REPORT

Building Safety

Development of new models and methods for the identification of early warning indicators

Summary report

K. Øien, R.K. Tinmannsvik, S. Massaiu, F. Størseth

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TITLE

Building Safety – Development of new models and methods for the identification of early warning indicators

Summary report

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ABSTRACT

The overall objective of the Building Safety project, *Building Safety in Petroleum Exploration and Production in the Northern Regions,* is to produce knowledge to build resilient operational organizations for petroleum production in the northern regions, with the ability to prevent unwanted events through early warnings/indications.

One of the research activities in Building Safety is entitled *"Development of new models and methods for the identification of early warning indicators"*, and has as its defined objective to develop new models and methods that can unveil early warnings of major accidents (for the northern regions in general and for the Goliat field in specific).

The report presents an overview and key findings from the following research tasks:
1. Problem description
2. Literature review
3. Study of accidents and development of methods
4. Case specific advice (for operation of the Goliat field)
5. Generic knowledge

The Building Safety project is funded by The Research Council of Norway and Eni Norge AS.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Safety	Sikkerhet
GROUP 2	Organization	Organisasjon
SELECTED BY AUTHOR	Resilience Engineering	Robust organisering
	Early warning indicators	Indikatorer for tidlig varsling

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1 Introduction

The Building Safety project addresses safety opportunities and challenges in petroleum exploration and production in the northern regions[1]. Building Safety aims to provide knowledge for building resilient operational organizations for petroleum production in the northern regions, and the principal objective is to reduce risk to personnel and environment. The project is funded by the program "Health, Environment and Safety in the petroleum sector" (HMSFORSK) by The Research Council of Norway and Eni Norge AS. The research work is carried out in close cooperation between SINTEF, IFE (Institute for Energy Technology), NTNU (Norwegian University of Science and Technology), and Eni Norge AS, using the development of the Goliat field as case studies.

The project has three main research activities:

- Human and organizational contribution to resilience
- Resilient decision processes in Integrated Operations (IO) Teams – Adequate prioritization of safety goals
- Early warnings of major accidents

This report presents an overview and key findings from the last research activity in the project: Early warnings of major accidents.

2 Early warnings of major accidents – introduction

The objective of this research activity was to provide early warnings of major accidents, which has partly required the development of new models and methods, and partly the adaptation of existing ones. This has been useful for providing early warnings of major accidents both in general, during petroleum exploration and production in the northern regions, and specifically during the operation of the Goliat field in the Barents Sea.

The objective of early warnings is to signal the need to take actions in order to avoid accidents or reduce the risk of accidents. Depending on the nature of the early warnings, the actions may be obvious or there may be a need for further investigation to determine appropriate actions. Actions, and thus also the need for early warnings, may be taken at different levels in an organization; by operators, supervisors, or managers.

3 Research tasks

3.1 Problem description

This task described the challenges related to early warnings of major accidents, and provided explicit statements of research questions to be addressed.

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[1] www.sintef.no/buildingsafety

It also consisted of a delimitation of the research area and an overview of the state-of-the-art (a preliminary assessment) of the previous research in the field. This was used as input to define the scope for the literature review.

Delivery:
- Problem description memo (Øien, 2008a).

3.2 Literature review

The literature review focused in particular on leading indicators for major accidents[2], and considered the effect of underlying causes on safety in a qualitative and semi-quantitative manner.[3] The literature review covered two lines of research:

1. Research on the development of safety or risk indicators
2. Research directed at understanding how underlying causes affect safety or risk.

Since the main focus area of the Building Safety project has been the offshore petroleum industry, the selection of literature has been focused on industries exposed to major hazards, such as the nuclear power industry, the chemical process industry, and transportation (aviation).

The literature review has been documented in a memo, but parts of the review have also been included in two journal papers.

Delivery:
- Literature review memo (Utne et al., 2008).
- Safety Science journal paper I (Øien et al., 2010a).
- Safety Science journal paper II (Øien et al., 2010b).

3.3 Study of accidents and development of methods

The development of methods for the establishment of early warning indicators has been directly or indirectly linked to the study of accidents as indicated in Table 1.

Table 1 Development of methods linked to the study of accidents

Method		Accident
I	Safety performance based (HSE, 2006)	Texas City, 2005
II	Risk based (Øien, 2001a,b)	NA
III	Incident based (Øien, 2008b)	Eirik Raude, 2005
IV	Resilience based (Øien et al., 2010c)	Texas City, 2005; Riser case (Eni Norge)

The method developments within the Building Safety project are mainly restricted to method III and IV. Method I has been described and applied in a parallel EU project in

[2] The focus is on major accidents (with a potential of several casualties) and not occupational accidents (usually only affecting one person). Sometimes the terms *process safety* and *personal safety* are used to distinguish between these two types of safety concerns.
[3] In general, there may be other types of early warnings than indicators, e.g., safety bulletins providing information of events experienced in other companies; however, in this project we have focused on providing early warnings in the form of indicators.

which the Goliat project has been used as a case. Method II is an existing method that is not based on a specific accident, but rather on a quantitative risk analysis (QRA).

The accidents have been described in a case description memo (Øien and Tinmannsvik, 2008), which is part of the delivery in work package 1 "Human and organizational contribution to resilience".

The incident based method (III) and the resilience based method (IV) have been described in conference papers (PSAM 9 and PSAM 10, respectively), and also referred to in the Safety Science journal papers mentioned in Section 3.3.

Finally, all four methods have been compared in a conference paper (Øien, 2010).

Delivery:
- PSAM 9 conference paper (Øien, 2008b).
- PSAM 10 conference paper (Øien et al., 2010c).
- 2nd iNTeg-Risk conference paper (Øien, 2010).

3.4 Case specific advice

The research results served as the basis for providing specific advice to the establishment of early warning indicators for the Goliat field.

Delivery:
- Power point presentation with explanatory notes pages (Øien et al., 2010d)

3.5 Generic knowledge

The generic knowledge is summarized in this report. The details can be found in the referenced memos and papers (see Section 9 and Appendix A-E).

4 Problem description

There are both general challenges, related to early warnings of major accidents, and specific user needs when operating oil fields such as the Goliat field in the Barents Sea. To better illustrate the general challenges, we use the Texas City accident as an example, which is described in Section 4.1. The specific user needs are discussed in Section 4.2, and here we use the Eirik Raude incident as an example of an event that should be avoided in an area such as the Barents Sea.

Both the Texas City accident and the Eirik Raude incident are included as common cases in the project, and described in more detail in a separate memo (Øien and Tinmannsvik, 2008).

4.1 General challenges

The Texas City accident (CSB[4], 2007a; 2007b)
On March 23, 2005, at 1:20 p.m., the BP Texas City Refinery suffered one of the worst industrial disasters in recent U.S. history. Explosions and fires killed 15 people and injured another 180, alarmed the community, and resulted in financial losses exceeding $1.5 billion. The accident occurred during the startup of an isomerization[5] (ISOM) unit when a raffinate tower[6] was overfilled; pressure relief devices opened, resulting in a flammable liquid geyser from a blowdown stack[7] that was not equipped with a flare. The release of flammables led to an explosion and fire. All of the fatalities occurred in or near office trailers located close to the blowdown drum[8]. A shelter-in-place order was issued that required 43,000 people to remain indoors. Houses were damaged as far as three-quarters of a mile from the refinery. The area at the refinery where the accident took place is shown in Figure 1.

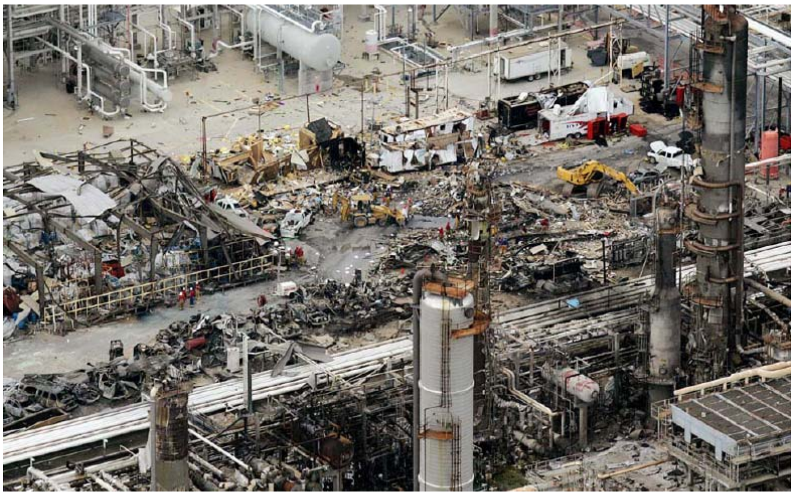

Figure 1. Destructions after the Texas City Refinery accident (CSB, 2007a)

[4] CSB – U.S. Chemical Safety and Hazard Investigation Board.
[5] The refining isomerization process converts straight chain normal pentane and normal hexane streams to the higher octane branched hydrocarbons isopentane and isohexane that are used for gasoline blending.
[6] The raffinate splitter is a distillation tower that takes raffinate, a non-aromatic, primarily straight-chain hydrocarbon mixture and separates it into light and heavy components.
[7] Venting equipment that can release build-ups of dangerous liquid or vapour in an emergency.
[8] Separators or accumulators used to separate liquids or vapor in an emergency.

On the morning of March 23, 2005, the raffinate splitter tower in the refinery's ISOM unit was restarted after a maintenance outage. During the startup, operations personnel pumped flammable liquid hydrocarbons into the tower for over three hours without any liquid being removed, which was contrary to startup procedure instructions. Critical alarms and control instrumentation provided false indications that failed to alert the operators of the high level in the tower. Consequently, unknown to the operations crew, the 170-foot (52 m) tall tower was overfilled and liquid overflowed into the overhead pipe at the top of the tower, as illustrated in Figure 2.

