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.

1 Introduction

Exploration and production of oil and gas in certain sensitive areas such as the Barents Sea and Lofoten, is a controversial topic of social debate in Norway, particularly due to environmental and fisheries interests. Political acceptance for opening of these prospective exploration acreages depends on public confidence in the ability to produce oil and gas without any harmful spills. Some limited exploration activity is presently taking place in the Barents Sea and the oil company Eni Norge AS has been granted permission to produce oil from an oil field (Goliat) for the first time in this area. Further expansion depends on the ability of the involved companies to avoid harmful spills during this initial activity. A zero tolerance regime for oil spills has been introduced for this area.

The production of oil and gas, with increased use of integrated operations/remote operations (a new production technology), in environmental sensitive areas previously not opened for oil production, constitutes an emerging risk.

One way of improving the ability to produce oil and gas without any harmful spills is to use early warning indicators. Different approaches for the development of indicators may be classified into:

- Safety performance-based indicators
    - Event indicators
    - Barrier indicators
    - Activity indicators
    - Programmatic* indicators
- Risk-based indicators
    - Technical indicators
    - Organizational indicators
- Incident-based indicators
- Resilience-based indicators

The great span in challenges and requirements for the Goliat field development calls for a triangulation approach, i.e., we need to utilize several different approaches and angles in the search for appropriate early warning indicators. The objective of the work presented in this paper is to describe and compare strengths and weaknesses of the different approaches for the development of indicators. The plans for further work are also described.

* *Programmatic performance indicators* (PPIs) are indicators that assist in assessing quality and performance of various programs, functions, and activities relating to the safety of the plant (Øien et al., 2010a).

2 Method Descriptions and Evaluations

2.1 Safety performance-based methods

The main function of a measure of safety performance is to describe the safety level within an organization, activity, or work unit. Safety measurements have been used for a long time as one means of assessing the safety performance. (Safety audit tools are examples of other ways of assessing the safety performance, but will not be treated here).

For offshore installations, process plants, and other areas of major hazards the accidents are so rare, that direct measures of safety (outcome measures) are inadequate.

In the early '80s, research started on assessing the effect of organizational and other factors on safety, and the term 'indicator' was introduced in the safety field (Osborn et al., 1983a; 1983b; Olson et al., 1984; 1985). Terms like safety indicators, safety performance indicators, programmatic performance indicators, indirect performance indicators, etc. were used. This initial work on safety indicators started with a set of factors assumed to have an effect on safety, and one objective was to demonstrate this relationship through e.g. correlation.

When the work was extended to cover underlying causes (i.e. the effect of organizational or programmatic factors), then safety performance measurements were not only useful to describe the safety level, but also to be used as early warnings.

Here we use the term 'safety performance-based methods' for those safety indicator methods which start from a set of influencing factors *assumed* to be important to safety. This was the basis for the first safety indicator methods, and still constitutes the bulk of methods.

One recent safety performance-based method, which we focus on here, is the HSE 'dual assurance' method emphasizing the need for both leading (proactive) and lagging (reactive) indicators.

2.1.1 Short description

The HSE method (HSE, 2006) describes a six steps procedure for the establishment and implementation of performance indicators, as illustrated in Figure 1.

