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Visualizing Safety Indicators

A Study of Requirements

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Safety, Health and Environment
Submission date: June 2013
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Preface

This master thesis was written at the Department of Industrial Economics and Technology Department at the Norwegian University of Science and Technology (NTNU) and is the end result of my Master of Science-degree in Health, Safety and Environment.

The reason I chose this assignment was the important aspect it has within safety and I think that visualization of indicators will become more important as Information and Communications Technology will develop even more rapidly with time, and also the fact that my specialization project was about these topics.

I had the privilege to have an excellent supervisor in Eirik Albrechtsen at NTNU whose insights within the field of safety helped me greatly along the way. He has been available for comments and feedback whenever needed. Big thanks to my co-supervisor Sizarta Sarshar at the Institute for Energy Technology (IFE) for greeting me at IFE, Halden and introducing me to the Integrated Operations Maintenance and Modification Planner (IO-MAP). And a last thank you to my family for being there and supporting me over the years.

Trondheim 10th of June, 2013

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Abstract

The thesis studied the visualization of safety indicators in oil and gas installations. Safety indicators measure the changes in the level of safety, and visualization communicates risk to safety management and specialists. Both aspects are important in the oil and gas industry where safety is a big part of daily operations because of the major hazards that is associated with the production of oil and gas.

The first part explored which traits are important for safety indicators and (risk) visualization respectively. This was based on a literature review on the two topics to gather critical points of the current knowledge including substantial findings as well as theoretical and methodological contributions. The findings were then organized into a spreadsheet where it was easy to see what requirements were recurrent and popular, and from this a set of requirements of visualizing safety indicators was then established. This selection of seven requirements was based on the goal that the requirements could apply to both indicators and the visualization, and the relevance of them.

The Integrated Operations Maintenance and Modification Planner (IO-MAP) was to be the case for this thesis in order to apply the set of requirements on a test. IO-MAP is a software tool that is developed to support the planning of maintenance and modification activities on offshore installations to help decision-makers gain a better overview which leads to enhanced safety.

Results from IO-MAP's review of the requirements suggest:

- Include a total risk picture to visualize the sum of risks connected to the planned tasks per day
- Adding more types of work that requires work permit (e.g. isolation of safety system, pressure testing, and work with dangerous and radioactive substances)
- Implementing more information about the tasks to get the full picture of the tasks and how they are done in practice

It was found that not all requirements were suited to test the safety-related information from IO-MAP. This could be due to the fact that not all information from IO-MAP could be directly transferred as visualizing safety indicators rather than being explicitly an indicator or a visualization technique.

Sammendrag

Denne masteroppgaven studerte visualiseringen av sikkerhetsindikatorer for olje- og gassinstallasjoner. Sikkerhetsindikatorer måler endringer av nivået i forhold sikkerhet, og visualisering formidler risiko to sikkerhetsledelse og andre spesialister. Begge aspekter er viktig i olje- og gassbransjen hvor sikkerhet er en stor del av daglige operasjoner på grunnlag av de store farene som knyttet til produksjonen av olje og gass.

Den første delen undersøkte hvilke egenskaper som er viktige for henholdsvis sikkerhetsindikatorer og (risiko)visualisering. Dette var basert på et litteratursøk på de to emnene for å samle kritiske punkter fra dagens kunnskap inkludert betydelige funn så vel som teoretiske og metodiske bidrag. Funnene ble organisert i et regneark hvor det var påfallende å se hvilke egenskaper som var gjennomgående og populære. Fra dette ble et sett med krav til visualisering av sikkerhetsindikatorer etablert. Valget av de kravene som var i settet var basert på målet om at de kunne anvendes på både indikatorer og visualisering samt relevansen av dem.

Integrated Operations Maintenance and Modification Planner (IO-MAP) er et software-verktøy som skulle gjennomgå kravene nevnt ovenfor. IO-MAP ble utviklet for å støtte planlegging av vedlikehold og modifikasjonsarbeid på offshore installasjoner for å hjelpe beslutningstakere få bedre oversikt under planlegging for å bedre sikkerheten.

Resultatene fra IO-MAPs gjennomgang av krav foreslår:

- Inkluder et samlet risikobilde for å visualisere summen av risiko koblet til arbeidsoppgaver per dag
- Legge til flere typer arbeid som krever arbeidstillatelse (f.eks. isolering av sikkerhetssystem, trykktesting og arbeid med farlige og radioaktive stoffer)
- Implementer ytterligere informasjon om arbeidsoppgavene for å få samlet bilde av arbeidsoppgavene og hvordan de blir gjort i praksis

Det viser seg at ikke alle kravene egnet seg til å teste den sikkerhetsmessige informasjonen fra IO-MAP. Dette kan skyldes at ikke all informasjon kunne tilskrives som visualisering av sikkerhetsindikatorer, men at den kunne være enten en indikator eller en visualiseringsteknikk.

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Chapter 1

Introduction

Background

There are many potential sources of harm to the health and safety of the workers on offshore installations and marine environment. The threat of typical industrial dangers combined with the hazards of oil and gas extraction can lead to threats to the structural integrity of the installation, explosions and fire, blowouts, dangers associated with drilling operations and injuries to personnel. A tragic example is the Macondo accident, where a blowout killed 11 workers on the Deepwater Horizon drilling rig, ignited a huge fireball that caused the rig to sink and leaving the well spewing crude oil which had a huge negative impact on the environment.

Previous to the accident Deepwater Horizon was issued pollution citations 18 times between 2000 and 2010, and had investigated 16 fires and other incidents. This was however not considered unusual in the Mexico gulf, but the oil rig had other serious incidents as well. It began to sink in 2008 after a section of pipe was accidentally removed from the platform's ballast system and 77 people were evacuated. In March 2010, the rig experienced a series of problems which lasted up until the disaster (DHSG, 2011). These problems should have indicated that the drilling rig was ready for some maintenance and modifications, but was instead driven with pressure of time and money, and thus compromising safety.

In addition to pressure of time and balancing between risk and safety, the future of the oil and gas industry holds many challenges such as less accessible oil discoveries, other energy sources may emerge, the global economic turndown and more complex operational challenges.

This, in turn, challenges the safety and the safety-management within oil and gas-production to think in new ways by utilizing new technologies and work forms and processes. IO (Integrated Operations) is such a concept. It refers to new work processes and ways of performing oil and gas exploration and production through new information and communication technology.

This thesis will explore which traits are important for respectively safety indicators and (risk) visualization. *Safety* indicators because it measures the changes in the level of safety, and *risk* visualization as it communicates risk to safety management and specialists. Both aspects are important in the oil and gas industry where safety is a big part of daily operations because of the major hazards that is associated with the production of oil and gas.

There are numerous types of indicators in the literature. In general, indicators are often used to measure the current state of a system or a process, or its future development. They often use data from models as a foundation where the right kind of information, effectively monitored and which inform decision making, will make a significant contribution to reducing the risks of accidents. Safety indicators differs in that they give a measure of safety performance, and as a result can identify what actions are (or going to be) successful in improving safety.

Risk visualization can help decision-makers and their support, but also others using it interpret information to provide the best solutions for minimizing risk e.g. when planning operations. As with indicators, extracting the right information can support the right decisions and actions.

While safety indicators have been in the industry for some time, risk visualization is not that wide-spread, but both are under constant development and are highly relevant in regards to safety. This is associated to the rapid development of information and communications technology.

Objective

The aim of this thesis is to make suggestions for further developments of IO-MAP and to develop a set of criteria for visualizing safety indicators.

The main contents of this thesis are to:

- Do a literature review of requirements to safety indicators
- Do a literature review of requirements for risk visualization
- Establish a set of requirements for visualizing safety indicators
- Extract the safety related information from IO-MAP
- Apply the requirements on the information from IO-MAP
- Make suggestions for improving IO-MAP

Thesis structure

Chapter 2 describes the methodology used in this thesis.

Chapter 3 gives the theoretical background with descriptions of safety indicators and risk visualization and a literature review of these two topics. A set of requirements are then extracted from both topics.

Chapter 4 examines the safety-related information from IO-MAP which is the case for this thesis.

Chapter 5 puts the safety-related information from IO-MAP through the requirements from the literature review.

Chapter 6 includes a discussion about the chapter 3 through 5 and summarizes the main findings.

List of notions

This part will explain key terms used throughout the thesis.

Requirements - a singular documented physical and functional need that a particular product or process must be able to perform. In classical engineering approach, sets of requirements are used as inputs in the design stages of product development, and an important input into the verification process.

Indicators - can be defined as something that helps us to understand where we are, where we are going and how far we are from the goal. Within engineering it can be an instrument that displays certain operating conditions in a machine, such as a gauge showing temperature, speed, pressure, etc.

Safety indicators – it is an extension of indicators by measuring the changes in the level of safety (related to major accident prevention, preparedness and response) as a result of actions taken. It can be related to defense lines such as physical barriers and safety functions.

Risk indicators – also an extension of indicators by measuring changes in the risk level on an installation by utilizing risk models and cover the most important risk factors with respect to major accidents having consequences for personnel onboard the installations.

Visualization - any technique for creating images, diagrams, or animations to communicate a message. Visualization through visual imagery has been an effective way to communicate both abstract and concrete ideas for millennia.

Risk visualization – it is the systematic effort of using (interactive) images to augment the quality of risk communication along the entire risk management cycle. This is done by utilizing graphic representations such as maps, charts, diagrams and visual metaphors.