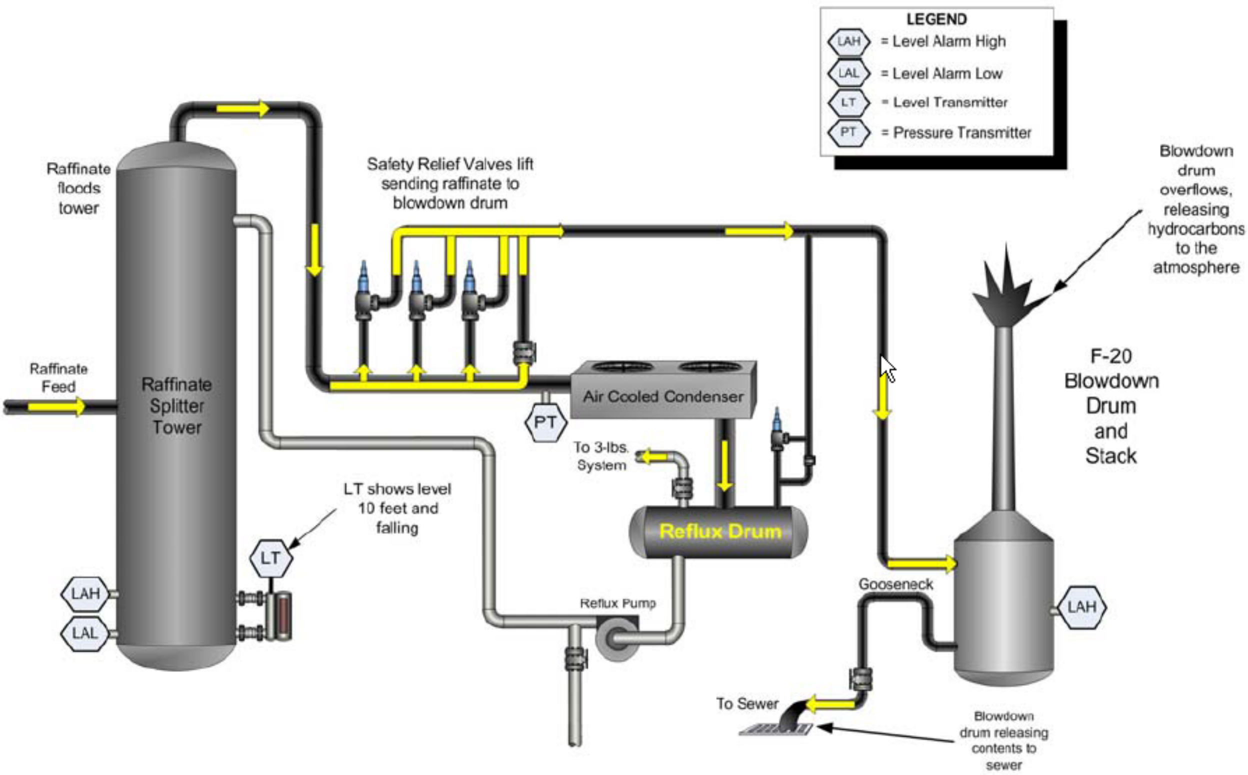

Figure 2. Tower overfills and blowdown drum releases hydrocarbons (CSB, 2007a)

The overhead pipe ran down the side of the tower to pressure relief valves located 148 feet (45 m) below. As the pipe filled with liquid, the pressure at the bottom rose rapidly from about 21 pounds per square inch (psi) to about 64 psi. The three pressure valves opened for six minutes, discharging a large quantity of flammable liquid to a blowdown drum with a vent stack open to the atmosphere. The blowdown drum and stack overfilled with flammable liquid, which led to a geyser-like release out the 113-foot (34 m) tall stack. This blowdown system was an antiquated and unsafe design; it was originally installed in the 1950s, and had never been connected to a flare system to safely contain liquids and combust flammable vapors released from the process.

The released volatile liquid evaporated as it fell to the ground and formed a flammable vapor cloud. The most likely source of ignition for the vapor cloud was backfire from an idling diesel pickup truck located about 25 feet (7.6 m) from the blowdown drum. The 15 employees killed in the explosion were contractors working in and around temporary trailers that had been previously sited by BP as close as 121 feet (37 m) from the blowdown drum.

In Figure 3 we have included some of the most important direct causes, contributing causes and root causes in the simplified causal chain.

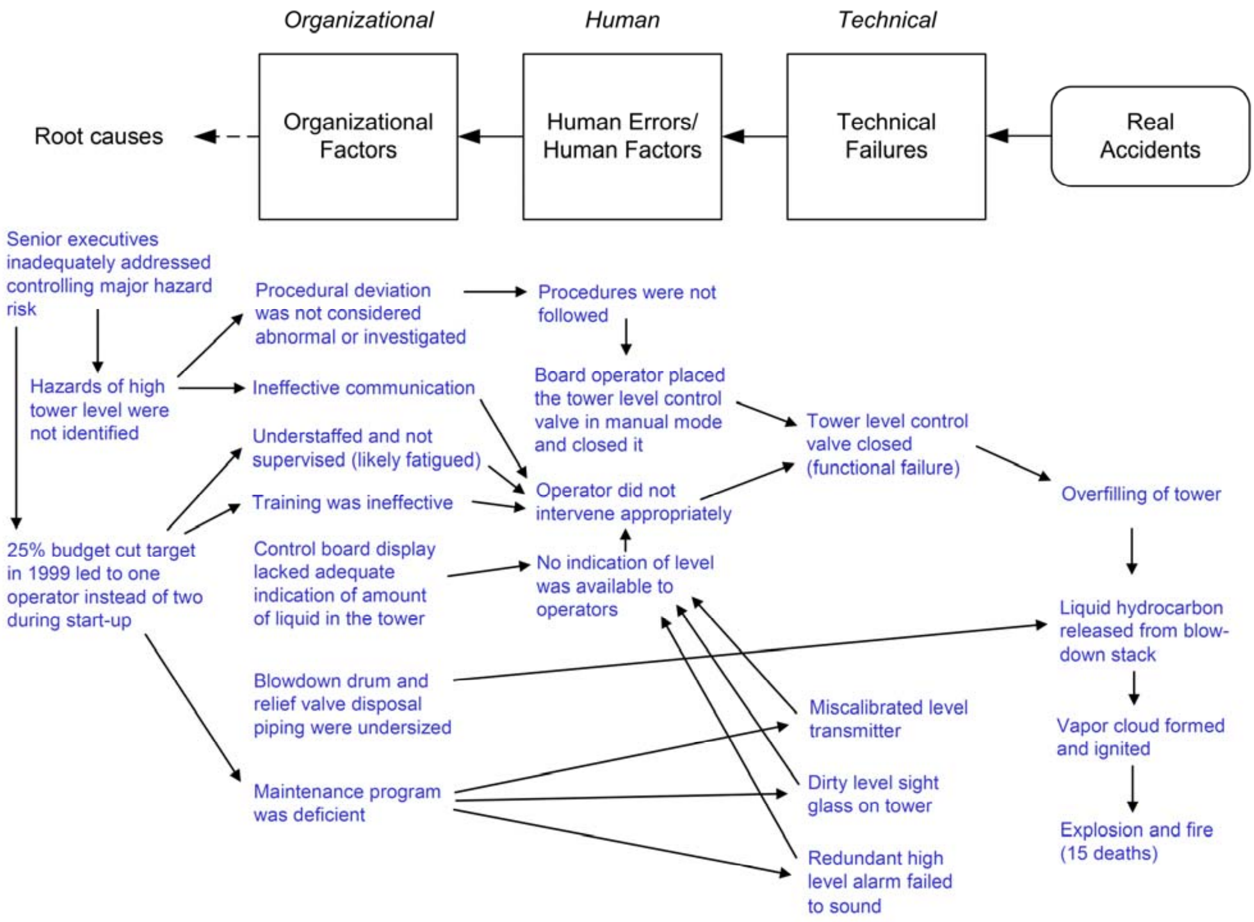

Figure 3. Important direct causes, contributing causes and root causes to the accident

Figure 3 is explained in detail in the case description memo (Øien and Tinmannsvik, 2008). What we will focus on here is the root cause that *senior executives inadequately addressed controlling major hazard risk.* Personal safety was measured, rewarded, and the primary focus, but the same emphasis was not put on improving process safety performance.

BP did not effectively assess and control the risks of major hazards at Texas City. In the events leading up to the accident, managers and operators lacked understanding of major risk: 1) the blowdown system had not been replaced, despite previous serious incident reports and policies that required converting it to a flare; 2) occupied trailers were placed dangerously close to running process units because the siting analysis failed to identify the risks; 3) non-essential personnel were not evacuated despite the hazards posed by ISOM unit startup; 4) the startup was authorized despite having inadequate staffing, mal-functioning instruments and equipment, and without a pre-startup safety review (PSSR); and 5) during the startup, no qualified supervision was present and procedures were not followed as had been the practice for some time.

Audits and assessments concluded that Texas City had serious deficiencies in identifying and controlling major risks. The 2004 GHSER[9] assessment concluded that "no formal system exists for identifying high level risks."

BP Group executives used personal safety metrics to drive safety performance. A key lesson from the U.K. Health and Safety Executive Grangemouth report is that BP needed a specific focus on KPIs for process safety because personal safety metrics are not a reliable measure of the risk for a major accident. BP did not adequately implement these lessons in its Group safety management or at Texas City, and, in fact, paid most attention to, measured, and rewarded personal safety performance rather than process safety. Personal safety metrics were exclusive measures in the GHSER policy, HSE assurance reports, business and personal contracts, incentive programs, and plant goals. Personal safety metrics are important to track low-consequence, high-probability incidents, but are not a good indicator of process safety performance. As process safety expert Trevor Kletz notes, "The lost time rate is not a measure of process safety"[10] (Kletz, 2003). An emphasis on personal safety statistics can lead companies to lose sight of deteriorating process safety performance (Hopkins, 2000).

Process safety KPIs provide important information on the effectiveness of safety systems, and an early warning of impending catastrophic failure (HSE, 2006). The sole use of lagging safety indicators, such as injury rates or numbers of incidents, has been described as trying to drive down the road looking only in the rear view mirror---it tells you where you have been but not where you are headed. Process safety good practice guidelines recommend using both leading and lagging indicators for process safety.

Leading indicators provide a check of system functioning – whether needed actions have been taken, such as equipment inspections completed by the target date or process safety management (PSM) action item closure. Lagging indicators, such as near-misses, provide evidence that a key outcome has failed or not met its objective. "Active monitoring" of both leading and lagging indicators is important to the health of process safety systems (HSE, 2006).

In response to the safety problems at Texas City, BP Group and local managers oversimplified the risks and failed to address serious hazards. Oversimplification means that evidence of some risks is disregarded or deemphasized while attention is given to a handful of others (hazard and operability, or HAZOP, Weick and Sutcliffe, 2001). The reluctance to simplify is a characteristic of HROs in high-risk operations such as nuclear plants, aircraft carriers, and air traffic control, as HROs want to see the whole picture and address all serious hazards (Weick and Sutcliffe, 2001)[11].

BP Group managers failed to provide effective leadership and oversight to control major accident risk. According to Hopkins, top management's actions and what they paid attention to, measure, and allocate resources for is what drives organizational culture (Hopkins, 2005). Examples of deficient leadership at Texas City included managers not

[9] GHSER – Getting Health, Safety, and Environment Right

[10] Kletz (2001) also writes that "a low lost-time accident rate is no indication that the process safety is under control, as most accidents are simple mechanical ones, such as falls. In many of the accidents described in this book the companies concerned had very low lost-time accident rates. This introduced a feeling of complacency, a feeling that safety was well managed".

[11] Weick and Sutcliffe (2001) further state that HROs (High Reliability Organizations) manage the unexpected by reluctance to simplify: "HROs take deliberate steps to create more complete and nuanced pictures. They simplify less and see more."

following or ensuring enforcement of policies and procedures, responding ineffectively to a series of reports detailing critical process safety problems, and focusing on budget cutting goals that compromised safety.

