety.

HSE (1987, p.14) reports a study of 502 maintenance related incidents: "Sixty four of the investigated incidents were identified as due to lack of, or failure of, permit-to-work systems. Nearly half of these incidents occurred during work on pipes, pumps and valves. The study indicates that permits are not being used as they should. Many cases were noted where a permit system failed when the checks required were not implemented. These circumstances point to the need for greater attention being paid by management to checking the use of the permit systems. Areas where current permits need to be improved relate mainly to the procedures for signing off a permit and handing the plant back to production staff. Greater attention also needs to be paid to physical isolation of plant."

Øien et al. (2010) focus on equipment criticality classification and how wrong classification or wrong use of classification can either result in critical equipment being insufficiently maintained or less critical equipment being overly maintained, thus increasing the probability of maintenance induced failures. Through the BP Texas City Refinery accident the authors exemplify that insufficient classification will increase the risk of major accidents and may lead to disasters.

Okoh and Haugen (2013) present a classification scheme for causes of maintenance related major accidents. The scheme is based on a combination of accident process and work process classification where the process based classification is further divided in active and latent failures. Many of the causes for latent failures correlate with the contributing factors in Section 2.2. Further, the authors correctly point out that major accidents are not caused by one causation factor alone, it is the combination of "lack of maintenance" or "lack of maintenance error" with "new hazard" or "initiating event" or other non-maintenance related causes that can cause major accidents (Okoh and Haugen, 2013, p.1064).

The Risk OMT project (Risk Modelling – Integration of Organisational, Human and Technical factors) (Gran et al., 2012; Vinnem et al., 2012) model the risk of hydrocarbon leakages using event trees to explain the relationship between planning and performance tasks, and the risk of leakages. Sarshar et al. (2012) study visualization of safety hazards, such as hydrocarbon leakage, on a geographical map of an installation and how this can contribute to raise awareness of potential hazard in a given situation.

Sanders (2005) study several maintenance induced accidents and process piping problems within the process industry and conclude as Wallace and Merrit (2003) that fundamentals of good practices for safe maintenance are:

1. Proper preparation for maintenance begins during the mechanical design of the process
2. The operating stuff must properly prepare for maintenance
3. Identify potential hazards and plan well in advance
4. Good communication are critical

The remaining of this section gives a brief overview of the planning process and the contributing factors that can affect the planning process based on major accident perspectives and investigation reports. Further details can be found in Sarshar et al. (2015).

2.1. Typical planning process in the Norwegian petroleum industry

The presented planning process described in this section is typical for the Norwegian petroleum industry. It has been developed and shaped by Integrated Operations (IO CENTER, 2015). One result is that much more administrative work is performed onshore than in the earlier days. Other results are that more of the time offshore is dedicated to execution of operation and maintenance and less to planning. Integrated operation builds on the capability to collaborate; via video conferencing; remote data and information sharing, and through fast access to expert advice from global support centres.

In accordance with this, the planning process is divided into a number of steps that are performed onshore, before the plan is sent offshore for execution. Fig. 1 illustrates the planning process ranging from operational plan (three months perspective) (step A–H) to work order (one–two weeks perspective) (step I–P) and work permit (day to day focus) (step Q–T) to execution of work (step U) offshore. The green roles represent onshore personnel and those with blue helmets represent offshore personnel. As can be seen, offshore personnel are only involved in the late phases of planning.

2.2. Factors that may influence major accidents

Factors that may influence major accidents were identified based on a theoretical review of major accident theories and a review of 24 accident investigation reports to identify direct and indirect causes of hydrocarbon leakages (Sarshar et al., 2015). A set of thirteen influencing factors was defined (Sarshar et al., 2015):

- Information flow – When information is missing, inadequate or not passed from one step to another in or across planning phases
- Communication – When communication channels are inadequate between roles and actors

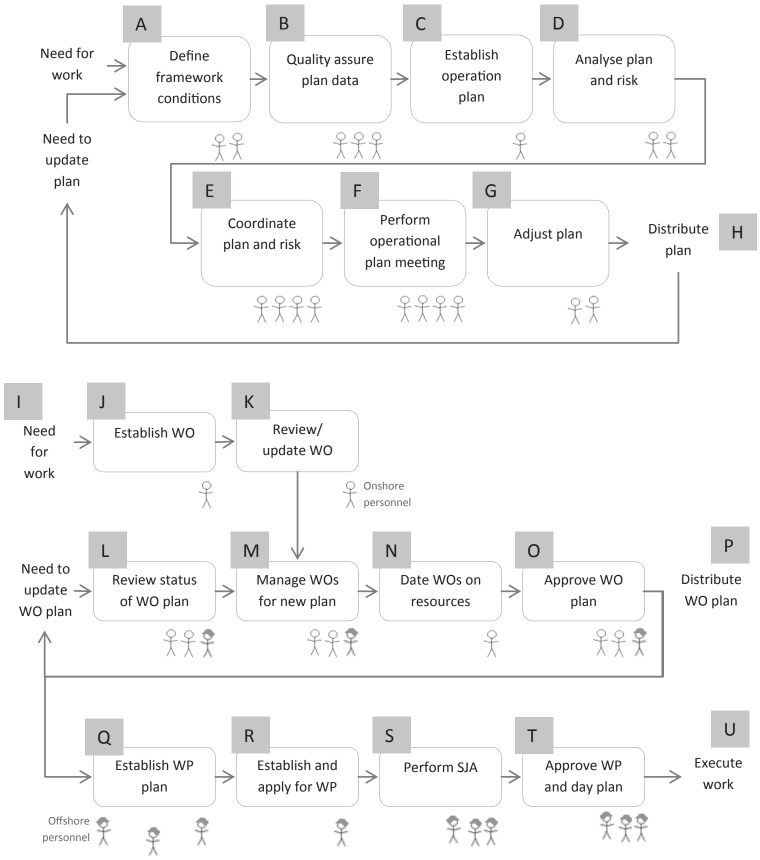

Fig. 1. The planning processes ranging from operational plan (step A–H) to work order (step I–P) and work permit (step Q–T) to execution of work (step U) offshore (Sarshar et al., 2015).

- Misunderstandings/misperception – When assumptions and misperceptions influence the quality of the work
- Documentation – When documentation is missing or not reflecting the real system
- Procedures – Missing, not available or imprecise procedures
- Planning quality – When the planning process is poorly performed or inadequately defined
- Plan quality – When the plan and its content is inadequately defined
- Competence – When required competence is not present
- Overview/situation awareness – Relates to overview of activities, their relations and complexity
- Work practice – When work practices deviate from procedures or defined processes
- Workload – Inadequate time and/or resources to perform an action or activity
- Risk assessment – Inadequate analysis or actions or measures not followed up
- Learning – One should consider learning from similar type of work when assessing it

Fig. 2 illustrates how the thirteen factors can be tied together around a planning and communication process: "1" shows how several of the factors concern the extent to which information is available and how it is communicated to the user. "2" covers the communication process itself. "3" represents the recipient of the information and the process of interpreting and making sense of the information provided. "4" contains the set of influencing factors that may affect the entire planning process. "5" represents the final outcome of the process, a plan with a given quality.

3. Method

In order to gather more information about potential challenges and suggestions for improvement of the planning process, as it is applied today, industry experts were gathered in a workshop. The workshop objectives were to:

1. Identify the industry challenges for major accident risk related to planning
2. Identify how the contributing factors affect the planning process in practice
3. Identify if there are additional challenges that are not covered by the contributing factors

Further, interviews with offshore personnel were conducted

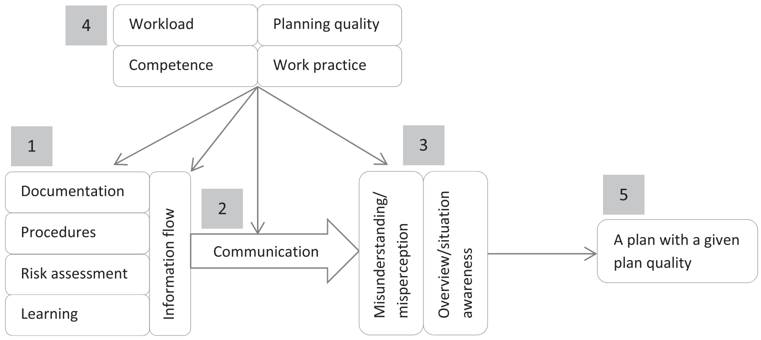

Fig. 2. Illustration of how the different factors relate to the planning and communication process.

with the objectives to (Sarshar et al., 2013):

4. Identify attributes of high-quality plans vis-á-vis preventing major accidents
5. Identify how the planning process should be organised to promote this

All participants in the workshop and interviews had good knowledge of the planning process.

3.1. Data collection

3.1.1. Workshop

The workshop included ten experts on planning, risk management, management and operation from the onshore organisation of one petroleum company. It was held at the operating company's location and lasted 4 h.

The workshop was organised as follows: After an introduction of all participants, an overview of the study from Sarshar et al. (2015) was provided. Then, the planning phases (Fig. 1) and the purpose of the different activities during the planning process were discussed. Next, the major accident perspectives were introduced (Sarshar et al., 2015, p.190) and the thirteen influencing factors (Sarshar et al., 2015, p.195) were discussed using examples from the investigation reports on hydrocarbon leakages (Sarshar et al., 2015, p.197) as reference. The major focus of the workshop was on identification of challenges and opportunities for improvements in managing major accident risk within the planning process using the thirteen influencing aspects as a reference.

All communication during the workshop was tape recorded. Data from the workshop were transcribed.

3.1.2. Interviews

Eight offshore staff members were interviewed. All interviewees had different roles during the planning process, and this ensures that the data reflect the planning process and its challenges from multiple perspectives. The positions covered were offshore installation manager, maintenance and operation leader, deck and marine leader, health and working environment team leader and one technician from each of the four disciplines process, instrument, electrical and mechanical.

The interviews were semi-structured and carried out individually, lasting 30–60 min. The main focus was on how information availability and information flow influence the quality of the plans.

The focus was on information flow between formal meetings and informal talks and discussions they participate in during daily operations. The attention was not only on the information and data used in meetings, but also during preparations and between meetings. Data from the interviews were transcribed.

The aspects relevant for this study which were discussed in the interviews include (Sarshar et al., 2013):

- Which circumstances can affect the planning process?
- Which aspects of a plan should have been dealt with earlier?
- Which aspects around the planning process are not fully supported?
- Have you experienced challenges with information flow?
- How is the relation between how a task is planned to be executed versus its actual execution?
- Which risk is related to the planning process?
- What is the relation between the risk picture and activity level?

3.2. Data analysis and management

The data sets resulting from the workshop and the interviews were initially treated separately, but following the exact same procedure. This was done to explore the extent to which onshore and offshore personnel's view on challenges would be similar, i.e. data obtained from the workshop and from the interviews, respectively.

The process was as follows: The entire dataset was decomposed into groups, which each consisted of one type of challenge. The identified challenges were then associated with the phases in the planning process, depending on when it was reported to arise. The outcomes of the part of the data analysis process are documented in Tables 1 and 2 in Section 4, respectively.

Following this, the challenges identified were grouped in four main topics. This was done in an attempt to identify the set of factors which it is most critical to address to reduce the risk that planning factors will contribute to the risk for major accidents. The four challenges were exemplified with industry experiences gathered through the workshops and interviews, as well as from the findings of studying the 24 investigations reports analysed by Sarshar et al. (2015).

The main topics are then discussed separately. In these discussions, the major accident perspectives and theories are used as basis. The outcomes of this part of the analysis are provided in Section 4.

Finally, proposals and suggestions for how to improve are then presented in Section 5. These are based on the workshop and interviews as well as learnings from investigation reports.

The data set that has been collected is limited in size and clearly not adequate for statistical analysis. However, the data are still considered to be useful and relevant for the purpose of identifying

Table 1
Issues highlighted from the workshop addressing the onshore perspective on planning related to the influencing factors and the planning process.

Influencing factors	Operational plan			Work order plan			Work permit plan		
	Est.	Assess	C&A	Est.	Assess	C&A	Est.	Assess	C&A
Information flow	Relevant information in meetings								
	Tools to structure information and make it available								
Communication	Risk communication and loss of information								
Misunderstandings	Misunderstandings in meetings								
Documentation									
Procedures									Not always followed
Planning quality	Late risk identification								
	Error propagation								
						Handling change			Handling change
									Re-planning
Plan quality									
Competence	Relevant competence in meetings								
			Transfer of competence						Transfer of competence
Overview of activities			Tools for visualizing simultaneous activities						
					Late risk identification				
Work practice					Adding work in morning meeting		Late risk identification		Adding work
Workload								Short time to assess	
Risk assessment	Late risk identification								
				Systematic analysis of risk					
						Dynamics in scope			Re-planning
Learning		Learning from incidents							Transfer of competence

Table 2
Issues highlighted from the interviews addressing the offshore perspective on planning related to the influencing factors and the planning process.

Influencing factors	Operational plan			Work order plan			Work permit plan		
	Est.	Assess	C&A	Est.	Assess	C&A	Est.	Assess	C&A
Information flow							Challenge to remember all said from meetings		
Communication									
Misunderstandings							Work permits need clarifications		
Documentation	Inadequate documentation and work descriptions								
Procedures									
Planning quality				Re-planning due to inadequate quality			Change handling		
Plan quality				Inadequate resource planning					
				Side activities not planned for					
Competence	Lack of offshore competence onshore								
Overview of activities							Inadequate overview of activities and operations		
Work practice									
Workload	More people needed in right positions during high activity periods								
				Decreased plan quality due to high workload			Pressure due to inadequate quality of work orders		
Risk assessment									
Learning									

challenges.

4. Challenges for managing major accident risk through the planning process

To give a better context for the challenges that have been identified, these are linked to the influencing factors and the planning process. Tables 1 and 2 present challenges identified through the workshop and the interviews, respectively. The columns represent the planning phases and their steps. Each planning phase is divided into establish activities and plan (Est.), assess the plan (Assess) and coordinate and approve its activities (C&A). The rows represent the influencing factors the topics relate to.

Based on the results from the workshop, interviews, accident reports and theoretical work, the challenges identified have been grouped into the following four main topics:

1. Inadequate plan
2. Inadequate planning
3. Inadequate shared overview and understanding
4. Late risk identification

The first topic relate to the quality of the plan (step 5 in Fig. 2) which is the result of the planning process that can have implications for major accidents. The remaining three topics relate to the planning process (step 1–4 in Fig. 2) and aspects that can prevent development of high quality plans.

In the following subsections, these topics are discussed. In each subsection, a brief description of the topic is provided, followed by a summary of the challenges identified in the workshop and interviews. Relations and aspects related to major accident perspectives and theories are included in the discussions.

4.1. Inadequate plan

4.1.1. Anchoring to phases in the planning process

A work order defines the need for work and is a formal request for the work that shall be done. The work orders are normally generated based on the operation plan. Before any of these can be performed, the personnel that shall execute a task must apply for a work permit which is a permission to perform a specific work task.

The preparations and quality of work orders and work permits are of high importance to ensure that potential risk associated with the job and the system the job applies to be identified and that measures are in place to perform the work safely.

4.1.2. Identified challenges – their basis and implications

For the offshore organisation, it is important that plans, work descriptions and assessments are done with sufficient quality to support and enable them to perform their work. Based on interviews of offshore personnel, Sarshar et al. (2013) identified a set of challenges related to plans, work descriptions and assessments. The main finding may be summarised using a formulation from one of the interviewees, who stated: *"… the major risk is that we do not have a common or shared understanding between onshore and offshore on the different activities. Activities are planned onshore and they perform risk assessment, but that is sometimes not satisfactory from the line management's point of view, or from an operational point of view or from the technician's point of view"*. Thus, additional assessment is performed offshore to get a satisfactory quality. This may be too late, resulting in task preparations having been performed in vain if the task cannot be performed after all because risks have not been addressed.