IO-MAP (Integrated Operations Maintenance and Modification Planner) - a software tool that is developed to support the planning of maintenance and modification activities on offshore installations within the operational concept Integrated Operations (IO).

IO (Integrated Operations) - refers to new work processes and ways of performing oil and gas exploration and production, which has been facilitated by new information and communication technology between offshore platforms and land-based offices.

Chapter 2

Methodology

The progress of this thesis was set in 5 phases. In order to test the quality and apply the safety-related information from IO-MAP on requirements, those requirements needed to be based on criteria from the current literature. All the safety-related information from IO-MAP were then extracted based on reports I received from Sizarta Sarshar, which has been involved in the IO-MAP process, and also based on the day I got to try it out in IFE, Halden. This information went through a checklist containing the requirements found, where a quantitative score and a comment were provided to each indicator and visualization technique.

Figure 1 The research process of this thesis

Phase 1 - Perform a literature review of requirements to safety (performance) indicators and risk visualization

A literature review of the requirements to safety performance indicators and risk visualization were to be the foundation of the thesis. This is to gather critical points of the current knowledge including substantial findings as well as theoretical and methodological contributions to the topic. The literature on safety performance indicators is rich and plentiful. Online searches of the topic led to many results, which meant I had to filter out a lot of literature, though the requirements were surprisingly similar. Literature on risk visualization is a lot less extensive, but it proved to be relevant in establishing criteria.

Phase 2 - Choosing the requirements from the literature

After gathering findings from the literature, it was organized into a spreadsheet where it was easy to see what requirements were recurrent and popular. Decisions then had to be made on which requirements to use. These decisions were based on the goal that the requirements could apply to both indicators and the visualization, and the relevance of them. The list was set to six final requirements to keep it concise.

Phase 3 - Find safety-related information from IO-MAP

Based on a usability study paper from the first version, a presentation of the second version of IO-MAP and testing the software tool first hand was sufficient to extract enough safety-related information to test them. The IO-MAP project is currently at ease and my impression is that it is not clear at the moment what the future of the project holds.

It would have been desirable to have more information about the project which is limited to the reports available and a day of trying it first-hand. If I had been present in every step of the IO-MAP project, I would have had more knowledge about the rationale of choosing every indicator and visualization technique, although I would then be a bit biased to them and also would have not been able to get my “own” first impression.

Phase 4 - Run the information from the case through the requirements

This phase consisted of running the information from IO-MAP through the requirements in order to break down the information and analyze its quality.

A quantitative scale with five levels was given to each “indicator” to demonstrate the level of operability/usability. The scale is a five-point scale with ranges: very inadequate – inadequate – adequate – good – very good.

Phase 5 - Recommendations for improving IO-MAP and comments to the set of requirements

The final phase consisted of gathering the analysis of the “indicators” that could be improved and the reasoning behind it to give suggestions for improving IO-MAP. A discussion about the literature review, comments to the set of requirements and the safety-related information in IO-MAP together with the process of running that information through the set of requirements is included in the last chapter.

Chapter 3

Theoretical background

This chapter sums up the theories and concepts that are relevant for this thesis. It will explain the basics of safety indicators and risk visualization, and present the state of the art as it is in the literature. To know the state of the art, and knowing what requirements the literature possess about safety indicators and risk visualization is important as several elements from IO-MAP will be run through those requirements.

What is an indicator

Indicators are used in many parts of the professional life, such as business, science and engineering. This means that indicators are used in many different ways, but in relation to safety science it can generally be a measure or pointer that monitors safety related processes.

Indicators are based on information from underlying data and models. It is important to choose the right type of information to represent the indicator, as lacking information would at best give partial indications of safety. The wrong information would lead the users of the indicators astray. The right type of information for indicators leads to early warnings or safer decisions, which leads to more confidence when further decisions are to be made. Indicators can also play an important motivational role, especially at the higher management levels, with making safety visible in a summary way and making it suitable for communication and comparison.

Two basic indicator versions are risk indicators and safety (performance) indicators. While risk indicators are developed from a risk based approach, utilizing a risk model and mainly quantitative, the safety indicator may be developed from a variety of methods, such as the safety performance method, the incident based method and the resilience based method.

Indicators can be defined by Øien (2001) as "a measurable or operational variable that can be used to describe the condition of a broader phenomenon or aspect of reality", and OECD (2008) defines safety performance indicators as “observable measures that provide insights into a concept – safety – that is difficult to measure directly.”

These two definitions are somewhat similar, meaning there is slight differences between indicator and safety performance indicator as terms, but they still possess much of the same qualities. There exist several other variations of indicators as well such as process safety- and personnel safety indicators, leading and lagging indicators, feedback, monitor and drive indicators etc.

In short, risk indicators measures changes in the risk level on an installation during normal operation in the time periods between updating the QRAs, thus obtaining an "indication" of the risk status on a regular basis. The risk indicators are developed from a risk based approach and cover the most important risk factors with respect to major accidents having consequences for personnel onboard the installations (Øien & Sklet, 2001).

This thesis will be concentrated around safety (performance) indicators which can be considered to be "a means for measuring the changes in the level of safety (related to major accident prevention, preparedness and response), as a result of actions taken" (OECD, 2003).

Holmberg et.al. (1994) defines safety indicator as an observable characteristic that presumably holds a positive correlation with safety, and has been selected, among other means, for the purpose of supervision of safety. The safety indicator can be related to defense lines according to defense-in-depth such as physical barriers and safety functions. (Defense-in-depth means in this case to minimize the system's vulnerability to human and technical errors by providing independent and diverse layers of protection.)

I recommend the definition by Holmberg et.al as it gives an extensive coverage of what a safety indicator is. This definition will be used throughout the thesis.

Safety indicators can be developed from a safety performance method, incident based method or resilience based method. The safety performance method starts from a set of influencing factors assumed to be important to safety. The goal of this method is to monitor the level of safety in a system, decide where and how to take action, and to motivate those in a position of decision making to actually do so.

The incident based method identifies early warning indicators by studying incidents or accidents. It identifies and sheds light on factors that contributed to one or more incidents/accidents. The factors that contributed must have the condition that if it had been adequate, then neither the particular incident/accident being analyzed nor similar incidents/accidents would have occurred.

Resilience based method is a specific approach to manage risk in a proactive manner. It is about engineering resilience in organizations and safety management approaches, by providing methods, tools and management approaches that help to cope with complexity under pressure to achieve success (Hollnagel & Woods, 2006). In order to be resilient, four abilities must be basic. These are responding to regular and irregular conditions in an effective and flexible manner learn from past events, understand correctly what has happened and why, monitor short-term developments and threats; revise risk models and anticipate long-term threats and opportunities.

Using these methods as a foundation together with adequate knowledge will produce indicators that will increase the level of safety in any organization.

The importance of indicators

In order to know where we are heading, we need indications that we are heading in the right direction. For practical safety work, this means measuring how well safety is being managed by a certain set of indicators. A safety indicator for occupational injuries has traditionally been used for many years, and these were the only type of indicators used in the offshore petroleum industry for a long time. Then in the late 1990-ties many experts acknowledged that additional indicators were needed, especially for aspects relating to major hazards, and prevention of such hazards (Vinnem et.al, 2006).

The Norwegian authorities (then the Norwegian Petroleum Directorate (NPD) and now the Petroleum Safety Authority (PSA)) defined a project called “the Risk Level Project” in order to develop necessary methods for additional indicators. This marked the fundamental need for indicators and the continuous development of indicators in the petroleum industry.

Indicators are used everywhere with regards to safety to give pointers as to how good a process or an installation is operated safely. Safety management needs tools that gives some measurable result which provides an indication of the state that one wants the risk picture of.

Indicators may be used in many different ways, and can be used for almost every safety aspect. The important aspect is to adapt it so that it gathers every possible risk influencing factor (RIF) and does its job of indicating hazards and/or deviations. This is a difficult task as the industry is focusing on extending the operational life of installations and systems gets more complex with new technology and innovations. It is, however, necessary as safety management needs pointers as to if a process or an installation is operated safely. (Dyrseth, 2013)

Requirements to safety indicators

It is not enough to just supply safety indicators to improve safety, or have many indicators you got. The sheer quality is also absolutely vital to get the best out of them, and therefore we need requirements when developing indicators. Below are some lists of requirements to indicators in the literature.

Hale (2009) uses what he calls a standard generic list as requirements for indicators. He points out that these criteria should be operationalized based on the purpose of the indicator.

- *Valid:* does it measure what we want to measure? Is correlation enough, or do we need the link to be causal? This includes using rates which take account of exposure when counting things such as accidents.
- *Reliable:* does it give the same measurement when used by different people on the same situation, or on different occasions by one person on that same situation?
- *Sensitive:* does it respond to changes in what it is measuring with sufficiently large changes in the indicator to become statistically significant over a reasonably short time?
- *Representative:* does the set of KPIs cover all the aspects that are relevant?
- *Openness to bias:* can it be manipulated to show better score without changing the underlying situation it is supposed to be measuring?
- *Cost-effectiveness:* does it cost more to collect the data than would be lost without the indicator to assist decisions?

Hale mentions KPIs which cover many aspects of an organization which defines and measure progress towards organizational goals like production and profit. This, in addition to the last requirement covering cost-effectiveness, is not included in this thesis' limitations and will not be pursued further.

Kjellèn (2000) lists a set of requirements for SHE performance indicators for use in feedback control which can be adopted for indicators in general.

- *Observable and quantifiable:* the first criteria specify that the indicator must be possible to observe and measure performance by applying a recognized data-collection method and scale of measurement. This means that we must be able to tell whether the result represents or will represent a deviation from a norm or not.