The BP Chief Executive and the BP Board of Directors did not exercise effective safety oversight. Decisions to cut budgets were made at the highest levels of the BP Group despite serious safety deficiencies at Texas City. BP executives directed Texas City to cut capital expenditures in the 2005 budget by an additional 25 percent despite three major accidents and fatalities at the refinery in 2004.

The CCPS[12], of which BP is a member, developed 12 essential process safety management elements in 1992. The first element is accountability. CCPS highlights the "management dilemma" of "production versus process safety" (CCPS, 1992). The guidelines emphasize that to resolve this dilemma, process safety systems "must be adequately resourced and properly financed. This can only occur through top management commitment to the process safety program." Due to BP's decentralized structure of safety management, organizational safety and process safety management were largely delegated to the business unit level, with no effective oversight at the executive board level to address major accident risk.

The Texas City accident provides a very good example of the need for early warnings through leading and lagging indicators. This is a need that refineries share with all high-risk industries, including the petroleum industry in Norway.

4.2 Specific user needs

The Eirik Raude incident (PSA[13], 2005; Statoil, 2005; Ocean Rig, 2005a)
The Ocean Rig owned drilling rig Eirik Raude was drilling the wildcat well 7131/4-1 (Guovca) located in the Finnmark East area in the Barents Sea for Statoil between April 2, 2005 and May 13, 2005. The location is shown in Figure 4.

On April 12, 2005, at 3:30 p.m., the BOP[14] carrier on the Eirik Raude drilling rig was taken out of isolation to enable the BOP skid frame to be removed in order to allow the installation of the work platforms for Slip Joint work. The BOP carrier had been run 24 hours previously, under Isolation Permit and SJA (Safe Job Analysis), and this was still active for continuation of running.

When the system was put on line, a leak was noted and the system was isolated by Senior Subsea (job supervisor). Upon inspection of the BOP carrier system below deck, it was apparent that the leak came from the drag chain system. The operation was stopped immediately. Approximately 930 – 1170 litres of hydraulic fluid were lost to the sea. The volume of fluid discharged to sea is estimated from review of tank level indicator reading before and after using the system.

Due to the weather at time of the spill (temperature and wind) and the nature of the flow through the burst hose, the spilled fluid was dispersed with no possibility to containment from the Standby Vessel spill containment equipment.

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[12] CCPS – Center for Chemical Process Safety
[13] PSA – Petroleum Safety Authority
[14] BOP – Blowout Preventer

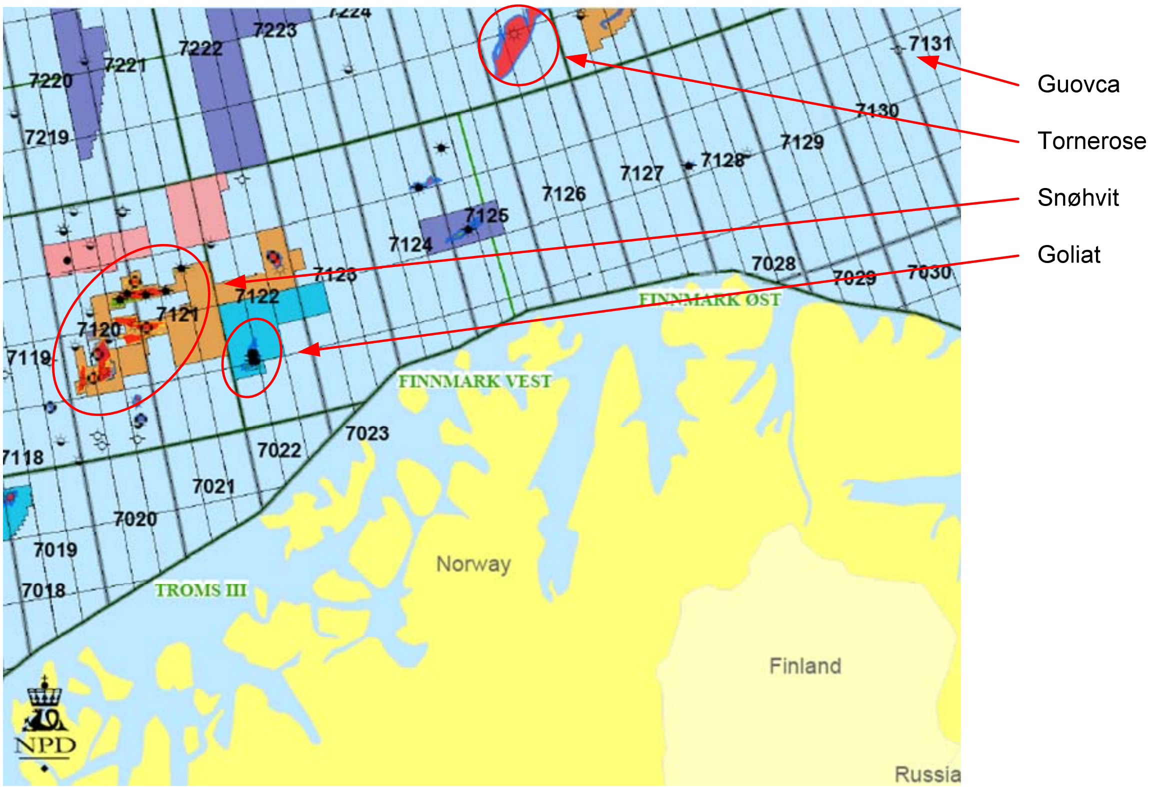

Figure 4. The location of the incident (Guovca)

The low water solubility and low acute toxicity indicate that the discharge of hydraulic oil from Eirik Raude did most likely not cause any acute toxic effects to organisms in the water column. Any dispersed oil may, however, have caused some smothering (physical) effects of aquatic organism. Physical effects may possibly have affected some organisms on the surface. However, due to the limited amount of oil, the effects are restricted to the individual level, and the spill has not caused any acute effects on population level of either aquatic or surface living organisms.

Figure 5 shows the Eirik Raude drilling rig and the damaged hydraulic hose.

Figure 5. The Eirik Raude drilling rig (Ocean Rig, 2005b) and the damaged hydraulic hose (Ocean Rig, 2005a)

The drilling operation was suspended for 18 days due to the accident.

The direct cause of the incident was mechanical wear and tear of the hydraulic hose over time resulting in burst of the hose as a consequence of defective material (Statoil, 2005).

Some of the contributing causes were (Ocean Rig, 2005a):

- Inadequate maintenance/maintenance routines
- Inappropriate design/construction
- Lack of knowledge/training
- Vague organisation of responsibilities – management of change
- Failure to warn/notify

An overview of the incident and the contributing causes is illustrated in Figure 6 using an influence diagram.

Figure 6. Overview of the Eirik Raude incident including some of the causes

Figure 6 is explained in detail in the case description memo (Øien and Tinmannsvik, 2008). The only thing we will point out here, in relation to early warning, is that one relevant source of information was the critical overdue maintenance log, since the need for replacement of the hydraulic hose was identified one month prior to the incident. However, even though the critical overdue maintenance log could provide an early warning, i.e., the system was in place, failure in using the system correctly resulted in the system failing to provide an early warning. The hydraulic hose was not marked as critical when the work order was entered into the maintenance management system, i.e., the data was not correctly entered into the system.

The Eirik Raude incident also shows that for petroleum exploration and production in the northern regions there is a need for extra focus on environmental risk. No harmful discharge is allowed in the northern regions and areas as the Barents Sea. This also applies for Eni Norge when operating the Goliat field. An early warning system must cover both risks for personnel (major accident risk) and environmental risk. One of the challenges with this is that it involves the surveillance of systems and equipment that previously have not been considered critical. Also, operating in a sub-artic area will likely pose additional challenges to which factors need to be under surveillance.

Uncertainty related to the lack of operational experience in the Barents Sea, in addition to stringent environmental requirements, gives a situation where the operators need to operate with an increased ‘safety margin’, also due to political reasons. Petroleum exploration and production in the northern regions is an area of social debate in Norway. One ‘minor mistake’ by one of the actors involved may harm the whole petroleum industry. Most likely, this is an additional incentive for the development and implementation of appropriate early warning systems.

4.3 Research needs

The aim was to develop an early warning system consisting of a set of appropriate indicators to signal a possible increase in the risk of accidents on a particular installation (e.g., a drilling rig or a production unit). These indicators may be used at different levels and by different functions within an organization (or between collaborating organizations), such as operators, supervisors, operator representatives[15], or managers, to take necessary actions when the indicator values approaches or passes given threshold values.

[15] Representatives from the operating company (onboard e.g. a drilling rig).

5 Literature review

5.1 Scope and delimitation of the literature review

The delimitation of the research area is described in the problem description memo (Øien, 2008a) where it is stated that *"in this project we will focus in particular on leading indicators for major accidents and consider the effect of underlying causes on safety in a qualitative or semi-quantitative manner"*.

This means that we have *not* included personal safety (occupational accidents), and we have *not* made use of a full quantitative assessment of the underlying causes' effect on risk.

The delimitation led us to two previous lines of research:

1. Research on the development of safety or risk indicators
2. Research directed at understanding how underlying causes affect safety or risk.

It should be noted, though, that these lines of research are overlapping, because sometimes underlying causes have been measured through the use of indicators.

Even though there is a close connection between safety and risk, it is important to distinguish between the concepts and their indicators. When looking at previous research, the qualitative safety approach and the quantitative risk approach have been undertaken by different research communities.[16] This is illustrated in Figure 7.

Organizational factors	Indicators	
I (Qualitative treatment)	II (Safety indicators)	Safety approach (proactive or retrospective)
III (Quantitative treatment)	IV (Risk indicators)	Probabilistic risk approach (predictive)

Figure 7. Distinction between the safety approach and the probabilistic risk approach

However, the safety approach is not purely qualitative, and the risk approach is not purely quantitative. Safety indicators (second quadrant) are often quantitative, and the quantitative/probabilistic treatment of organizational factors (third quadrant) also includes qualitative aspects.

[16] This is sometimes referred to as the "school of system safety" and the "school of probabilistic risk assessment", (McIntyre, 2000).

Safety indicators (second quadrant) used for the measuring of organizational factors, which are potential underlying causes of major accidents, are of core interest in this literature review, since they are so-called leading indicators. They measure factors early in the causal chain, and may provide early warnings of major accidents.

Relevant research related to classification and evaluation of organizational factors (i.e., the first quadrant) other than measuring through safety indicators, are included. These topics are:

- Normative models for safety management
- Safety audit methods
- Classifications of organizational factors
- Human reliability analysis (HRA) methods[17]

Since the main focus area of the Building Safety project is the offshore petroleum industry, the selection of literature has been focused on industries exposed to major hazards, such as the nuclear power industry, the chemical process industry, and transportation (aviation).

