Abstract—This paper reports on a software test bed, called the Maintenance and modification Planner (IO-MAP) which has been developed 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 integrated operation (IO) work practices. Preliminary findings from the first study in the series are also outlined. The objective of IO-MAP is to enhance the quality of planning and, in particular, improve interaction between onshore- and off-shore based personnel in the planning process. Further, IO-MAP is 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. Preliminary findings indicate that such tools have the potential to play an important role in preparing and undertaking the planning process as such as well as serving as the basis for precise communication and discussion of plans that have already been made.

Keywords—Risk visualization, planning and decision making.

I. INTRODUCTION

Integrated operation (IO) is an operational concept that is gradually being introduced in Petroleum Companies operating at the Norwegian Continental Shelf (NCS). IO has been defined as “real time data onshore from offshore fields and new integrated work processes” [1]. In IO in the petroleum sector on the Norwegian Continental Shelf (NCS), focus is on enabling new ways of working in operations through implementation of innovative technologies [2][3]. In some cases, however, these new technologies have turned out to be more innovative than enabling.

In an ideal situation, one would first identify the desired work practice and then select technologies to enable this way of working. In reality choices are also technology driven, and technology constraints and possibilities often shape the work practices, sometimes with unforeseen effects. Technology imposed change is only purposeful if it contributes to alignment with the organization’s strategies and the standards of the industry. One set of such standards and strategies are those that pertain to safety risks.

The purpose of our studies is to investigate whether technology characteristics can improve risk identification and thus decisions in future IO work practices, with special focus on technology for risk visualization applied by individuals and teams planning maintenance activities.

In line with the current trend, most of the planning stages take place onshore in close interaction with personnel offshore. The planning and the associated interactions typically deal with tasks within a multitude of disciplines in a complex setting with a risk potential. The planner is expected to build into plans the required safety and work environment considerations as well as other requirements such as optimal utilization of available resources, effectiveness and quality requirements.

In terms of planning aimed at the short-term perspective, heads of the various professional disciplines offshore, such as mechanics, instrumentation, electricity, and automation, as well as the operation and maintenance leader and the platform leader, are the main actors. The work processes of today usually imply that the heads of the various professional disciplines prepare plans for their area of responsibility. These initial plans are brought into a joint meeting with participants from all professional divisions together with the production and maintenance leader and the platform leader where a final overall plan for the activity the coming day is worked out. In terms of planning aimed at the medium-term perspective, these are performed by onshore planners, i.e., a staff member who is explicitly dedicated to planning activities. The onshore planner(s) will develop a suggestion to how the fourteen-day plan may look, which will later serve as input for the joint planning meeting involving both onshore and offshore staff. Figure 1 illustrates the planning processes in both short-term and medium-term perspectives.
During 2008 and 2009, features that may have effects on teamwork and risk perception were identified in two exploratory observational studies of IO collaboration, field visits, and surveys in 6 different organizations [4][5][6].

Based on these findings, a software test-bed, called the IO Maintenance and Modification Planner (IO-MAP) has been developed by researchers in close collaboration with actors in the industry. The development approach takes into consideration work practices and processes, with frequently performed user tests with a number of companies and disciplines. The work has been performed stepwise and iteratively. The present test-bed focuses mainly on how to enter, combine and visualize information related to tasks to be planned and to risks that need to be taken into account. The test scenarios have been built with the industry and have been refined during data collections. Similarly, the test-bed has been regularly improved based on user inputs.

The software design is inspired by location based geographical information systems. IO-MAP contains easily comprehensible overviews, showing information on work in various stages of planning together with known conditions in the work area. This is combined with functionality for visual identification and description of safety risk.

In this paper we report on the IO-MAP test-bed and preliminary findings of the first usability study, conducted in 2009, focusing especially on findings concerning risk identification. Based on results obtained across all studies mentioned, we, moreover, discuss challenges and measures to improve safety, learning, productivity, and performance in IO work practices.

II. THE IO MAP AND FIRST USABILITY STUDY

A. Test-bed design and development

The IO-MAP test-bed is designed to support planning of maintenance and modification activities in short to medium-term perspectives, i.e., planning directed at the activities to be performed today or in few weeks time. This implies that two different groups of employees can be defined as “users”: short-term and long-term planners.

During a field visit to the one of the oil and gas installations on the NCS, the IO-MAP project team discussed user requirements for IO-MAP with off-shore staff engaged in short-term planning. The starting point for these discussions was graphic sketches of the displays to be contained in the test-bed. The system was very well received by the staff, and a range of suggestions emerged on how to improve the design of the system. All these ideas and requirements have not been added to the IO MAP test-bed for the first usability study, but all have been recorded and rated by importance, and many of these will be carried on further into the design process. The identified functionalities have been prioritized and functionality important for planning, usability and risk visualization selected for the research team to design and implement. The test-bed contains enough functionality to enable investigation of how the users, i.e. maintenance planners, perceive the present risks, when planning typical oil-platform related work.