- *Valid indicator of the risk of loss:* this criteria demands that we measure what we intend to measure, i.e. do we get actual indications of proper safety or do we measure something that has no effects on safety.
- *Sensitive to change:* the indicator must allow for early warning by capturing changes in an industrial system that have significant effects on the risk of losses due to accidents.
- *Compatible:* the indicator must also be able to exist with other safety indicators without conflict to prevent the decision-makers receiving contradictory control signals.
- *Transparent and easily understood:* meaning it is apparent and compatible with the users' theoretical understanding and unconscious mental models.
- *Robust against manipulation:* a variation of the validity requirement. Through SHE performance monitoring and feedback we want to achieve reductions in the risk of accidents. We expect the monitored organization to change its behavior in order to achieve improvements. The question is here whether the indicator allows the organization to "look good" by, for example, changing reporting behavior, rather than making the necessary basic changes that reduce the risk of accidents.

Herrera (2012) uses, amongst other, Kjellèn to build further with criteria for safety indicators. Her purpose of the indicators is to support monitoring and more specifically anticipate and support actions before something happens, which is close to this thesis' purpose also.

- *Meaningful:* indicators are relevant to production and safety, and can be used to address what is happening to the system in a specific context. Indicators provide information which guides future actions.
- *Sensitive:* Indicators provide a clear indication of changes over a reasonable period of time.
- *Reliable:* Indicators lead to the same interpretations when used by different people for the same situation. The interpretations are related to the system and its operational context.
- *Measurable:* The values of indicators can be rendered in a concise manner, either quantitatively or qualitatively.
- *Verifiable:* It is possible to confirm the correctness of the value or description of the indicators.
- *Inter-subjective:* Indicators are understood in the same manner by different people, either from same technical community or from society at large.

- *Operational:* The indicators can be used to support concrete actions within the operational context.
- *Affordable:* The cost of obtaining and using the measures is affordable vis-à-vis the benefits.

Haugen et.al (2012) has developed a generic method for identifying major accident risk indicators in which they list certain properties that should be considered in the process. These properties highlight what they consider to be key criteria.

- *Validity:* The indicator must be a valid measurement of the factor that it is an indicator for. This means that it must be able to reflect changes in the underlying phenomenon that is to be measured and that its status co-varies with the status of the factor.
- *Measurability:* It must be possible to express the status of the indicator in a way that can be recorded and compared with previous and future results. Quantifiable indicators are preferable, but as a minimum it must be possible to classify the status into different categories (e.g. High/Medium/Low, Grade A-F)
- *Comprehensibility:* The link between the indicator and the factor must be easy to comprehend (intuitive), and the meaning of an indicator must be self-evident in order to understand what variables to measure.
- *Reliability:* The results from measuring the status of an indicator must be reliable in the sense that if a measurement is repeated (at the same time), the same results are obtained. Further, measurements must be comparable with previous measurements, i.e. the context of measurement must remain stable over time, so that changes in the status reflects actual changes in the underlying phenomenon (factor), not changes in the measuring process.
- *Useful* in the sense that the users have the possibility to influence their status in some way.
- *Cost effective* so that the effort of gathering data for the indicator not is too excessive compared to the benefits gained by using the indicator. This may impact on whether an indicator is used or not, but it may also impact on how often an indicator is measured.

Haugen et.al (2011) highlights key criteria from e.g. Vinnem (2010) and Øien et.al. (2010):

- *Validity:* the indicator must give a valid measurement of the status of a certain risk influencing factor

- *Quantifiable:* the indicator should be quantifiable, i.e. possible to measure or at least categorize in a consistent manner
- *Regular monitoring:* it should be possible to monitor the status of the indicator on a regular basis (e.g. monthly), and under comparable conditions with not too extensive effort required
- *Sensitivity to change:* the indicator should be able to reflect even minor changes in the status of the factor
- The set of indicators should not be too large.
- The set should be manageable for regular monitoring and follow-up

Visualization of information

Visualization is generally any technique used to create and project images, diagrams and animations to communicate a message. Given the rapidly growing potential of digital work surfaces, visualization will become more and more popular in the industry and safety management.
As with indicators there are different versions of visualization:

Knowledge visualization

The field of knowledge visualization examines the use of visual representations to improve the creation and transfer of knowledge between at least two people. It thus designates all graphic means that can be used to construct and convey complex insights. It is the transport of facts as well as the transfer of insights, experiences, attitudes, values, expectations, perspectives, opinions and predictions, making it possible for someone else to reconstruct these insights correctly.

Information visualization

This form uses the visual representations of abstract data to reinforce human cognition. The abstract data include both numerical and non-numerical data, such as text and geographic information. It can be defined as “the use of computer-supported, interactive, visual representations of abstract data to amplify cognition.” (Card et.al., 1999)

Risk visualization

The field of risk visualization is quite undeveloped and research is scarce, but we know that it is important when it comes to safety in the industry. Risk visualization can make an important difference with its numerous cognitive and communicative advantages in comprehending and conveying risks through its cognitive and communicative advantages. This is done by utilizing graphic representations such as maps, charts, diagrams and visual metaphors. The term risk visualization was defined by Eppler & Aeschimann (2008) as the “the systematic effort of using (interactive) images to augment the quality of risk communication along the entire risk management cycle.” Doing this correctly, i.e. presenting relevant data to the right audience and making sure it is not overly complex, can improve the understanding and subsequent management of risks in specialist and management teams or stakeholder groups.

The definition of information visualization is similar to that of risk visualization, but the latter is more specific as it includes the work of communicating risk, which relates to this thesis and will be used throughout this report.

Caution when using visualization

There can be possible pitfalls mentioned by Bresciani & Epler (2008) when safety indicators are being visualized. These disadvantages and risks associated with the use of visual representations of information can eventually inflict the quality of decision making. Some pitfalls are that they may appear more convincing and sound than they really are, misleading the perception of reliability of visualization. Another issue can be the (multiple) implicit meanings inherent in visualizations leading to ambiguous interpretations. Other drawbacks of visualization can be when misleading map types are used or sufficient data is not available.

We can classify visualization disadvantages by their *causes* or *effects.* The *cause* of a visualization disadvantage can be the designers intentionally or unintentionally introduce mistakes or drawbacks, or the users' interpretation of visualization.

This user can exposed to a number of *effects* e.g. confusion, distraction, misinterpretation, limited reflection and delay. These effects can come from factors such as lack of experience, time pressure, problems in the users' personal life or negative stress.

How can indicators back up visualization of safety critical information?

Indicators have information about the state of safety and if deviations are indicated it is the intention to visualize, by extracting the right information, and projecting this to the decision-makers. In a hectic work day we are gathering tons of information with all our senses, so to get the critical information to be noticed through visualization we need indicators.

An example of this is the Aker Kvaerner accident. One of the main causes to the accident in Aker Kvaerner, Verdal that took place February 8th, 2012 was caused by interference from other operations in the area. In the investigation report it is stated that "due to coherent operations on 8 February in the actual area, the crane was not positioned correctly for conducting paint inspection on the outside of the jacket." (Kværner ASA, 2012) An indication of where the cranes may not be positioned in the area regarding placement of the crane and turning radius, with the help of 3D-mapping, could in this case have given a prohibition to start the work until the area was cleared.

Requirements to risk visualization

The risk visualization field is currently an emergent, explorative and fragmented domain. The field still lacks systematic approaches that try to combine the rich area of visualization studies with the needs and requirements of modern risk management. There exists however some requirements from the literature related to this.

Vatn (2012) lists several operators that are applied on a risk picture which is a set of undesired events, the causes and factors that may contribute to an undesired event, the possible consequences of the event with corresponding influencing factors, and uncertainties related to all these issues.

The operators are:

- Filtering: with filtering we mean to filter out several aspects of the risk picture. Primarily filtering means to focus on only one hazardous event and/or a limited set of end consequences, e.g. only number of fatalities.
- Aggregation: with aggregation we mean the process of summing more than one event, more than one cause etc. to give a sum of various events, causes and so on.
- Merging: with merging we mean the process of grouping several similar outcomes into one category representing several outcomes.
- Zooming: with zooming we mean to view part of the risk picture for a specific location (in space and/or time)
- Hiding/unhiding: with hiding we mean to hide important information when presenting the complete risk picture. Typically we hide causes behind the hazardous event, factors that influence whether causes could lead to the hazardous event or not, and factors that influence the severity of the hazardous event, i.e. the probability distribution over the possible end consequences.

Kjellèn (2000) lists some important requirements to a SHE information system to support feedback control and diagnosis processes. This can be used for visualization as it is basically about spreading information in regards to safety.