The relevant literature has been identified by searching for books and articles in relevant library databases, survey of references in articles and books, participation in seminars and workshops, and interviews with experts.

The structure of the literature review is described in the next section. Here the concept of "two perspectives" is introduced, which is related to Figure 7, i.e., the safety approach and the probabilistic risk approach. In order to better explain the connection between these two approaches, we start by comparing the retrospective safety approach with the probabilistic (and predictive) risk approach, which provides us the "predictive versus retrospective" perspective. However, for further treatment it is the proactive safety approach that is of most interest to us.

To facilitate the comparison between the safety approach and the probabilistic risk approach, we also introduce a simplified causal chain, i.e., technical – human – organizational causes, as a "perspective" (this is actually the first of the two perspectives mentioned in Section 5.2).

5.2 Structure of literature review – two perspectives

The literature review is structured according to a combination of two perspectives. The first perspective relates to the development in the search for causes of accidents moving from technical, to human, and further to organizational causes (Reason, 1997). However, this perspective is viewed in the light of a second perspective, which is the question of a predictive versus a retrospective view. It makes a big difference whether we try to predict the possibility of having a major accident "tomorrow", including all possible causes, or if we "only" try to establish the causes after the event (in retrospect).

[17] The focus has been on the so-called second generation HRA methods.

If we limit the understanding of organizational factors to accident investigation, that is, hindsight, then we can talk about different "ages" in the development moving from technical, to human, and further to organizational causes. We can even look for more remote causes as external pressure and regulation. Wilpert (2000) suggests that we now have entered the period of "inter-organizational relationships". However, Reason (1997) raises the question whether "the pendulum has swung too far" in our search for the origins of major accidents. This search should add explanatory, predictive and/or remedial value, but particularly the added remedial value is questionable, and thus we should concentrate on the changeable and controllable.

The organizational factors' effect on safety/risk is by no means well understood. One token of this can be found in Wilpert (2000). There is a general lack of consensus regarding the classification of organizational factors, and there are no identical classifications. About 160 different factors have been suggested in those 12 classifications assessed by Wilpert (each of the classifications usually consists of 10-20 factors).

For the prediction of risk, as for accident investigation, we can talk about a development from technical, to human, and even to organizational causes. This does not imply that all features of risk assessment can be classified according to a technical-human-organizational "scheme". There are features that cut across these aspects, such as dependent failure analysis and uncertainty analysis. However, some aspects can be attached to primarily one of the causal categories, for example, human reliability analysis (HRA) attached to the human causes of accidents.

Based on the two presented perspectives; the technical-human-organizational, and the predictive-versus-retrospective, we now establish a conceptual model in order to structure and illustrate the previous research. This simplified model is shown in Figure 8. Only some topics related to quantitative risk assessment (QRA) are illustrated here (FTA is Fault Tree Analysis, and ETA is Event Tree Analysis).

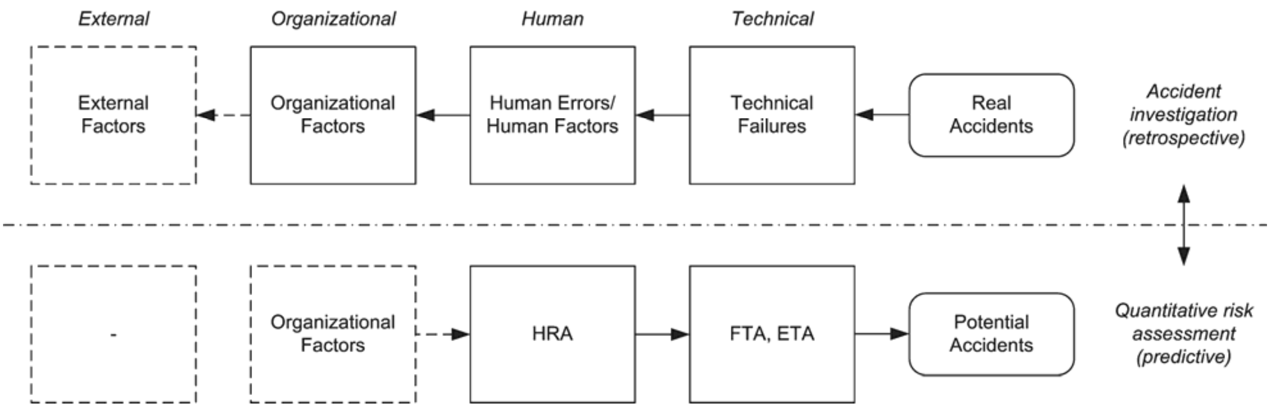

Figure 8. Retrospective investigation versus predictive assessment

The "technical-human-organizational" perspective is illustrated horizontally and the "retrospective-versus-predictive" perspective is illustrated vertically. For retrospective purposes, such as accident investigation, organizational factors have been included "for a long time", at least since the Three Mile Island accident in 1979. For predictive purposes organizational factors have only recently been included or attempted to be included.

The probabilistic predictive approach is not the only proactive approach for the assessment of underlying factors effect on safety or risk. It has been a long tradition especially within social sciences to assess the effect of organizational factors on safety, and this can be illustrated by reversing the arrows in the upper part of Figure 8. This is shown in Figure 9 (in addition, we have simplified the illustration even more).

A major obstacle to the assessment of organizational factors' effect on safety with respect to industrial accidents is that these accidents are so rare that a direct measure of safety is not possible. Instead indirect safety measures are sought, usually termed “indicators” (performance indicators, safety indicators, safety performance indicators, direct performance indicators, indirect programmatic performance indicators, etc.). These safety performance indicators are either assumed to have an effect on safety, or efforts are put into establishing correlation between the indicators and safety. This is also the case for the organizational factors' effect on safety, where “indirect programmatic performance indicators” is one of the terms that have been used for measuring organizational factors. These indicators can be seen as quantitative measures. However, there has also been a lot of work on qualitative assessment of the “goodness” of organizational factors by the development of so-called safety audit methods.

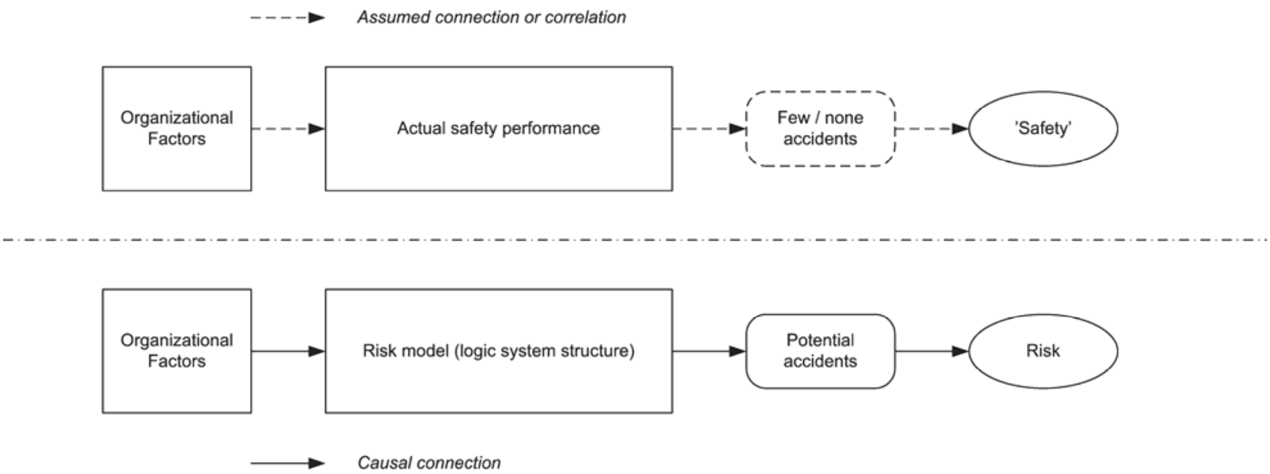

Figure 9. Proactive assessments of organizational factors' effect on safety or risk

Within the probabilistic approach (lower part of Figure 9) the question is not so much how to measure the effect of organizational factors on risk as an isolated effort. Since the probabilistic approach is dealing with potential accidents, it does not matter how rare the events are (except with respect to uncertainty and credibility). Risk is estimated based on the existing risk model, and the question is how this risk estimate changes and perhaps becomes more “correct” when the organizational factors are explicitly accounted for. This is the main objective of some of the current attempts, even though not the only objective. An explicit inclusion of organizational factors also makes it possible to estimate the effect of proposed organizational risk reducing measures, and may thus be a valuable support for decision-making in the operational phase, as in the design phase.

There have been two quite different development paths, as depicted in Figure 9, the probabilistic approach has to some degree built on previous “safety performance work” carried out by, e.g., psychologists, sociologists, and organizational theorists. In some rare cases multi-disciplinary project teams (social and natural scientists) have carried out this kind of research.

An overview and structuring of the proactive safety research is illustrated in Figure 10.

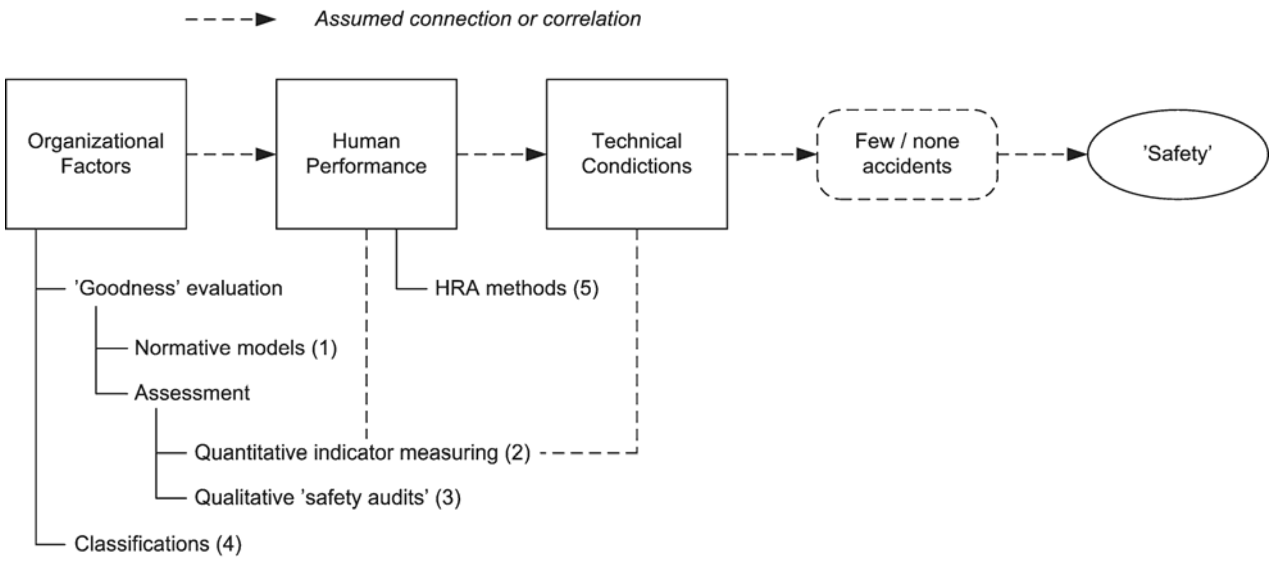

Figure 10. Overview and structuring of proactive safety research

The proactive safety research can be divided in five different sub-areas (lines of research).

