SINTEF A22026- Unrestricted

Report

Guideline for implementing the REWI method

Resilience based Early Warning Indicators

Authors
Knut Øien, SINTEF
Salvatore Massaiu, IFE
Ranveig Kviseth Tinmannsvik, SINTEF

SINTEF Technology and Society
Safety Research
2012-03-30

SINTEF Teknologi og samfunn
SINTEF Technology and Society

Address:
Postboks 4760 Sluppen
NO-7465 Trondheim
NORWAY

Telephone:+47 73593000
Telefax:+47 73592896

ts@sintef.no
www.sintef.no
Enterprise /VAT No:
NO 948007029 MVA

SINTEF

SINTEF Teknologi og samfunn
SINTEF Technology and Society

Address:
Postboks 4760 Sluppen
NO-7465 Trondheim
NORWAY

Telephone:+47 73593000
Telefax:+47 73592896

ts@sintef.no
www.sintef.no
Enterprise /VAT No:
NO 948007029 MVA

KEYWORDS:
Safety
Resilience
Indicators

Report

Guideline for implementing the REWI method

Resilience based Early Warning Indicators

VERSION
1.3

DATE
2012-03-30

AUTHORS
Knut Øien, SINTEF
Salvatore Massaiu, IFE
Ranveig Kviseth Tinmannsvik, SINTEF

CLIENTS
The Research Council of Norway
Eni Norge

CLIENT'S REF.
Espen Forsberg Holmstrøm
Liv Nielsen

PROJECT NO.
60S084

NUMBER OF PAGES/APPENDICES:
40

ABSTRACT

Resilience based Early Warning Indicators – the REWI method

This guideline describes how to implement the REWI method, which is a method for establishing safety indicators based on resilience thinking. The concept of resilience is made operational through a set of factors (Contributing Success Factors), for which issues and indicators are identified.

The main REWI method steps are:

1. Establish the organizational arrangements
2. Identify and select the indicators
3. Implement the indicators and interpret the data
4. Review and update the indicator system regularly
5. Integrate REWI indicators with other self assessment initiatives

The goals are to provide early warnings and prevent major accidents, and to improve organizational safety and performance in the long run.

PREPARED BY
Knut Øien

SIGNATURE
Knut Øien

CHECKED BY
Ranveig Kviseth Tinmannsvik

SIGNATURE
Ranveig Kviseth Tinmannsvik

APPROVED BY
Lars Bodsberg

SIGNATURE
Lars Bodsberg

REPORT NO.	**ISBN**	**CLASSIFICATION**	**CLASSIFICATION THIS PAGE**
SINTEF A22026	978-82-14-05479-8	Unrestricted	Unrestricted

SINTEF

Document history

VERSION	DATE	VERSION DESCRIPTION
1	2011-12-22	REWI 2012 Draft
1.1	2012-01-26	REWI 2012 Draft
1.2	2012-03-11	REWI 2012 Draft
1.3	2012-03-30	REWI 2012

* Picture on front page history: Digital art by ME Kozdron called "Resilience – light, bright overtaking darkness with passion!" (www.fineartamerica.com). In our case: Resilience attributes defeating the dark forces generating major accidents.

Table of contents

Foreword

One strategy to avoid major accidents is to be continuously vigilant through the use of indicators. Often, hindsight has shown that if signals or early warnings had been detected and managed in advance, the unwanted event could have been prevented. This includes, e.g., the accident at the Esso natural gas plant in Longford, Australia in 1998, killing two workers (Hopkins, 2000), and the accident at the BP Texas City refinery in 2005, killing 15 workers (Baker et al., 2007). Recognizing signals/early warnings through the use of proactive safety indicators will reduce the risk of such major accidents (Øien et al., 2011).

Resilience refers to the capability of recognizing, adapting to, and coping with the unexpected (Woods, 2006). Thus, resilience based indicators may be an aid in situations of incomplete knowledge about what may go wrong.

