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.

1. INTRODUCTION

Exploration 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.

One way of improving the ability to produce oil and gas without any harmful spills is to use early warning indicators. The objective of the work presented in this paper is to explore the possibility of developing early warning indicators based on the concepts of resilience and Resilience Engineering.

Resilience refers to the capability of recognizing, adapting to, and coping with the unexpected [1]. 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 [2].

2. METHOD

2.1. Overview of Method Development

The method that has been established for the development of early warning indicators is based to some extent on a method developed by U.S. Electric Power Research Institute (EPRI) known as Leading Indicators of Organizational Health (LIOH) [3,4]. This method has been adapted mainly in two ways. First, the factors seen as important to the management of safety (seven 'themes') has been replaced by

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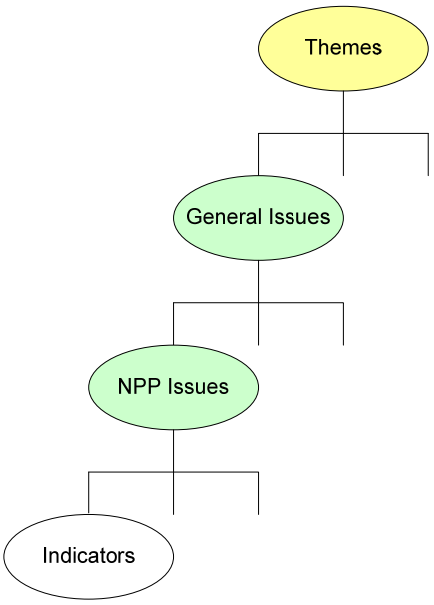
attributes of a resilient organization (eight 'contributing success factors') developed in a research project named 'Building Safety in Petroleum Exploration and Production in the Northern Regions' [5,6]. Secondly, for each of the contributing success factors a set of general issues has been suggested and accompanied with proposals for early warning indicators. I.e., a list of general issues with proposed early warning indicators has been developed and included as part of the method, which is a deviation from the original LIOH method. In addition, there will be an option for including new general issues and early warning indicators during the workshop sessions in which the method is applied and indicators established/selected.

2.2. The LIOH Method

The principle parts of the LIOH method [3,4] are illustrated in Figure 1.

Figure 1: Principle parts of the LIOH method (based on [3])



The organizational and management factors seen as important to the management of safety – the seven themes – were developed from the literature on organizational performance and safety. The themes are:

1. Management commitment
2. Awareness of safety performance
3. Preparedness for problems
4. Flexibility built in for responding to problems
5. Just culture (to promote reporting of errors and failures)
6. Learning culture (to promote fixing of problems)
7. Transparency[†] (visibility of safety performance)

The LIOH method is a contributory based method in which the users of the indicators take part in workshops and define their own issues (general and nuclear power plant – NPP – specific) for each theme, and for each issue they define indicators. There are no predefined examples of issues prior to the workshops, and no candidate indicators are in place prior to the workshops.

The case studies of the LIOH method show that there is often only one level of issues used, i.e. the issues are not divided into general and NPP issues [3,4]. A second observation is that the results (the

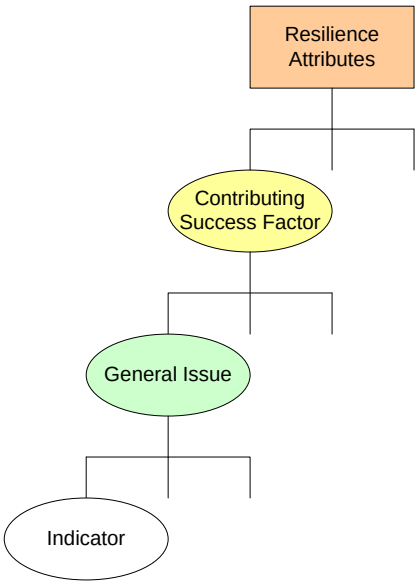
[†] In LIOH this theme is titled 'Opacity', the only one indicated by a negative term. We use transparency for the sake of clarity in our synthetic presentation.

issues and indicators defined) from identical power plant units (with different participants in the workshops) are very different. The reason for this difference is that there are no guidance with respect to issues and indicators, and that there have been different participants in the workshops in each of the case studies.

2.3. The Resilience Based Early Warning Indicator (REWI) Method

The main parts of the resilience based early warning indicator (REWI) method are illustrated in Figure 2. This illustration allows for a comparison with the LIOH method.

Figure 2: Principle parts of the REWI method



The REWI method consists of eight contributing success factors (CSFs) being attributes of resilience. For each CSF there is a set of issues contributing to the fulfillment of the goals of the CSF. There is only one level of issues – denoted general issues – for which indicators are developed.