The evaluation of the "goodness" of organizational factors includes how they should be adequately treated, which is described by normative models (1), or how adequately they are treated, which is determined through assessments. The assessment can either be measuring by the use of indicators[18] (2) or assessment by the use of qualitative safety audit methods (3). All of these methods include explicitly or implicitly a classification of the organizational factors. There is also work that has been totally devoted to classification (4) without any further attempt to measure the "goodness" or quality. Finally, we have included some of the recent developments in HRA methods (5), the so-called second generation methods. These HRA methods have some relation to organizational factors since they include performing shaping factors that also can be of an organizational type.

All of these five sub-areas are further elaborated in the literature review. The only one we will look further into here is the measuring by the use of indicators. An overview is provided in Figure 11.

From the early '80s on, the US Nuclear Regulatory Commission (US NRC) initiated a lot of work on the effects of organizational factors on safety. Most of this work belongs to the upper part of Figure 11, and uses indicators for measurement. Much of the early work focused on establishing a connection (through correlation) between underlying programmatic factors (measured by programmatic performance indicators – PPIs) and direct safety performance manifested by minor events and failures (and measured by direct performance indicators – PIs).

[18] It is illustrated in Figure 10 (with dashed lines) that indicators are not only developed for organizational factors but also for human performance (human errors) and technical conditions (technical failures) representing so-called direct performance indicators.

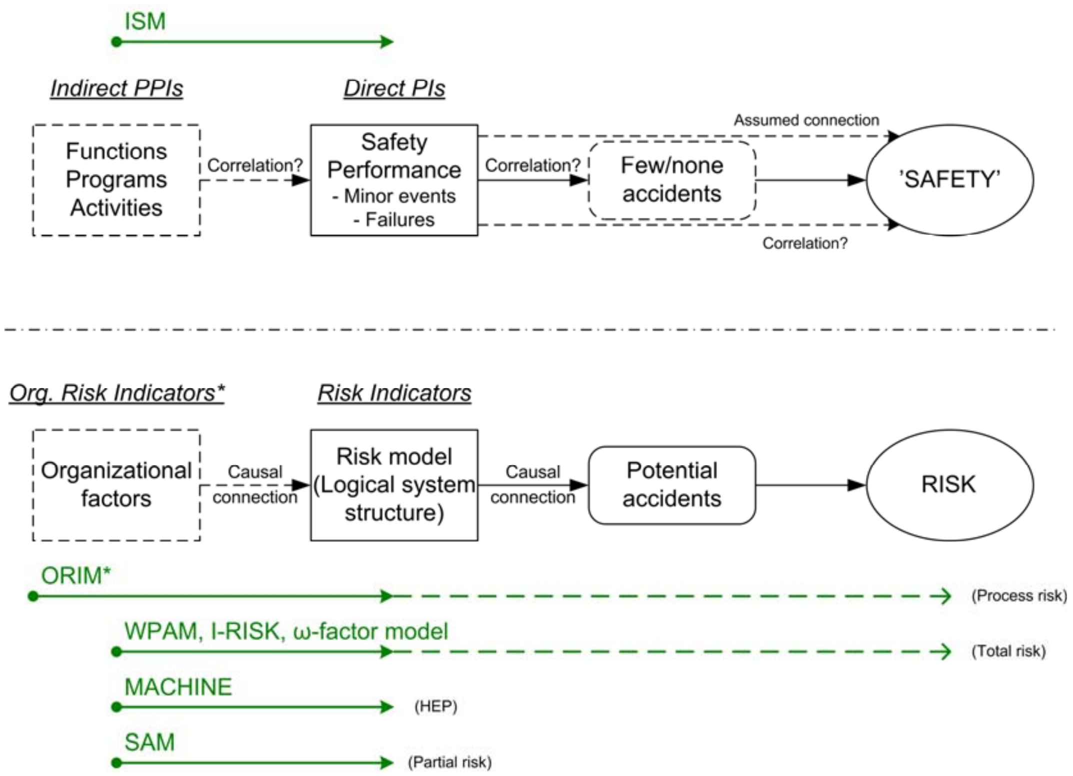

Figure 11. Overview of early work on safety and risk indicators

We have also included, mostly in the bottom part of Figure 11 (and in green color), the organizational factor frameworks that have attempted to link the organizational factors to the risk quantitatively. For these frameworks we are particularly interested in the qualitative parts, i.e. the organizational models or sets of factors. The frameworks included are:

1. SAM (System Action Management), *Murphy and Paté-Cornell, 1996*
2. MACHINE (Model of Accident Causation using Hierarchical Influence Network), *Embrey, 1992*
3. ISM (Integrated Safety Model), *Modarres et al., 1992*
4. ω-factor model, *Mosleh et al., 1997*
5. WPAM (Work Process Analysis Model), *Davoudian et al., 1994a,b*
6. I-RISK (Integrated Risk), *Oh et al., 1998*
7. ORIM (Organizational Risk Influence Model), *Øien, 2001b*

For further detailed explanation of Figure 11 and the corresponding research work and frameworks, we refer to the literature review document (Utne et al., 2008).

The frameworks listed above, and also the sub-areas shown in Figure 10, use "traditional" types of organizational factors, e.g., training, procedures, communication, supervision, etc. However, there have also been some attempts to explain or model the effect on safety based on characteristics of an organization/enterprise such as complexity and couplings (Perrow, 1984), organizational redundancy and improvisation (Weick and Sutcliffe, 2001), and variability and resonance (Hollnagel, 2004). Such "unconventional" types of organizational factors/characteristics also require other types of indicators for measurement and follow-up. This line of research has also been pursued as a possible basis for the development of early warnings.

6 Study of accidents and development of methods

As indicated in Section 3.3 and Table 1, the development of methods for the establishment of early warning indicators has been directly or indirectly linked to the study of accidents.

We further stated, in Section 3.3, that the method developments within the Building Safety project mainly have been restricted to the incident based method (method III) and the resilience based method (method IV). The description of method developments in this section are therefore restricted to these two methods, and a comparison between all four methods (i.e., also the performance based method – method I, and the risk based method – method II).

6.1 The incident based method

Incident based methods (or incident/accident analysis based methods) identify early warning indicators by an in-depth study of one or more incidents or accidents. The focus is on identifying those less than adequate factors that contributed to the incident/accident, and the measuring of these factors, i.e. with the use of indicators.

The presumption is that if these contributing factors had been adequate, then neither the particular incident/accident being analyzed nor similar incidents/accidents would have occurred.

Here, we briefly describe the incident based method (Øien, 2010). For further details, see Øien (2008b).

6.1.1 Short description

The method consists of eight steps as illustrated in Figure 12.

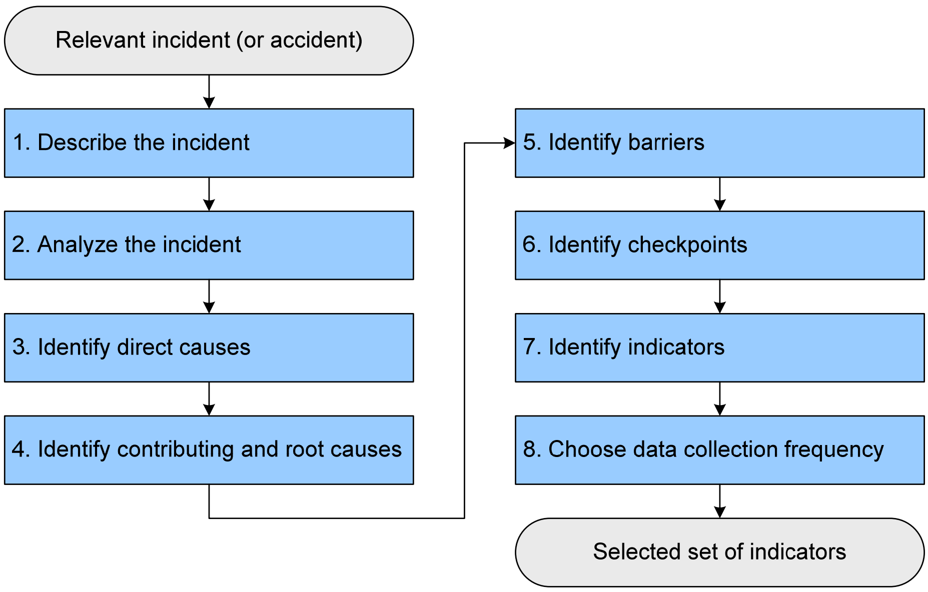

Figure 12. Method steps of the incident based indicator method

The incident investigated was a hydraulic oil leak from the Eirik Raude drilling rig during exploration drilling in the Barents Sea in April 2005.

The identification of barriers (step 5) to prevent direct causes (step 3) and root causes (step 4), for the specific incident being analyzed, is illustrated in Figure 13.

