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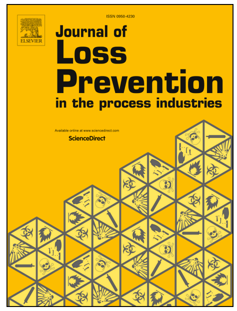

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Risk-related information needed through the planning process for offshore activities

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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, we identify 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 result is an overview of the analysis and information needs for four main decision arenas through the planning process. The paper builds on previous studies on the planning process for maintenance activities, studies of major accident theories and investigations reports for hydrocarbon leaks, interviews of offshore and onshore personnel, observations of meetings and workshop with two operating companies from the Norwegian Continental Shelf.

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., 2015), 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. The study identified that having the right information available at the right time was an important basis for developing good plans and making good decisions during the planning process. 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 needed to support certain considerations and decisions.

Of the identified factors influencing major accident risk in the planning process (Sarshar et al., 2015), some 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.

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 make the assumption that personnel involved in planning have required competence and time available to utilize the information in a relevant manner. 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
HRA	Human reliability analysis
HSE	Health, safety and environment
OPS	Operational plan
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

This section first describes a general planning process for the offshore maintenance activities, second describes the different decision arenas and their focus on major accident risk, and third provides an overview of relevant work.

2.1 The planning process

A general planning process for offshore maintenance activities has been described in earlier papers (Sarshar et al., 2015; 2016a). To provide the operational context a brief description of the planning processes is provided next.

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.

The three planning phases focused on in this study include: operational, work order and work permit plan. They contain several steps including: identifying the need for performing the work, establishing and assessing the activities, coordinating them on a plan and approval of the plan.

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 decision making. In other words, information that contributes to reduce and understand the uncertainties about activity, technical and external factors contributing to the overall system risk.

The different planning steps for the operational plan, the work order plan and work permits are provided in Table 1 with a description and an overview of major accident related assessments. These are based on Sarshar et al. 2015 (Table 1 and Table 2).

Table 1: 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.

Planning step	Description	Major accident assessment
		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	
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.

Aspects from major accident theories related to planning (Sarshar et al., 2015) 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 e.g. new circumstances. Assumptions made in earlier planning phases must now be known so they can be verified before new decisions are made.

The relation found between the planning process, and the potential for major accidents is mediated by the influence of a set of contributing factors (ibid). 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.

These findings highlight the need for clarifying what type of risk-related information is needed through the planning process to manage major accident risk related to maintenance activities.

2.2 Decision arenas and meetings

Within the planning phases there are decision arenas such as meetings in which work activities and plans are discussed and approved (illustrated in Figure 1). 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.

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 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* 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 analysis needs (performed in the steps prior to the meetings) and their need for risk-related information.