An example of a mismatch of understanding is if personnel from technical integrity (onshore) focus on e.g. facility hazards (CCPS, 2010, p.182), the offshore technician who is to disconnect equipment is more interested in the specification document and steps involved in opening the equipment.

The interviewees were also asked which aspects of a plan that preferably should have been dealt with in an earlier planning phase (CCPS 2010). The majority of the responses to this question were related to what the offshore personnel expected from the onshore organization regarding the quality of the work order. The work orders form the basis for applying for a work permit. Thus, if a work order has insufficient descriptions, poor risk assessments or other shortcomings, this will cause problems and delays in the work flow for applying for and approving a work permit. The most important impact a low quality plan has on offshore staff is that they sometimes *end up doing preparations or assessment themselves that they would have expected to be in place already during preparations* of the work orders. In some cases, larger projects and jobs are sent back onshore for better planning with comments on what to include and improve. Issues that are not captured onshore are expected to be identified offshore, and the plans can thus go through iterations and improvements. One of the reasons given for this was that onshore staff without offshore experience has "no way" of identifying or imagining the challenges that may arise related to a job that is to be carried out offshore.

The "Process Safety Competency" by IChemE Safety Centre (IChemE, 2015a) is one of the major industry competency standards for individuals performing risk assessment activities. The statement from the interviewee may imply that more personnel with installation specific competence should be part of the planning steps.

Another aspect is that a job often requires support from one or more of the technicians offshore and the need for such additional resources are often not part of the plan. Some of the disciplines are involved in a lot of such support activities though it is not in their discipline's original plans. This implies that activities are not actually planned properly.

Inadequate quality of work and plans may result in additional work for the offshore organisation which affects the workload and hence time-pressure. Rasmussen's conflicting objectives perspective (Rasmussen, 1997) explains causation of accidents as the result of actors transcending the operational envelope of the systems they operate. Conflicting objectives may influence the steps for establishing and managing work orders and work permits (Sarshar et al., 2015). Time and cost pressure can result in staff not taking the necessary time to prepare the work, not considering all aspects of the work (e.g. with respect to HSE, resources, or competence needed) and the focus being on scheduling and date/time for the work. High workload was identified as one contributing factor causing an incident with hydrocarbon leakage (Sarshar et al., 2015, Table 6). Another factor was *procedures*: *not precise procedures (which valves that should be opened and in which order)*. This issue should have been identified earlier in the preparation of the work. This should be clear to those making the procedures and those who use them should have a channel to communicate such inadequacies back to those preparing the procedures. Robust procedures (operating and maintenance) are fundamental to an effective process safety management system. A relevant guideline relating to the development, auditing, and maintenance of key procedures is given by Center for Chemical Process Safety (CCPS, 2012).

An inadequate plan may create latent conditions, which contribute to the risk of major accidents. These conditions can be summarized as follows:

- The quality of the work orders does not meet the requirements from the offshore organisation. Issues include:
  - Inadequate work descriptions
  - Inadequate resource allocation
  - Side activities not foreseen or planned
- The workload and time-pressure for offshore personnel increase.

It may be argued that involvement of offshore personnel can be easily resolved by simply doing more of the planning offshore. However, this is also a cost issue – it is far more expensive to have personnel offshore than onshore and it is presently not feasible to do all planning offshore. Besides, with a lot of the technical expertise being located onshore, we will clearly loose something by moving everything offshore also.

4.2. Inadequate planning

4.2.1. Anchoring to phases in the planning process

External framework conditions, status on technical barriers and risk of activities must be analysed and seen together to ensure that the installation's risk picture is acceptable. These, and assumptions made during risk assessment, need to be documented and available for detailed assessments occurring in later steps. While this is the case within the operational plan (see the steps for operational plan in Fig. 1), the same process does not apply to the work order and work permit phases. The risks identified and analysed differ in the different planning phases. The intention is that the framework conditions, risk assessments and quality assured data from the operational plan are made available and used in later phases of the planning process. If risk is identified in the operational plan phase and this is not properly communicated to the work order plan phase, information of critical importance for ensuring safety is lost. The identified and documented risk must be available and understandable to decision makers during planning and execution of maintenance and operations.

Another aspect is circumstances that can cause changes to a plan before it is executed. Such circumstances can include disturbances, incidents, consequence of work and poor work description in the work permit phase and lack of material, personnel or competence in the work order phase. Re-planning and reassessment of plans would require that framework conditions and assumptions made in earlier planning phases are available and understandable.

4.2.2. Identified challenges — their basis and implications

One workshop participant explained how risk assessment performed in earlier steps and phases of the planning process have a different focus than executing personnel offshore may expect. The focus of offshore personnel is often on occupational safety, and they will not necessarily address major accident risk factors, as these are expected to have been taken care of by operation and maintenance leader and area responsible, process engineers who prepare the process equipment for maintenance, etc. As one gets close to execution of work, the focus is more on occupational injury risk and less on major accidents (Leistad and Bradley, 2009). However, the executing personnel must be aware of both the occupational and major accident risk. They should understand that he or she can drop the valve when removing it and injure their feet, but also that removing the valve may e.g. disable the firewater system in the area. Maintenance and operations personnel must understand process safety in their context, since these personnel are at the sharp end in operating and maintaining the facility (IChemE, 2015a).

Another workshop participant explained that there is a large difference in the *dynamics of scope*, as the approval of a work order plan gets close. Based on internal workshops the company had held with their operating groups on how they work with the work order plan and how they prepare work permits, they found that some operating groups have a long time horizon on plans with few changes while others have many changes during the last days before approval. Keeping the risk assessment up to date with a living scope is no easy task. This potentially creates a set of conditions in which a major accident becomes more likely. Hence, the quality of the long term planning affects and sets the preconditions for maintaining control of risk at the sharp end.

From the study on investigation reports and their relation to the planning process (Sarshar et al., 2015, Table 6), examples of influencing factors can be related to managing and dating work orders (step M and N in Fig. 1). These include *Misunderstandings*: *misperception around the criticality of the work* and *Planning quality*: *failure in prioritizing of work order with respect to consequence* and *material needs not coordinated with prioritization*.

In the morning meetings, one may *add additional work* that is not planned for in a work order. It may be argued that this should not happen, but one of the most common causes of this is failures and other events that have occurred in the last couple of shifts. These may be failures which are critical for production and/or safety and therefore have to be fixed quickly. Very late changes to the plan will therefore occur from time to time. There are also examples of *re-planning* or including jobs that were not in the original plan due to an unplanned event, e.g. a production stop in a segment. An incident caused by re-planning due to such a stop was explained by a participant: *As the stop was focused on in a morning meeting, the team decided to move a job that was planned to be done weeks later to this day as this job required a shutdown. The intention was good and the control room had low activity level so they wanted to take advantage of the high capacity of the operators. However, they only identified the positive aspects of moving the test to this date and did not consider potential downsides. They changed the plan without considering preconditions for the jobs on the plan and they got an incident due to simultaneous activities*. This statement provides a good example of the necessity of robust and effective management of change. Lorenzo et al. (2015) explain how failure to recognize change is typically the primary reason a company's management of change system fails. Individuals often overlook changes if they assume there is no hazard associated with them. On the other hand, if a hazard is created and recognized, workers realize it should be considered a change and a management of change evaluation is warranted. The authors further detail how training can contribute in enhancing workers in hazard identification.

Based on one of the participant's experience, when unplanned events occur, the plans seem to be put aside and the unplanned event gets all the attention and focus. This occurs even if it is not a critical event and even if the impact of the change in the plan is not (re)assessed. Such events can also escalate and create large backlogs (since the original plan is rejected) which again can make it difficult to maintain overview of activities on board. This often has effects for months to come.

It was further stated that robustness with respect to competence available and manning could increase the quality of plans. The threshold to include expertise from e.g. planning and operation centres should be lower, both in abnormal but also normal operation.

From the investigation reports (Lorenzo et al., 2015) some examples are found that can be related to re-planning. These include for the factor *Planning quality*: *work permit modified after approval* (This can be related to management of change), *Plan quality*: *not precise description of new activity added to an already assessed work order*, and *Overview of activities/situation awareness*: *onshore had no overview of activities offshore when plans were changed to include test on Emergency Shutdown valve (ESDV), no new assessment of plan*.

Though beside the scope, the importance of capturing changes caused by the execution of the work (can be new activities) was also highlighted in the workshop. Wallace and Merrit (2003) discuss the hazards posed by maintenance activities and present good practices identified from investigations. The paper focuses on risk to people during maintenance which often comes from its human—machine interface. Their recommendation is to identify hazards in advance and a plan developed to proceed safely if precautions cannot be met. If, during the course of work, it is discovered that hazards may be present, it is important to stop work and conduct hazards analysis.

Inadequate planning and change handling can contribute to the risk of major accidents. The challenges can be summarized as follows:

- Inadequate planning quality
  - Short preparation time
  - Offshore expertise not present
- The impact of changing the plan is not (re)assessed.

  - The personnel may not have qualification to assess the quality of a revised plan from a safety perspective – locally and globally.
  - Are there enough resources to perform the necessary reassessment?
- In the morning meetings, one may *add additional work* that is not planned for in a work order.
- When unplanned events occur, the plans seem to be put aside and the event gets all the attention and focus even if it is not a critical event.
- Capture changes which the work causes (can be new activities)

4.3. Inadequate shared overview and understanding

4.3.1. Anchoring to phases in the planning process

From the point in time when jobs are put on a plan they shall be assessed for simultaneous relations. This applies to the operational, work order and work permit level. Some activities cannot be performed simultaneously due to risk or shared resources needed and others might be best performed in sequence.

4.3.2. Anchoring to ICT tools used in the planning process

It is important to have relevant information available, and good ICT (Information and Communication Technology) tools can be a key means for ensuring this. Today, there are different tools available in different planning phases. The operational plan is established and managed in systems such as Microsoft Project or SAFRAN Project (Safran, 2015). Risk assessment of work in the plans are performed and documented separately in other systems, such as Excel and Word.

The work orders are established and managed in systems such as SAP. One workshop participant said that the systems used for the operational plan and the work order plans do not communicate: The operational plan resides in one system and the work order plan in another. The work permits are in the same system as work orders. These have a relation: one normally needs a work permit to execute the work order.

These tools are made for planning and scheduling and not for communicating risk. Results from risk assessments are documented separately and may be attached to a job in the operational plan or in the work order plan.

The companies studied do have systems for work planning and scheduling, risk analysis, management of change, and incident reporting and investigations. These are however not fully integrated.

4.3.3. Identified challenges – their basis and implications

Both interviewees and workshop participants pointed out that it is challenging to have a total overview of activities and their risk. With today's systems, it is challenging to assess many work orders and work permits for risk simultaneously, even if they can be assessed individually. The potential risk information is recorded in text format for all operations. This makes the information available but does not enable assessment or presentation to provide an overview of all potential risks in an area or within a given period. *Information must be available in a structured* and readily accessible way to support the work and decision-making processes. It was stated in the workshop that *we are actually dependent on a good tool to communicate and visualize this to all actors involved in the processes*.

During high activity periods getting such an overview requires more effort; more people are needed in the right positions and it is more important that the onshore planning is done properly (that enough resources, material and personnel are available).

Work permits and descriptions sometimes need clarification. Several informal meetings and discussions occur between the formal meeting activities. These can be between offshore staff and with the onshore support centre. Some offshore engineering disciplines discuss the work with one of the process engineers or the M&O leader before the work permit is created. This could also be a requirement of the organisation. The work permit meeting may clarify HSE aspects related to each work permit, another area for capturing misunderstandings is in the central control room (CCR) were the operators activate the work permit for execution. There could also be other aspects that are important to evaluate at that time, and involving the CCR early in the work permit process is beneficial for increasing their understanding of the work permits.

From the study of investigation reports and their relation to the planning process (Sarshar et al., 2015, Table 6); some examples are found that can be related to the influencing factor O*verview of activities/situation awareness*. Three examples of lack of overview are provided. The examples are: *Onshore had no overview of activities offshore when plans were changed …, Bleed to unsafe area was not coordinated with other activities*, and *(Very) high activity level at the installation*.

A problem related to information transmission could be the amount of information available or received. It is important to be clear about what information is worthy of attention, and to provide some ideas or tools for the facilitation of sorting information with respect to importance.

Another issue with ICT tools and new technology solutions is technology literacy. Sarshar and Rindahl (2014) explain how collaboration and decision arenas fail in good communication and obtaining good shared understanding due to poor technology literacy. This can be overcome with sufficient resources allocated to training. Support for training on all required tasks must come from the highest levels of the organisation.

Inadequate shared overview and understanding may contribute to the risk of major accidents. The challenges can be summarized as follows:

- Inadequate overview of:
  - Simultaneous activities
  - Area risk
  - Barrier status and conditions
  - Process status
- Inadequate information flow and communication
- Poor ICT tools and technology literacy

4.4. Late risk identification

4.4.1. Anchoring to phases in the planning process

Risk related to major accidents is identified in the operational plan phase where one considers larger simultaneous activities such as heavy lift operations. In the work order phase, the activities are detailed and dated on resources, and in the work permit phase they are assessed when work permits for the activities are applied for. It is in this last phase, shortly before execution, that one identifies risk related to specific work such as work type, need for Safe Job Analysis (SJA) and simultaneous activities. SJA is a systematic and stepwise review of all risk factors prior to a given work activity or operation, so that steps can be taken to eliminate or control the identified risk factors during preparation and execution of the work activity or operation.

The work order is focused on describing what should be done and what equipment and resources are required. This also includes considerations of major accident risk since this may have an impact on resources required. The considerations include that required risk controls are identified, work specific aspects that can impair existing barriers and compensating measures required are identified and that a work operation can represent a major accident risk.

When managing work orders for new plan, the focus is on getting the right activities on the plan based on certain criteria such as criticality of the work and "required end", and to be able to carry out all the work on the plan. This is then scheduled with respect to resources and put on the plan to have the right workload for all technicians. Next, the work order plan is evaluated for approval as illustrated in Fig. 1.

4.4.2. Identified challenges — their basis and implications

After the establishment of the work orders, there is no good way to identify hazards and risk to support systematic analysis of risk in the work order plan (as the risk identification comes first in the work permit level).

Both onshore and offshore expertize is required in hazard and risk identification and analysis. Some aspect could and should be managed earlier in the process by the onshore staffs which have a wider overview of things while aspects closer to execution must involve offshore maintenance and operation personnel.

The challenges of late and inadequate risk identification in the planning process may contribute to the risk of major accidents and can be summarized as follows:

- The work order plan is not assessed for simultaneous operations before approval. Risk assessment is performed when establishing individual work orders, but the ones on the plan are not assessed all together. This is first done at the work permit level.

4.5. Remarks

Though many of the challenges highlighted in this chapter can be addressed by e.g. robust procedures, good competency systems, HSE management systems, management of change and compliance with governing documentation and standards — incidents and accidents do occur. The findings point to areas where systems can be improved, while we also have to acknowledge that it is unrealistic to assume that systems that are introduced always work perfectly. There is in some cases a gap between what is intended to be good practice versus what is the current practise.

In Section 5, proposals discussed in the workshop for some of these challenges are presented. It is underlined that the intention not has been to address all challenges that have been identified above.

Further, the study reported on implies that the IO concept is not fully implemented with respect to the e.g. information sharing, and through fast access to expert advice from global support centres. The challenges related to information flow illustrates that the potential of information sharing is not obtained and the challenges related to having installation specific competence easily available illustrates that fast access to expert advice is not present in the studied organisation.