The influence diagram in Figure 13 is an extract from the complete influence diagram of the incident. (The complete influence diagram has altogether 50 nodes.)[19]

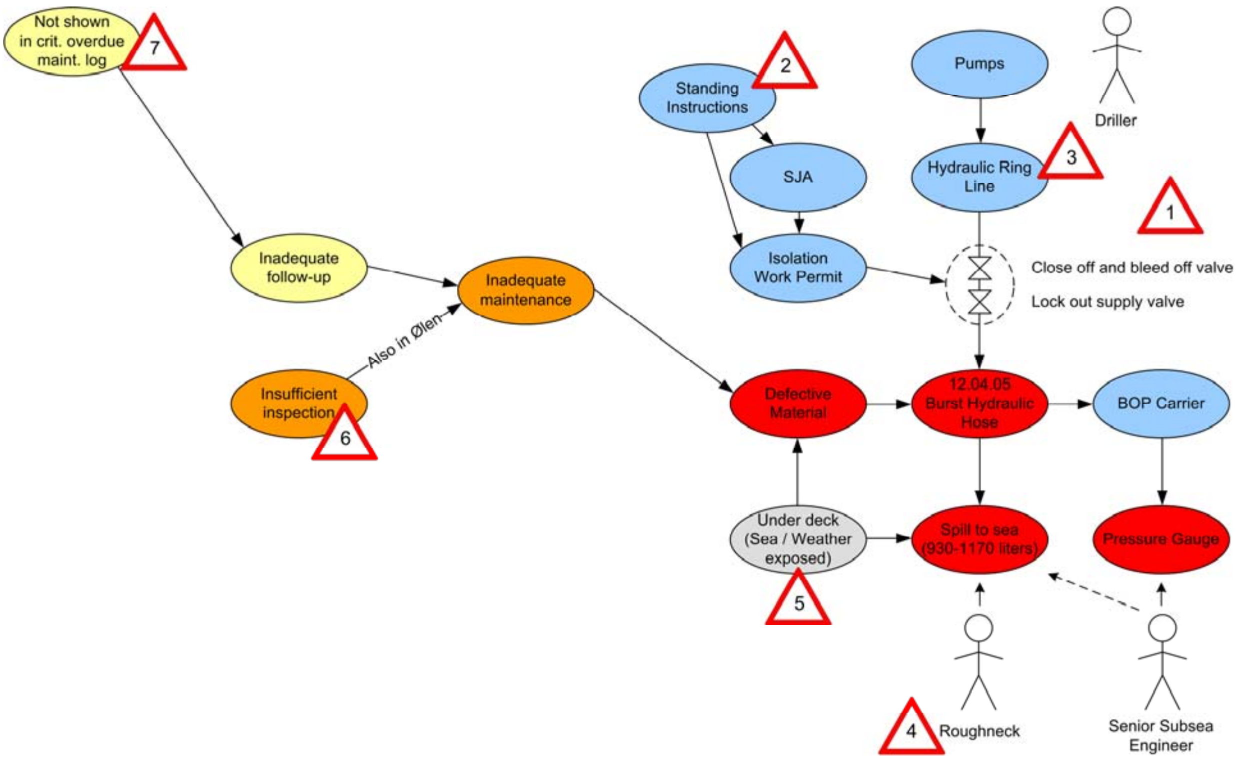

Figure 13. Identified barriers for critical hydraulic systems

6.1.2 Example indicators

Preliminary suggestions for early warning indicators are presented in Table 2. We have also proposed a data collection frequency for each of the indicators.

[19] A red triangle is used to symbolize a barrier. Grey node refers to design/construction of the system (hydraulic ring line). Orange nodes cover two main aspects of maintenance that was deficient. Yellow nodes cover maintenance in more detail. Red nodes describe the direct chain of events, whereas the blue nodes indicate normal situations, i.e. not included as part of the direct chain of events. (However, recall that Figure 13 is just an extract of the complete influence diagram, ref. Figure 6.)

Table 2. Early warning indicators

Early warning indicators		Data collection frequency
1	Rate of inadequate depressurization of isolated systems	Daily
2	Rate of inadequate use of Work Permit and Job Safety Analysis	Daily/Weekly
3	Rate of inadequate visual inspection of system prior to use	Daily/Weekly
4	Rate of inadequate use of a watchman	Daily
5	Rate of failure to comply with weather restrictions [a]	Daily/Weekly
6	Number of Prev. Maintenance work orders for hydraulic hoses in backlog	Weekly/Monthly/Quarterly
7	Number of critical Corrective Maintenance work orders in backlog [b]	Weekly/Monthly/Quarterly

[a] Given bad weather, i.e. not counting use of hydraulic systems in good weather
[b] Not necessarily restricted to hydraulic hoses

6.1.3 Strengths and weaknesses

Some of the strengths of the incident based indicator method are as follows:

- Relatively easy to identify the risk influencing factors (RIFs)
- Relevance for major accidents is apparent (if incident has major accident potential)
- Relevance for major accidents easy to communicate
- Includes underlying causes (to the degree the investigation has identified these)
- Practical and relatively simple
- Not so resource intensive

Some of the weaknesses of the incident based indicator method are as follows:

- Depends on the occurrence of relevant events
- Depends on thorough and well documented investigation of events
- Not risk based – only event based, i.e. covers what has already happened

6.2 The resilience based method

Resilience refers to the capability of recognizing, adapting to, and coping with the unexpected (Woods, 2006). Resilience Engineering 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 and Woods, 2006).

Here, we briefly describe one specific method, i.e. the Resilience based Early Warning Indicators (REWI) method (Øien, 2010). For further details, see Øien et al. (2010c).

6.2.1 Short description

The method consists of seven steps as illustrated in Figure 14.

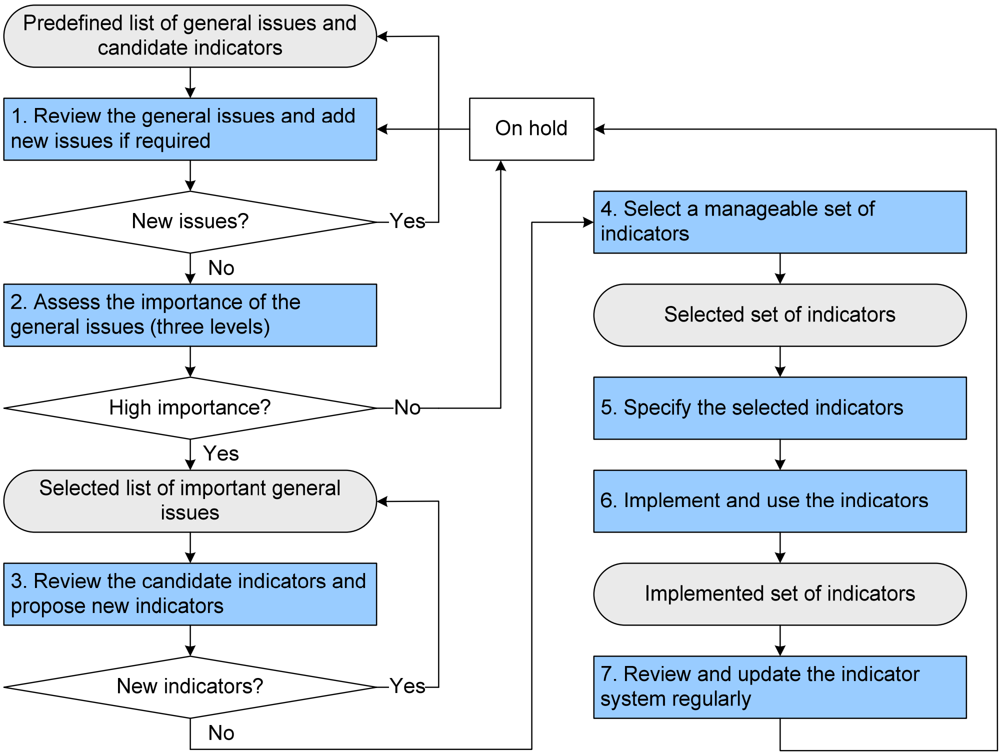

Figure 14. The Resilience based Early Warning Indicators (REWI) method steps

General issues are derived from eight Contributing Success Factors (CSFs), which in turn are attributes of resilience. The CSFs are based on some key literature sources (e.g., Woods, 2006; Woods and Wreathall, 2003; and Tierney, 2003), and they were empirically explored in a study on successful recovery of high risk incidents (Størseth et al., 2009). The CSFs are shown in Figure 15.

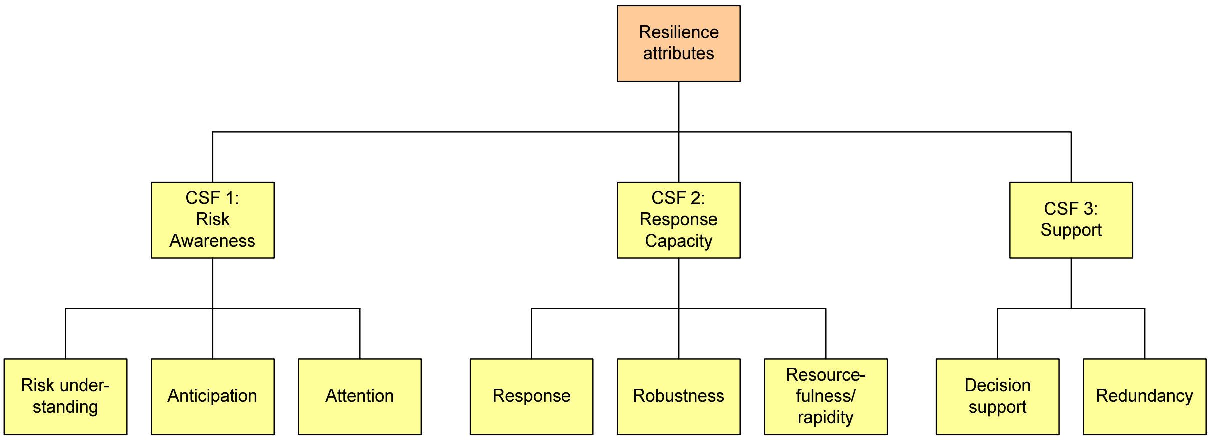

Figure 15. Contributing Success Factors

Candidate indicators have been proposed for each general issue under each of the eight CSFs. The general issues are shown in Figure 16.