Planning sessions are in general efficient meetings and supposed to be of short duration. The additional requirement of combining simplicity and intuitive interfaces with salient and clear visualization of safety impacts was therefore put on the IO-MAP test-bed. Icons and highlights must in such a situation be few and unambiguous, as shown in [6]. On the other hand it is important that all necessary information is easily available and it must therefore require little effort to move between different levels of detail in aggregated information. If an application is more complex than perceived necessary by the users or in general difficult to use, it will probably not be used in work sessions of this kind.

To accommodate this need, the test-bed was designed using techniques from Information Rich Design (IRD). This is a concept developed and design patented by institute for energy technology (IFE) [8][9]and is currently becoming the reference design standard for Large Screen Displays (LSD) for Norwegian oil and gas installations. The concept, initially designed as an operator type of display with interaction possibilities, has however solely been implemented as a LSD type of display. Prototypes of IRD large screens are also in later years developed for the nuclear industry in joint Nordic projects [10].

Designing visual interfaces raises several challenges, one of the main issues being to avoid information overload. Safety and process displays may cover hundreds of data points, something that can lead to overload and strain on the end user, since the human knowledge-based memory typically only holds a few arbitrary digits. There are however methods to access the brain in more efficient ways. One model that the IRD principles are based upon is the SRK model; Skills, Rules, Knowledge [11][12]:

Skills: Based largely on unconscious processes; large capacity
Rules: Partly unconscious; high capacity but more demanding
Knowledge: Knowledge-based principles; low capacity (5-7 arbitrary digits).
Conscious control systems (knowledge-based) are easily disrupted by affective state, neurological or psychological disability, whereas unconscious systems (skills/rules based) are robust and resist interference from external sources. Unconscious systems are also relatively invariant across the population [13].

It is possible that the evidence of overload reflects more on an inappropriate display than on limitations of the perceiver [13][14]. The challenge is in that case to reach the users’ unconscious high capacity supporting skills/rules based operation. One possible way to do this is by supporting pattern recognition. The use of IRD technology typically replaces numerical values with analogue graphs and pattern recognition schemes, alignment of comparable data and color-layering techniques.

The IRD concept refers to data displays that combine the dull screen color principal [15] with analogue normalized integrated trends to obtain high data density displays without causing information overload. A key feature is that visual forms should be possible to read using different strategies depending on the user’s current preference. The reason for the use of grey colors and low contrast for background data is to provide a display where safety relevant conditions and factors with alarm colors (red, yellow) easily can be detected. The dull screen approach also contributes to a pleasant working environment for the operator, as strong vibrant colors and high contrast can be exhausting in the long run.

The carefully selected colors in the test-bed, in Figure 2, contribute to a pleasant working environment. The dull grey background color does not contain any elements of alarm type colors such as yellow and red; this is in accordance with the dull color principles as found in the IRD principles. Unnecessary use of frames and thick lines are also avoided to make the display look less crowded while maintaining high data density [16][17][18]. The figure also shows that static text is presented using light grey colors, while the important dynamic information such as “hot-work” uses more visual and salient colors. This type of layering technique, placing less important static information on less salient graphical layers is one of the cornerstones of IRD design; this is also described in [16][17][18].

Alignment of comparable type of data can help the user scan the display for larger quantities of data with less use of cognitive resources. The table found in the lower left corner of the test-bed design is one example of this type of IRD alignment technique. The work permits in the table can easily be scanned vertically to see if they appear at the same time, or same type (hot work, entry etc.). The technique of alignment of data is described in [16][17][18].
Designs using IRD technology aims at high data density, reducing the need for multiple screens and displays to reduce the need for navigation, hence reducing the “key-hole effect” [8]. This is solved for the test-bed display by presenting the platform, selected deck and work-permits and information integrated in one display only, avoiding pop-up windows. This reduces the cognitive workload for the end user, and presents a design in accordance with IRD principles.

In the top area of the test-bed the user can navigate through the different decks or levels of the installation, and chose the area of interest for visualisation. An excerpt of implemented functionality includes:

- Pan and zoom functionality of the map to view different areas of the selected deck.
- Select an item or task on the deck.
- Filter the list of tasks to display work orders, work permissions and notifications.
- Hide and show different type of information on the map area.
- Edit information for a selected task.
- Add and modify risk elements for a selected task.

The bottom part of the test-bed provides a list of planned and unplanned tasks. The same tasks are placed geographically on the map area view. The list of tasks is filtered based on the navigation of decks. Navigation to another deck will automatically update the list of tasks to apply to the chosen deck. On top of the task list is a timeline that allows the user to determine the date and period of interest to filter tasks on. This allows the user to narrow the list of tasks by date, interval period and area of interest. When a task is selected from either the map view or the task list, it is highlighted both places.