- Distribution and presentation of information
    - Relevance: We are concerned with the decision-makers' experience of the benefits of receiving additional information in relation to the perceived "costs" (time, attention) in finding the information. To avoid information overload, the information that is presented to the decision-maker must be relevant in relation to the decision-making context. Relevance is dependent on the types of use of the information and the associated needs of data:

    - In SHE performance monitoring, the user is concerned with information on a few so-called *key performance indicators*. The SHE information system must be able to provide information on these indicators.
    - In analysis of accident statistics and risk analysis, the user is concerned with a limited set of factual data on each accident and near-accident occurrence of interest. As long as the user only applies standard analysis methods, the type of data needed is rather limited and can often be determined in advance.
    - When searching for answers to specific questions, the user may need to put a whole range of queries to the database, i.e. the "memory" of the SHE information system. He/she may also be interested in results of earlier queries in order to build experience. Since it is not possible to know all types of queries in advance, the relevance will be decided by the coverage of the data.
    - A common use of SHE information systems is in monitoring the status of accident counter-measures. In this case, relevant information has to do with responsibilities for actions, deadlines and the extent to which they have been met or not. The aim is to ensure that the feedback loop has been closed.
- Comprehensible and easy to survey: to avoid information overload, especially for managers at top level must not be overwhelmed by detailed accident data, where it is impossible to "see the wood for the trees".
- Timeliness: is important in order to avoid hazardous deterioration of a system resulting from the non-detection of hazardous changes over a long period. In safety inspection, the maximum time lag is determined by the inspection frequency. This means that the inspection frequency must be higher at workplaces that remain unchanged during long periods.
- Availability of the information when it is needed: Computer support has significantly improved the possibilities of accessing experience data for use in decisions. We distinguish between periodic reporting, follow-up of actions and querying. In the first case, the user must have access to the SHE information system at periodic instances in time to get support in generating the necessary standard reports. Decision-makers need to access the information system easily at any time to get the status of outstanding actions. Users making queries have similar needs. When a company buys a new truck for example, the person responsible for purchasing may be interested in reviewing earlier truck accidents for use as input to specifications.

Eppler and Aeschimann’s second step of the risk visualization framework (2008) provides a checklist of the key factors to consider or take into account when visualizing risks or risk-related information.

When to use (or not to use) visualization in risk management and communication:

- *Don't precipitate the use of risk visualizations.* Visualizations reify thoughts or opinions, i.e. 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.
- *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.

How to use (or not to use) visualization in risk management and communication:

- *Make sure that the risk visualization respects the basic rules of visualization and perception.* In designing visualizations, you need to respect the basic laws of visual perception (i.e. seeing objects in their entirety before perceiving their individual parts) and the conventions of graphic design, namely:
    - 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 colors 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 key message it contains.

- *Avoid decorative visualization without added benefit.* Check whether your risk visualizations add value, e.g. by making a risk easier to understand or assess, by communicating risk-related information quicker or by being more memorable than text alone. Avoid unessential elements in visualization, such as shading, borders, too many colors, animation effects, etc.
- *Think visualizing, not visualization.* The power of visualization lies in its potential to surface implicit assumptions and capture different perspectives. 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.
- *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 table of requirements

The results from the literature review are shown in these tables. Those requirements that are recurrent are seen as important and therefore chosen. All the requirements from each piece of literature are shown vertically with the summary to the far left. Notice the colors which are used for some of the requirements in both tables. They constitute the set of requirements which will be used further in the thesis.

Table 1 The different requirements to indicators

Summary (indicators)	Hale	Kjellèn	Herrera	Haugen	Haugen et.al.
Valid: measure what we intend to measure	Valid: measure what we want to measure. Is correlation enough, or do we need the link to be causal?	Valid indicator of the risk of loss: measure what we intend to measure	Veriafiable: possible to confirm the correctness of the value or description of the indicators	Validity: able to reflect changes in the underlying phenomenon that it is to be measured and that its status co-varies with the status of the factor	Validity: must give valid measurement of the status of a certain risk influencing factor
Reliable: indicators lead to same results when used by different people	Reliable: give the same measurement when used by different people on the same situation		Reliable: lead to the same interpretations when used by different people for the same situation	Reliability: if a measurement is repeated (at the same time), the same results are obtatined. Context of measuremet must be stable over time	
Sensitive: respond to changes and provide a clear indication of change over a reasonable period of time	Sensitive: respond to changes in what it is measuring	Sensitivity to change: must allow for early warning by capturing changes.	Sensitive: provide a clear indication of changes over a reasonable period of time		Sensitivity to change: should be able to reflect even minor changes in the status of the factor
Observable and quantifiable		Observable and quantifiable: must be possible to observe and measure performance by applying a recognised data-collection method and scale of measurement	Measurable: the values of the indicators can be rendered in a concise manner, either quantitatively or qualitatively	Measurability: must be possible to express the status of the indicator in a way that can be recorded and compared with previous and future results. Quantifiable indicators are preferable	Quantifiable/possibility to monitor: must be possible to measure or at least categorize in a consistant manner
Robust against manipulation	Openness to bias: can it be manipulated to show better score without changing the underlying situation it is supposed to be measuring?	Robust against manipulation: a variation of the validity requirement, i.e. whether or not the indicator allows the organisation to "look good" by changing it			
Compatible		Compatible: must be able to exist with other safety indicators without conflict to prevent the decision-makers receiving contradictionary control signals			
Transparent, easily understood and comprehensible		Transparent and easily understood: apparent and compatible with the users theoretical understanding and unconscious mental models			
Meaningful			Meaningful: relevant to production and safety, and provide information which guides future actions		
Inter-subjective			Inter-subjective: understood in the same manner by different people, either from same technical communiy or from society at large		
Cost effective	Cost-effectiveness: cost more to collect data than would be lost without the indicator to assist decisions?		Affordable: the cost of obtaining and using the measures is affordable vis-à-vis the benefits	Cost effective: the efforts of gathering data should not be too excessive compared to the benefit	
Operational			Operational: the indicators can be used to support concrete actions wihtin the operational context		

Table 2 The different requirements to visualization

	Vatn	Kjellèn	Eppler	Haugen
Prevent information overload	Filtering: filter out aspects of the risk picture. Focus on only one hazardous event.	Relevance: benefits of receiving additional info in relation to the percieved "costs"/relevant in relation to the decision-making context	Avoid decorative visualization without added benefit.	
Keep information simple	Hiding/unhiding: hide important information when presenting the complete risk picture. Typically hiding information.	Comprehensible and easy to survey: must not be overwhelmed by detailed data	Consider the application context and its constraints (and time, resources)	Comprehensability: the link between the indicator and the factor must be easy to comprehend (intuitive)
Timeliness		Availability of the information when needed	Don't precipitate the use of risk visualizations: carefully time the use of a graphic risk representation.	
				Accuracy: the attributes of visual elements shall match the attributes of data items, and the structure of the visualization shall match the structure of the data set
	Aggregation: summing more than one event or one cause to give a sum of various events, causes.	Timeliness: inspection frequency (higher at workplaces that remain unchanged during long periods)		Utility: help users achieve the goal of specific tasks.
	Merging: grouping several similar outcomes into one category representing several outcomes			Efficiancy: reduce the cognitive load for a specific task over non-visual representations
	Zooming: view part of the risk picture for a specific location			
			Think visualizing, not visualization. The power lies in its potential to surface implicit assumptions, capture different perspectives.	

The literature review helped me in understanding what aspects are important with visualizing safety indicators. Below is a summary of the literature review from this chapter to justify the selection of requirements.

Requirements for safety indicator

There are many similarities between the requirements from different sources, which imply the importance of these requirements. Validity is a recurring criteria which is important for a solid foundation in developing indicators. A valid indicator reassures safety management that their decisions based upon these indications are correct. The level of sensitivity in an indicator determines how easy it is to detect changes in a system over time, giving better leeway in determining whether or not safety is good enough. Reliability is needed to give a clear picture of the situation regardless of who the user of the indicator is. The indicator needs to be robust against manipulation which will help securing the validity and reliability of it.

Requirements for risk visualization

Information from the literature shows that visualizing relevant information is a key aspect, which is done by filtering out unnecessary information. This reduces cognitive load and makes it easier to understand and assess information. Comprehensibility is mentioned by Kjellèn and Haugen et.al respectively about visualization and indicators which shows the significance of the attribute. It should show changes in the status of the factor in a way that if negative effects on safety were to happen, users would be bound to notice it.

Table 3 The final set of requirements

Valid and accurate	We measure what we want to measure with a complete and accurate visual representation of the data
Reliable	Lead to the same results when used by different people in the same situation
Easily comprehensible, intuitive	Should be intuitive, and the context between the factor and the indicator must be easy to comprehend
Efficient and simple information	Avoid decorative visualization to prevent overwhelmingly detailed data and reduce cognitive load
Sensitive to change	Able to reflect and visualize changes in the status of the factor
Robust against manipulation	It should not be possible to override indications of hazardous situations.