5. Proposed improvements

Proposals and suggestions for how to improve on the challenges are presented in this section. These are based on the workshop and interviews as well as recommendations from the investigation reports studied in Sarshar et al., (2015). Many of the recommendations from investigations are incident specific and we would expect that these have been implemented. However, generic recommendations that can be related to the planning process or the influencing factors (Section 2.2) are included as proposed improvements in this section.

The improvements can be grouped in the following three categories:

- Improvements to the planning process
- Improvements for risk structuring
- ICT tool to provide shared overview

Specific proposals for these categories are presented and discussed in the following subsections. Table 3 links the challenges from Section 4 to the proposed improvements discussed in this section. Some of the proposals are very specific and concrete while some are more abstract and generic.

5.1. Improvements to the planning process

Proposed improvements that affect the work order and work permit process are illustrated in Fig. 3. The potential consequences of these proposals are discussed in Section 6. The proposals are to extend some of the activities and adding new ones:

- Extend step J "Establish WO": During the establishment of a work order, the work type and possible known associated risk specific to the work/activity type should be specified. Offshore competence will probably be required. This will further allow for earlier risk assessment (new step before step O).
- Extend step J or K "Review/update WO": As discussed below it is proposed to perform a preparation step onshore for the SJA offshore. The preparation step onshore is performed either in step J or K. Offshore competence will probably be required.
- New step before step O "Approve WO plan": The new step shall be to assess the WO plan with respect to major accident risk. There is today no assessment of the WO plan for this purpose.
- Detail step S "Perform SJA": The activity of performing SJA offshore should take input from the SJA preparation step onshore.

When the work order plan is established, before approval, the plan that is due to be executed in the next few days should be assessed with respect to the consequences of the planned work for major accident risk on the installation under the framework conditions applicable at that time.

The workshop participants argued that risk identification and identification of measures reducing and controlling risk in the work order should be in place when establishing the work order plan in order to put the risk on the table and give decision makers the opportunity to have a better total picture. This could also mitigate fragmentation, that one only considers work individually as is often the case for the work orders and that one can consider the overall activities together before one reaches the work permit meeting the day before execution.

When establishing the work order, one can in many cases also define the work specific risk, such as work type, need for SJA and whether the work has constraints for simultaneous activities. This may however require offshore/execution competence of the work. Specifying such information for an activity earlier allows for improved risk understanding and better work description when assessing the work order plan before approval.

In the MIRMAP project, a method for characterizing risk related to specific work activities is proposed (Haugen et al., 2015). The steps in the method include screening of all jobs to determine their risk potential, and then perform simplified handling of jobs with low risk potential and detailed handling of jobs with high risk potential. Simplified handling essentially means that no further evaluation of the job is done, except for a continuous monitoring of status. Detailed handling includes gathering relevant risk information to assess the risk per barrier function for each job, assess

Table 3
Identified challenges and proposed improvements.

Identified challenges

Plan quality	Inadequate work descriptions, resource needs and side activities not foreseen or planned
	Increased workload and time-pressure offshore
Planning quality	Short preparation time
	Offshore expertise or installation specific competence not present
	Impact of changing the plan is not (re)assessed
	Capture changes which the work causes
Shared overview and understanding	Inadequate overview of activities
	Inadequate information flow and communication
	Poor ICT tools
Late risk identification	Work order plan not assessed before approval

Proposed improvements

Risk characteristics for the job should be identified when establishing the work order	Planning process
Perform a SJA preparation step onshore	
Assess work order plan with respect to major accident risk before approval	
Use separate notification on additional jobs	
Include installation specific competence and experience more often in job preparation and risk assessment	
Structure risk information from operational plan to work order plan and to work permits	Risk structuring
Make results from risk assessments visible	
Visualise simultaneous activities, area risk and potential hazards	ICT tool
Make information available for all involved in the planning and execution process	

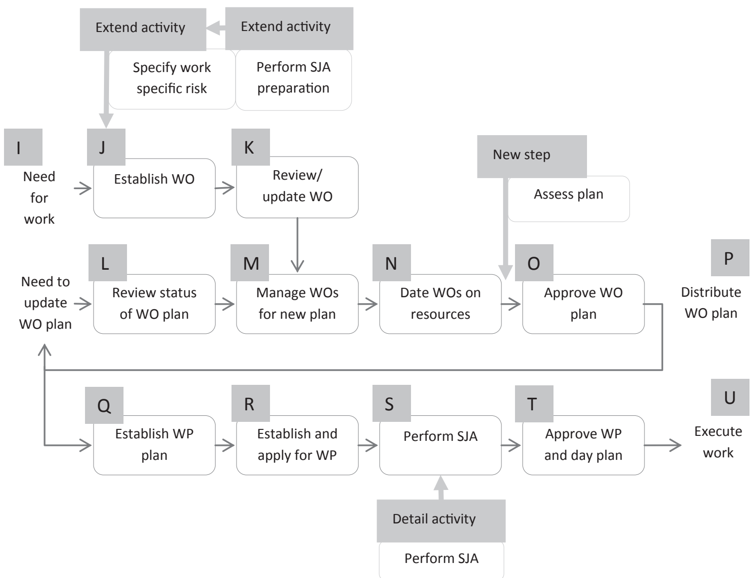

Fig. 3. Proposed improvements to the work order and work permit planning processes.

area risk and total risk. Such risk characterization should be done at the work order level with input from the operational plan, and can form the basis for assessment as one move to work permit level. The purpose of the method is to detect changes that may increase the risk potential of a job as planning progresses.

From the study of investigation reports and their relation to the planning process (Sarshar et al., 2015, Table 6) some examples of contributing factors that could be related to the establishment and review of work orders are provided (step J and K in Fig. 3). These include for the factor *Documentation*: *inadequate documentation and drawings of a valve*, *Plan quality*: *the work description did not fit the criticality and importance of safety of the work* and *Competence*:

there is a procedure for the work which was not known and used. Preparing the work order with necessary documentation and attachments should help the risk assessment in later steps. A comprehensive HSE management tool which integrate establishment of work order and risk analysis would be helpful.

Other examples of influencing factors from the study can be related to managing and dating work orders (step M and N in Fig. 3). These include for the factor *Misunderstandings*: *misperception around the criticality of the work* and for the factor *Planning quality*: *failure in prioritizing of work order with respect to consequence*, and *material needs not coordinated with prioritization*. These examples stress the need for assessing the plan before approval as proposed above.

Another proposal from the workshop was to perform a preparation step to SJA. The preparation step shall be performed onshore where onshore expertise gives input, and the SJA step offshore (as is today) by the executing personnel who also verify the input from onshore. Framework conditions for the activity can be gathered from the operational plan to form the background for the preparation step. In this way, onshore expertise and experience can be gathered and structured as background information for those who are to execute the work. One or two of the involved roles, e.g. SJA responsible/leader, should participate in both steps to ensure good information flow and avoid misunderstandings. A recommended guideline for SJA is provided by the Norwegian Oil and Gas (NOG, 2011).

In turnaround plans, risks and need for SJA are identified months in advance. Turnaround plans are planned work that is to be carried out during shutdown periods, and the pressure to execute the work in time is high. Work permits and SJA are established well before they are put on plan. If the same could be done with maintenance work, we would move in the right direction with respect to identifying risks: *better time to identify risk*.

More offshore experience is needed in the planning processes onshore. Some key steps in the planning process where offshore or installation specific competence could improve the quality include step J and K in the work order plan and step D, E and F in the operational plan.

A recommendation from investigations is related to change management offshore. The proposal is to make use of separate notification on additional jobs that emerge. This is to ensure correct treatment and risk assessment. Similarly, risk shall be reassessed when prerequisites for work or external factors change (e.g. weather conditions).

5.2. Improvements for risk structuring

It was suggested by a workshop participant to include a field at the top of the work permit forms for risk information related to that work. Exactly what type of information this field should contain was not specified. It was also stated that this should have been linked all the way back to the plan framework so the same fields in the form where brought forward for each step and all the way to the work permit. One could begin with identified risks in the main plan, add more in the operational plan and further more as one move towards the work order and work permit. This background is important through all steps in the process.

Results from risk assessment and risk measures identified should not be stored in a document attached to a job description. It should be made visible so it can be understood and taken into account, not only for the personnel who are to execute the specific job, but also for those who are to assess it for risk and work in nearby modules or areas. The need for a HSE management tool is discussed in Section 5.3.

A related recommendation from investigations is on the quality of deviations and weakness in barriers: compensating measures must be specific and be available as tasks for executing personnel. These tasks must be verified for correct implementation.

Sklet (2006) presents a set of scenarios that may lead to hydrocarbon release on offshore oil and gas platforms. The scenarios are described by an initiating event (i.e. a deviation), the barrier function introduced to prevent the initiating event from developing into a release, and how the barrier functions are implemented in terms of barrier systems. Both technical and human/operational safety barriers are considered. The barrier functions in these scenarios that are related to maintenance activities can provide valuable input to define how and which activities can weaken these barrier functions. This could help personnel when e.g. establishing work orders to include aspects for how the activity influence barrier functions.

5.3. ICT tool to provide shared overview

Albrechtsen (2013) points out the benefits of IO, being that it "supports risk-informed decision-making (for example, by improving the quality and relevance of safety-related data, including real-time data), provides more information, offers better ways to visualize risk information (more information is available and can be accessed anywhere – anytime) and provides access to experts in multidisciplinary onshore support teams. On the other hand, inadequate IO solutions may be a factor that contributes to major accidents through, for example, poor collaboration and integration of onshore–offshore teams and lack of information flow between relevant actors" (Albrechtsen, 2013, p. 11).

Regardless of solution, good information has some characteristics that should be in place as described by Westrum (2014):

- It provides answers to the questions that the receiver needs answered. The information should respond to the needs of the receiver, not the sender.
- It is timely. If not it may lead to a wrong decision since information is used in decision-making.
- It is presented in such a way that the receiver can effectively use it.

Communication of information related to risk is not straightforward. Roth (2012) points out that ever-increasing volume of risk data are produced every day with the intention of supporting risk analysis and decision-making. It is a challenge to communicate accurate information to users such that it can be understood and used in operational risk analysis and decision-making.

To enable assessment of the work order plan with regards to major accident risk (as proposed as a new step in Section 5.1), a comprehensive HSE management tool may assist in this by integrating work processes and risk analysis. For example, a work order related to a specific piece of equipment could automatically link to all previous risk analysis related to that equipment, previous incidents and management of change documents, as well as incidents in other units or facilities related to similar equipment work. In this instance, the software tools aid the organisation in bringing risk information related to the work at hand closer to the user, so that the maintenance and operations organisation can make better informed decisions as to how to plan and execute the job. Even with software assisting the effort to make the information more readily available, the risk information should still be reviewed by those closest to the execution of the task – the personnel offshore.

There exist various tools for HSE management where of some integrate work planning and scheduling, work orders, work permits, risk analysis, management of change, and incident reporting and investigation to some extent. Such tools can include EXP, Intelex, OSSuite, iEHS, KMI, VisiumKMS, SAP EHS Management, Visavi LivePlan and iSee. A follow up study of the work reported in this paper is to evaluate these with respect to how well such tools communicate risk throughout the planning process to execution of the planned activities.

6. Discussions

The outcome of the present study has some potential biases. The empirical part of the study is based on investigation reports, a workshop with one operating company, and interviews of offshore personnel from another company. The challenges and proposals gathered from these sources represent what the expert participants involved have experienced and do not necessarily represent all industry challenges and opportunities. Further, the findings are limited to the challenges and recommendations identified by Sarshar et al. (2015) based on 24 investigation reports analysed. Many of the recommendations from these investigations are incident specific and we would expect that they have already been implemented. Very few were generic recommendations that can be related to the planning process. The most common was to *go through the incident with all shifts for learning and improvement*.

An observation from Tables 1 and 2 on issues highlighted from the workshop and interviews related to the influencing factors and the planning process is that the onshore organisation (workshop data) identified no challenges related to plan quality while the offshore organisation (interviewee data) identified several. This illustrates the challenges of shared understanding between the two groups of what is expected. Lack of offshore experience among onshore personnel can be one reason for this.

6.1. Challenges and their constraints

The challenges identified can be related to some key aspect of the resilience engineering perspective. The practice of resilience engineering (Hollnagel et al., 2011) requires that anticipation, monitoring, responding and learning are considered and addressed at all levels of the organization. The challenges in ensuring this, however, are many. Resilience assumes that one can foresee the changing shape of risk before failure or harm occurs. It requires monitoring key indicators to observe how close the organization is to the safety space boundary. The organization must then have the capability to respond by adapting or being flexible to the measured changes and opportunities. The loop is not complete until lessons learned are incorporated with regular revisions of performance standards. For instance, key performance indicators related to work orders or work permits are important indicators of an effective process safety management system (iChemE, 2015b). Examples can include KPI on plan efficiency, plan periodic achievement and plan productivity.

Some aspects from the resilience engineering perspective which may affect the planning process:

- Preparedness – ability to respond to problems ahead of time is challenging when the plans and their activities are inadequately prepared. This would require adequate installation specific competence in the onshore organisation.
- The ability to adapt to changing conditions is challenging when decision makers do not have necessary information and overview to manage change in plans. This can be the result of inadequate planning (preparedness), inadequate communication of plans and/or inadequate information on ongoing activities.
- Buffering capacity – having available resources necessary to respond to arising problems and complex issues is challenging if the organisation already is under pressure (time and cost) due to inadequate plans and planning. Time and cost pressure actually has two effects in this case: Inadequate time for the planners will lead to low-quality plans which in term may lead to time-pressure to those performing the work because the work is not sufficiently planned.

6.2. Some implications of the proposals

The proposals on extending and adding new activities in the planning process (Section 5.1) may demand more time spent in preparing the work orders and the work order plan. As these activities are performed onshore, this should not be in conflict with the principle of spending time mainly on execution offshore, rather than on administrative work. An important aspect to consider is how these proposals can be implemented without increasing workload, having in mind the conflicting objectives of efficiency versus safety.

Regarding the SJA preparation step onshore, a potential consequence is that the SJA itself (performed offshore) may assume that all risk has been identified in the preparation step onshore. The idea is, however, that the first step prepares and includes technical integrity in the SJA process. The SJA offshore must still include all executing personnel offshore as is required today. An aspect worth studying can be if offshore personnel's risk understanding decreases over time if they in practice are less involved in risk assessments (preparation of the SJA). Another aspect is whether this may affect knowledge transfer between offshore personnel; if offshore personnel are contractors, will they base their work on the assumption that all risk has been identified earlier and will they be sufficiently familiar with the platform to identify all risks?

The latter two proposal categories concern information and risk structuring and ICT tools for managing and visualizing these. These proposals require more effort and introduction of new technologies for risk management. An issue with ICT tools and new technology solutions is technology literacy. Sarshar and Rindahl (2014) explain how collaboration and decision arenas may fail in good communication and obtaining good shared understanding due to poor technology literacy: *Rolling out new technology or ways of working can be difficult when people are busy with their daily tasks and skilled in their old ways of doing them. Leaders can assist with this introduction to new concepts by using the collaboration technology regularly themselves, demonstrating how it works, and systematically encouraging team members. Dedicated training may also allow all members of the teams to become familiar with the interface and useful configurations of this, and point out the benefits and added value of working this way. Technology shall support and enable a desired work practice, and not the other way around and it is recommended to train as you work. In some organizations, leaders perform much of this training for their staff by being good role models, and by handing over the touch panels, mouse and keyboard to their less practiced colleagues* (Sarshar and Rindahl, 2014, p.6).

Taylor et al. (2014) study how leaders can use technology to enhance risk perception and communication and state that risk visualization tools are not sufficient in themselves for risk management, an overall risk communication strategy is needed to ensure effective communication targeted to the needs of the different teams of personnel in planning and execution.