The lower right corner of the test-bed design provides additional information for a selected work permit and allows the user to change the status of the work permit and modify its elements (elements are explained in the next section). An excerpt of this view is provided in Figure 3.

B. Studies on risk perception and visualization

The purpose of the IO-MAP studies is to evaluate the technology to study how it influences on situation awareness, including risk identification, goal conflicts (balancing concerns, trade-off between safety goals and other types of goals [4]), trust in colleagues and user acceptance.

IO-MAP can be configured to include different datasets for the usability tests. The facilitator can add tasks to the IO-MAP at different stages of the planning process, ranging from notifications (someone has been made aware that a job probably needs to be done and reports it in for planning) to work permits (a job that has been planned and evaluated with respect to health, safety, and environment (HSE) standards, criticality and feasibility). The IO-MAP application will then automatically highlight several types of risks associated with the jobs and (if any) risks associated with the combinations of jobs, by comparing the implications of the potential plans with the safety standards of the organization in charge. If, e.g., a plan implies that a group of workers will come to work in an unsafe area (e.g., due to the risk for falling objects from the decks above), the conflict between the safety goal of maintaining staff safety and the efficiency goal of getting the required job done, will be highlighted on the system’s display using the different types of elements.

It is important to convey to the users that IO-MAP cannot be trusted to automatically show all the risks, which the plans may imply, and to encourage the users to look out for potential risks related to the suggested plans. The users should be encouraged to add potential threats to the safety goals in real time during the planning process, based on their own perception of the situation at hand.

IO-MAP provides such functionality where the user can add a hazard, prohibit, comment or connect element, see Figure 4. This option is also vital from a psychological perspective, as it encourages the team members to actively search for safety threats.
An element is an entity which contains some type of information that is attached to the work permit, work order or notification. In this version of the test-bed, we have defined four types of elements which are related to communicating risks. The first three elements refer to risk visualization, which the test-bed automatically identify based on information about the characteristics of the installation and the standards of the organization in charge of the operation:

- **Hazard**, which represents general hazards associated with the particular location, e.g., risk for explosion.
- **Prohibited**, which shows that different types of activities are not allowed, e.g., it is not allowed to work without wearing a safety helmet.
- **Comment**, each user of the IO-MAP can provide information about risks, which they believe is present in the particular situation, e.g., based on information from colleagues, first-hand impression of the state of a component, information obtained from the criticality logs, etc.
- **Connectors**, meaning that if two tasks are performed as currently suggested in the plan, it will imply a safety risk. *If – for instance - a task is planned to be performed at a deck right under where another task is also performed, there might be a risk that objects will fall and hit staff working at the lower deck.*

Further, the tasks displayed in IO-MAP can be categorized by their work type. Some of the work types have certain risks related to them and are therefore visualized using colours. Tasks which are of hot work class A or B are displayed in red, work involving entry into tanks are displayed in green, work over sea is displayed in blue and work on hydrocarbon carrying systems is displayed in orange. When hot work and work on hydrocarbon carrying systems is conducted in nearby areas at the same time, there is heightened risk for explosions. Tasks which have an element are visualized with a yellow triangle on the map.

The joint visualization of risks identified automatically by the IO-MAP and risks identified and entered to the system by the users should contribute to ensure that the team will construct a comprehensive and correct common understanding of the risks associated with the various plans, and thus provide a basis for adjustments of plans if necessary for safety reasons. The option of adding risks in real time is of key importance, as the safety standards that can be applied for providing automated guidance will not cover all the potential safety challenges that may arise.

An important requirement to the test-bed is the documentation of a meeting’s decisions, including postponed or down-prioritized actions and tasks delegated to team members for clarification or execution. This is to ensure traceability, and that history is part of future decisions. Risk-related information entered into the IO-MAP during the planning process will also be available for other teams later in the work process. The visualization will thus also contribute to prevent that threats identified by one team are later forgotten.

### C. First usability study and early indications

The IO-MAP is developed using an iterative design process. Formative usability evaluations will be carried out throughout the design process to expose usability problems and thus allow for design adjustments.

The first usability evaluation was performed with one maintenance planner at the time. It, thus, focused on individual usability, i.e., the extent to which individual users can adequately operate the system to perform their allocated tasks. Even though the IO-MAP will be designed to be a groupware technology, this approach is used, based on the assumption that an adequate level of individual usability is needed, before the IO-MAP can come to fulfil its purpose in a team context.1 The first usability evaluation had two main, highly inter-related foci: (1) The extent to which the IO-MAP supports the users in identifying, understanding, and handling risk associated with the plans developed. (2) The extent to which the IO-MAP can adequately support the performance of risk user. Moreover, the evaluation sessions were used to collected data that would help prepare the IO-MAP for functioning in a team setting and for performing groupware evaluations.