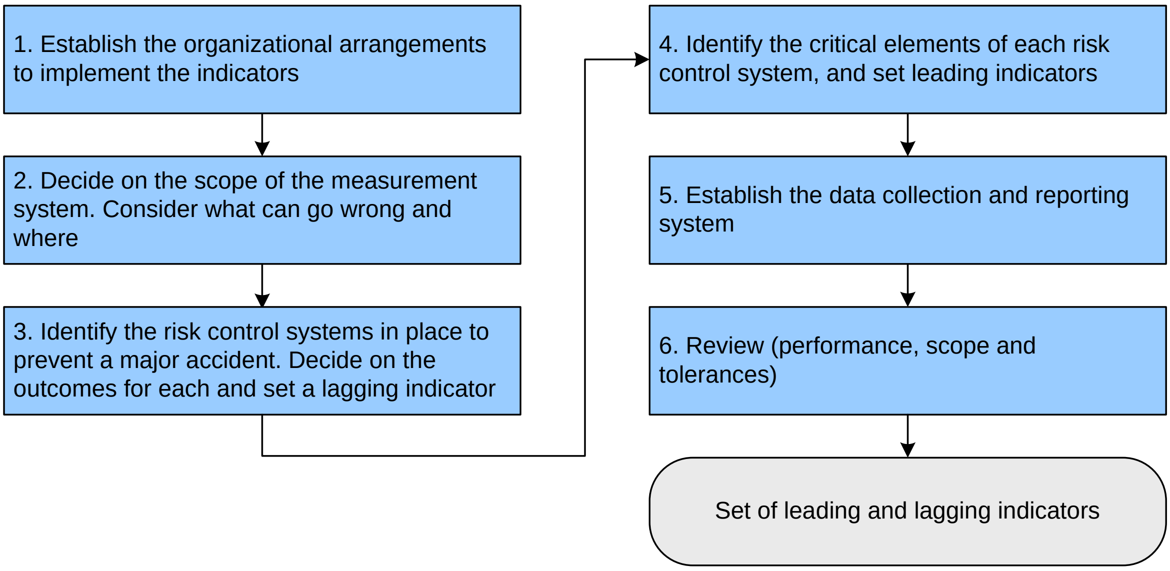

Figure 1. Method steps of the HSE method

The 'process safety management system' describes those parts of an organization's management system intended to prevent major incidents arising out of the production, storage and handling of dangerous substances. 'Risk control system' (RCS) describe a constituent part of a process safety management system that focuses on a specific risk or activity, e.g., plant and process change, permit to work, inspection and maintenance etc.

The main difference between the HSE approach and other guidance on performance measurement is the introduction of the concept of 'dual assurance' that key risk control systems are operating as intended. Leading and lagging indicators are set in a structured and systematic way for each critical risk control system within the whole process safety management system. In tandem they act as system guardians providing dual assurance to confirm that the risk control system is operating as intended or providing a warning that problems are starting to develop.

Leading indicators are a form of active monitoring focused on a few critical risk control systems to ensure their continued effectiveness. Leading indicators require a routine systematic check that key actions or activities are undertaken as intended. They can be considered as measures of process or inputs essential to deliver the desired safety outcome.

Lagging indicators are a form of reactive monitoring requiring the reporting and investigation of specific incidents and events to discover weaknesses in that system. These incidents or events do not have to result in major damage or injury or even a loss of containment, providing that they guards against or limits the consequences of a major incident. Lagging indicators show when a desired safety outcome has failed, or has not been achieved.

2.1.2 Example indicators

We are particularly concerned with the development of early warning indicators, and for this purpose the leading indicators are of most interest. Thus, in Table 1 we have shown some of the leading indicators suggested in the worked example by HSE (2006).

Table 1. Leading indicators (from HSE, 2006)

Leading indicators	
1	Percentage of safety critical plant/equipment that performs to specification when inspected or tested
2	Percentage of maintenance actions identified which are completed to specified timescale
3	Percentage of procedures which are reviewed/revised within the designated period
4	Percentage of functional tests of safety critical instruments and alarms completed to schedule
5	Percentage of work conducted in accordance with permit conditions
6	Percentage of staff/contractors who take the correct action in the event of an emergency

2.1.3 Strengths and weaknesses

Some of the strengths of the HSE indicator method are as follows:

- Relatively easy to establish influencing factors (that are *assumed* to be important)
- It includes leading indicators, which are directly relevant as early warning indicators
- Renowned and practical (application guide with examples have been issued)
- Not dependent on the occurrence of events (but this may strengthen the choice of factors)

Some of the weaknesses of the HSE indicator method are as follows:

- May be difficult to determine the relevance for major accidents[†]
- Difficult to determine the risk significance and relative importance of the factors/indicators
- May be difficult to communicate the relevance for major accidents
- Theoretically challenging to distinguish between leading and lagging indicators[‡]
- Relatively resource intensive (requires, e.g., senior management involvement)

2.2 Risk-based methods

Risk-based methods (or risk analysis based, PSA based, QRA based, etc) differ from safety performance-based methods in that they utilize a risk model as a basis. This is usually an existing risk model, but the development of a risk model (either a complete new model or an extension of the existing model) may also be part of the method.