7. Conclusions and further work

The aim of the study was to identify challenges related to planning that may influence major accident risk. This was done based on theoretical and empirical studies. The theoretical part was from a study of major accident theories. The empirical part included interviews with offshore personnel, workshop with onshore organisation and analysis of investigation reports. The challenges identified were grouped into four main topics including inadequate plan, inadequate planning, inadequate shared overview and understanding, and late risk identification. The challenges were subsequently addressed through a set of proposed improvements, which are aimed at improving the planning to better manage major accident risk. These were grouped in the following categories: improvements to the planning process, improvements for risk structuring, and ICT tool to provide shared overview. The assumptions made by Sarshar et al. (2013) that *low quality planning processes lead to low quality plans, which in turn may increase the risk for major accidents*, is supported through this study.

Further work includes evaluating these proposals with the industry, including an assessment of the extent to which the proposals may contribute to reduce the risk for accidents and further study the latter proposal on a new concept to manage information and provide shared overview throughout the process, from planning to execution offshore. How resources could be better leveraged in the IO structure is another area of study to reduce major accident risk.

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Article 4

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Abstract

Planning and plan quality influence safe and efficient execution of work in offshore oil and gas activities. An important basis for developing good plans and making good decisions during the planning process is to have the right information available at the right time. In this study a top-down approach is used to describe what risk-related information that is needed at what stages in the planning process to develop plans in which the risk for major accidents has been explicitly addressed. The paper presents an approach for organizing risk-related information to support decisions made through the planning process of offshore activities and that can influence the risk from major accidents.

Keywords	Major accident prevention; decision making; assessments; risk-related information; offshore activities; planning process
Taxonomy	Operations Research, Process Safety

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Major accident decisions made through the planning process for offshore activities

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Abstract

Planning and plan quality influence safe and efficient execution of work in offshore oil and gas activities. An important basis for developing good plans and making good decisions during the planning process is to have the right information available at the right time. In this study a top-down approach is used to describe what risk-related information that is needed at what stages in the planning process to develop plans in which the risk for major accidents has been explicitly addressed. The paper presents an approach for organising risk-related information to support decisions made through the planning process of offshore activities and that can influence the risk from major accidents.

1. Introduction

Major accidents are characterized by complex causal patterns with many factors influencing the occurrence of such accidents. Related to maintenance and operations in the offshore petroleum industry, the causes can be found not just in the execution of the work, but also in the preparations and planning before performing the work. In an earlier paper (Sarshar et al., 2014), we reviewed 24 investigation reports of gas leaks on the Norwegian Continental Shelf and found that in 18 of these cases, factors related to planning could be identified as contributing factors to the incidents. Through the planning process of offshore work activities, significant risks to HSE (Health, Safety and Environment) are to be identified and addressed. This forms the basis to enable safe and efficient performance of work with the time and resources available. In the same study (ibid), the planning process was studied in detail with respect to how major accident risk is managed. An important basis for developing good plans and making good decisions during the planning process is to have the right information available at the right time (this was identified as one of the contributing factors). The planning process works as an organisational barrier which enables management of major accident risk through risk identification, prioritization, mitigation and compensating measures. This is however not utilized to its potential today as one might not be precise on what type of information is actually needed to support certain considerations and decisions.

Our aim is to contribute to promote safe and efficient production and maintenance on offshore petroleum installations. The objective of this study is to describe *what risk-related information* is needed *when* in the planning process to develop plans in which the risk for major accidents has been explicitly addressed. The paper presents an approach for organising risk-related information to support decisions made through the planning process of offshore activities and that can influence the risk from major accidents.

The scope of this paper is limited to the planning processes for operational, work order and work permit planning. It focuses on the information needed to establish a sound basis for the planning process and not on how the information should be used. The decision-making process itself is therefore not addressed. We also have the assumption that personnel involved in planning have required competence and time available (to consider the information we make available) for decision making. The focus in our study is on major accident risk and not on occupational safety and health, although we acknowledge the importance of safe execution of work.

The paper is structured as follows. Section 2 discusses earlier work related to the scope of this paper. Section 3 describes the research method applied. Section 4 provides the main results. Section 5 and Section 6 discusses and concludes the work.

Abbreviations:

CCR	Central control room
FAR	Fatal accident rate
HAZID	Hazard identification
HAZOP	Hazard and operability study
HRA	Human reliability analysis
HSE	Health, safety and environment
IO	Integrated operations
MAH	Major accident hazard
OPS	Operational plan
OSH	Occupational safety and health
POB	People on board
POG	Production optimization group
PSAN	Petroleum safety authority of Norway
QRA	Quantitative risk assessment
SJA	Safe job analysis
TRA	Total risk assessment
WO	Work order
WP	Work permit

2. Background

In an earlier paper (Sarshar et al., 2015), we identified a number of factors influencing major accident risk in the planning process that are related to sharing information, e.g. «Information flow», «Communication" and "Misunderstandings". The challenges related to these factors were elaborated in a second paper (Sarshar et al., 2016a). In this paper, we move into the topic of information in more detail, and address the following problem: *what types of information are required to ensure that the best possible basis is available for making good decisions in the planning phase*? One way of approaching this problem is to frame it in terms of what decision support people engaged in planning need, i.e. what type of decisions are made and what information is required to make these decisions and to maintain focus on major accident prevention throughout the planning process.

Kongsvik et al. (2015) suggest several principles for improving decision support for major accident prevention in industries. While many decisions today are based on a high degree of uncertain information, they see a need to deploy more factual information to make the risk picture more relevant for both operational and instantaneous decisions. A basic premise for improvements in the decision process is the need to be conscious regarding the type of decision that is to be made. They suggest three decision types to address: whether it is a strategic, operational or instantaneous decision. Yang and Haugen (2015) add a fourth decision type to this list, emergency decisions, and group the four decision types in *planning* which includes strategic and operational decisions and *execution* which includes instantaneous and emergency decisions. These decision types all use information about risk as input, yet it is not necessarily the same information.

Traditionally risk is measured in terms of an expected loss which is calculated by multiplying probability and consequence. Haugen and Edwin (2016) describe that this is a useful measure for strategic decisions since it can be used to minimize expected loss over a long period. For operational decisions focusing on short-term activities, this is not necessarily the best criterion for managing risks.

Haugen et al. (2016) study activity based risk analysis. The modelling is based on the barrier functions and the activity characteristics are reviewed to identify if the activities may directly or indirectly cause an impairment or deviation in the barrier. Based on planned activities and other conditions affecting the barrier status, the risk can then be calculated on a daily basis.

Andersen and Mostue (2012) found that risk analysis methods are mostly used in design and modification projects and not during daily operation. Based on their surveys, safe job analysis was the most commonly used method for work in daily operation. HAZID and HAZOP were performed sometimes for difficult or special activities. The main reason for not using many formal risk assessment methods in operation was their limited ability to give valuable safety information for operational tasks. This was especially valid for extensive quantitative methods like QRA/TRA. The generation of risk knowledge in operation was instead mainly based on three approaches that were identified (ibid): (1) formal procedures and governing documentation, (2) plant specific competence and common sense, and (3) the planning processes.

The three planning phases focused on in this study include: operational, work order and work permit plan. They contain several steps: identifying the need for performing the work, establishing and assessing the activities, coordinating them on a plan and approval of the plan. These steps where assessed with respect to major accident theories in a previous paper (Sarshar et al., 2015). These included the energy and barrier perspective (Gibson, 1961; Haddon, 1980), conflicting objectives (Rasmussen, 1997), man-made disasters (Turner, 1978; Turner and Pidgeon, 1997), high reliability organisations (HRO) (La Porte and Consolini, 1991) and resilience engineering. Of these, the first four offer insights into how the planning phases may serve as barriers to protect against major accidents, including factors that are critical for upholding the planning phases as barriers (Sarshar et al., 2015):

- *Energy and barrier:* The different steps in the planning process represent organisational barriers since major accident risk is considered and required risk controls are identified. At the work permit stage, the approval process ensures that the work can be performed safely and (as part of that) ensure that the work can be performed safely simultaneously with other activities (coordination).
- *Conflicting objectives:* Management's focus on efficiency can increase time and cost pressure (versus safety) or favour production optimization ahead of maintenance operations. One example is that not enough time is allowed to prepare the work and therefore all aspects of the work (e.g. with respect to HSE, resources, or competence needed) are not considered. One might also deliberately choose not to perform such assessments and take the necessary time for preparations or cut on safety measures because one considers these unnecessary.
- *Man-made disasters*: A key factor in this is that information must flow between the activities and between the roles and actors involved, and discussions should address misunderstandings.

Communication channels and feedback loops should not only be within a planning phase but also across different planning phases. In addition, the work package may not contain all relevant information needed to communicate hazards and risk. For the planning process this means that information may not flow between the activities in the (onshore and offshore) processes and between the roles and actors. Misunderstandings and misperception of information or between actors and roles in the planning processes can cause activities being approved based on inadequate basis.

- *HRO*: Many of the steps in the work processes are collaboration activities which works as organisational redundancy with overlapping tasks and competence, eye-to-eye contact and which easily communicate with each other. The evaluation and quality assurance of e.g. the work order plan is a collaboration activity involving different key responsibilities. Some organisations include the offshore lead technicians in this step and hence include decentralised decision making.

Information is one of the key aspects that must be managed through the planning process. With information we refer to risk related information that supports assessment and decision making. In other words, information that contributes to reduce the uncertainties about activity, technical and external factors contributing to the overall system risk.

3. Method

The work has been performed in three steps and builds on previous work performed by the authors. The results are presented in Table 1 (Section 4), where the last three columns represent the steps of the method as follows:

1. *Decision*: Describe the decisions that are made through the planning process. This is based on the work process documentation available from two operating companies. The decisions made within the specific decision arenas are gathered from documents describing the work process which that decision arena is part of. In previous work, the planning process was studied with respect to major accident decisions and these were related to the major accident theories (Sarshar et al., 2015).
2. *Major accident assessments and analysis needs:* Identify which assessments needs to be done to support decisions made in the planning process. This is also based on the work process documentation and input from subject matter experts through interviews and workshops. The list of assessments provided are gathered from specific documents describing the work process where assessments needs to be made. In addition the list builds on the authors own experience of what should be assessed based on interviews and workshops with personnel involved in the planning process. In previous work, interviews were performed with offshore personnel and workshops were held with onshore organisations regarding major accident risk (Sarshar et al., 2013; Sarshar et al., 2016a).
3. *Risk-related information needs:* Describe/analyse what type of information is needed to support the assessments and decisions. This step is based on the planning data used by two operating companies, logical reasoning and input from a subject matter expert. In addition the list builds on the authors own experience of what should be assessed based on interviews and workshops with personnel involved in the planning process and observations of information flow between

meetings (Sarshar et al., 2013; Sarshar et al., 2016a). Where possible, the risk related information needs are grouped in activity, technical and organisational related information.

This is a top down approach starting at the decision needs, which are broken down to assessments and information needs. This ensures selection of relevant and critical information that supports the decisions needed to be made when in the planning process to manage major accident risk.

4. Major accident decisions made through the planning process

4.1 System risk

To identify and understand what type of information is needed we first study the different factors that influence the *system risk* – the overall risk picture for an installation. A proposed breakdown of information is shown in Figure 1. The system risk can be influenced by activity, technical and external factors. Activity factors can include operation of the facility, modification projects and maintenance activities. Specific examples are e.g. the activity level, high risk activities and simultaneous activities. Non-technical barriers[1] are also included in the activity factors (leadership, competence, procedures, human hazards etc.). The technical factors include the process equipment (tanks, valves and pumps, etc.) and the technical barriers in place. The external factors may include dependencies between facilities (e.g. sharing pipelines), weather conditions, etc.

Figure 1: Risk influence structure for a system

These factors represent areas where information is needed to support decision making. One need to e.g. have control of the activity level and high risk activities, have control of the technical integrity of the installation and assess external influence on the system risk.

Activity risk has the greatest focus by planners and personnel involved in the planning process. The attention is on describing the need for work, the sub activities it requires, resource needs and so on. As one moves closer to execution of the activities, the more detailed the descriptions become. Similarly, the uncertainty around an activity is high when it is planned months ahead. As the activity gets more detailed the uncertainty also decreases as assumptions made early on can be verified or rejected.

In order to make plans that will achieve their objective safely one important input to the planning process is information on barrier status, from barrier management. For technical barriers, the focus is on technical integrity. To support the consideration of how e.g. an activity may influence the technical systems or vice versa, information about the technical factors is required. When a facility is new it is normally in accordance with its design criteria. Few facilities are however in this shape after being in operation for some time and it is therefore important to know about weaknesses at the facility. Examples of such weaknesses can include corroded pipes in an area and degraded control system (e.g. in case of shutdown, the probability for this system to shut down properly is low). A technical overview and barrier management system is therefore crucial to manage weaknesses and deviations from the facility’s design intent. Based on three workshops with two operating companies on the Norwegian Continental Shelf (Sarshar et al., 2016a), it seems that barrier management

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[1] Technical, operational and organisational elements which are intended individually or collectively to reduce possibility/for a specific error, hazard or accident to occur, or which limit its harm/disadvantages (PSAN, 2013).

systems are not fully integrated with the systems used during planning of activities. They make use of different types of barrier panels as a tool on the side of planning while barrier management should be a complimentary part of the planning process.

External factors that may, e.g., influence risk is weather conditions that can e.g. make a life boat unavailable (Specific wave heights and wave directions might cause some life boats to be unavailable as they might drop and be forced under the installation with the danger of colliding with the structure), this will reduce the activity level allowed due to limited capacity to escape in case of an emergency. Weather conditions can also affect some planned activities so they must be postponed. Another example on an external factor is when an installation shares pipelines with other facilities.

4.2 The planning process

The planning process for offshore activities that form the basis for this study is typical for the Norwegian petroleum industry and has been developed and shaped by Integrated Operations (IO CENTER, 2017). Integrated operation builds on the capability to collaborate; via video conferencing, remote data and information sharing, and through fast access to expert advice from support centres.

Planning of maintenance, corrective and preventive, and offshore operations are normally done by the onshore organisation and communicated to the offshore organisation which is responsible for execution of the plans, along with handling unplanned activities. The time horizon of the different plans spans from years to days. The main plan spans for a year, the operational plan for up to three months, the work order plan for up to two weeks and work permits are applied before the job is executed the following day. Approving the main plan can be regarded as a strategic decision (long term decisions related to future modification, projects and design), while approval of the operational plan, work order plan and work permits are operational decisions (short term decisions with a time horizon of days and weeks, and involve coordination and planning for the safe and effective completion of concrete tasks such as maintenance work). Decisions made during execution of the work are seen as instantaneous decisions (Kongsvik et al., 2015).

Within the planning phases there are decision arenas such as meetings in which work activities and plans are discussed and approved (illustrated in Figure 2). Daily meetings are highlighted with grey background while less frequent meetings have dashed outlines. Activities and actions occurring between these meetings are shown with a white background. Four meetings are highlighted with bold border, these are the ones focused on in our study: operational plan meeting, work order meeting, morning meeting and work permit meeting. While the operational plan meeting and the work order meeting are on the different plans, the morning meeting and work permit meeting are on activities on these plans that are to be executed the same and the following day respectively. Other meetings and arenas also make important decisions with respect to managing risk, but these four represent the most important decisions arenas through the planning process and are emphasized in our study.

The production and optimization group meeting focuses on the production and wells while the operational plan meeting onshore focuses on the major activities within the next three months. The morning meeting between the onshore and offshore organisations occurs daily and addresses HSE, daily activities, production and logistics. It is one of the most important arenas for risk communication and information flow between the onshore and offshore organisations. Work order and technical meetings are established as needed to discuss specific activities on the plans between subject experts. All meetings offshore are related to the execution of work which relies on the work permit system. However, not all activities require a work permit (NOG, 2015).