Chapter 4

Safety-related information in IO-MAP

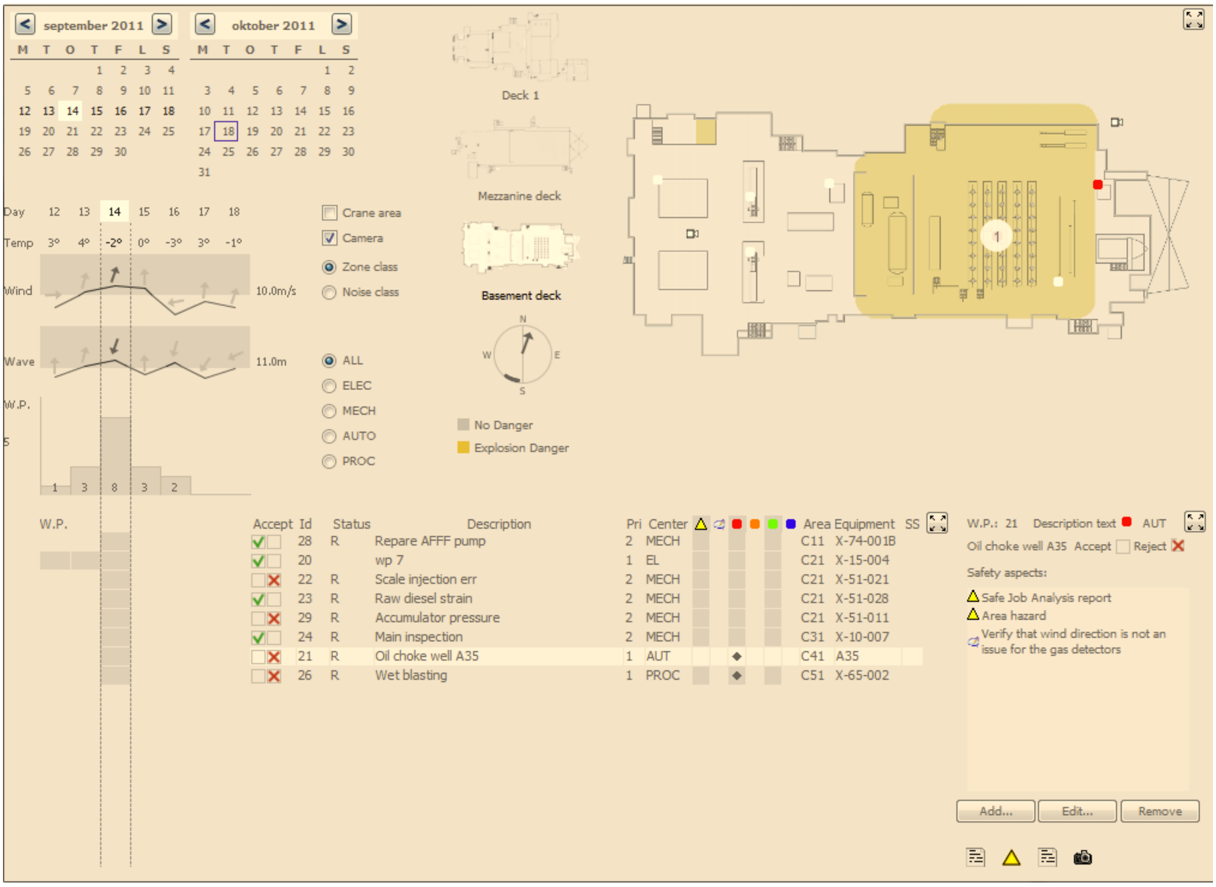
This chapter will present the safety-related information that IO-MAP possesses. This information has been found in "The Integrated Operations Maintenance and Modification Planner (IO-MAP) – The first usability evaluation – study and first findings" (2011), "Improving Oil & Gas Installation Safety through Visualization of Risk Factors" (2012) and testing the software itself.

The Integrated Operations Maintenance and Modification Planner, *IO-Map*, is a software tool that is developed to support the planning of maintenance and modification activities on offshore installations within the operational concept Integrated Operations (IO). The tool is designed to serve planners working individually, e.g. discipline specialists, and for planners working in a group that makes final decisions. IO-Map aims to visualize risks such as hot work, potentially falling objects, workload and weather data to help decision-makers gain a better overview when planning which leads to enhanced safety. The tool therefore contains a wide set of safety-related information which will be identified in this chapter. IO-MAP is an iterative process and not yet fully developed, so information presented here about the project is preliminary.

Integrated Operations (IO)

IO refers to new work processes and ways of performing oil and gas exploration and production, which has been facilitated by new information and communication technology, e.g. the use of always-on videoconference rooms between offshore platforms and land-based offices. This has enabled the possibility to move some personnel onshore and use the existing human resources more efficiently which saves money, but could in turn affect safety. Splitting the team between land and sea demands new work processes, which together with ICT, is the two main focus points for IO. Tools like videoconferencing and 3D-visualization also creates an opportunity for new, more cross-discipline cooperation. One of these tools is thus IO-MAP.

Figure 1 Screenshot of IO-MAP



Measurements

Indicators have been defined in this thesis as a "observable characteristic that presumably holds a positive correlation with safety, and has been selected, among other means, for the purpose of supervision of safety." IO-MAP possesses several functions that cover this definition.

The work permits status bar contains color indications that classifies if the work has safety issues connected to it. These safety issues are:

- Hot work, class A or B – work with equipment and tools that constitute an effective ignition source and which, during normal usage, could ignite an explosive atmosphere and/or solid substances or liquids.
- Entry – work that includes full or partial entering of closed rooms or confined areas that do not normally have natural or mechanical ventilation, e.g. tanks, pipes, chain wells and exhaust pipes.
- Work over sea – work that takes place outside of permanent railings. Exceptions are work in hydraulic baskets and work on approved scaffolding when an extra safety measure (barrier) is used, such as anti-fall securing system, manrider or net.
- Work on hydrocarbon carrying system – work on pipe systems, tanks and associated components that can pose a danger of releasing oil/gas/condensate.

Another feature in the status bar is four elements related to communicating risks. These are entities which contains information that is attached to the work permit, work order or notification.

- Hazard – represents general hazards associated with the particular location, e.g. risk for explosion
- Prohibited – shows that different types of activities are not allowed, e.g. it is not allowed to work without wearing a safety helmet
- Connectors – 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, there might be a risk that objects will fall and hit staff working at the lower deck
- Comment – this lets each user of the IO-MAP 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.

Members of the IO team can add jobs to the IO-MAP at different stages of the planning process, ranging from notifications to permissions to work. 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.

Design theory

The IO-MAP design has used the following design rationale:

- Presenting the data with a high degree of visibility, with a natural consistent mapping between information importance and visual salience
- Presenting the data as "in the world", not only as information "in the head" for less cognitive strain
- Using high "data-ink" ratio, present as much valuable information as possible without clutter
- Direct intuitive manipulation of data

A high degree of data-ink ratio has been used, meaning careful use of colors and contrast to support the impression of visual layers. "Data" is in this case described as the meaningful values in the display, visual attributes such as borders, shades and lines, and used with caution since it can be useless "ink" in the display.

When information is hidden in tabs or you have to click or navigate to visualize data, it can be cognitively demanding and is known as information "in the head". IO-MAP frees mental resources by presenting information as "in the world"

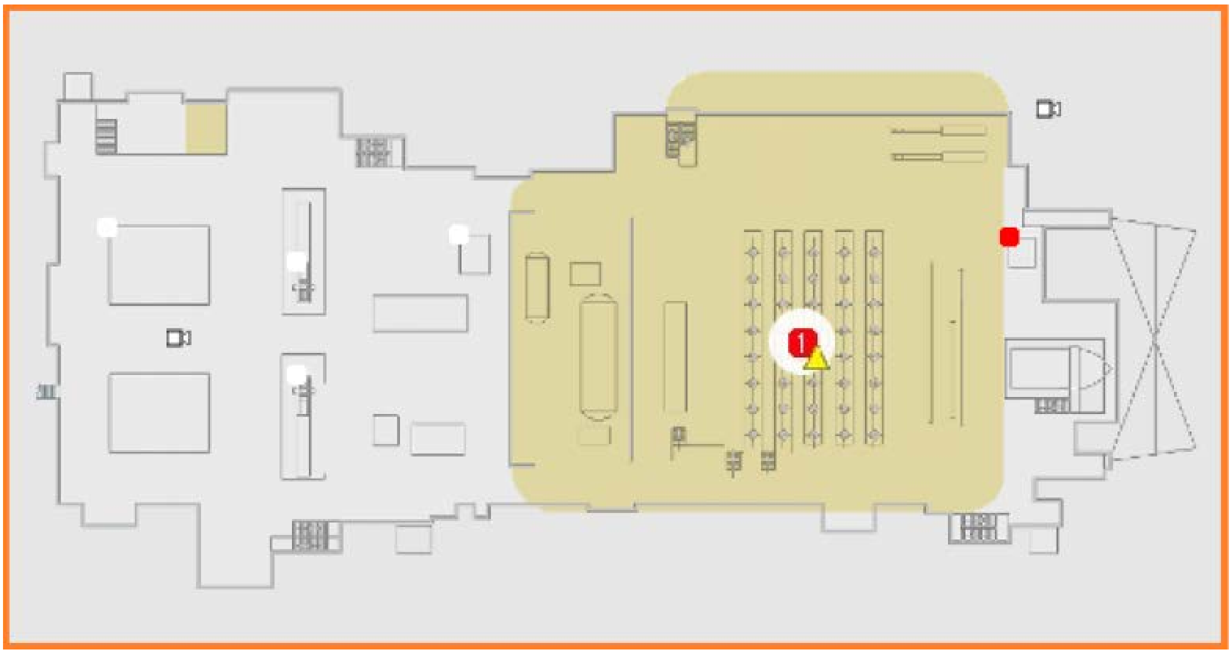
By using direct intuitive manipulation of data, the user can immediately see the effect of the changes, and a novice can quickly learn basic functionality since the whole information space is visualized in the user interface. The graphs and results of action are continuously updated in IO-MAP as the user changes the input data as feedback is important.

Functions used in IO-MAP

A physical map of the offshore installation to help the planners and their teams get an overview of the area. It strengthens the natural mapping of the data through the physical position of risk factors, as well as contributing to building a correct mental model of the installation and risks. This is important as the planners are located onshore with a variable degree of knowledge about the installation, and not being able to go onsite inspections whenever they want.