The CSFs were developed based on a literature review and an empirical study on successful recovery of high-risk incidents; thus, the term contributing *success* factor [6].

The general issues and proposals for candidate indicators were developed based on a series of workshops with scientists with various background including engineering, psychology, organizational theory and human factors. These workshops were followed up by workshops with domain experts.

The REWI method consists of a predefined set of general issues and also a set of candidate indicators for each general issue. This is a main difference compared to the LIOH method, and makes it less "open ended". However, it is still a contributory based method and new general issues may be added during the workshops for identification of indicators.

The predefined set of general issues and sets of candidate indicators are first of all a foundation for the triggering of suitable indicators, which may not be included already, but at the same time it forces the participants to assess the a priori set of general issues and candidate indicators. Thus, it counteracts the tendency to identify indicators during workshops just as random "indicators of the day".

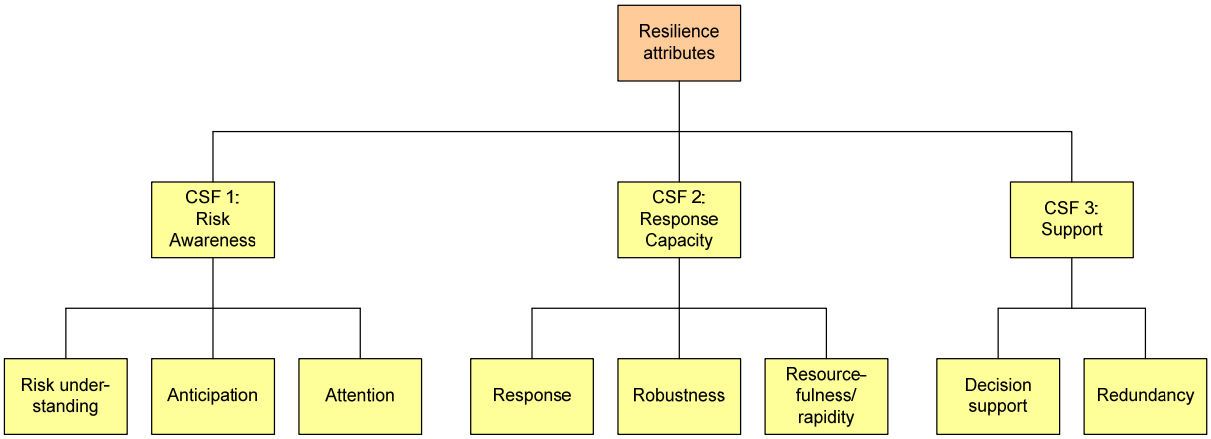
2.3.1. Contributing success factors (CSFs)

The concept of resilience is made operational through the CSFs. The CSFs are based on some key literature sources (e.g., [1], [7], and [8]), and they were empirically explored in a study on successful

recovery of high risk incidents [6]. The study identified where in the organization (organizational layers and positions) the resilience elements could contribute in recovery scenarios. The CSF operationalization is based on the assumption that a key characteristic of the resilience idea is the interaction and interchange between different (organizational) system layers, levels, and focal points. Thus, a resilience approach is assumed to be based on premises that suggest both intra- and inter-layer dynamics within an organization (and between organizations). In this line of thought, the CSFs should be seen as resilience elements or focus areas that may be specified on any organizational layer.

The CSFs are shown in Figure 3.

Figure 3: Contributing Success Factors



For the purposes of the REWI method, and as illustrated in Figure 3, the CSFs are considered to consist of two levels. The CSFs at the first level are:

1. Risk awareness – make sure that risk awareness is maintained (avoid underestimation of risk)
2. Response capacity – be able to provide necessary capacity to respond, given a deviation or incident
3. Support – be able to support decisions (remedy of goal-conflicts) in order to maintain critical functions (given a deviation or incident)

The CSFs at the second level (and the corresponding questions we need to answer) are:

1.1 Risk understanding – how do we achieve knowledge and experience about risk/hazards?
1.2 Anticipation – what can we expect?
1.3 Attention – what should we look for?
2.1 Response (including improvisation) – what must we do?
2.2 Robustness (of response) – how can we ensure completion of the response (without suffering damage)?
2.3 Resourcefulness/rapidity – how can we ensure timely and sufficient response?
3.1 Decision support – how do we support the trade-off between safety and production?
3.2 Redundancy (for support) – how do we compensate for degradation to uphold/maintain critical functions?