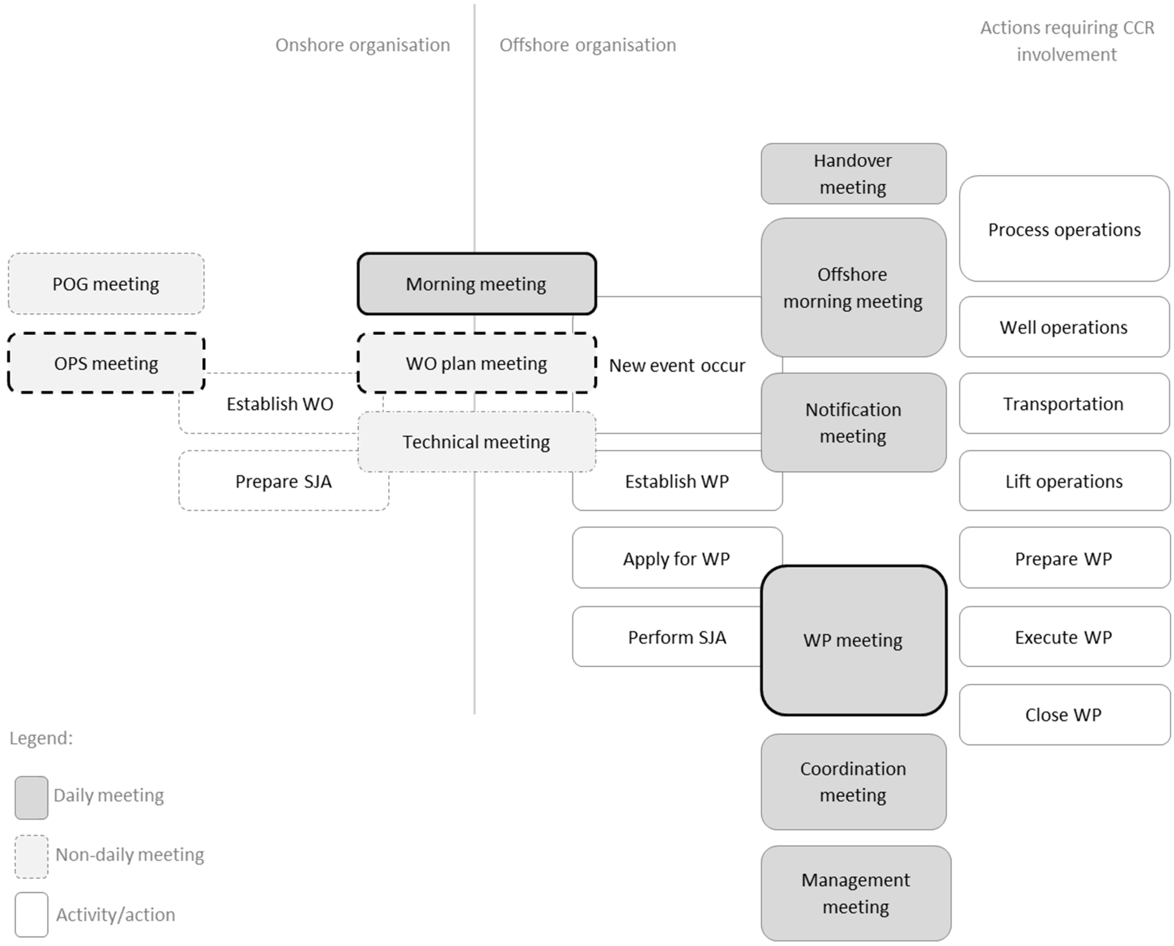

Figure 1: Meetings and activities/actions close to execution of offshore maintenance and operations.

2.3 Related work

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; (2) include more formal risk considerations of preparation and resetting task related to maintenance. This issue is also highlighted by Skjerve et al. (2011).

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 in (Sarshar et al., 2015).

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).

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.

3. Method

This work is primarily a theoretical study, but with important input from subject matter experts.

The work has been performed by studying the steps involved in the planning process and by studying data gathered through three workshops with industry partners. Based on these studies we generate an overview of risk-related information needed in the different steps of the planning process with respect to managing major accident risk.

Through the study of the different planning steps and what their focus, four steps that seemed the most important with respect to managing major accident risk where selected and studied further. These were the operational planning meeting, work order meeting, work permit meeting and morning meeting.

Based on the work process documentation available from two operating companies who participated in the study, we identified the objective and main decision for the selected planning steps.

The analysis needed to support these decisions were gathered based on the work process descriptions. This was further complimented with data gathered through interviews and workshop with personnel involved in the planning process and observations of information flow between meetings (Sarshar et al., 2013; 2016a). These studies focused on factors that affect risk for major accidents when in the planning process and the challenges and opportunities of manging these factors through the planning process. The participants highlighted their experience and thoughts on analysis needs in the different planning phases. The participants were offshore and onshore personnel involved in planning, assessment of plans and execution of maintenance activities.

To identify and understand what type of information is needed we studied the factors that influence the system risk (the overall risk picture for an installation) – the activities, technical and external factors. The identification of information need was further based on the planning data used by the two operating companies, previous studies on the planning process, major accident theories and study of investigations reports (Sarshar et al., 2015), interviews and workshops with the industry partners, and logical reasoning.

An overview where then made for each of the planning steps listing the analysis and risk-related information needed. This was reviewed by a subject matter expert and updated based on his feedback. The overview is provided in Table 2.

4. Risk-related information needed through the planning process

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 2**Error! Reference source not found.**. 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.

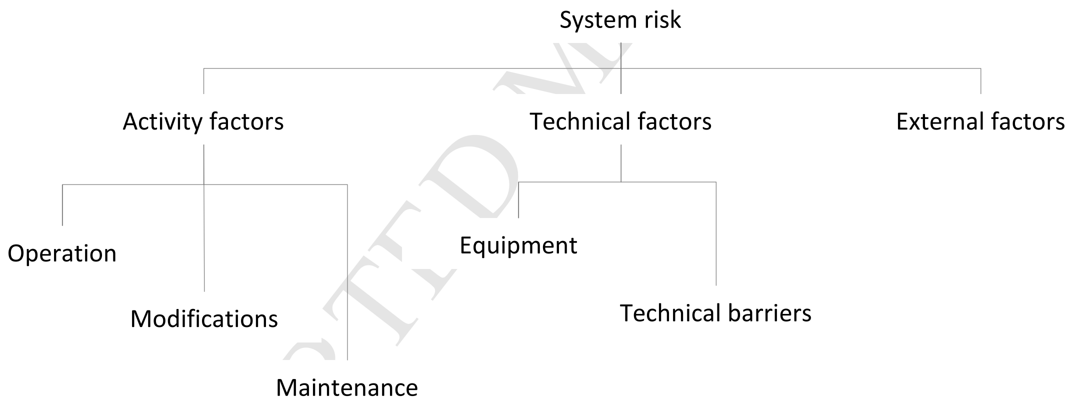

Figure 2: Risk influence structure for a system

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.

[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).

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 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.

Based on the documentation available from the industry partners involved in the study and the learnings from previous studies on the planning process (Sarshar et al., 2015; 2016a) we have prepared an overview of assessments and information needs in Table 2. 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.

In general, when establishing work or evaluating 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?

To evaluate a plan, the planner need to take into consideration a range of information about the activities to be carried out, the areas in which work should be executed, the barriers in place and their status etc., including the followings:

- 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 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 today.

The results (decisions, assessments and information needs) from this study has been critically reviewed by a subject matter expert and updated based on his feedback.

Table 2: 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?	

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 2 the assessments and information needs become 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 (Almklov et al., 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 system together with information collection and information visualization plays an important role in supporting the planning process. The role of such an information system would be to manage and present the relevant information in the planning steps where they are to be used (to support 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 2**Error! Reference source not found.**. 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 system 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.

6. Conclusions and further work

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. In this study, we identified 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 focus in our study has been on major accident prevention through the planning process. This has been addressed by studying important decision arenas in the planning process 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.

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. An innovative concept for visualization based on the risk-related information identified in this study is presented in Sarshar and Haugen (2017) with the purpose of supporting planning of work orders and work permits.

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- 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.