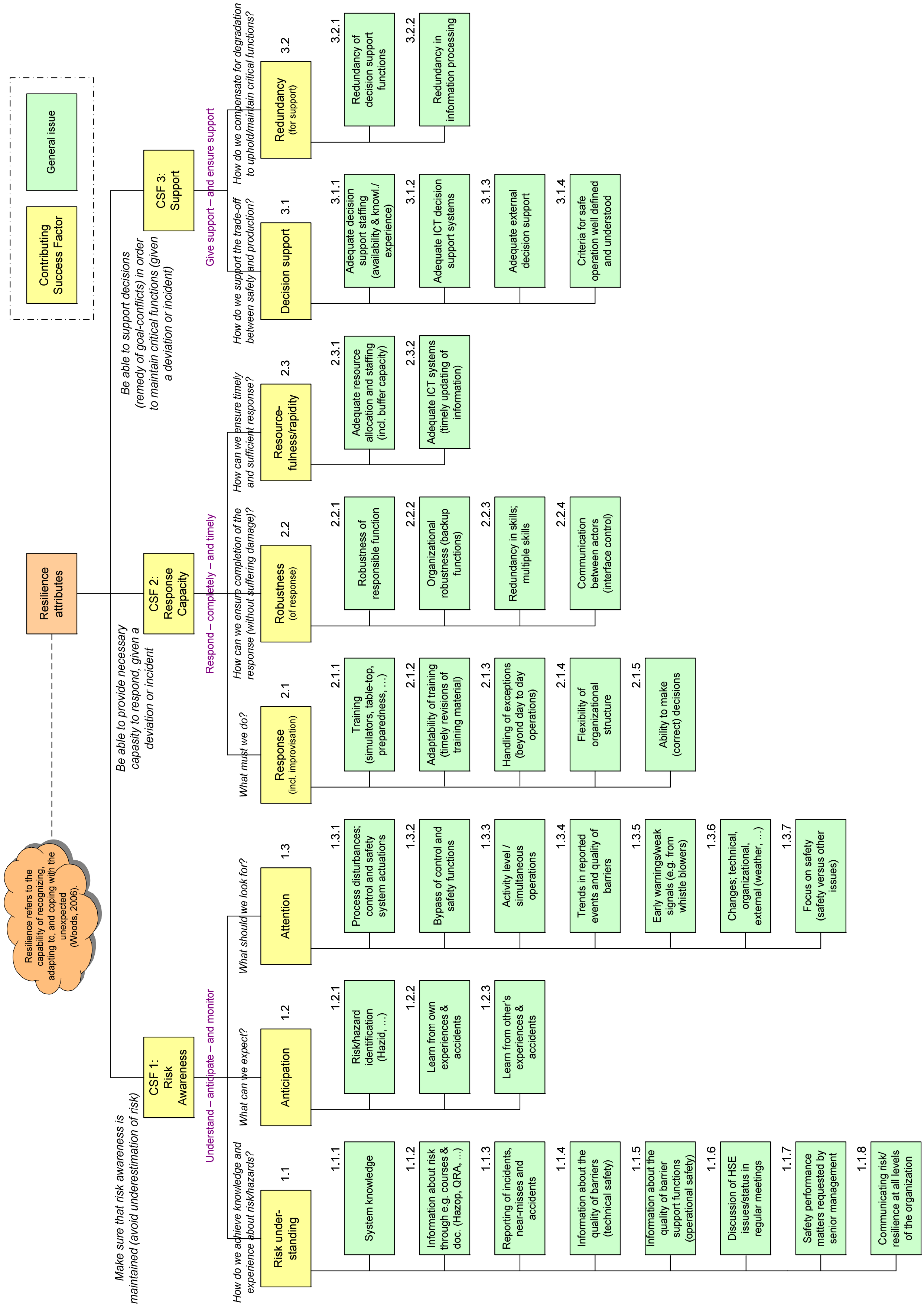

Figure 16. Structuring of candidate indicators according to general issues

6.2.2 Example indicators

As an example, the candidate indicators related to risk understanding are presented in Table 3.

Table 3. REWI Candidate Indicators (related to risk understanding; CSF 1.1)

Resilience attributes			
CSF 1: Risk Awareness			
Contributing Success Factor	**General issue**	**Candidate indicators**	
1.1 Risk Understanding	1.1.1 System knowledge	1.1.1.1	Average no. of years experience with such systems
		1.1.1.2	Average no. of years experience with this particular system
		1.1.1.3	Portion of operating personnel involved during design & construction
		1.1.1.4	Average no. of hours system training last 3 months
		1.1.1.5	Portion of operating personnel receiving system training last 3 months
		1.1.1.6	No. of violations to authorized entrance of systems
		1.1.1.7	Portion of operating personnel familiar with design assumptions
		1.1.1.8	Turnover of operating personnel last 6 months
	1.1.2 Information about risk through e.g. courses & doc. (Hazop, QRA, …)	1.1.2.1	Portion of operating personnel taking risk courses last 12 months
		1.1.2.2	Portion of staffing taking risk courses last 12 months
		1.1.2.3	Portion of operating personnel informed about risk analyses last 3 months
		1.1.2.4	Average no. of SJA operating personnel have attended last month
		1.1.2.5	No. of different persons having facilitated/led SJA during last month
		1.1.2.6	No. of tool-box meetings last month
		1.1.2.7	No. of violations to assumptions/limitations in the risk analysis (QRA)
	1.1.3 Reporting of incidents, near-misses and accidents	1.1.3.1	(On hold)
		1.1.3.2	(On hold)
		1.1.3.3	(On hold)
	1.1.4 Information about the quality of barriers (technical safety)	1.1.4.1	Average availability of RNNP safety systems last 3 months
		1.1.4.2	No. of red faces/traffic lights in Eni's system for barrier control
		1.1.4.3	No. of overrides of safety systems last month
		1.1.4.4	No. of overrides of safety systems extended to next shift during last month
		1.1.4.5	Fraction of serious loss of barriers treated adequately last 6 months
		1.1.4.6	No. of internal audits/inspections covering technical safety last 6 months
		1.1.4.7	Fraction of internal technical audits behind schedule during last 6 months
	1.1.5 Information about the quality of barrier support functions (op. safety)	1.1.5.1	No. of hours backlog in Preventive Maintenance on safety critical equipment
		1.1.5.2	No. of hours backlog in Corrective Maintenance on safety critical equipment
		1.1.5.3	No. of procedures not up to date
		1.1.5.4	No. of feedbacks on procedures (tracked in ENIMS)
		1.1.5.5	Fraction of feedbacks treated within 1 month
		1.1.5.6	Fraction of responses to feedback within 1 month after feedback
		1.1.5.7	No. of internal audits/inspections covering operational safety last 6 months
		1.1.5.8	Fraction of internal operational audits behind schedule during last 6 months
	1.1.6 Disussion of HSE issues/status in regular meetings	1.1.6.1	Average fraction of major accident risk issues discussed each month
		1.1.6.2	No. of risk issues presented and discussed offshore last month
		1.1.6.3	No. of risk issues from QRA presented and discussed offshore last month
		1.1.6.4	No. of meetings discussing the status on safety performance indicators
	1.1.7 Safety performance matters requested by senior management	1.1.7.1	Fraction of serious loss of barrier cases with senior management involvement
		1.1.7.2	Fraction of red events with senior management involvement
		1.1.7.3	Fraction of red faces/traffic lights with senior management involvement
		1.1.7.4	Average no. of risk issues/cases discussed during weekly mgmt meetings
		1.1.7.5	No. of HSE initiatives taken by senior management
	1.1.8 Communicating risk/resilience at all levels of the organization	1.1.8.1	No. of risk issues communicated to the entire organization each month
		1.1.8.2	Portion of company actively using the risk register
		1.1.8.3	Portion of company having received information about HSE topic of the month
		1.1.8.4	No. of success stories communicated to the entire organization last month

SJA – Safe Job Analysis; QRA – Quantitative Risk Analysis; RNNP – Risk Level in the Norwegian Petroleum Industry; ENIMS – ENI Management System; HSE – Health, Safety and Environment

The candidate indicators are used during workshops to trigger discussion for other, hopefully even more appropriate, indicators. An example of a list of selected candidate indicators, based on a workshop, is shown in Figure 17.

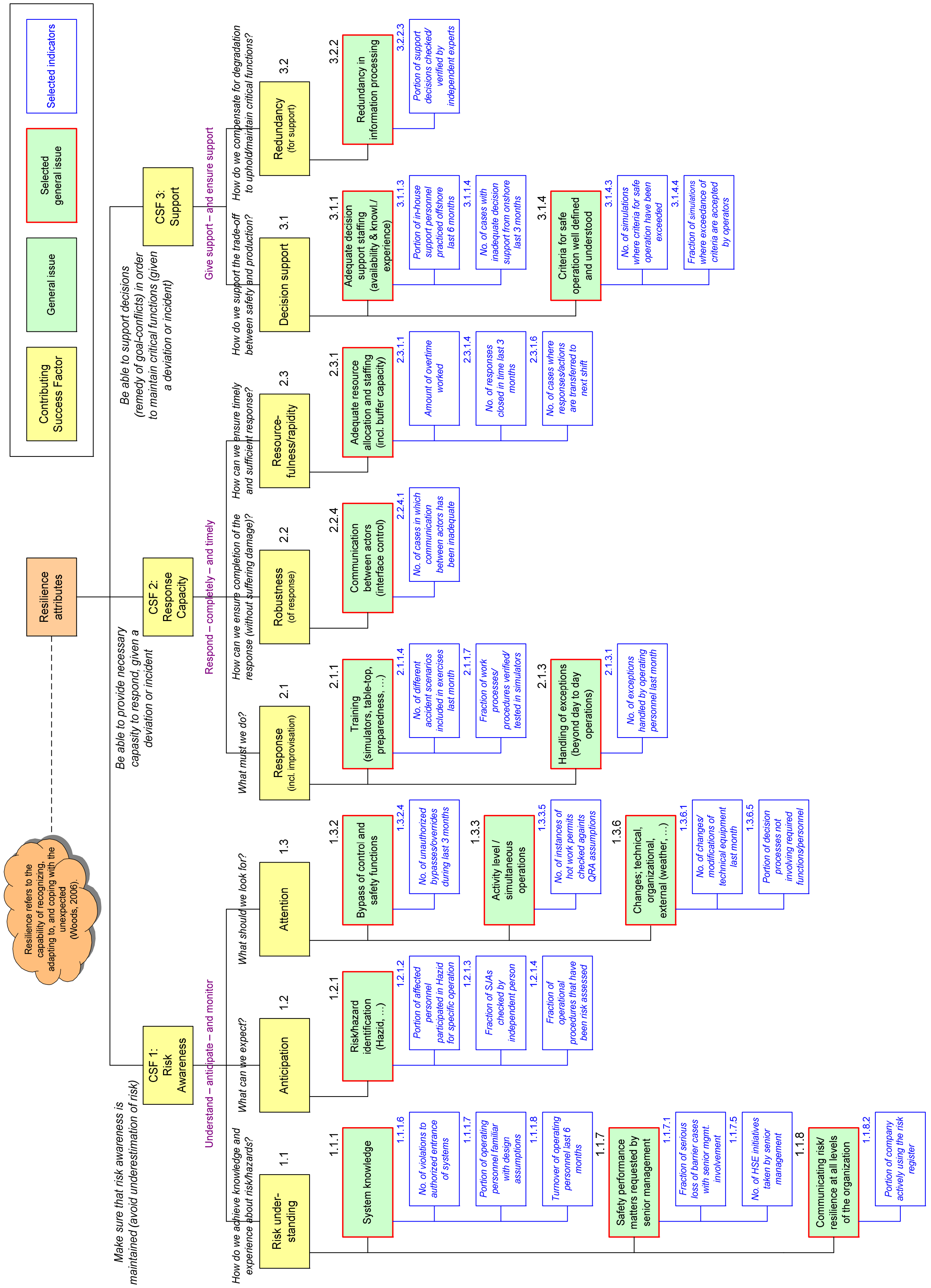

Figure 17. Example of a list of selected candidate indicators

Then, from the list of selected candidate indicators a final set of indicators will be selected for implementation and use. The final set of indicators must be manageable; thus, it will only be a subset of the candidate indicators, e.g. 10-20 indicators, which will be finally selected. This means that we can focus on the most important general issues, and that we only need to define in detail the selected indicators.