The CSFs represent our operationalization of the concept of resilience. The next step was to establish the general issues for each of the CSFs.

2.3.2. General issues

The general issues represent the third level in the method. The initial list of general issues for CSF1 – Risk awareness – is presented in Table 1.

Table 1: General Issues for CSF1 – Risk Awareness

No.	CSF level 2	General issue
1.1	Risk understanding	
1.1.1		System knowledge
1.1.2		Information about risk through e.g. courses & documents
1.1.3		Reporting of incidents, near-misses and accidents
1.1.4		Information about the quality of barriers (technical safety)
1.1.5		Information about the quality of barrier support functions (oper. safety)
1.1.6		Discussion of HSE issues/status in regular meetings
1.1.7		Safety performance matters requested by senior management
1.1.8		Communicating risk/resilience at all levels of the organization
1.2	Anticipation	
1.2.1		Risk/hazard identification
1.2.2		Learn from own experiences & accidents
1.2.3		Learn from other's experiences & accidents
1.3	Attention	
1.3.1		Process disturbances; control and safety system actuations
1.3.2		Bypass of control and safety functions
1.3.3		Activity level/simultaneous operations
1.3.4		Trends in reported events and quality of barriers
1.3.5		Early warnings/weak signals (e.g. from whistle blowers)
1.3.6		Changes; technical, organizational, external (weather, …)
1.3.7		Focus on safety (safety versus other issues)

The final task is to establish indicators for the general issues.

2.3.3. Candidate indicators

The candidate indicators represent the fourth and final level in the method. The candidate indicators for the risk understanding's (1.1) 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 2.

Table 2: Candidate Indicators – examples

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.

3. RESULTS

3.1. The REWI method - overview

The main result is the development of the method itself, the REWI method, from which we can select indicators for implementation and use. The application of the method consists of the following seven main steps:

1. Review the general issues and add new issues if required
2. Assess the importance of the general issues
3. Review the candidate indicators for the most important general issues and propose new indicators
4. Select a manageable set of indicators
5. Specify the selected indicators
6. Implement and use the indicators
7. Review and update the indicator system regularly

In addition we need to perform some preparatory work, such as:

- Defining the system to be monitored and its boundaries
- Defining who is going to use the indicators
- Determining who will attend the workshops
- Determining how many workshops that will be arranged
- Planning the workshops

We will not go into the details of the preparatory work in this paper. The seven main steps are elaborated on in the next section.

3.2. The REWI method steps

3.2.1. Review the general issues

The general issues are fairly generic and applicable to any major hazard industry, but it is important that the general issues are reviewed to ensure that all relevant issues are covered for the specific system/plant/unit in question.

The general issues already included in the method serves an important role as a basis for identifying an as complete as possible list of general issues. It forces the participants to consider all the issues already included; thus, providing a better foundation for the identification of all relevant issues.

New additional issues are added to the existing list of general issues.

3.2.2. Assess the importance of the general issues

A screening process is suggested in which only the most important general issues are considered for the development of indicators. A simple three level assessment has been applied:

Level 1: Most important issues

Level 2: Important issues
Level 3: Less important issues

Only the general issues on level 1 are considered for identification of indicators. However, this initial assessment may be changed in the review and updating in Step 7.

3.2.3. Review the candidate indicators for the most important general issues

A list of candidate indicators exist for the most important general issues prior to the workshops dedicated to the identification of additional indicators. These new indicators are identified in a brainstorming session/workshop on the basis of the existing candidate indicators, and are preferably even more relevant for the specific system/plant/unit in question than the existing candidate indicators.

The main point is not to review or criticize the existing candidate indicators, but to suggest better and more appropriate indicators.

This process may be repeated with new workshops and new user groups/participants as many times as the company in question finds necessary. Often, it is discovered during a workshop that additional expertise is required with respect to a specific issue or a specific indicator.

3.2.4. Select a manageable set of indicators

When the indicators have been processed in a final workshop, i.e., no more general issues or new indicators are added to the list of candidate indicators, a number of indicators have to be selected for implementation and use. This must be a manageable set, and could typically consist of 10-20 indicators in total, depending on whether or not these indicators are the only indicators being used, or if other indicators based on other approaches are added to this set of resilience based indicators.

The selection of a set of indicators also includes the consideration of how to distribute the indicators between the contributing success factors (CSFs) and the general issues.

The initial selection may be changed during the review and updating in Step 7. Some or all of the selected indicators may be replaced at regular reviews.

3.2.5. Specify the selected set of indicators

The indicators selected need to be specified in detail. This includes definition of the specific subject being measured, the measuring period, and the input data required.