The plans are prepared through the steps prior to the different meetings where the activities are assessed and analysed. In the meetings, the activities and their risk are presented and discussed with respect to coordination, simultaneous operations etc. The preparation steps are as important when it comes to managing major accident risk as the meetings where plans get discussed and approved. They form the basis and input for decisions made in the meetings.

Operational plan meetings occur every second week and looks three months ahead. The operational plan contains information about the activities on the installation with respect to drilling, operations, maintenance, inspection and modifications. It is to maintain the installation's total risk picture with respect to major accidents, production and development. The plan focuses on risk levels, priorities and resources within and across installations. This is to ensure regulation of the activity level to stay within the framework conditions. The objective is to assess activities for HSE issues, their influence on area risk, their criticality and the technical integrity.

Figure 2: Meetings and activities/actions close to execution of offshore maintenance and operations

Work order plan meetings occur every week and look two weeks ahead. The objective is to plan for safe, efficient and sustainable execution of work on the installation. The main activity is to schedule and coordinate activities on plan according to resource needs.

Work permit meetings occur every day and focus on the following days activities. The objective is to assess work permits, coordinate and assess them for simultaneous execution.

Morning meetings occur daily and focus on today's activities. The objective is to emphasize required preparations and coordination for execution of the work.

4.3 Decisions, assessments and information needs

In general, when establishing work or assessing a plan the following includes examples of assessments needed to identify hazards:

Establish work

- Does the activity require specific procedures, expertise, resources, isolation etc.?
- How does the activity affect the technical system, the area and other nearby activities?
- How may the technical system or area hazards affect this activity?

Assess plan

- Which activities require isolation?
- Which activities require crane lift over process area?
- Which activities depend on specific barriers?
- Which activities take out or degrade some barriers?
- Which areas have potential diffuse leaks?
- Which areas have potential for hydrocarbon leakage and ignition?
- Which systems and areas have bypass of hydrocarbon carrying systems?

- Should activities be limited in execution time due to e.g. noise/vibration limitations?
- Are emergency escape ways blocked?
- Can execution of some activities introduce latent hazards?

The planning phases focused on contain several steps: identifying the need for performing the work, establishing and assessing the activities, coordinating them on a plan and approval of the plan. While these are the steps primarily for the operational plan and work order plan, the work permit system focus on correct execution of the planned work offshore. For the operational and work order plan there are several assessment and coordination activities prior to the *operational plan meeting* and *work order plan meeting* respectively. In these meetings the plan is discussed and approved. Offshore, the *work permit meeting* address the work permits and their approval while the *morning meeting* focus on approval of today's activities. In our study we focus on the decisions made in these meetings, the assessments and analysis needs (performed in the steps prior to the meetings) and their risk-related information needs.

The results are summarized in Table 1. The four meetings emphasized are listed in each row with the columns describing their objectives, decisions, major accident assessment and analysis needs, and risk-related information needs.

Table 1: Overview of main decision arenas in the different planning phases, with their main decisions for managing major accident risk and their assessment and information needs.

The assessments and risk related information contributes to coordinate and approve activities and the different plans. Where possible, the risk related information needs are grouped in activity, technical and organisational related information. While the activity and technical aspects have been discussed, the organisational aspect can e.g. relate to correct performance of human critical tasks. The focus is on people as a barrier rather than as a source of errors. During operation it can be to verify that an isolation plan is correctly set. For work on hydrocarbon carrying systems the isolation and reinstatement of the system are critical tasks that require verification of correct performance (NOG, 2013). For planning it can be that critical expertise or personnel input is required in assessment of the plan and its activities.

The results illustrate what should be addressed, assessed and made available through the different planning phases and their respective decision arenas and is based on our previous and current studies on the topic (observation of the different planning meetings; interviews with planners, personnel working with technical integrity, platform managers and technicians offshore; and by studying different planning and work order and permit management tools). It should be noted that in practice, the described decisions and assessments are not necessarily performed by the operating companies (contractors may be involved) and some aspects may be performed only to a limited extent. Similarly, the information needs do not represent what is actually available of information through the planning process.

As part of the analysis, the results (decisions, assessments and information needs) from this study has been assessed by a subject matter expert and adjusted.

5. Discussions

An important aspect of managing risk through the planning process is uncertainty. PSAN (2014) defines risk as the consequences of an activity with an associated uncertainty. Early in the planning process, there is significant uncertainty in various aspects of the work being planned. As illustrated in Table 1 the assessments and information needs becomes more detailed as the plan goes from operational to work order and to execution phase. This is a way to cope with the uncertainties through the planning process. Assessing a plan for simultaneous activities is e.g. performed in all planning phases. At the operational plan where the uncertainty is higher, the activities are e.g. coordinated based on their criticality and POB (people on board). At the work order level the focus is more on scheduling as one has information about resources and constraints. At the work permit level coordination is on work types that should not be executed simultaneously due to increased risk as one is more certain about the activity steps and operations. If uncertainty can be seen as lack of information, a systematic process to information collection must be applied to reduce this uncertainty (NTNU, 2017).

Information management is therefore of key importance to assure transparency and flow of risk related information between the planning phases, mainly from the operational plan and to execution of the planned activities. Such an information carrier together with information collection and information visualization plays an important role in supporting the planning process. The role of such an information carrier would be to manage and present the relevant information in the planning steps where they are to be used (to support assessments and decisions).

A thorough overview of risks in plans is also required. Such an overview should include the activities, the technical and external factors as illustrated in Figure 1. This requires aggregation of risk related information from different software systems into an overview to support the decisions needed to be taken in the different decision arenas.

In practice, it is the personnel involved in the different phases of the planning process that have to understand the risk involved in the plans and make the final decisions. Establishing a thorough overview of risks in plans also involves collaboration between the onshore support centres and the offshore organisation to understand and identify how the system risk can e.g. affect the planned activities and their framework conditions. The subject matter expert involved in our study highlighted that there is a gap between our analysis of what should be assessed and how personnel involved in the planning process can be enabled to perform the assessments. A skilled worker can traditionally assess her own activity, but the aim is to also assess how it may influence other activities and technical factors and how other activities and technical factors can influence her activity. The last part is supported to a limited extent today.

On the work order level the attention is traditionally on scheduling and activity performance and little attention is given to their risk impact. While the intention of the planning process is to detail and deal with uncertainties as one plan towards execution at the sharp end, it seems like there is a break in continuity in the information flow from the operational plan to the work order plan (Sarshar et al, 2016a). It is not until the work permit level that risk assessments are performed again.

Based on the outcome of our study it should be possible to review current work processes and practices for maintenance planning in a petroleum company to assess the extent to which the information needed to make decisions that address the risk for major accidents during planning are present. Some operating companies have different software tools to manage the work activities at the different planning phases; this does not necessarily mean that all necessary information is made available and is used in the different stages of the planning process.

By monitoring when risk related information is added to the information carrier over time one can possibly trend when different types of considerations are made to help identify where effort and focus is needed e.g. to identify risk earlier. Is for instance the activity's influence on the facility identified at the operational plan, when establishing the work order, when the work order plan is assessed or is it identified in several steps but detailed and made more precise as one move towards the sharp end? Late risk identification leads to a range of inadequacies in planning, e.g. insufficient work descriptions, and relevant information which remains unaddressed during the planning process. These are factors that can lead to unsafe and less effective task execution. A planning process allowing for earlier risk identification may increase the plan quality in several ways (Sarshar et al., 2016b):

- Descriptions of identified risks are included as part of the work description through several steps of the planning process, and hence the probability of identifying important aspects increases because risk is iteratively assessed.
- Proper documentation of risks early implies that the probability of aspects identified are forgotten later is reduced.
- Changes late in the process before the job is to be executed are avoided. In practice, the later in the process changes are made, the pressure towards proceeding with the plan even if safety is not fully ensured is likely to increase.

A topic not addressed in this paper is cost. Damnjanovic and Røed (2016) argue that improved operational safety can be achieved concurrently with increased operational efficiency. Their approach focuses on planning as a means of managing systems' response uncertainty and consequently reducing both major accident risk and the cost of operations. When the process (planning or execution) is interrupted, the end result is a delay, non-productive time and a new "on-the-ground" situation that often brings new safety risks. The more certain we are about the systems' response, the more efficient the operations become, and the lower the chances are for a major accident. However, there is a limit to how much planning can reduce the uncertainty at an early planning phase. Another point is being aware of the uncertainty based on what type of and the amount of information available.

6. Conclusions and further work

The study results in a process for how to organise risk-related information to support decisions made through the planning process of offshore activities. The process shall deliver a sound plan which has been assessed for major accident risk to ensure safe and efficient execution of the work at the installation.

The focus in our study has been on major accident prevention through the planning process. This has been addressed using a top-down approach where major accident decisions are described, which assessments and analyses these are based on and what risk related information they need. The study has highlighted what information is needed when in the planning process to manage major accident risk with focus on activity, technical and some organisational factors.

The findings point to areas where information systems can be improved to manage information through all planning phases:

- to assure transparency and flow of risk related information between the planning steps,
- to make information available at the planning step it is needed and in the context of the assessments it needs to support,
- to visualize and present the information in an intuitive way for the users to understand and interact with, and
- to support the plan and its risks to support decision making.

There are many information types that have been identified through this study and information overload can be seen as a challenge. The information selected to be presented should support the decisions to be made and considered. A top-down approach is therefore important to guide the information selection process. A good design philosophy is then required to present the information in a way that raises questions about activities and the plans to identify hazards and manage their risk. Aggregating and presenting the information types to the personnel involved in the planning process is a challenge we study through a new concept for risk visualization in a follow up paper.

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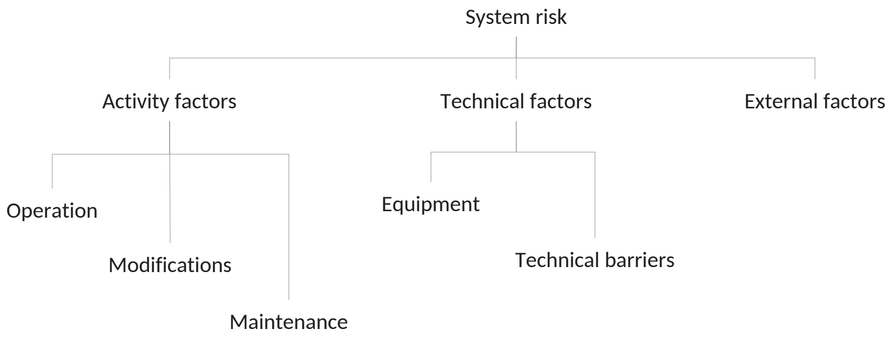

Figure 1: Risk influence structure for a system

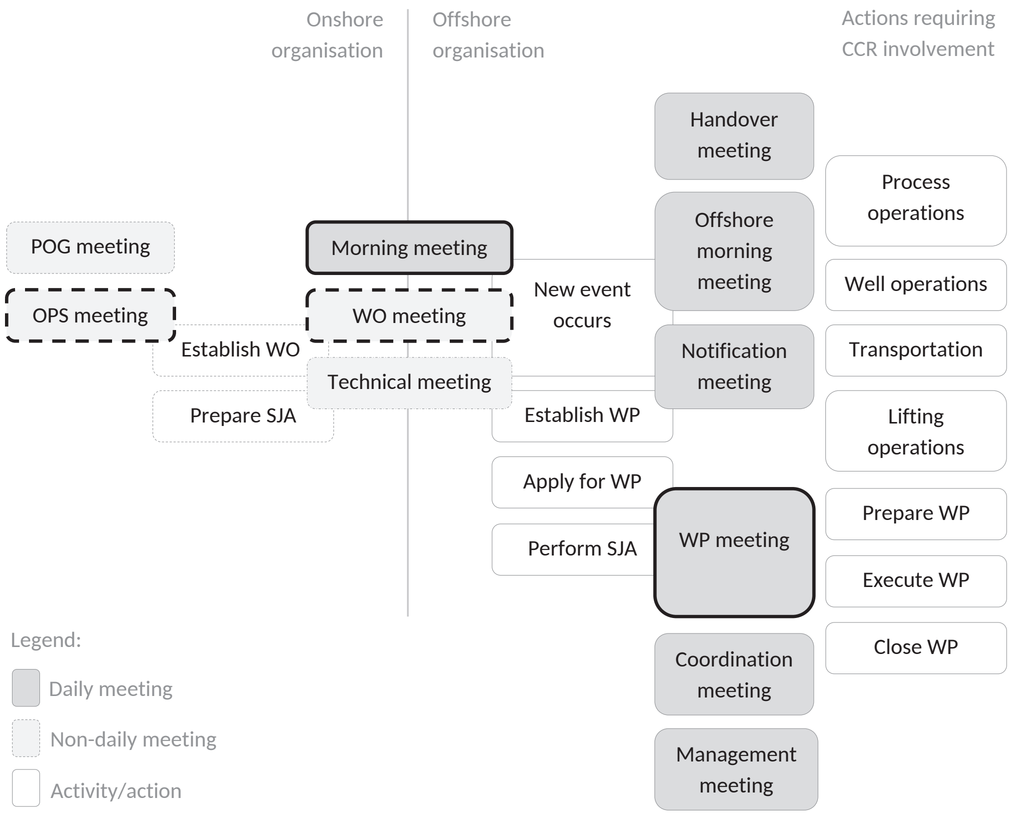

Figure 2: Meetings and activities/actions close to execution of offshore maintenance and operations

Table 1: Overview of main decision arenas in the different planning phases, with their main decisions for managing major accident risk and their assessment and information needs.

Decision arenas	Objective	Decisions	Major accident assessments and analysis needs	Risk-related information needs
Operational plan meeting *Occurs every second week and looks three months ahead*	Assess activities for HSE issues, their influence on area risk, their criticality, and the technical integrity	- Approve operational plan	- Assessment of planned activities in the context of the framework conditions with respect to e.g. POB, high risk activities (such as heavy lift over process area, hot work or work on hydrocarbon carrying systems). - Are there weakened technical, operational and organisational barriers? - Risk analysis of how activities or absence of activities can degrade the technical integrity. - Risk analysis of how activity may influence or be influenced by area risk. - Assessment of activities with respect to priority and criticality. - Simultaneous operations analysis	Activity related information: - Description, priority, criticality - Work type Technical related information: - Status of barriers for the installation - Weaknesses and degradations and their status - Deviations and their status - Area risk - FAR/QRA data
Work Order plan meeting *Occurs every week and looks two weeks ahead*	Schedule and coordinate activities according to resource needs	- Approve work order plan	*In addition to the above:* - Activity hazard and risk analysis - Can some activities introduce latent hazards? - Are activities that take out or depend on barriers identified? - Are adequate compensating measures identified and planned for? - Are all resource needs identified? - Is new risk assessment performed when changes occur in the work order plan? - Are there critical human aspects of the work execution? - Need for preparing SJA?	*In addition to the above:* Activity related information: - Responsible technicians - Description of equipment: functional hierarchy, documentation, maintenance history - Applicable procedures - Tools required - Space required - Resource needs: expertise or other technicians, scaffolding, material movement on site, crane operation - Hazards and risks Technical related information: - Status of barriers for the installation - Weaknesses and degradations and their status - Deviations and their status - Area specific risk - Process and instrumentation diagrams - Maintenance history Organisational related information: - HRA data on critical activities
Work Permit meeting *Occurs daily and focus on the following day*	Assess work permits, coordinate and assess for simultaneous execution	- Approve work permits	- Are the activities coordinated correctly? - Is safe job analysis required and performed? - Is isolation plan required and prepared? - Are activities coordinated with respect to simultaneous execution? - Is the weather within framework conditions? - Are required personnel available for the job? - Which activities require isolation plan? - Which activities require crane lift over process area? - Which activities depend of specific barriers? - Which activities take out or degrade barriers? - Which areas have potential diffuse leaks? - Which areas have potential for hydrocarbon leaks and ignition? - Should activities be limited in execution time due to e.g. noise/vibration limitations? - Are escape ways blocked? - Safe job analysis - Prepare isolation plan	*In addition to the above:* Activity related information: - Work type Technical related information: - Overview of installation decks and modules, and location of planned activities - Hazardous area classifications - Noise classification - Crane reach - Escape routes and emergency equipment - Master P&ID
Morning meeting *Occurs daily and focus on today's activities*	Preparations for and coordination during execution	- Approve execution of today's activities	*In addition to the above:* - Is HSE focus maintained? - Are all coordination issues solved? - Do technicians know what to do in case of an event with the planned activities? - Are required personnel prepared and ready for the job?	