6.2.3 Strengths and weaknesses

Some of the strengths of the resilience based indicator method are as follows:

- Includes underlying causes directly through the CSFs and the general issues
- Practical, contributory based, and simple
- Not very resource intensive
- Not dependent on the occurrence of events
- Mental change from ‘what went wrong’ to ‘what went right’ (and why)

Some of the weaknesses of the resilience based indicator method are as follows:

- Challenging to establish measurable influencing factors being attributes of resilience
- Challenging to determine the relevance for major accidents
- Challenging to determine risk significance and relative importance (of general issues and indicators)

6.3 Comparison of methods

In Table 4 we have compared the four different methods/approaches with respect to the establishment of early warning indicators (ref. Table 1):

I. Safety performance based method (the HSE ‘dual assurance’ method)
II. Risk based method
III. Incident based method
IV. Resilience based method

Table 4. Comparison of different indicator methods

	Characteristic	I Perform. based	II Risk based	III Incident based	IV Resilience based
1	Easy to identify influencing factors	☺	☺	☺	☹
2	Relevant for major accidents	☹	☺☺	☺☺	☹
3	Easy to determine risk significance/importance	☹☹	☺☺	☹☹	☹☹
4	Relevant as early warnings	☺☺	☺	☺	☺☺
5	Practical, simple, well-documented	☺☺	☺	☺	☺
6	Resource intensive	☹	☹☹	☺	☺
7	Easy to communicate	☹	☹	☺☺	😐
8	Independent of the occurrence of events	☺	☺☺	☹☹	☺
9	Independent of thorough accident investigation	☺	☺☺	☹☹	☺☺
10	Focusing on ‘what went right’ (positive signals)	☹	☹	☹	☺☺

☺☺ - Very favorable; ☺ - Favorable; 😐 - Neutral; ☹ - Unfavorable; ☹☹ - Very unfavorable

There are pros and cons with all methods, as illustrated by Table 4. All methods are very favorable with respect to some characteristics and at the same time very unfavorable to some other characteristics.

In addition, there are inherent differences in scope and depth of the methods. The incident based methods will usually only cover specific systems and not a complete installation, but may go deeper into an area/system, which the other methods perhaps will not cover at all. One example is the hydraulic systems (covered by the incident based method), which usually are not covered by a QRA (and therefore neither by the risk based method).

Also the performance-based method will usually narrow the scope to certain systems/activities. The risk based approach will cover the whole installation and all risks, since it is an intrinsic property of this method to narrow the focus to the most important risk factors. The resilience based approach can in principle cover a complete installation with all its risks.

There are clearly advantages and disadvantages with all the methods, which also differ in terms of resource intensiveness and the need for contribution from management and/or operating personnel, and in the scope and depth of analysis. This suggests that we should be flexible with respect to the choice of methods, and preferably use more than one method, since they are also complementary, at least to a certain degree. Thus, the main conclusion is that it is favorable to have the possibility to use several different methods for the establishment of early warning indicators.

The choice of method(s) is also affected by maturity of the organization using the methods and implementing the indicators, as well as timing. In the case of Goliat, it is still 'early days' when it comes to the settling of early warning indicators, since production start-up is not foreseen before 2013, at the earliest.

7 Case specific advice

The case specific advice is provided in a separate document to the operating company (Eni Norge AS). The main focus in this document is the development of the resilience based early warning (REWI) method, and the use of this method in a series of workshops by the operating company.

A preliminary set of early warning indicators has been identified.

8 Generic knowledge

Generic knowledge has been described in this report. Further details can be found in the referenced documents.

9 Publications

An overview of articles, papers, reports and memos are provided in this section. See also www.sintef.no/projectweb/Building-Safety/Publications/ for an overview of publications.

9.1 Articles and papers

The following *two journal articles* have been produced within WP4:

1. Øien, K., Utne I.B., Herrera I.A., 2010a. Building Safety Indicators. Part 1 – Theoretical foundation. Safety Science 49(2), pp. 148-161.
2. Øien, K., Utne, I.B., Tinmannsvik, R.K., Massaiu, S., 2010b. Building Safety Indicators. Part 2 – Application, practices and results. Safety Science 49(2), pp. 162-171.

The following *three conference papers* have been produced within WP4:

1. Øien, K., 2008b. Development of early warning indicators based on accident investigation. PSAM 9. International Probabilistic Safety Assessment and Management Conference, 18 - 23 May 2008, Hong Kong, China.
2. Øien, K., Massaiu, S., Tinmannsvik, R.K., Størseth, F., 2010c. Development of early warning indicators based on Resilience Engineering. PSAM10, International Probabilistic Safety Assessment and Management Conference, 7-11 June 2010, Seattle, USA.
3. Øien, K., 2010. Remote operation in environmentally sensitive areas; development of early warning indicators. 2nd iNTeg-Risk Conference, 15-16 June 2010, Stuttgart, Germany.

9.2 Reports and project memos

The following *four reports and memos* have been produced within WP4:

1. Øien, K., 2008a. Building Safety WP4: Early warnings of major accidents. Task 4.1. Problem description. MEMO, SINTEF Technology and Society, Trondheim.
2. Utne, I.B., Øien, K., Massaiu, S., Tinmannsvik, R.K., 2008. Building Safety WP4: Early warnings of major accidents. Task 4.2. Literature review. MEMO, SINTEF Technology and Society, Trondheim.
3. Øien, K., Massaiu, S., Tinmannsvik, R.K., Størseth, F., 2010d. Building Safety in Petroleum Exploration and Production in the Northern Regions; Resilience based early warning indicators (REWI). Case specific advice. (Restricted.)
4. Øien, K., Tinmannsvik, R.K., Massaiu, S., Størseth, F., 2010e. Building Safety – Development of new models and methods for the identification of early warning indicators; Summary report. SINTEF Report, A16930, Trondheim.

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Appendix A: Journal article – Safety Science Part 1

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Building Safety indicators: Part 1 – Theoretical foundation

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A B S T R A C T

Development of early warning indicators to prevent major accidents – to 'build safety' – should rest on a sound theoretical foundation, including basic concepts, main perspectives and past developments, as well as an overview of the present status and ongoing research. In this paper we have established the theoretical basis for development of indicators used as early warnings of major accidents. Extensive work on indicators have been carried out in the past, and this could and should have been better utilized by industry, e.g., by focusing more on major hazard indicators, and less on personal safety indicators. Recent discussions about safety indicators have focused on the distinction between leading and lagging indicators; however, a discussion on terms should not impede the development of useful indicators that can provide (early) warnings about potential major accidents.

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Appendix B: Journal article – Safety Science Part 2

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Building Safety indicators: Part 2 – Application, practices and results

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ABSTRACT

Petroleum exploration and production in the Barents Sea is a controversial topic. The Goliat field outside the northern coast of Norway will be the first offshore oil development in this region, with planned production start in 2013–2014. Avoiding major accidents at Goliat is critical; not only to reduce the risks to human lives and the environment, but also to gain political acceptance. Providing early warnings of major accidents for Goliat is one of the main objectives of the research project 'Building Safety'. The objective of this paper is to describe the development of early warnings in the form of indicators. In addition, the paper includes an overview of current status of early warnings of accidents in other major hazard industries; the nuclear power industry, the chemical process industry, and aviation. Experiences from these industries, including lessons learned from recent major accidents, have been used as important input to the development of early warning indicators.

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Safety Science 49(2), pp. 162-171; http://dx.doi.org/10.1016/j.ssci.2010.05.015

Appendix C: Conference paper – PSAM9

In Proceedings of the Int. Conference on Probabilistic Safety Assessment and Management (PSAM 9), Hong Kong, China, 18-23 May, 2008.

Development of Early Warning Indicators Based on Incident Investigation

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Abstract: This paper explores the possibility of developing early warning indicators based on incident investigation. The use of early warning indicators may contribute to ensure that oil companies produce oil and gas without harmful spills. The incident investigated was a hydraulic oil leak from the Eirik Raude drilling rig during exploration drilling in the Barents Sea in April 2005. The incident is analyzed using influence diagrams, from which seven general barriers against hydraulic leaks have been identified. For each barrier both checkpoints and indicators have been developed, which provide information about the status of the barriers and early warning of potential spills. The work described in this paper has shown that it is possible to develop early warning indicators based on incident investigation. Several of the proposed checkpoints/indicators may have prevented the oil leak at Eirik Raude, if they had been in use prior to the incident.

Keywords: Early Warning Indicators, Incident Investigation, Offshore Industry, Oil Leak.

Link to paper:
http://www.sintef.no/project/Building%20Safety/Publications/PSAM9-paper-early-warning-indicators.pdf

Appendix D: Conference paper – PSAM10

Development of Early Warning Indicators based on Resilience Engineering

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Abstract: This paper describes a new method for the development of early warning indicators based on resilience and Resilience Engineering. This resilience based early warning indicator (REWI) method consists of three main parts. The first part is a set of contributing success factors being attributes of resilience, the second part is general issues for each of the contributing success factors ensuring that the goal of each contributing success factor is fulfilled, and the third part is the indicators established for each general issue, i.e., the way of measuring the general issues. This research has shown that it is possible to develop 'an indicator system' based on resilience engineering theory from which early warning indicators can be established. It may be used as a stand-alone system, or indicators established by other approaches may be included for the final selection of indicators. Further work is necessary in order to investigate to what degree these resilience based indicators are complementary to other safety performance indicators, for instance whether they provide a more appropriate measure of the ability to 'cope with the unexpected'.

Keywords: Early Warning Indicators, Resilience, Resilience Engineering, Offshore Industry.

Link to paper:
http://www.sintef.no/project/Building%20Safety/Publications/PSAM%2010%20-%20Development%20of%20early%20warning%20indicators%20based%20on%20resilience%20engineering.pdf

Appendix E: Conference paper – 2nd iNTeg-Risk conference

Paper presented at 2nd iNTeg-Risk Conference, 14 – 18 June, Stuttgart, Germany

Remote Operation in Environmentally Sensitive Areas; Development of Early Warning Indicators

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Abstract: Exploration and production of oil and gas in certain sensitive areas such as the Barents Sea and Lofoten, is controversial and further expansion depends on the ability to avoid harmful spills. One way of improving the ability to avoid such spills is to use early warning indicators. The objective of the work presented in this paper is to describe and compare strengths and weaknesses of different approaches for the development of early warning indicators. The approaches that have been compared are: safety performance-based methods; risk-based methods; incident-based methods; and resilience-based methods. There are pros and cons with all methods. All methods are very favorable with respect to some characteristics and at the same time very unfavorable to some other characteristics. They are also different in terms of scope and depth of analysis. This suggests that we should be flexible with respect to the choice of methods, and preferably use more than one method. Thus, the main conclusion is that it is favorable to have the possibility to use several different methods for the establishment of early warning indicators.

Keywords: Early Warning Indicators, Remote Operation, Sensitive Areas, Offshore Industry.

Link to paper:
http://www.sintef.no/project/Building%20Safety/Publications/2nd%20iNTeg-Risk%20Conference%20ERRA%20C2%20final.pdf

The Building Safety project has produced the following summary reports:

- Human and Organizational Contribution to Resilience (Størseth et al., 2009)
- Resilient Decision Processes in Integrated Operations (Kaarstad et al., 2010)
- Development of new models and methods for the identification of early warning indicators (Øien et al., 2010)

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