The evaluation has produced insights into how the design of IO-MAP can be further improved, e.g., in terms of which system characteristics that should be added, eliminated, or redesigned – also in situations where IO-MAP should serve in a team setting. Prior to the study, pilot tests of the usability evaluation approach were performed with two users from the selected user group, i.e. on shore planners, to adjust and the usability evaluation procedure was adjusted based on the lessons learned.

The usability evaluations were performed in the home organizations of the maintenance planners (n=8). The users were mainly on-shore planners, representing four petroleum companies: Statoil, Eni Norge, Norske Shell, and GdF Suez E&P Norge.

To carry out the evaluation, two scenarios of approximately 30-40 minutes duration were applied. The scenarios were developed in a close collaboration with subject-matter experts. Each scenario was designed to contain a basic line of events which jointly constitute a set of tasks, which the user may realistically face on normal work day. In between these tasks, additional tasks were imposed. These tasks contained inherent risks that were not obvious at a first glance.

Each usability evaluation session followed the same procedure: The participating planner filled out a background questionnaire before they were introduced to and train to use the IO-MAP test-bed. Then, they performed one scenario. The scenarios implies that they were given the task to evaluate a given plan of work orders and work permits and identify risk associated to these tasks using the IO-MAP test-bed. The users were observed in different ways during the usability study; 

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1 The second usability evaluation will focus on the usability of the IO-MAP in a group context, i.e., to support a distributed team of planners in effectively developing maintenance and modification plans in which safety goals are adequately prioritized. It will thus involve an entire crew of planners.
test-bed automatically logged every function the user made use of, the research team observed and documented the process, and the session was video recorded for post analysis. The user was also able to get help for the test-bed by a present expert on technology. Following the completion of the scenario, the participants filled in a questionnaire, and then performed the last scenario. Finally, the participants filled in a set of questionnaires, and were interviewed about his/her assessment of the IO-MAP and how the system might be further improved.

Early indications of the usability study indicate that the IO-MAP display makes all risks identified readily visible to all members of the planning team, and may thus serve as a common frame of reference for understanding of risks during the planning process.

System Usability Scale (SUS) is used for global assessments of systems usability [19]. SUS consists of ten questionnaire items formulated as statements concerning the user’s experience with using a computer system. The user responds on a 5-point scale, to the items on a rating scale from 1 (Strongly Disagree) to 5 (Strongly Agree) (see Appendix C). SUS scores ranges from 0-100. 0 implies very little satisfaction, whereas 1000 implies very high satisfaction. According to [20], average satisfaction scores are usually between 65 and 70. The usability score of the IO-MAP was 80.3.

Further the following functions were highlighted as beneficial:

- The tool fills an important function in visualizing risks in connection to tasks and locations, offering an extra highlight and reminder of risks on the map.
- Planners with off-shore planning experience (usually pre-IO) may have an advantage in identifying risks connected to work orders or operations at an early stage because of their off-shore knowledge and “gut feeling”.
- It also seems that IO-MAP may help planners who never worked off-shore to get a share of “gut feeling” through visualisations.
- A limited number of additions to the system will turn it into a groupware for distributed collaboration. The needs will differ between users; this can be accommodated.
- The tool serves to focus discussion between cross-disciplinary participants.
The introduction of risk elements for adding hazards, prohibit, comment and connectors were well received by the participants of the usability study.

The study also highlighted some challenges and measures that need to be addressed:

1. There is a need to visualise work tasks that are not covered by the work permit system. Not all tasks require a work permit, such as minor routine tasks. These can, however, introduce risk which the system does not consider in this version. This is true, e.g., in situations where a risky task scheduled to be performed close to a routine task.

2. IO-MAP needs to visualise the whole work process, from notification to implementation.

3. It was suggested to design the IO-MAP to facilitate the work processes associated with maintenance planning, i.e. using a task-based design. This type of display would assist the maintenance planner in remembering to check and evaluate all relevant aspects of the operational situation as part of the planning process.

III. CONCLUSION AND FURTHER WORK

We have presented a test-bed developed for a series of usability studies on how technologies may support risk informed planning of maintenance and minor modifications in the petroleum industry on the NCS. The test-bed has been investigated in the first of a series of usability studies, and was favorably received by users from several different oil companies.

Findings will now be further analyzed, and the test-bed will be updated for the next study. In the first study focus was on individual usability. In upcoming studies the IO-MAP test-bed will be adapted for and used in collaboration sessions mediated through video conferencing, and investigations will include team work, goal conflicts and collective risk identification.

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