Here we focus on one specific risk-based method developed for offshore installations (Øien, 2001a; 2001b).

2.2.1 Short description

The risk indicator method consists of two parts; one technical part and one organizational part as illustrated in Figure 2.

[†] Unless a risk analysis (QRA, safety case, …) is used as basis, which is the usual case for the HSE method.
[‡] This refers to the discussion launched by Hopkins (2009). However, it is seen as less of a practical problem.

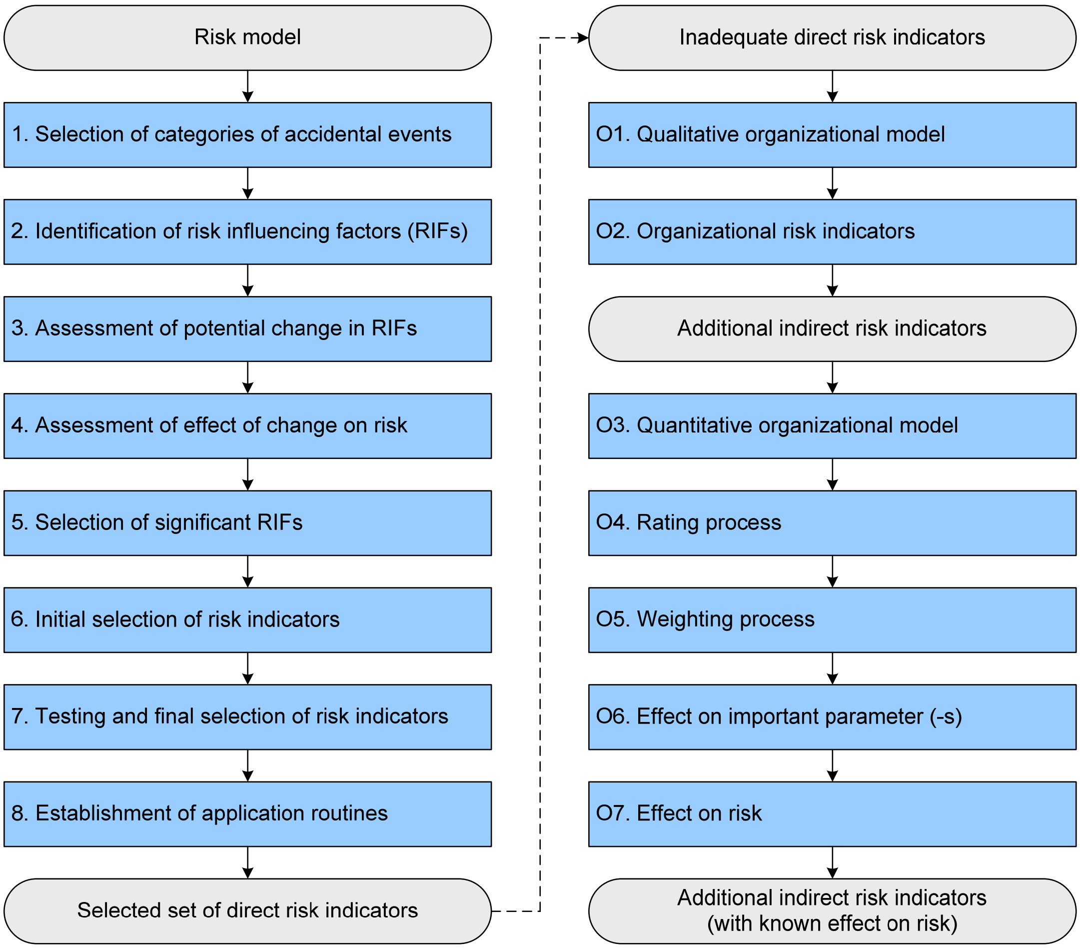

Figure 2. Method steps of the risk-based indicator method

The main function of the risk indicators developed by this method is risk control, which means that direct indicators are adequate (and preferred) if there is sufficient data to be obtained in the data collection period chosen (e.g. each month or each three months). The organizational part of the method is normally foreseen used, only for significant risk factors with insufficient data.

However, in the case of development of early warning indicators the organizational risk indicators are of particular interest, which means that the organizational part should be used even if there is sufficient amount of data for direct risk indicators.

2.2.2 Example indicators

The indicators in Table 2 are organizational risk indicators developed for one specific offshore installation. However, they may be relevant for other installations and process plants as well.

Table 2. Organizational risk indicators (from Øien, 2001b)

	Organizational risk indicators