3.2.6. Implement and use the indicators

When the selected indicators are specified in sufficient detail, they are ready for implementation and use. Some adjustments in an initial trial period must be expected. This includes the definition of indicators, but also how and whom being responsible for extraction of data, quality assurance of data and presentation of results.

3.2.7. Review and update the indicator system regularly

The indicator's performance will most likely change over time, and it is recommended to review and update the indicator system regularly. New issues and indicators may be identified, either through a regular review or a systematic assessment, e.g., by checking whether accidents or incidents that have occurred are covered by the indicator system.

One reason for change can simply occur due to increased focus on the selected indicators. They may be managed so well, that they no longer work as efficient as desired as early warnings.

The regular reviews and updating will bring in new issues and indicators; thus, continuously improving the indicator system. In this sense it is a living system.

4. DISCUSSION AND CONCLUSION

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 based on other approaches may be included for the final selection of indicators.

The specific method established – the REWI method – was based on certain ideas taken from the LIOH method [3,4] used within the nuclear power industry, but some new features have been included, which is seen as an improvement of the original method. The main differences are:

1. The seven LIOH themes have been replaced by eight contributing success factors that have been empirically tested
2. The general and specific issues in the LIOH method have been replaced by only one level of issues, i.e. general issues
3. A predefined set of general issues exist prior to the workshops with the user groups in the REWI method, whereas the LIOH method starts from scratch without any predefined issues
4. A predefined set of indicators exist for each important general issue prior to the workshops with the user groups in the REWI method, whereas the LIOH method has no predefined indicators

The seven LIOH themes (management commitment; awareness; preparedness; flexibility; just culture; learning culture; transparency) resembles characteristics of resilience, but was developed prior to and as input to the specific approach denoted Resilience Engineering. An extensive literature review of various models of organizational performance in high-reliability organizations contributed to the LIOH framework [3].

The eight contributing success factors (risk understanding; anticipation; attention; response; robustness; resourcefulness/rapidity; decision support; redundancy) are based on a literature study including more recent literature on resilience and Resilience Engineering. In addition, a study was carried out with the specific objective to empirically explore this set of resilience based factors [6]. The study focused on incidents that could have developed into accidents, but were successfully recovered. The study supported the hypothesis that the identified resilience based factors may contribute in terms of successful recovery; they were *contributing success factors* (CSFs).

The REWI method has been simplified compared to the LIOH method by only including one level of issues, i.e. general issues. This was partly based on the results of case studies using the LIOH method in which only one level of issues were applied [3,4], even though the method itself prescribes both general issues and specific (NPP) issues [3].

The LIOH method generates issues during workshops without any other guidance than the seven themes. For the REWI method it is seen as beneficial that all participants in the workshops consider the same base set of general issues, and can use this as an aid in identifying additional issues. Without this aid, it is more likely that some issues are missed simply because nobody identify and raise this issue during the workshops. Furthermore, the predefined structure will help preserve the resilience principles in the final indicator set.

A similar situation is related to the indicators. In the LIOH method there are no predefined candidate indicators, whereas the REWI method includes a set of candidate indicators, which can be used as an aid to trigger ideas for other, and hopefully more appropriate, indicators. As for the general issues, this will ensure that relevant indicators at least are considered, and not left out simply because no one recalled the particular indicator during the workshops.

One may claim that indicator based approaches are inconsistent with fundamental principles of resilience engineering. For instance, the resilience engineering line of thoughts would deny that we can establish valid relationships between measurements (indicators) and the concept they ultimately are supposed to measure: safety. Or in other terms, that models based on hindsight (measured entities) and tabulation can help organizations to increase their safety.

This is a complex discussion that is beyond the scope of this paper. Suffice here to say that a major benefit of developing an early warning indictor system is the process that such activity generates in the organization. Specifically:

- It provides a common language for talking about safety
- It requires the mobilization of resources for monitoring and evaluating safety-relevant activities over time
- It requires a dialogue across departments/units/people on safety issues.

An early warning indicator system will fail to achieve its scope (i.e. facilitating preventive actions) as much as for lack of engagement in the organization developing/using/updating it, as because of intrinsic deficiencies of the indicator set.

The REWI method is first of all a method for establishing a set of early warning indicators for the prevention of accidents. Development of early warning indicators for the production installation on the Goliat field in the Barents Sea are still in progress and further work is necessary to finalize the identification and selection of indicators for this particular installation.

Further work is also necessary in order to investigate to what degree these resilience based indicators are complementary to other safety performance indicators (e.g., [9-11]), for instance whether they provide a more appropriate measure of the ability to 'cope with the unexpected'.

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