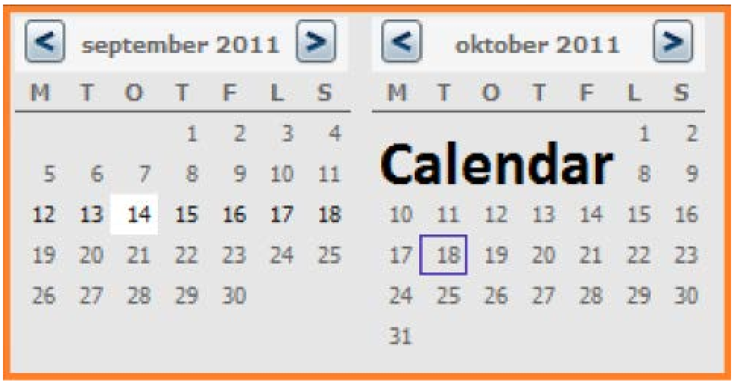
There is also the function of toggling the background between zone and noise classification. Zone classification shows where there is explosion danger which is marked with yellow as you can see from Figure 2 below. The noise classification displays the noise level by a color scale.

Figure 2 The physical map of the installation



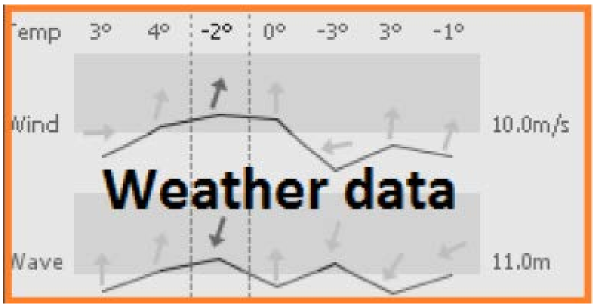
A calendar is used to easily see which jobs are planned on selected days by clicking on it. This is placed on the upper left corner in accordance to the western way of reading things from left to right.

Figure 3 The calendar used in IO-MAP



A weather data graph showing temperature, wind speed and wave height is aligned with the calendar. For increased readability, regardless what day that is selected, the weather data for that day will be shown.

Figure 4 Different weather data used in IO-MAP



A graph showing workload is placed under the calendar and weather data. This graph can show all the work permits for each day, or divide it into the electronic, mechanic, automation or process discipline. If a planner needs to add a job in the plan, he/she can view the graph to see how strained an area is and make a decision based on it.

Figure 5 The workload bar showing number of work permits per day

An acceptance and rejection of work permits column placed to the left of the work permit status bar. This allows the planner to quickly identify those work permits that needs further investigation in order to get approved. This functionality is required in the work permit meeting where onshore and offshore staff goes through each work permit before accept or reject planned jobs.

Findings from the study

The safety-related information that will be tested up against the requirements is:

Measurements:

- Work permit system
  - Hot work, class A or B
  - Entry work
  - Work over sea
  - Work on hydrocarbon carrying system
- Elements
  - Hazard
  - Prohibited
  - Comment

Design theory:

- Presenting data as “in the world”
- High data-ink ratio
- Direct intuitive manipulation of data

Functions:

- Physical map
- Graphs
  - Calendar
  - Weather data
  - Workload graph

Chapter 5

Testing the safety-related information from IO-MAP

In this chapter the IO-MAPs information found in chapter 4 will be run through the set of requirements found in chapter 3. Every measurement, design theory and functions will be compared to every requirement in the set in order to break down the information and analyze its quality.

A qualitative score of five levels will be presented to demonstrate the level of operability/usability and to give a simple depiction of how good the information from IO-MAP is. The range of the score is:

Very inadequate – inadequate – adequate – good – very good.

Hot work, class A and B

Work with equipment and tools that constitute an effective ignition source and which, during normal usage, could ignite an explosive atmosphere and/or solid substances or liquids.

	Comment	Rate
Valid and accurate	This indicators measures hot work, class A and B, although it does not separate between the classes on the physical map. The locations of the tasks on the map are also in a fixed position which may not reflect the real location of tasks. This can be a risk factor together with e.g. work on hydrocarbon carrying systems.	Inadequate
Reliable	This indicates that other tasks can't be coordinated with hot work, and should pretty much lead to the same results.	Good
Easily comprehensible, intuitive	It is very easy to comprehend the context between the indication of hot work and the fact that heat sources will occur.	Very good
Efficient and simple information	The information given is specific and to the point, without unnecessary decorations.	Very good
Sensitive to change	Changes in work permits will update the risks connected to it, visualizing the change in the status of the factor.	Very good
Robust against manipulation	It is not possible to change/manipulate the set risk influencing factors linked with hot work once it is indicated. It is thus robust against manipulation.	Very good

Welding, soldering, cutting and brazing are common processes known as hot work and a source for ignition which presents a great risk on oil and gas installations. The indicator for hot work in IO-MAP is thus an important one.

When e.g. hot work and work over sea is the factor of a specific task, only hot work will be indicated on the map with a red mark on the physical map. Also the indicator does not change whether it is in an explosion zone or a “safe” zone. Changing the indicator mark to something that warns a user that the hot work is planned in an explosion zone may be beneficial for the safety.

Elements (hazard, prohibited & connector)

This analysis takes the elements (hazard, prohibited and connector) as they have some of the same features. The first one represents general hazards associated with the particular location, e.g. risk for explosion. Prohibited shows different types of activities that are not allowed, e.g. it is not allowed to work without wearing a safety helmet. The connector indicates 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, there might be a risk that objects will fall and hit staff working at the lower deck

These elements are based on information about the characteristics of the installation and the standards of the organization in charge of the operation.

	Comment	Rate
Valid and accurate	Not all hazards are be discovered by IO-MAP. It is important to remind the users of this, as they could use IO-MAP as a cushion.	Adequate
Reliable	This indicator relies on what is said in the paragraph above and mentions all the risks that are connected to them. This should lead to the same results when used by different people.	Very good
Easily comprehensible, intuitive	These indicators are marked by a small symbol which appears on the physical map, given that at least one element is added to the work permit. This makes the context between the factor and the element easy to comprehend.	Very good
Efficient and simple information	Information about the elements are given in the downright corner.	Very good
Sensitive to change	If some changes in the status of the factor are done, then the elements would be automatically updated.	Very good
Robust against manipulation	The user can't manipulate the elements as they are based on data which automatically posts connected risks.	Very good

Not all hazards are discovered by IO-MAP, so it is important to continuing the communication of risks amongst the planners and their teams rather than trust IO-MAP with every decision.

Entry work

Entry includes full or partial entering of closed rooms or confined areas that do not normally have natural or mechanical ventilation, e.g. tanks, pipes, chain wells and exhaust pipes.

	Comment	Rate
Valid and accurate	This is a valid measurement of how many jobs that requires entry guard, but if a job also requires hot work then the hot work will be visualized on the physical map with a red mark.	Adequate
Reliable	The status bar indicates if there is entry work in the work permit. Different planners should be able to notice this, and plan accordingly.	Good
Easily comprehensible, intuitive	It is easy to understand that certain guidelines needs attention when entry work is indicated and included in the work permit.	Very good
Efficient and simple information	It could be useful to include information about the use of personal protective equipment (PPE) when entry work is plotted on the IO-MAP, i.e. not enough details.	Good
Sensitive to change	Changes in work permits will update the risks connected to it, visualizing the change in the status of the factor.	Adequate
Robust against manipulation	It is not possible to change/manipulate the set risk influencing factors linked with entry work once it is indicated. It is thus robust against manipulation.	Very good

The indication of entry in IO-MAP is easy to comprehend, but there is maybe a lack of information available in IO-MAP regarding work of this kind. More specifically what type of personal protective equipment is needed based on the level of ventilation in the room or area. Although this type of information is probably available in the Safe Job Analysis (SJA), it could be useful to inform what type of ventilation is readily available at certain locations.

Graphs (calendar, weather, workload)

The graphs contain a calendar to select the day wanted, a weather graph showing temperature, wind speed and wave height, and a workload graph showing the density of tasks per day.

	Comment	Rate
Valid and accurate	The wind and wave graph gives a static forecast which may affect the decisions on whether a job can be safely done or not. Predictions about the weather are never exact, but it is "as good as it gets". The calendar and workload are accurate.	Adequate
Reliable	People may interpret information differently in the cases of weather/workload, which may lead to different results, e.g. users of IO-MAP undervaluing wind speed can cause adverse situations.	Inadequate
Easily comprehensible, intuitive	The graphs are uniform and easy to get information out of. The calendar is similar to those used on other applications e.g. on the internet. Weather and workload are using an x-y axis, where x is time and y is pressure load, which is pretty standard.	Adequate
Efficient and simple information	The graphs are aligned vertically so that all information from the day that is chosen is readily available.	Very good
Sensitive to change	Workload adjusts itself as work permits are added or changed, while weather can be updated regularly, thus changing the data automatically.	Very good
Robust against manipulation	Any upper limits for weather and workload can be interpreted differently, unless governmental or company regulations gives specific requirements. If a job is urgent, planners can ignore indications of strain from weather and workload.	Ok

Most people are used to reading graphs which makes the calendar, weather and workload graph easy to comprehend, and the information given is intuitive, and the alignment in the graphs makes the information easy to read. The workload graph is updated whenever there are changes in the work permits and the weather graph can be updated regularly which indicates change over a reasonably period of time.

However, the users of IO-MAP have to interpret the data themselves. Onshore planners may not be aware of how much weather can affect jobs, or how much workload that may strain the workers offshore. There is also no visualization of values of weather or workload that may be affiliated with too much risk for either some tasks or all tasks.

High data-ink ratio

A high degree of data-ink ratio has been used, meaning careful use of colors and contrast to support the impression of visual layers.