1	Proportion of process technicians having formal system training
2	Average number of areas in which the process technicians are trained
3	Average number of years experience on this installation for relevant personnel
4	Proportion of relevant personnel having received Job Safety Analysis (JSA) training
5	Proportion of relevant personnel having performed JSA last year
6	Number of control of JSA preparation and application
7	Proportion of critical jobs being checked
8	Number of corrective maintenance work orders on leak exposed equipment

2.2.3 Strengths and weaknesses

Some of the strengths of the risk-based indicator method are as follows:

- Relatively easy to identify significant risk influencing factors (RIFs)
- Relevance for major accident risk is known
- Risk significance and relative importance are known
- Includes organizational risk indicators, which are most relevant as early warning indicators
- Relatively well documented
- Not dependent on the occurrence of events

Some of the weaknesses of the risk-based indicator method are as follows:

- Resource intensive
- The risk models may be difficult to understand for non-risk analysts

2.3 Incident-based methods

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 focus on one specific incident-based method, utilizing influence diagrams (Øien, 2008).

2.3.1 Short description

The method consists of eight steps as illustrated in Figure 3.

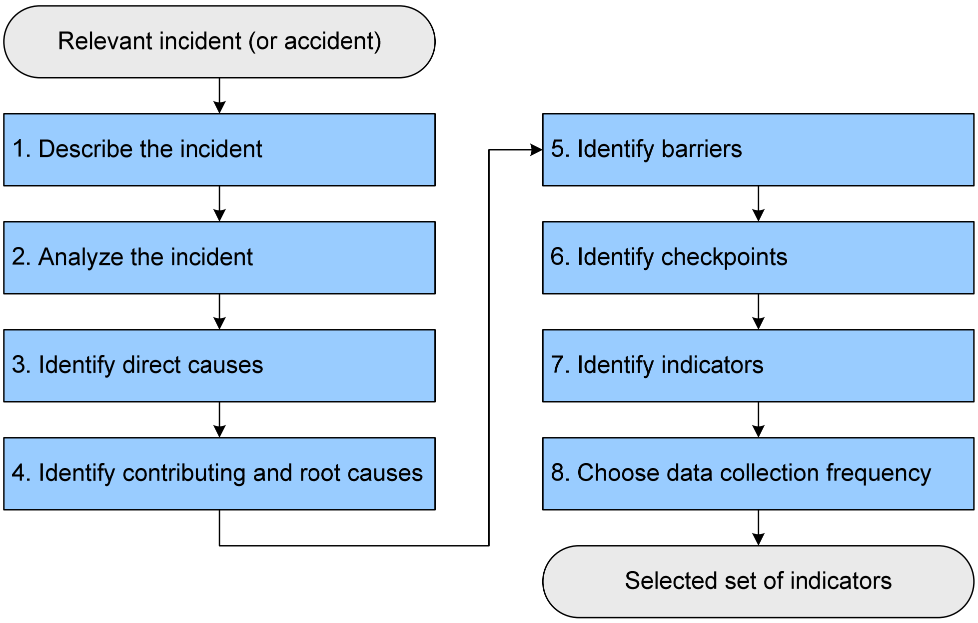

Figure 3. Method steps of the incident-based indicator method

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 4.