- The findings point to areas where information systems can be improved to manage information through all planning phases
- Assessments needed to support decision for managing major accident risk are described.
- Risk-related information needed to support the assessments and decisions are identified.

Article 5

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Visualizing risk related information for work orders through the planning process of maintenance activities

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A B S T R A C T

Major accidents are characterized by complex causal patterns with many factors influencing the occurrence of such accidents. Within the offshore petroleum industry the causes can be found not just in the execution of maintenance work, but also in the preparations and planning before performing the work. Planning of the work activities plays an important role in managing the activities and installation risk by identifying hazards and ensuring measures are planned for. One important basis for developing good plans and plan the work properly is to have the right information available at the right time in a format that facilitates understanding of important risk related aspects of the work. This paper presents a computerized display for a concept for how risk related information can be visualized in an operational context when establishing work orders. Design iterations have included participants from operating companies on the Norwegian continental shelf.

1. Introduction

Planning of maintenance activities serves several purposes, of which the most obvious ones are to provide a basis for efficient performance of the activities with the time and resources available. However, in hazardous industries, maintenance planning also serves to manage risk, by identifying hazards and ensuring that measures are planned for that can contribute to reduce risk to an acceptable level. In the oil and gas industry offshore, evidence shows that there is significant scope for improvement in this area. Sarshar et al. (2015) looked at 24 investigation reports of gas leaks on the Norwegian Continental Shelf (NCS) and the review showed that in 18 of the cases, factors related to planning were identified as contributors to the incidents. An example includes that unoriginal parts were used for a job on a hydrocarbon leakage which caused a leak incident.

There can be many reasons why the planning process is not sufficient, but an important basis for developing good plans and making good decisions is clearly to have the right information available at the right time in a format that facilitates understanding of important risk related aspects of the work. Fig. 1 gives an overview over the process. The starting point is that there are certain hazards, with associated probability and consequence that need to be managed. One identify relevant factors that influence risk and develop risk models to analyse risk. The output from this is a risk picture. In addition, Sarshar et al. (submitted for publication) also identified other relevant risk related information that is necessary to make good decision. This needs to be presented to the decision-makers (planners and others). Before a decision can be made, the information must be interpreted by the decision-makers and they have to make sense of it within the context of the work that is going to take place. The focus in this paper is on the presentation of the information to the decision-makers, or the visualization as it is described in the figure.

Relevant information has been identified by Sarshar et al. (submitted for publication) and the objective of this paper is primarily to investigate how we can present information about major accident risk in a manner that provides improved decision support in the planning process for activities on offshore oil and gas installations.

The scope of this paper is limited to the establishment of work orders and their assessment. These steps are followed by assessment and approval of a work order plan which is then sent offshore for performance. Earlier planning stages and execution of the work that has been planned is not studied as such, although an important outcome of a good plan is its safe execution.

The rest of the paper is structured as follows. Section 2 provides background and discusses work related to the scope of this paper. Section 3 and 4 describes the approach and process for the study. Section 5 provides the main results of the concept developed. Section 6 concludes the work and comments on future work.

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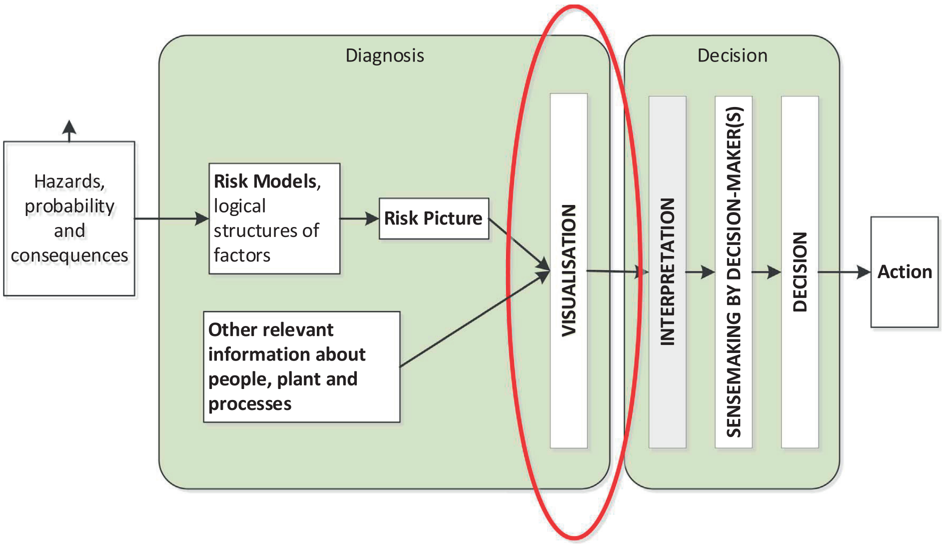

Fig. 1. Diagnosis-Decision-Action (simplified version of figure from Albrechtsen et al., 2013).

2. Background

Sarshar et al. (2015) identified several factors influencing major accident risk in the planning process that are related to information, e.g. «Information flow», «Communication" and "Misunderstandings". The challenges related to these were elaborated in a second paper (Sarshar et al., 2016). In a third paper (Sarshar et al., submitted for publication), the authors moved into the topic of information in more detail, and looked specifically at what types of information are required to ensure that the best possible basis is available for making good decisions in the planning phase - to develop plans in which the risk for major accidents has been explicitly addressed. In this paper, we follow a design process to present the information in a manner that provides maximum support to the planning process and the decisions made in the planning process.

2.1. The planning process

A typical planning process offshore has been described in earlier papers (Sarshar et al., 2015, 2016). To provide the operational context for work orders a short description of the planning processes is provided.

Planning of maintenance and offshore operations can be divided in several phases spanning from several years to a daily plan. The planning is normally done by the onshore organisation and communicated to the offshore organisation which is responsible for execution of the plans, along with handling unplanned activities. The time horizon of the different plans spans from years to days. The main plan spans for a year, the operational plan for up to three months, the work order plan for up to two weeks and work permits are applied for before the job is executed the following day. To provide some context to work orders, the following operational planning steps are described related to the scope of this paper:

- *Establishing work orders.* Work orders are essentially descriptions of work that needs to be done in a plant. This is typically prepared by those that have technical responsibility for the plant and includes description of the work, when it needs to be done and resources required. In some cases, this can be done a long time before the work actually is performed, depending on the urgency of the work. Addressing major accident risk at this early stage can help to identify and manage critical aspects at an early stage.
- *Establishing a work order plan.* This implies piecing together a plan for all activities that will be performed within (typically) a two-week period. This takes the individual work orders as a starting point, with key constraints being available resources. From a risk point of view, the key concern is now whether the total risk level in any given period is too high and whether there are interactions between work orders (activities) that can increase risk.
- *Approving work permits.* Some of the operations or sub-activities that a work order consists of require work permits that need to be applied for and approved. Approval of work permits is the final stage in the planning process before execution. An approved work permit is necessary before an activity can be executed and the focus at this stage will be similar to the two above stages combined: Accepting that individual activities are safe to perform and that the total activity level on a given day is acceptable.

In this paper, we are focusing on what may be called operational planning decisions (Yang and Haugen, 2015). Decisions can be divided into planning decisions and execution decisions, where the main distinction lies in the time available for systematic comparison and evaluation of alternatives. Execution decisions are typically made purely on basis of experience, intuition and context, without careful evaluation of alternatives. This may be compared to "Fast thinking" decisions as described by Kahneman (2011). Planning decisions may also be based on the same background, applying "Fast thinking", but at least time allows for more systematic analysis of alternatives.

2.2. Risk visualization as a tool

Based on our knowledge and experience through work with the petroleum industry operating at the NCS, most companies make use of separate tools and systems to manage different aspects of maintenance planning. Some operating companies have different software tools to manage the work activities in the different planning phases; different tools for managing barrier management, process and instrumentations diagrams, hazard analysis etc. These different systems often use tabular and textual formats to present information. Using these tools do not necessarily mean that all necessary information is made available and is used in the different stages of the planning process.

On the work order level the attention is traditionally on scheduling and activity performance and little attention is given to their risk impact. While the intention of the planning process is to detail and deal with uncertainties as one plan towards execution at the sharp end, it seems like there is a break in continuity in the information flow from the operational plan to the work order plan (Sarshar et al., 2016). It is not until the work permit level that risk assessments are performed again.

Based on the outcome of Sarshar et al. (submitted for publication) there are areas where information systems can be improved to manage information through all planning phases:

- to assure transparency and flow of risk related information between the planning steps,
- to make information available at the planning step it is needed and in the context of the assessments it needs to support,
- to visualize and present the information in an intuitive way for the users to understand and interact with, and
- to support the plan and its risks to support decision making.

The objective of our visual design is to support the personnel involved in establishing and managing work orders and work permits in identifying potential hazards related to the activities planned. The intention is to present information in a way that raises questions about activities and the plans for discussion (alternatively; one could aim at developing a concept which provided a solution automatically). This requires mapping of the information to the decisions.

When presenting risk related information it is important that a risk is linked to its consequences to have a meaning. Consequences in narrative form are one form of visualization. A visual presentation of consequences will often generate a better insight than textual. Maps have been used for centuries to visualize spatial data. They help their users to better understand spatial relationships. From maps, information on distances, directions and area sizes can be retrieved, patterns revealed and relations understood (Kraak et al., 1996).

Eppler and Aeschimann (2008) describe that using visual metaphors have several distinct advantages when compared to typical diagrams or simple text: “They attract more and longer attention, they facilitate understanding by relating what is already known by the audience to unfamiliar information that is new and they are remembered better than text or diagrams, especially if the metaphor is unusual, but still fitting. As visual metaphors never perfectly fit the target domain, they also trigger sense making and discussions about the risks and the shortcomings of the chosen metaphor. In this way, they help to clarify risk understanding in groups by sparking lively debates.”

2.3. Context and information to present

The information required supporting the decision types can be structured in *activity* and *technical* related factors. The activity factors presents information which is valuable when establishing work, but also when assessing several activities in a plan. The technical factors present information on the status of the installation. The system information together with weather information and other operations at the installation form the operational context. Table 1 provides examples of some relevant activity and technical information to present regarding the work (Sarshar et al., submitted for publication). However, the information selected to be presented should support the decisions to be made and considered. A top-down approach is therefore important to guide the information selection process and good design principles to e.g. avoid information clutter.

The information presented should among others support the following assessments related to identifying hazards during establishment of work order (ibid):

Table 1
Relevant activity and technical information to present.

Activity information	Technical information
• Description and steps • Work type, category, criticality and prioritization • Responsible technicians • Description of equipment: – Functional hierarchy – Documentation – Maintenance history • Resource needs – Expertise or other technicians – Isolation and blinding list – Scaffolding – Material movement on site – Crane operation – Area/process coordination – Production/CCR coordination • Applicable procedures • Tools required • Space required • Safe job analysis	• Overview of installation, decks and modules – Zone classification – Noise classification – Crane reach area – Routes and emergency equipment – FAR/QRA data – Area specific hazards and risk • Overview of main equipment • Description of equipment – Criticality – Functional hierarchy – Documentation/specification – Maintenance history – Procedure for work – Special tool requirements – Equipment attributes (vibration, temp, etc.) • Process and instrumentation diagrams • Barriers and their status – Status of barriers for the installation – Weaknesses and degradations and their status • Deviations and their status

- Risk analysis of how activities or absence of activities can degrade the technical integrity.
- Risk analysis of how activity may influence or be influenced by area risk.
- Assessment of activities with respect to priority and criticality.
- Can activities introduce latent hazards?
- Are activities that take out or depend on barriers identified?
- Are adequate compensating measures identified and planned for?
- Are all resource needs identified?
- Are there critical human aspects of the work execution?
- Is there need for preparing SJA (Safe Job Analysis) from onshore?
- Does the activity require specific procedures, expertise, resources, isolation etc.?
- How does the activity affect the technical system, the area and other nearby activities?

We strive for a more thorough overview of activities and their hazards in our concept development and propose that the plan should be seen as a whole whenever possible and not divided in separated parts. This means that when e.g. a work order is established and assessed, its sub activities should be viewed in the same context as the work order. Such sub activities often require a work permit to execute and form the basis for these. The challenge is that they normally are viewed as a separate activity and when assessed, they are not assessed in the context of the work order. The result is that information and hazards identified at the work order is not seemingly included when establishing and assessing the work permit.

2.4. Related design projects

There exist several research and commercial tools for supporting the planning process. The authors do not have extensive knowledge of all such tools, but are aware of some relevant projects that are briefly presented here. Lessons learned from these projects where used when developing the first visual design for the concept reported on in this paper. IOMAP (Integrated Operations Maintenance and modification Planner) was a prototype tool developed to promote risk-informed decision making by enabling earlier identification of risks by onshore staff

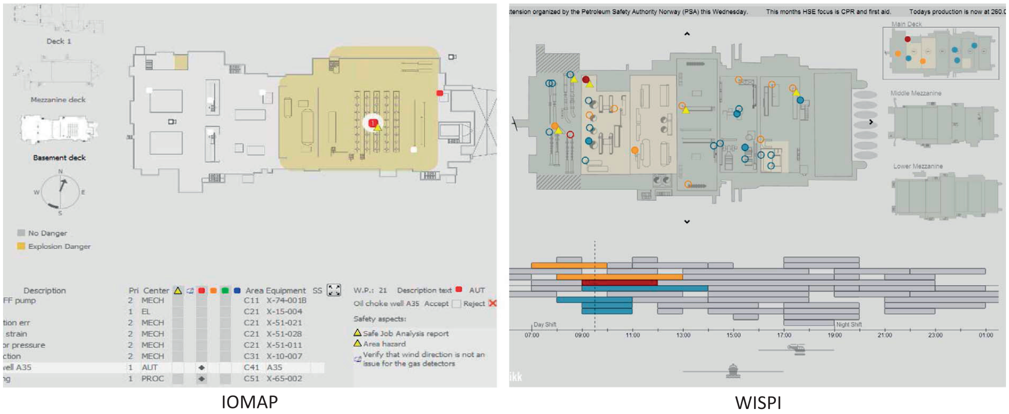

Fig. 2. Excerpt of the IOMAP (Braseth and Sarshar, 2012) and WISPI (Olsen et al., 2014) research prototypes.

when planning maintenance and modification tasks for offshore installations (Skjerve et al., 2011; Braseth and Sarshar, 2012). A thorough usability study was performed on the prototype with planners from the Norwegian Continental Shelf (NCS). A second version of the design was further developed by Braseth and Sarshar (2012). The intention was to study presentation of information about safety standards, job locations and occupational hazards in a way that supports identification of risks through pattern recognition and by highlighting key information. It makes use of a graphical map of the installation and presents the planned activities on top of it at their specific location. It presents calendar functionality and weather data. The planner can navigate through the different decks of the installation, and can also navigate through the different tasks planned for that 24-h period.

A second prototype tool WISPI (Web based Information Surface for a Petroleum Installation) focused on visualizing activities planned for and in execution for a given day (Olsen et al., 2014; Sarshar et al., 2014). An excerpt of IOMAP and WISPI are illustrated in Fig. 2. Scenario composer is another prototype tool developed to plan for personnel on board planning in relation to planned activities. This prototype has been further developed into a commercial tool applied for an operating company in Norway. Another operating company has developed their own tool for visualizing planned activities on platform drawings and include risk related information from QRA and area risk for their installations, and other companies are exploring such tools to better support their operations.