	Comment	Rate
Valid and accurate	N/A	N/A
Reliable	It leads to less room for misinterpretations and more uniform results/decisions when “as much valuable information as possible” is presented which is the situation.	Good
Easily comprehensible, intuitive	Although there are no visual borders or lines used in the software, it is easy to identify the areas of the various functions.	Very good
Efficient and simple information	Some info is hidden, e.g. camera/pictures of the location, and information about work permits. This reduces cognitive load. In addition there are no border, shades or lines to make it look clean, and preventing unnecessary “ink”.	Very good
Sensitive to change	N/A	N/A
Robust against manipulation	It is not possible to use this feature for manipulating results.	Very good

This function makes IO-MAP simpler and easier to navigate in the menu. The requirements “Valid and accurate” and “sensitive to change” does not apply to this function as it is not directly an indicator, but it could be helpful to include it nonetheless. All in all this visualization technique is successful in supporting the impression of visual layers.

Work on hydrocarbon carrying system

This includes work on pipe systems, tanks and associated components that can pose a danger of releasing oil/gas/condensate.

	Comment	Rate
Valid and accurate	All equipment and machinery has a tag in IO-MAP which makes it easy to check out if the hydrocarbon carrying system is used or not.	Adequate
Reliable	It is a reliable measurement of the risk of hydrocarbon release.	Very good
Easily comprehensible, intuitive	It is easy to comprehend that work on such a system poses a risk of releasing flammable substances, which should lead to certain guidelines and precautions.	Very good
Efficient and simple information	This indicator holds the essential information needed.	Very good
Sensitive to change	Changes in work permits will update the risks connected to it, visualizing the change in the status of the factor.	Very good
Robust against manipulation	It is not possible to change/manipulate the set risk influencing factors linked with work on hydrocarbon carrying system once it is indicated. It is thus robust against manipulation.	Very good

This is an approved indicator as it fulfills the requirements. It is concise and explains what you need to plan safely. Although, as with entry work, the indicator does not show on the physical map if hot work is planned at the same place as the hot work indicator takes its place with a red mark. But it may be unlikely that hot work and work on hydrocarbon carrying system are planned on the same day for the same place.

Work over sea

This is work that takes place outside of permanent railings. Exceptions are work in hydraulic baskets and work on approved scaffolding when an extra safety measure (barrier) is used, such as anti-fall securing system, manrider or net.

	Comment	Rate
Valid and accurate	This is a valid measurement of the risk of falling from heights/sea.	Very good
Reliable	Should lead to the same results when used by different people. Though as the IO-MAP report says "high-waves combined with work over sea implies that a standby boat should be present." This implies that a definition of high-waves should be clarified.	Adequate
Easily comprehensible, intuitive	Easy to put the context between the factors playing in and the indicator together.	Very good
Efficient and simple information	It holds the essential information needed which reduces cognitive load.	Very good
Sensitive to change	The safety when working over sea is influenced by amongst other one factor, the weather, which is updated regularly.	Very good
Robust against manipulation	It is not possible to change/manipulate the set risk influencing factors linked with work over sea once it is indicated. It is thus robust against manipulation.	Very good

As with the indicator for work on hydrocarbon carrying system, work over sea is also an approved indicator. It seems as though care must be taken to check the weather forecast when planning work over sea as it may affect the safety of the workers. A stronger link between the two indicators could be beneficial.

Direct intuitive manipulation of data

By using direct intuitive manipulation of data, the user can immediately see the effect of the changes, and a novice can quickly learn basic functionality since the whole information space is visualized in the user interface. The graphs and results of action are continuously updated in IO-MAP as the user changes the input data as feedback is important.

	Comment	Rate
Valid and accurate	N/A	N/A
Reliable	N/A	N/A
Easily comprehensible, intuitive	This function makes IO-MAP more intuitive as the whole information space is visualized in the user interface.	Very good
Efficient and simple information	Information is updated automatically when changes in IO-MAP is made which makes this feature successful	Very good
Sensitive to change	The goal of this design is to upgrade graphs and results of actions made, so it is naturally sensitive to change.	Very good
Robust against manipulation	It is not possible to use this feature for manipulating results.	Very good

This design theory manages to give vital feedback to the users based on the continuously update of graphs and results of actions. As it cannot be described as an indicator, I feel that the requirements “valid and accurate” and “reliable” are not applicable to this test.

Physical map

Provides an overview of the area, and strengthens the natural mapping of the data through the physical position of risk factors, as well as contributing to building a correct mental model of the installation and risks. The physical map also displays functions such as zone and noise classification, crane and camera area and the possibility to choose a discipline.

	Comment	Rate
Valid and accurate	There are several measures within this map. The zone classification which shows the risk of explosion in certain areas indicates either explosion zone or no explosion, which I feel is a bit "black and white".	Adequate
Reliable	The objective of the map is to build a mental model of the installations and risks. This should lead to the same interpretations when used by different planners.	Very good
Easily comprehensible, intuitive	The map makes this software what it is, and ties many indicators together to make IO-MAP itself comprehensible.	Very good
Efficient and simple information	The map is simple and without unnecessary equipment or other graphic decorations. It leaves a clean and simple appearance.	Good
Sensitive to change	IO-MAP automatically posts work tasks on the map once they are added, and changes the indicators/marks on the map if the work permits themselves are changed.	Very good
Robust against manipulation	It is not possible to use this feature for manipulating results.	Very good

The map is an important part of IO-MAP which should be able to tie the software together. It does manage to provide a mental picture of the installation with further help from the live cameras and the possibility to view different decks of the installation.

The zone classification tells you where risk of explosion is present, but it could have been made like the noise classification which displays the noise level by a color scale. The risk of explosion can vary from place to place instead of either being present or not.

Presenting data as “in the world”

When information is hidden in tabs or you have to click or navigate to visualize data, it can be cognitively demanding and is known as information “in the head”. IO-MAP frees mental resources by presenting information as “in the world”

	Comment	Rate
Valid and accurate	It was found that work permits could have been linked to more information.	Good
Reliable	This function enhances reliability as less cognitive efforts leads to more similar choices.	Very good
Easily comprehensible, intuitive	The less information that is hidden, the more IO-MAP is easier to comprehend.	Very good
Efficient and simple information	This function makes the information easier to gather and is thus successful.	Very good
Sensitive to change	All changes are shown directly when information is presented “in the world” which makes it sensitive to change.	Very good
Robust against manipulation	It is not possible to use this feature for manipulating results.	Very good

This function is very practical in making it easier for the user to gather and assess the situation. It reduces the amount of clicking and tabs which leads to less cognitive strain and frustration. It is all in all a successful feature of IO-MAP.

IO-MAP

In chapter 3 several operators were described by Vatn that can be applied to a risk picture which is a set of undesired events, the causes and factors that may contribute to an undesired event, the possible consequences of the event with corresponding influencing factors, and uncertainties related to all these issues. A risk picture is said to be a *rich* risk picture if it is possible to apply operators on the risk picture. An operator is a tool that operates on the risk picture to present it in a certain manner. These operators can be applied to IO-MAP itself to test it for its overall performance.

	Comment
Filtering	Filtering requires a risk picture that contains information such that it is possible to search for e.g., hazardous events of a specific type. This can be attributed to the work permit system which includes hot work, entry work, work over sea and work on hydrocarbon carrying system, but in reality there are several other hazardous events on an installation which is not included by IO-MAP, e.g. isolation of safety system, pressure testing, work with dangerous and radioactive substances which all require work permits (Norwegian Oil and Gas Recommended Guidelines, 2003).
Aggregation	There is maybe a lack of an aggregated risk picture to get a picture of what kind of tasks are on the agenda per day. This can be helpful in understanding the comprehensive risk picture for the whole installation. By taking the Quantitative Risk Analysis (QRA) of the installation and other risk analysis, we can graph this risk picture.
Merging	This can also be attributed to the work permit system. Take work over sea as an example which represents several outcomes, but can be similar in nature i.e. man over board or some other close relation with water.
Zooming	There is the possibility of selecting one deck at a time, and also the possibility of limit the time to days, but not hours. Zooming is thus possible for both space and time.
Hiding/unhiding	This operator is somewhat similar to the requirement “efficient and simple information”, as the goal is to present data so that conclusions can be easily made without lavish data. I think IO-MAP in general succeeds in doing so.

IO-MAP holds up pretty well against these operators, but it could be beneficial to add a risk picture for the installation as a whole to depict the situation in a given time. It would also help to include more hazardous events such as isolation of safety system, pressure testing and work with dangerous and radioactive substances to be able to filter in IO-MAP

Chapter 6

Results

This chapter contains the results from reflections made after testing the software first hand, and testing the safety-related information from IO-MAP against the set of requirements from the literature review.

IO-MAP

The Integrated Operations Maintenance and Modification Planner (IO-MAP) overall purpose is to investigate how software technology can support a distributed team of planners in developing plans for maintenance and modification activities in which safety issues are adequately prioritized.

A day of testing the IO-MAP was necessary to get the feel of the software. In my experience it had useful functions and indicators that would benefit the planners in gaining fragmented overview over the platform. A tidy work surface was the first impression where functions were split into different sections. This made it also possible to avoid pop-up or new web browser windows, which can be confusing and ads strain to the users.

It can be difficult when programming such software to determine the interface of how much information about the tasks should be available for the user to see. In my experience it lacked sufficient information to get the full picture of the tasks and their practices.

Results from testing the safety-related information

Entry work

When entry work is planned it can be useful to include what type of personal protective equipment (PPE) is to be used for the particular task. This can be included in e.g. the comment section.