The influence diagram in Figure 4 is an extract from the complete influence diagram of the incident. (The complete influence diagram has altogether 50 nodes.)[§]

[§] 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. (However, recall that Figure 4 is just an extract of the complete influence diagram.)

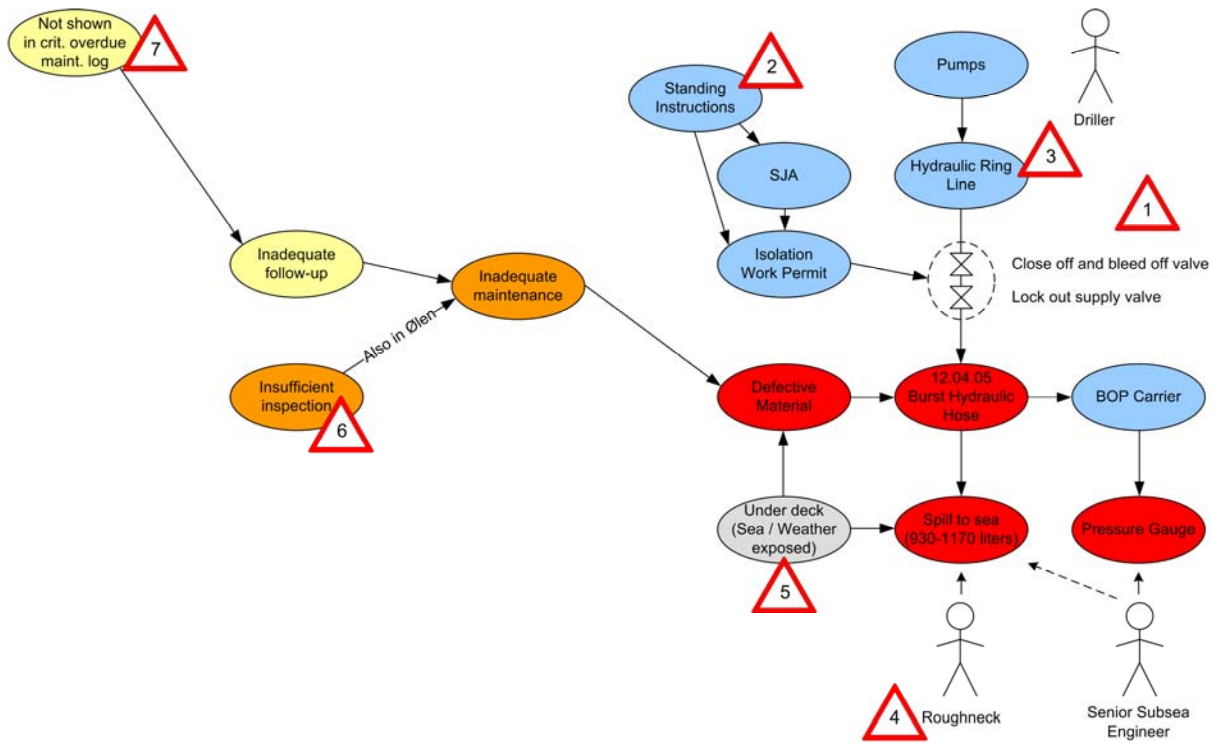

Figure 4. Identified barriers for critical hydraulic systems

2.3.2 Example indicators

Preliminary suggestions for early warning indicators are presented in Table 3. We have also proposed a data collection frequency for each of the indicators.

Table 3. 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

2.3.3 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 the 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

2.4 Resilience-based methods

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 focus on one specific method, i.e. the Resilience-based Early Warning Indicator (REWI) method (Øien et al., 2010b).