3. Method

To develop a concept for risk visualization for the planning process an iterative design process was followed. First, what information is needed when in the planning process is defined through studies with industry involvement. An iterative design process is then followed to develop design concepts for how to visualize the information. The design ideas and proposals are assessed in cooperation with industry partners through the design cycles in form of workshops. Based on the iterations a final visual design is specified.

1. Step one is to set the objectives and requirements. Define context and information required to support decision making through the planning process. This was done through previous studies by Sarshar et al. (2013, 2015, 2016, submitted for publication).
2. Step two is to describe the users and their information needs through user stories (Cohn, 2004), presented in Section 4.1. This requires identification of specific risk related information that is to support assessments and decisions to manage risk (based on Sarshar et al., submitted for publication).
3. Step three is rapid concept development with assessment and detailing in cooperation with industry partners through multiple design cycles in form of workshops. The first version of the concept built on learning's from previous projects with visual design of similar concepts. Based on these learning's, a first visual design was developed to include the new information on activities and system aspects. The concept development was done with assessment and detailing in cooperation with industry partners through the workshops. There were three workshops in total with two different operating companies. This is presented in Section 4.2.
4. Step four was to specify the final visual design. This is presented in Section 5. The final design was presented to three different companies operating in the oil and gas industry in Norway. Their feedback is presented in section 5.

4. Design process

There is a large variety of personnel involved in the planning process, but they all share the common goal to prepare and perform the activities planned in a safe and efficient manner.

The concept developed in this paper focus only on assessment of work orders though it may also serve as a platform for work permits. The personnel involved in establishment and assessment of work orders are normally technical experts from the disciplines mechanic, electrician, automation and process engineer, personnel from technical integrity, maintenance and operation manager and the planner. They contribute with different expertise through different steps in the process. While the technicians often describe the work and involved steps, personnel from technical integrity and maintenance and operation manager verifies and adds on technical factors. Hazard identification is preferably performed by all who contribute in preparing the work.

4.1. User stories

To capture the human-computer interactions between the users and the visual concept, we focus on creating user stories. A user story normally includes a short and simple description of a feature perceived by a user following a simple template (Cohn, 2004).

Establishing user stories requires a breakdown of the considerations to be made in decision making to functionality and visualization needs. Excerpts of these are provided in Table 2. The first 10 are for a user who establishes work orders while nr 11–13 is for a user who applies for work permits. The last column describes how the user needs are achieved in the developed concept which is presented in Section 5.

Table 2
User stories.

ID	User stories	Achieved through
1	As a user who *establishes work* orders, I want to provide work description, so I can describe the work package	The user can edit the description of a work order by defining the problem, how it shall be solved and the goal of solving the problem. Remarks may be provided and priority, start date and duration form part of the work order description
2	…specify which equipment or system the work is on, so I can find relevant procedures, specifications and documentation	The user specifies the equipment and the concept provides the system this is part of, its criticality, location on the installation and description. Applicable procedures for work on the equipment, checklists, specifications, pictures and other media are also listed
3	…see the history of maintenance on the equipment, so I am up to date with the history	The maintenance history is provided with the date for the maintenance activities, description and the technician responsible for it. The maintenance history is represented as a link so the user can navigate to the relevant work order to get more details
4	…see if any incidents have occurred with previous work on the system	Together with the maintenance history, any incidents registered on the specific system are displayed with date and description
5	…specify which work operations are required to perform the work package, so I can break down the work	A designated part of the display present all the sub activities of the work order with information of sequence, status, activity type, short description, responsible, estimated hours, resource needs, work type, required procedures and potential hazards Several of these information fields are normally not specified at the work order level, but by providing it in the cases one have the information available, it will allow for earlier constrain and risk identification
6	…for each work operation be able to specify who is responsible for it, hours, resource needs, applicable procedures and work type, so I can better plan execution of each work operation	For each work operation, the user specifies its execution step (in sequence or parallel with the other operations), estimated hours for the operation, technician responsible, applicable procedures, work type, resource needs and whether it is planned carried out during daytime or night time The concept allows the user to expand a work operation and get more details about it. This is displayed without jeopardizing what is already displayed and hence the user can assess the work operation in the context of the whole work package. Examples of such work operations can include setting isolation plan or a work permit to replace a valve
7	…specify hazards for the work operations, so I can mitigate them to avoid accidents	A hazard table is provided to document hazards applicable to the work package. It consist of describing the hazard, the work operation and system it applies to, what causes it, its effect, proposed mitigation, barriers it affect, who is responsible for the mitigation and also whether the event of the hazard occurring trigger a major change so re-planning and reassessment is necessary. The concept allows hazards to be linked to the work operations so one can be more accurate on which hazards are applicable to which steps
8	…specify which barriers that the work depends on (that must be in place), so I can plan for safe execution of the work	There is field for specifying dependability to barriers and to support the process of identifying the relevant barriers:
9	…specify which barriers this work degrade or take out, so barrier degradation is taking into consideration when approving the work	– the P & ID of the equipment and system the work applies to is presented – the location of work on the relevant level of the installation is presented – an overview of barrier functions for the specific equipment or system is presented
10	…know the status of barriers on the system I plan work for and in the area the work is to be executed, so I can identify potential hazards	The status of the barriers on the system are provided through the P & ID, the location and barrier presentations by visual clues and metaphors representing e.g. diffuse leaks, temporary and permanent barrier degradations and dispensations from requirements
11	As a user who *applies for work permits*, I want to build on the work order information when applying for work permit for one or several of the work operations, so I can have access to all work related information in one place and see the link between the operations in the work package	By selecting a work operation, the user gets the option to establish a work order for that operation. This allows to have the work permit information as part of the overall work order and one can consider the work permits in relation to all the work operations for the work order. As some operations do not require work permits (e.g. isolate the process equipment by applying the valve and blinding list), the relation between them is not easily visible with today's work permit systems. Here, these are all represented as part of the entire work order
12	…have access to all previous assessments done with the work order, so I can be updated with previous steps	The history of the work order is displayed; such as when it was notified about need for work, planned, assessed, executed etc.
13	…specify work specific type and hazards, so I can document risk related aspects	The user can specify work permit attributes such as work type under the work operation and potential hazards in the hazard table of the visual display

These user stories are based on interviews with onshore and offshore personnel involved in the planning process, observations of different planning meetings onshore and offshore and workshops with industry partners. They represent general user stories for what establishment of work orders include and are not based on specific interviews with the aim of retrieving user stories.

4.2. Iterations

An overview of the concept development, main evaluation aspects and proposed improvements from the workshops are provided in Table 3. There were three workshops in total with two different operating companies.

4.3. Visualization

Eppler and Aeschimann (2008, p. 26–27) present a set of guidelines to follow when attempting to visualize risks. These guidelines relate to the proper context of risk visualization, and the correct and user friendly visual rendering of risks. In Table 4 the guidelines are discussed in relation to our concept study. These and the design principles by Shneiderman (1983, 2010), Kraak et al. (1996), Ware (2008), Roth (2012) have been applied to the developed concept.

Aggregating different data from different sources into one visual display is a challenging task. There are many pitfalls which can cause the user to be overflowed with information that would require high mental capability to digest and interpret.

The concept developed in our study is a visual concept (static) with

Table 3
Concept description, evaluation and improvements of the design iterations.

Iteration	Concept development	Evaluation	Improvements
1	Present important information to support establishment of work orders, link the activity to the equipment and include list of hazards and affected barriers. To support hazard identification and providing a visual representation of the work, the activities and hazards are visualized in a P & ID, area map and a barrier overview	Many of the information aspects presented are normally not used at the work order level, identifying the presented aspects earlier is very good. By visualizing this way several persons with less domain expertise can also contribute as it allows the user to easily relate to the work and the system the work applies to. *Evaluation by leader for operational plans and work orders*	Add information of known incidents to the system Add reference to other planned work orders or events on the same system Add temporary degradations and dispensations to the technical integrity on the visual representation of the map area
2a	The equipment's maintenance history, incidents history and other planned work for are visualized using a timeline with the different events rather than listed textually	It is very visual and effective to see all the events, history and planned work, for the equipment we plan work for. Brings to attention to dig into earlier events and check for coordination aspects for other planned work. All information presented is really good and necessary to support risk identification. The operational degradation causing diffuse discharges are good. To avoid many of the incidents we have experienced we need good tools to help us manage these (presented) data through such tools. *Evaluation by a platform manager.*	Highlight if there are planned (other) work on the blinds or valves involved in the isolation plan Add technical degradations on the system, but also on other related systems nearby as is done for the firewall, e.g. corroded pipes or degraded shutdown function for parts of the system Add safe job analysis as part of the hazard table
2b		The inclusion of barrier information and the link between planning and barrier management is very interesting. *Evaluation by a process engineer*	The historical timeline has a system/equipment perspective, one could also add activity aspects making us able to analyse what we went through; such as when it was notified about need for work, planned, assessed, executed etc.
3	Modified the timeline to also include activity history		

Table 4
Risk visualization guideline.

Guideline	Concept study
Don't precipitate the use of risk visualization. *Visualizations reify thoughts or opinions: Once something has been represented in an image, it is difficult to view it in another way. Thus carefully time the use of a graphic risk representation, as simple risk conversations can be more flexible than fixing them to an image too quickly*	In some cases one might want to wait showing a risk overview, and first collect individual opinions. In our concept the known technical hazards are visualized to help the user to identify how the work order may affect or be affected by these. The hazards represented are not to provide complete list of risks, rather to support risk identification
Consider the application context and its constraints *It is not always possible to make productive use of visualizations in risk management contexts because of lacking time, tools, or space. Thus, consider the time, resource and know-how constraints in a given situation and whether your audience would react positively to visualization or not. Visualizations may also detract attention from a presenter in a verbal communication setting. In addition, in inter-cultural risk committees the use of visuals may cause confusion because of differing expectations and conventions*	The concept, being a support tool to identify and manage hazards related to work order and work permits, is based on feedback from the workshops a way to present factual information and gathers experts to discuss potential hazards
Make sure that the risk visualization respects the basic rules of visualization and perception – *Items that are bigger should conceptually be more important or significant (as they attract more attention).* – *Items that are more centrally placed in a graphic are perceived to be more important than those at the periphery of a diagram.* – *Items that are placed close to one another are perceived to be similar or to be part of one group.* – *Visualize the same things with the same symbols and colours and different things differently. Use a consistent representation style.* – *Don't overload a diagram. Eliminate unnecessary elements whenever possible.* – *Time is usually mapped from left to right.* – *Provide a clear informative title for each diagram or map that indicates the so-what or key message it contains.*	The concept developed tries to follows these basic laws of visual perception and the conventions of graphic design. As examples, the visual representation of the work order is the same symbol used in the timeline, P & ID and area view. The diagrams are simplified to avoid unnecessary elements
Avoid decorative visualization without added benefit *You should always check whether your risk visualizations add value, for example by making a risk easier to understand or assess, by communicating risk related information quicker or by being more memorable than text alone. You should also try to avoid unessential elements in a visualization, such as shading, borders, too many colours, animation effects, etc.*	The hazards are both presented in table form (textual) and visual in the P & ID and are mapped when possible (given that they have a space or process relation that fits the diagrams)
Think visualizing, not visualization *The power of visualization lies in its potential to surface implicit assumptions, capture different perspectives, and reveal night insights. This is especially true if visualization is used interactively by a group of managers and risk analysts. The process of creating and modifying a risk visualization is as important (if not more) as the final result*	Through all workshops and iterations with the design, the work has been presented as preliminary work in progress that invites for changes and modifications, rather than as a polished final product. The visualization has therefore been improved through the knowledge of the workshop participants
Pre-test the risk visualization *Have somebody who was not involved in the creation of the visualization give you spontaneous feedback on its comprehensibility*	The different iterations were discussed with colleagues not involved in the concept development process before they were used in the workshops with industry partners

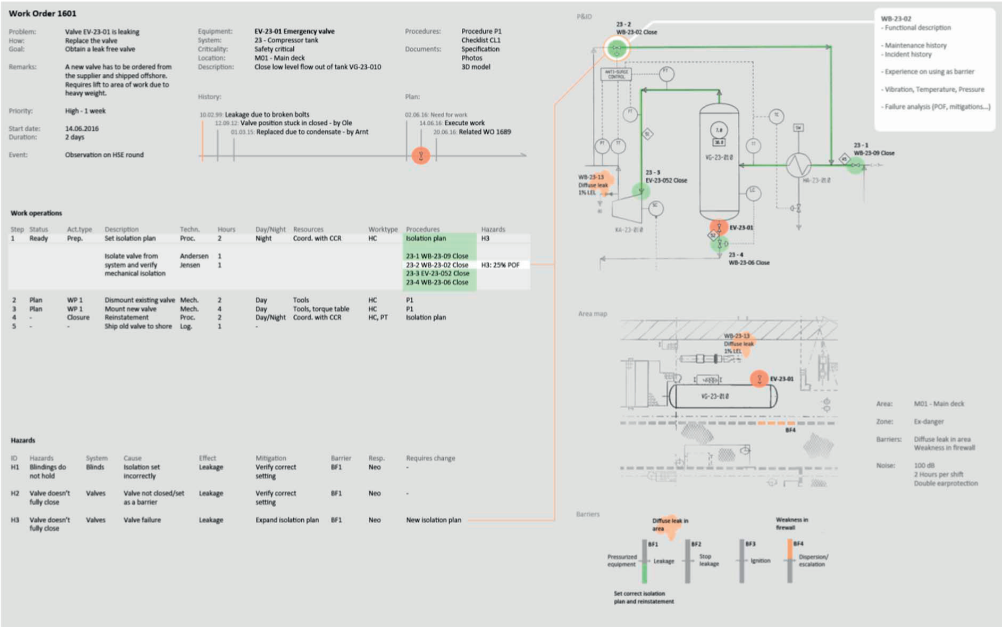

Fig. 3. Concept for establishing and working on a work order.

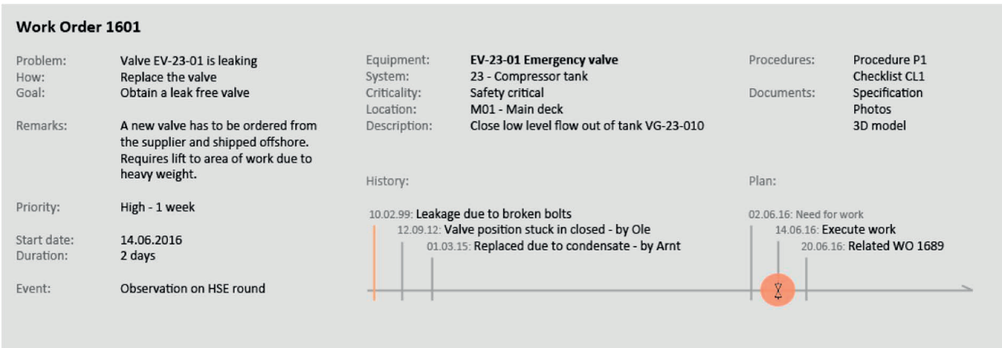

Fig. 4. Work and equipment description and history.

no real user interaction as it is not a prototype. We apply the design principles described as best fits our purpose. The principle we aim for is to increase users' risk understanding through the visual representation of a work order and its context.

5. Results

The final design of the concept for work order visualization and interaction is presented in Fig. 3. The screen consists of a part which contains information and descriptions about the work (left part) and a graphical part which present the work and its sub activities in process and instrumentation, plot and barrier diagrams (right part). The information provided is carefully selected to support risk identification and risk management through the planning of the work order activities.