Also if both hot work and entry work is needed for the job, then hot work is indicated (red mark) on the physical map of the installation and the entry work (green mark) is hidden. Although, if a task nearby has safety conflictions with entry work this would possibly be indicated with a connector. Maybe a number on the mark itself indicating how many safety issues are connected with the task will alert the planners of this issue.

Graphs (calendar, weather and workload)

Onshore planners may not be aware of how much weather can affect jobs, or how much workload may strain the workers offshore. To give an indication of this it may be suitable to propose measures for extreme wind or temperatures, too much workload etc. This can be indicated by a range of colors where e.g. red is indication of inadequate safety, yellow indicates caution and green indicates ordinary practices.

Hazard

Once a hazard is added in IO-MAP, maybe some sort of action should be required to provide adequate safety before the planners can go ahead with other tasks.

Hot work

The indicator for hot work does not change in any way regardless of it being in an explosion zone or “safe” zone, or if the hot work is of class A or B. It could be beneficial to show this e.g. in the workload bar. This would give valuable information to the risk picture as a whole.

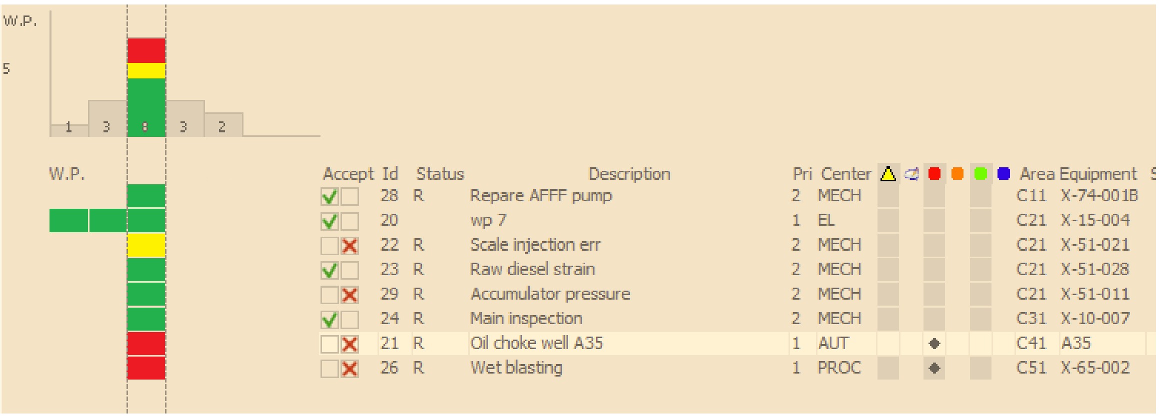
IO-MAP

There are several tasks that require work permits and among those are hot work, entry work, work over sea and work on hydrocarbon carrying system which is included in IO-MAP, but there are more tasks than that. According to Norwegian Oil and Gas Recommended Guidelines (2003) work such as isolation of safety system, pressure testing, work with dangerous and radioactive substances etc. requires work permit. It may be beneficial to add the remaining tasks to IO-MAP as they affect safety as well.

Tasks that have been successfully done (i.e. absence of injuries, damages and near misses) are not “stored” so that any new experiences gained will not show when the same/similar tasks are due to be done later in time. Valuable information discovered when planning these tasks could get lost in the system.

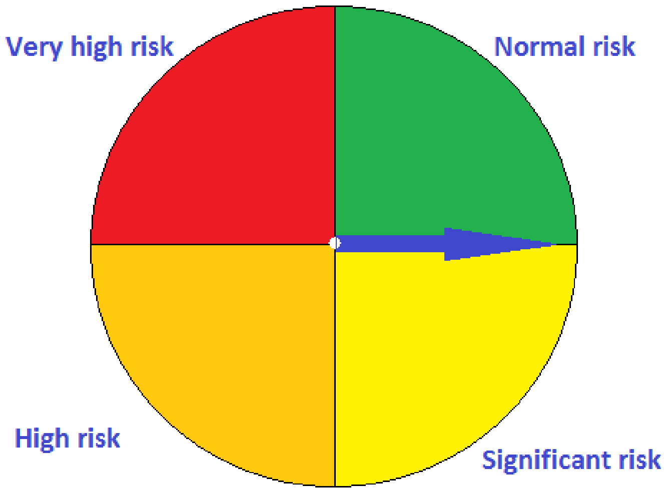
By marking the different tasks according to how much risk that is associated to it is easy to get a quick overview over the total risk picture. Below is an example of how it can be done. Marking the different tasks with a green-yellow-red indicator system, where green tasks are linked with more or less no risk of hazard, yellow tasks are linked with tolerable risk of hazard and red tasks are linked with high risk of hazards.

Figure 6. An example of how the total risk picture can be visualized on a certain day using work permits



This gives each day a comprehensive risk picture which can be useful to see how much "pressure" there is on safety. This risk picture can be presented to management or other personnel who has no knowledge of the software to make it easy for them to see "the big picture". This kind of risk picture can be established based on barriers and safety functions available on the installation, risk influencing factors (RIFs) and operational aspects. Combining these factors will give a prognosis of the risk picture over time. Vatn's operators (p. 17) can be of help to make this a reality.

Figure 7 Example of presenting the risk at a given time for the installation



Discussion

This chapter will present a discussion about safety indicators, risk visualization, the literature review, the set of requirements and the methodology for testing the safety-related information in IO-MAP. The section is rounded off by discussing the visualization of safety indicators.

Findings from the literature review shows that safety indicators have an extensive field of research and literature and still remain a hot topic of discussion within safety professionals in the industry. The borders between safety indicators and other indicators are somewhat diffuse as the discussion in the literature and the safety science debate shows.

The literature on risk visualization is not rich in data and research in this field is rather limited. Risk visualization is the systematic effort of using (interactive) images to augment the quality of risk communication along the entire risk management cycle. We may use literature on just visualization which is broader and more extensive, but we than have to make sure it can be used to communicate risk in a proper way. Risk visualization is an exciting topic that has a lot of opportunities for improvement.

It was discovered from the review that many professionals from safety had a lot of the same view on several requirements within safety indicators, with the exception of a few. These requirements were thus natural to include in the set of requirements to test IO-MAP.

Validity is a recurring criteria which is important for a solid foundation in developing indicators. A valid indicator reassures safety management that their decisions based upon these indications are correct. The level of sensitivity in an indicator determines how easy it is to detect changes in a system over time, giving better leeway in determining whether or not safety is good enough. Reliability is needed to give a clear picture of the situation regardless of who the user of the indicator is. The indicator needs to be robust against manipulation which will help securing the validity and reliability of it.

Information from the literature shows that visualizing relevant information is a key aspect, which is done by filtering out unnecessary information. This reduces cognitive load and makes it easier to understand and assess information. Comprehensibility is mentioned by Kjellèn and Haugen et.al respectively about visualization and indicators which shows the significance of the attribute. It should show changes in the status of the factor in a way that if negative effects on safety were to happen, users would be bound to notice it.

After putting IO-MAP to the test, it was discovered that not all requirements were suited to test the safety-related information found in chapter 4. This could be due to the fact that not all information from chapter 4 can be directly transferred as visualizing safety indicators rather than being explicitly an indicator or a visualization technique. However, the decision to include this information nonetheless is that it can be useful to test them based on the remaining requirements that can be used to extract information.

Visualizing safety indicators is not the same as the two aspects visualizing and safety indicators. But if we combine the definitions of the two we can say that visualizing safety indicators is the means for using images to augment the quality of measures in the changes in the level of safety as a result of actions taken by the safety management. This combines and satisfies both definitions.

Conclusion/main findings

The aim of this thesis is to make suggestions for further developments of IO-MAP and to develop a set of criteria for visualizing safety indicators. Safety indicators was defined as an observable characteristic that presumably holds a positive correlation with safety, and has been selected, among other means, for the purpose of supervision of safety. The safety indicator can be related to defense lines according to defense-in-depth such as physical barriers and safety functions. Risk visualization was defined as the systematic effort of using (interactive) images to augment the quality of risk communication along the entire risk management cycle.

This thesis has researched the literature to find what requirements are best suited for visualizing safety indicators. Through the research it was discovered some recurrent requirements which was natural to include which served the purpose and amounted to a set of requirements. The safety-related information from IO-MAP was then extracted so that the set could test this information from Integrated Operations Maintenance and Modification Planner (IO-MAP). This information consisted of measurements (the work permit system and elements), design theory (presenting data as "in the world", high data-ink ratio and direct intuitive manipulation of data) and functions (the physical map and functionality graphs).

Table 1 The set of requirements

Valid and accurate	We measure what we want to measure with a complete and accurate visual representation of the data
Reliable	Lead to the same results when used by different people in the same situation
Easily comprehensible, intuitive	Should be intuitive, and the context between the factor and the indicator must be easy to comprehend
Efficient and simple information	Avoid decorative visualization to prevent overwhelmingly detailed data and reduce cognitive load
Sensitive to change	Able to reflect and visualize changes in the status of the factor
Robust against manipulation	It should not be possible to override indications of hazardous situations.

After testing the safety-related information from IO-MAP some points were discovered that could be improved. Main points from the results were:

- Include a total risk picture to visualize the sum of risks connected to the planned tasks per day
- Adding more types of work that requires work permit (e.g. isolation of safety system, pressure testing, and work with dangerous and radioactive substances)
- Implementing more information about the tasks to get the full picture of the tasks and how they are done in practice

It was found that not all requirements were suited to test the safety-related information from IO-MAP. This could be due to the fact that not all information from IO-MAP could be directly transferred as visualizing safety indicators rather than being explicitly an indicator or a visualization technique.

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Appendix