2.4.1 Short description

The method consists of seven steps as illustrated in Figure 5.

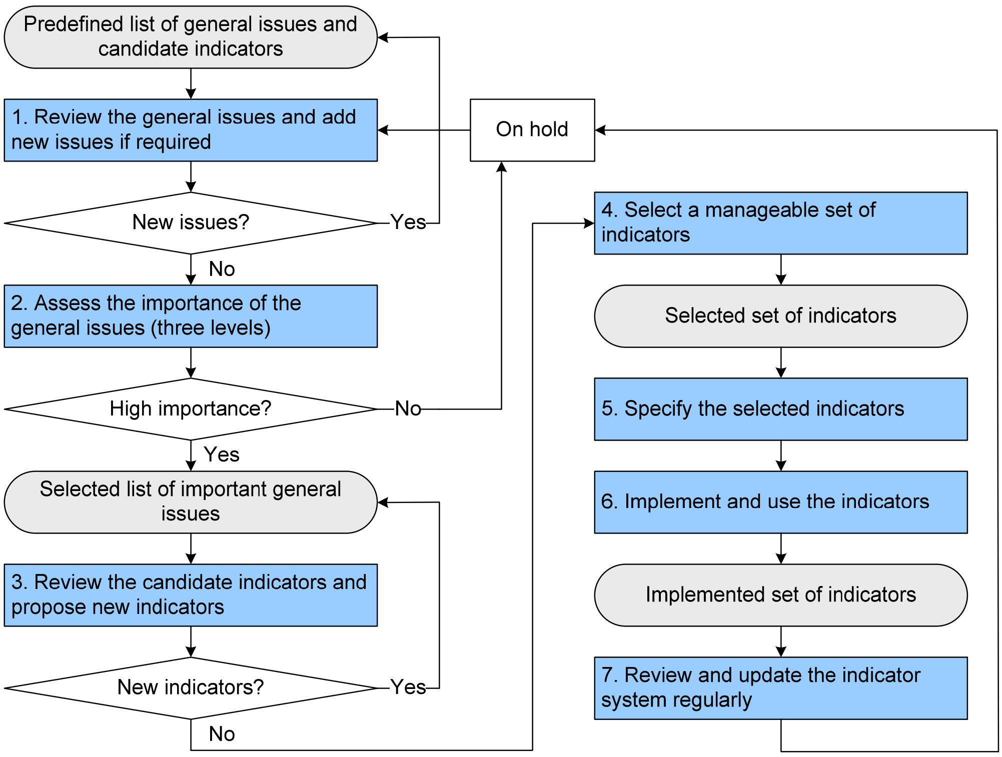

Figure 5. The Resilience-based Early Warning Indicator (REWI) method steps

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 6.