The main new features of the concept include:

- Integrate the planning process with barrier management by presenting merged plan and risk related information.
- Visualise the work planned in the process and instrumentation diagram and area view simultaneously as all work descriptions, work operations and hazards are present.
- Present information about technical factors such as weaknesses and barrier status using visual clues in the process and instrumentation diagram and area view.
- Allow work operations to be assessed in the context of the entire work package as work operations are expanded and managed in the same view as for the work order.
- Allow for evaluating not only the specific equipment the work order applies to, but also e.g. equipment being part of the isolation plan (barriers) and their associated hazards and weaknesses.

The different parts of the concept are presented in the following. Though they are presented in separate parts, they are viewed together by the user and the different parts are linked and support each other. The work order used as case is related to replacing a valve that is leaking hydrocarbons. The illustrations and text used in the concept are

Work operations

Step	Status	Act.type	Description	Techn.	Hours	Day/Night	Resources	Worktype	Procedures	Hazards
1	Ready	Prep.	Set isolation plan	Proc.	2	Night	Coord. with CCR	HC	Isolation plan	H3
2	Plan	WP 1	Dismount existing valve	Mech.	2	Day	Tools	HC	P1	
3	Plan	WP 1	Mount new valve	Mech.	4	Day	Tools, torque table	HC	P1	
4	-	Closure	Reinstatement	Proc.	2	Day/Night	Coord. with CCR	HC, PT	Isolation plan	
5	-	-	Ship old valve to shore	Log.	1	-				

Fig. 5. Work operations.

Work operations

Step	Status	Act.type	Description	Techn.	Hours	Day/Night	Resources	Worktype	Procedures	Hazards
1	Ready	Prep.	Set isolation plan	Proc.	2	Night	Coord. with CCR	HC	Isolation plan	H3
			Isolate valve from system and verify mechanical isolation	Andersen Jensen	1 1				23-1 WB-23-09 Close 23-2 WB-23-02 Close 23-3 EV-23-052 Close 23-4 WB-23-06 Close	 H3: 25% POF
2	Plan	WP 1	Dismount existing valve	Mech.	2	Day	Tools	HC	P1	
3	Plan	WP 1	Mount new valve	Mech.	4	Day	Tools, torque table	HC	P1	
4	-	Closure	Reinstatement	Proc.	2	Day/Night	Coord. with CCR	HC, PT	Isolation plan	
5	-	-	Ship old valve to shore	Log.	1	-				

Fig. 6. Work operations – work operation one selected.

for demonstration purposes only and do not represent a real system.

The left part of the display is further divided in three parts, work order and equipment description and history (Fig. 4), work operations (Fig. 5 and Fig. 6) and hazards (Fig. 7).

The work order and equipment description and history are illustrated in Fig. 4. The work order description is provided as a problem statement, how the problem shall be solved and what the end goal of the work is. Remarks and comments are specified in a separate field from the problem statement. The priority, estimated start date, duration and how the need for work occurred (the event triggering it) are also provided. Next, when the equipment has been specified, the equipment name, the system it is part of, its criticality, location and description (purpose) is provided. In addition, applicable procedures for work on the equipment and specific technical documents are listed as links. These are meant to be gathered automatically by the system. Then a timeline is used to present history related to maintenance activities on the equipment and any incidents. In the example a leakage incident that occurred in 1999 is marked in orange while the previous maintenance activities are marked in grey. To the right on the timeline the work order is displayed with the symbol of a valve on an orange circle. The orange colour is used to specify work on hydrocarbon carrying systems and is related to hydrocarbons. In addition to the specific work, future planned work on the same system that is already in the system is also displayed. The timeline allows the user to see the maintenance and incident history together with this and other planned activities on the system. This function is to our knowledge not part of existing systems used during planning of work orders or their operations.

The work operations are illustrated in Fig. 5. Each line represents one sub activity. These are specified with their step number, status, activity type, short description, responsible technical discipline, estimated hours, whether it is to be performed during day or night shift offshore, resource needs, work type, required procedures and potential hazards. The work type is normally associated with the steps including work permit level 1. In this example HC is used as the acronym for work on hydrocarbon carrying system. The hazard field is a reference to the hazard table (Fig. 7) where hazards for the specific step/sub activity are specified. Any of these work operations can be selected to expand additional information.

Fig. 6 illustrates the additional information for work operation one "set isolation plan". A pattern layout (Meirelles, 2013) is used as visual mean so expanded information is an add-on to what was already displayed and not a replacement. The expanded information is located directly underneath the short information already visible. The description is more detailed; the responsible technical discipline is now specified with the personnel who is planned to do the job; the hours are divided among the personnel; the isolation plan is detailed with a list of which valves that must be set to open or closed position; and the hazard "H3" is further detailed to apply for the second step of the isolation plan. The description of hazard H3 is provided in the hazard table (Fig. 7).

The intention is to use similar expansions to manage e.g. work permits which would be applicable to work operation two and three in the example. This would allow the work permit to be assessed in the context of the work order, as one of the work operations and with all the data already presented to be applicable for all work operations. This function is to our knowledge not part of existing systems used during planning of work orders or their operations.

The hazard overview is provided in Fig. 7. Potential hazards are listed with an ID, description of the hazard, which system it applies to, what causes the hazard, its effect, mitigating measures, barriers it

Hazards

ID	Hazards	System	Cause	Effect	Mitigation	Barrier	Resp.	Requires change
H1	Blindings do not hold	Blinds	Isolation set incorrectly	Leakage	Verify correct setting	BF1	Neo	-
H2	Valve doesn't fully close	Valves	Valve not closed/set as a barrier	Leakage	Verify correct setting	BF1	Neo	-
H3	Valve doesn't fully close	Valves	Valve failure	Leakage	Expand isolation plan	BF1	Neo	New isolation plan

Fig. 7. Hazards.

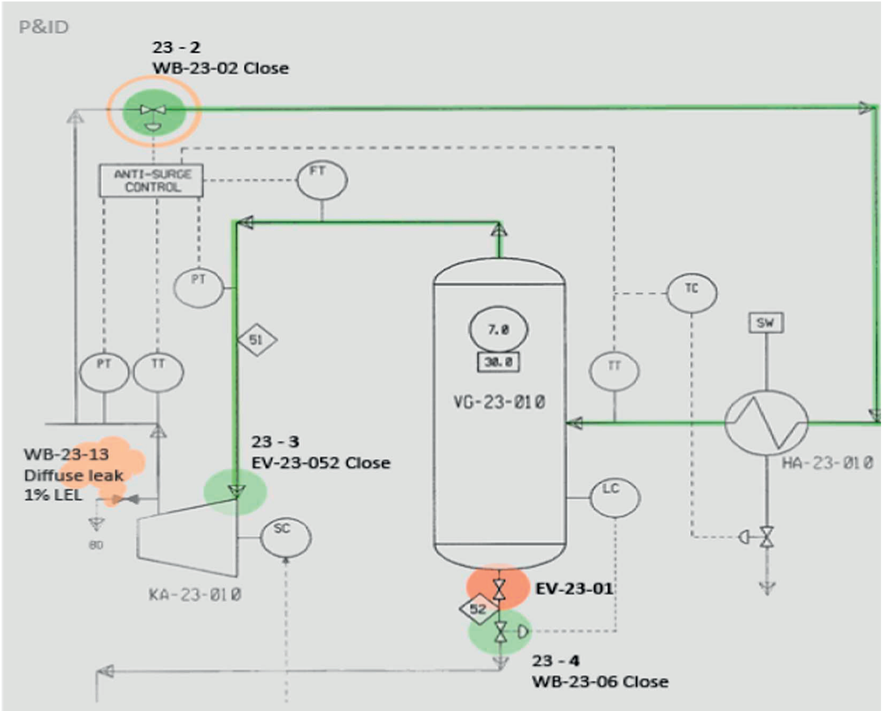

Fig. 8. Process and instrumentation diagram.

affects or is depending on, responsible personnel to follow up mitigations, and whether the occurrence of the hazard would require any change. In the example, hazard H2 and H3 are similar but have different causation. H2 is caused by the valve not being closed or that it is not correctly set as a barrier (some valves have special procedures for setting as a barrier compared to “simply” closing them). There may be many reasons why this could happen, human error during execution of the job being one of them. H3 on the other hand has valve failure as its cause. This is normally due to technical weakness of the design or degradation. If a pressure test unveils that the valve does not close properly, a required change in the plan might be to expand the isolation plan. For the work operation “set isolation plan” the hazard H3 is specified to apply to the valve WB-23-02 with 25% probability of failure (see Fig. 6). The hazard H3 is also presented visually on the process and instrumentation diagram (Fig. 8, upper left). This type of information is normally not available to the personnel involved in the planning process. Through this concept we illustrate one way it may be included to increase awareness of status and hazards associated to related equipment and systems to the equipment the work is planned on. One feedback from iteration two of the concept development was to include safe job analysis as part of the hazard table. Though this is not included in the example, the hazard table supports including aspects from safe job analysis.

The right part of the screen provides a visual presentation of the work and its sub activities in process and instrumentation (Fig. 8), plot/area (Fig. 9) and barrier (Fig. 10) diagrams. The process and instrumentation diagram for the specific system is presented by the system (as illustrated in Fig. 8) with the work order (applicable on valve EV-23-01) being displayed with orange circle around (the same way as was displayed at the timeline in Fig. 4). When the isolation plan is specified, it can be presented in the same view. In this example the valves included in the isolation plan and the pipelines being isolated and which needs to be gas free are highlighted in green. Their IDs, names and position is also specified in the diagram. At the upper left part of the picture, the valve WB-23-02 has an orange circle around it. This is to highlight that the hazard H3 is applicable to this valve (see also Fig. 6). Other weaknesses on the technical system that can be related to the diagram can also be visualized to provide the user with addition status and context. In this example there is a small diffuse leak at 1% LEL on WB-23-13. This is illustrated by an orange “cloud” at the left part of the picture. All parts of the diagram should be “clickable” so the user can get additional information about e.g. a specific piece of equipment. Such additional information could include functional description, maintenance and incident history, experience setting it as a barrier, operation parameters (vibration, temperature, pressure, etc.), failure analysis (POF, mitigations, etc.).

Fig. 9 illustrates an area map of the facility where the work order takes place with the specific work visualized using the same symbol as earlier. In addition, weaknesses and factors that may cause potential hazards can be presented given that they have a location which is nearby the work order. In this example the diffuse leak also presented on the P & ID is displayed. Another weakness presented is on a firewall with the title BF4 which is an acronym for Barrier Function 4 “Prevent dispersion and escalation”. At the right part additional information of the area is provided including the area name, its zone classification, known weaknesses, noise level and requirements for work in the area.

When using maps, information can be presented in different layers. One could have background layers representing the noise level, zone classification, emergency pathways etc. These aspects have not been further developed in this concept.

The final part of the concept is a barrier overview specific to the work order. For a leakage scenario there are four main barrier functions in place: BF1 “Prevent leakage”, BF2 “Contain leakage”, BF3 “Prevent ignition” and BF4 “Prevent dispersion and escalation”. Setting correct

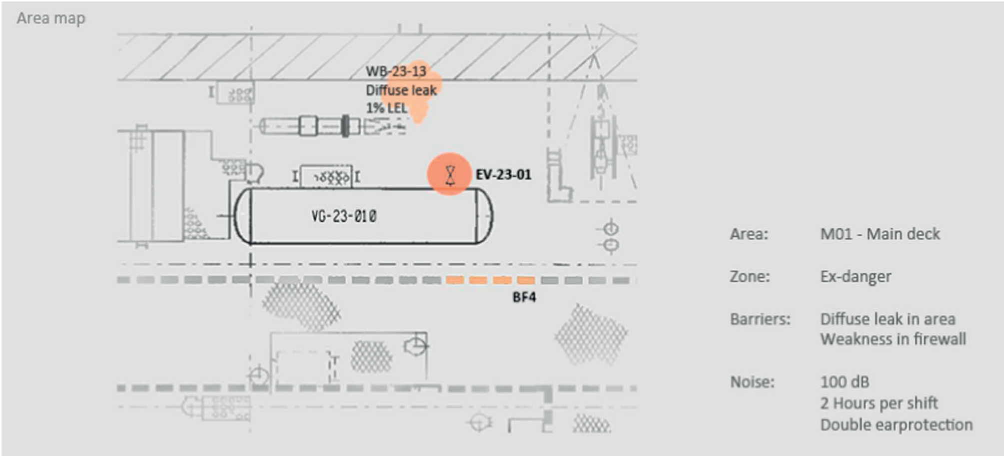

Fig. 9. Area map.

isolation contributes to strengthen BF1 and is here marked in green to give "credit" to plan for, set and reinstate the system correctly. The diffuse leakage is again displayed between BF1 and BF2. If execution of the work order would cause a leakage, the diffuse leak in the area is negligible. However, there are other activities that might be required as preparation in the area that should be aware of the diffuse leak, e.g. setting up scaffolding. The weakness in the firewall nearby the work area is highlighted in orange.

All together, these different parts form the concept developed to present information in a way that may enhance hazard and risk identification.

6. Conclusions and further work

In this paper a concept for visualizing risk related to work orders has been developed. The focus has been on enabling the personnel involved in establishing and managing work orders to identify and manage hazards for major accidents. Based on feedback from the participants at the design iterations the concept is easy to understand and present very valuable information that is not normally available to them in their existing systems.

The final design of the concept study is based on the iterations with expert evaluations that was possible to perform during this study and is not meant to be a final product of any sort, it rather demonstrates how information can be aggregated from different sources (work order systems, barrier management systems, hazard and risk analysis, safe job analysis, etc.) and presented in a way that supports hazard identification and decision making processes related to managing work orders. Ideally, we would have run many more iterations and with personnel involved in establishing and assessing work orders and work permits to get an even better evaluated concept. Yet, the iterations we managed to have through the workshops has highlighted the potential and needs for studying risk visualization further.

The final design has been presented to three different companies operating in Norway with the following feedback summed up:

- The concept illustrates that it is possible to present a lot of valuable data in a single screen and in an understandable way.
- The concept provides good overview of work orders and their sub activities.
- The concept should allow for better hazard identification than systems in use today.
- Some operators have most of the data available, but in different systems and in other formats than presented here.

Some aspects that differentiate this concept from existing tools typically used by the operating companies include:

- Integrates the planning process with barrier management by visualizing the plan and barrier data in the same view and context
- Visualization of simultaneous operations and activities
- Provides context to the planned activities in contrast to SAP and other planning tools
- Can view all activities in the light of the work order
- Assess not only the equipment the work is on, but also associated and required equipment

The intention of this concept development has not been to make a product, rather to show how simple visualization means can help address and communicate risk related information through the planning

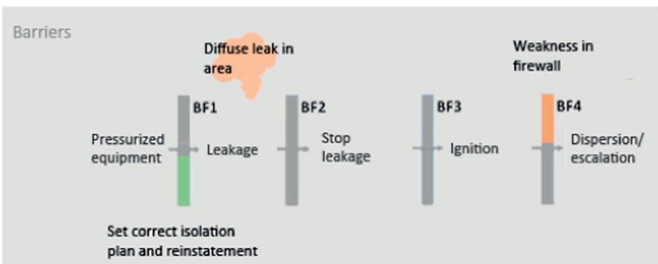

Fig. 10. Barriers.

process.

Further extension to the concept can include

- Visualizing critical human factors related to the work order steps, for example for verification and validation steps. For the work operation "set isolation plan" (Fig. 6) a critical human task is to verify that the isolation is set according to the approved isolation plan. Similarly for verification of correct reinstatement before the process equipment is handed back to the central control room operators for e.g. production. For work on hydrocarbon carrying systems the isolation and reinstatement of the system are critical tasks that require verification of correct performance (NOG, 2013).
- Highlighting work activities and steps that deviate from procedures.
- Establishing an overview of a plan using the same design principles.

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