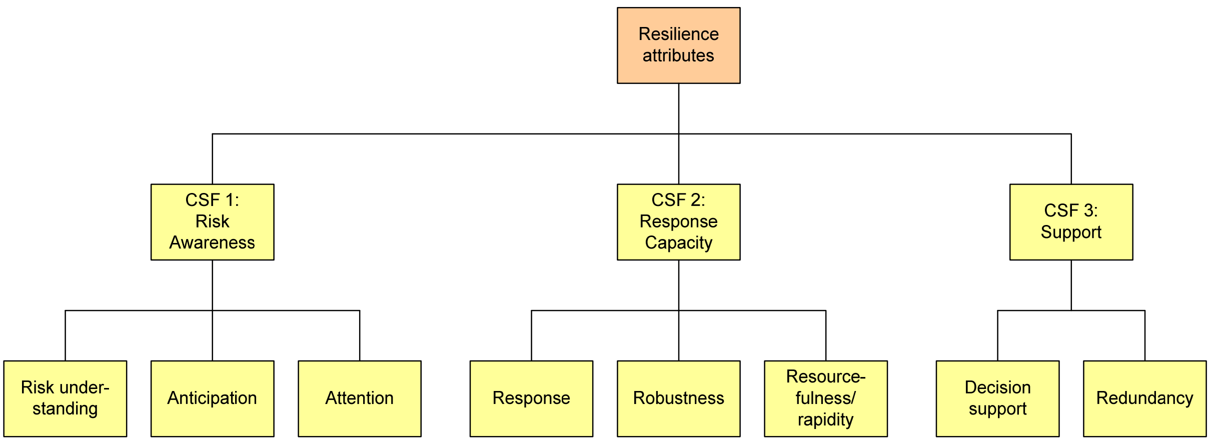

Figure 6. Contributing Success Factors

Candidate indicators have been proposed for each general issue under each of the eight CSFs.

2.4.2 Example indicators

The candidate indicators for the risk understanding's two first general issues (i.e. 1.1.1 – system knowledge and 1.1.2 – information about risk through e.g. courses and documents) are presented in Table 4.

Table 4. REWI Candidate Indicators

No.	General issue	Candidate indicator
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	Info. about risk	
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[1] 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[2])

[1] SJA – Safe Job Analysis; [2] QRA – Quantitative Risk Analysis

The candidate indicators are used during workshops to trigger discussion for other, hopefully even more appropriate, indicators. Then, from the final list of candidate indicators a set of indicators will be selected for implementation and use.

The selected set of indicators must be manageable; thus, it will only be a subset of the total list of candidate indicators, e.g. 10-20 indicators, which will be 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.

2.4.3 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
- Determining the relevance for major accidents
- Determining risk significance and relative importance (of general issues and indicators)

3 Comparison of Different Approaches

In Table 5 we have compared the four different methods/approaches with respect to the establishment of early warning indicators:

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

Table 5. 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	Dependent on 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 5. All methods are very favorable with respect to some characteristics and at the same time very unfavorable to some other characteristics. (See the next chapter for further discussions.)

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.

4 Discussion and Conclusion

The safety performance-based method is very favorable when it comes to practicality, simplicity and documentation. The indicators are also very relevant as early warnings. The main weakness is that the risk significance is unknown, which is also the case for the relative importance between the chosen influencing factors.

The risk-based method provides indicators that are very relevant for major accidents, it is easy to determine the risk significance (including relative risk importance between the various risk influencing factors), and it is not dependent on any accident investigation since it is also independent of any occurred events. One of the favorable inherent features is that it models potential scenarios, and need not wait for accidents to happen. The main weakness is that it is rather resource intensive, especially if organizational risk indicators are developed, which is desirable since they are most relevant as early warnings.

The incident-based method provides indicators that are very relevant for major accidents, especially if the event investigated was a major accident or it had major accident potential. It is also very easy to communicate, since it is based on a factual incident or accident. This is also its main weakness, i.e. that it depends on the occurrence of a relevant incident or accident, and that the accident investigation needs to be very thorough and well documented. In addition, the risk significance and relative importance of the underlying causes in general are unknown.

The resilience-based method's main advantage is that it focuses on positive signals, and not only on failures, for which there may be lack of data (i.e. the 'controller's dilemma'). It does not depend on information from occurred events and the indicators are relevant as early warnings. The main drawback is that the risk significance and relative importance of the influencing factors (or general issues) are unknown.

It is clearly advantages and disadvantages with all the methods, and they are also different 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.

5 Further Work

The present plan is to use all the methods, except the risk-based method, to develop early warning indicators for Goliat. The risk-based method is excluded mainly due to the resource intensiveness (especially since organizational risk indicators are needed as early warning indicators).

The safety performance-based indicators will be developed using the HSE ‘dual assurance’ method, and the production installation’s QRA will be used as a basis.

The indicators that have been developed using the incident-based method need to be adapted, since they were developed for a drilling rig, and not a production installation.

Finally, the resilience-based method needs some further development of candidate indicators, before the process of selecting indicators is initiated. This is a contributory based process, which depends on the availability of responsible persons within the operating company.

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