The Resilience based Early Warning Indicators (REWI) method is a method to identify, select, implement and use resilience based indicators. This guideline describes how to implement the REWI method.

The REWI method is a contributory based method, meaning that those who will be measuring and/or be measured by the indicators participate actively in the identification and selection of indicators in workshop sessions.

The goals are to provide early warnings to prevent major accidents, and to improve organizational safety and performance in the long run.

SINTEF and IFE have developed the REWI method through several projects, and we would like to acknowledge the following supporting projects:

- Resilience based Safety Management and Monitoring for petroleum exploration and production in the Arctic (ReSMaM)
- Building Safety in Petroleum Exploration and Production in the Northern Regions (Building Safety), http://www.sintef.no/buildingsafety
- Early Recognition, Monitoring and Integrated Management of Emerging, New Technology related Risks (iNTeg-Risk), http://www.integrisk.eu-vri.eu/

This guideline is the REWI 2012 version (March 2012), and it will most likely need regular updating as experience with the implementation and use are gained.

Knut Øien

Knut Øien
Senior Scientist
SINTEF Technology and Society, Safety Research

Part 1: Introduction

The Resilience based Early Warning Indicators (REWI) method is a set of self-assessment measures that provide information to senior managers and safety professionals within an organization about fundamental attributes of organizational resilience. The goals of the method are to provide early warnings to prevent major accidents, and to improve organizational safety and performance in the long run.

The fundamental attributes of resilience covered by the REWI method are called contributing success factors (CSFs) and are: risk understanding, anticipation, attention, response, robustness, resourcefulness/rapidity, decision support and redundancy. For each CSF the REWI method defines a set of general issues contributing to the fulfillment of the goals of the CSF. Measurable indicators are developed for the issues. These three levels of the REWI method are shown in Figure 1.

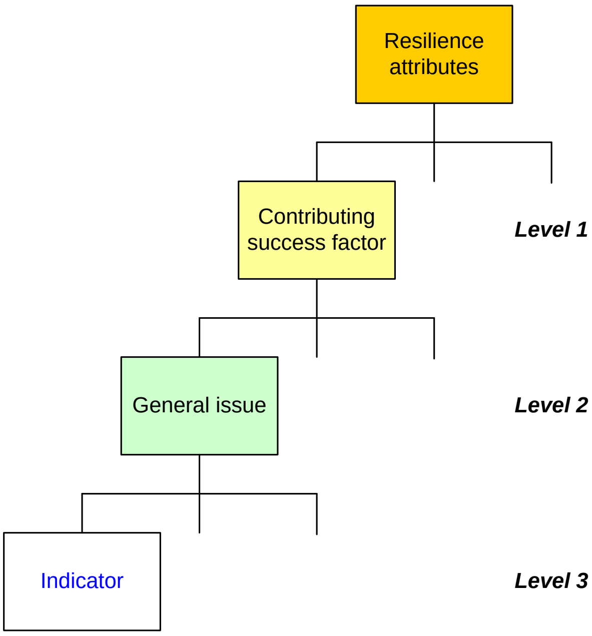


Figure 1 The three levels of the REWI method

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 (Størseth et al., 2009). The general issues and the pre-defined 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 development of the method is based on e.g. the LIOH (Leading Indicators of Organizational Health) method from the nuclear power industry (EPRI, 2000; 2001), and it has used cases from the offshore petroleum industry (Øien et al., 2010). However, the method is generally applicable for any high-hazard industry.

The REWI method includes a predefined set of general issues and its associated candidate indicators for each contributing success factor. However, the method allows new general issues and indicators to be added by the users (Step 2.1 in Figure 2). The predefined set of general issues and sets of candidate indicators is first of all a foundation for the triggering of suitable indicators, which may not be included already. 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 being just random “indicators of the day”. This guarantees that the measurement system stays focused on the fundamental attributes of organizational resilience.

A flowchart of the REWI method is provided in Figure 2. It will be elaborated in more detail in Part 3 of the guideline.

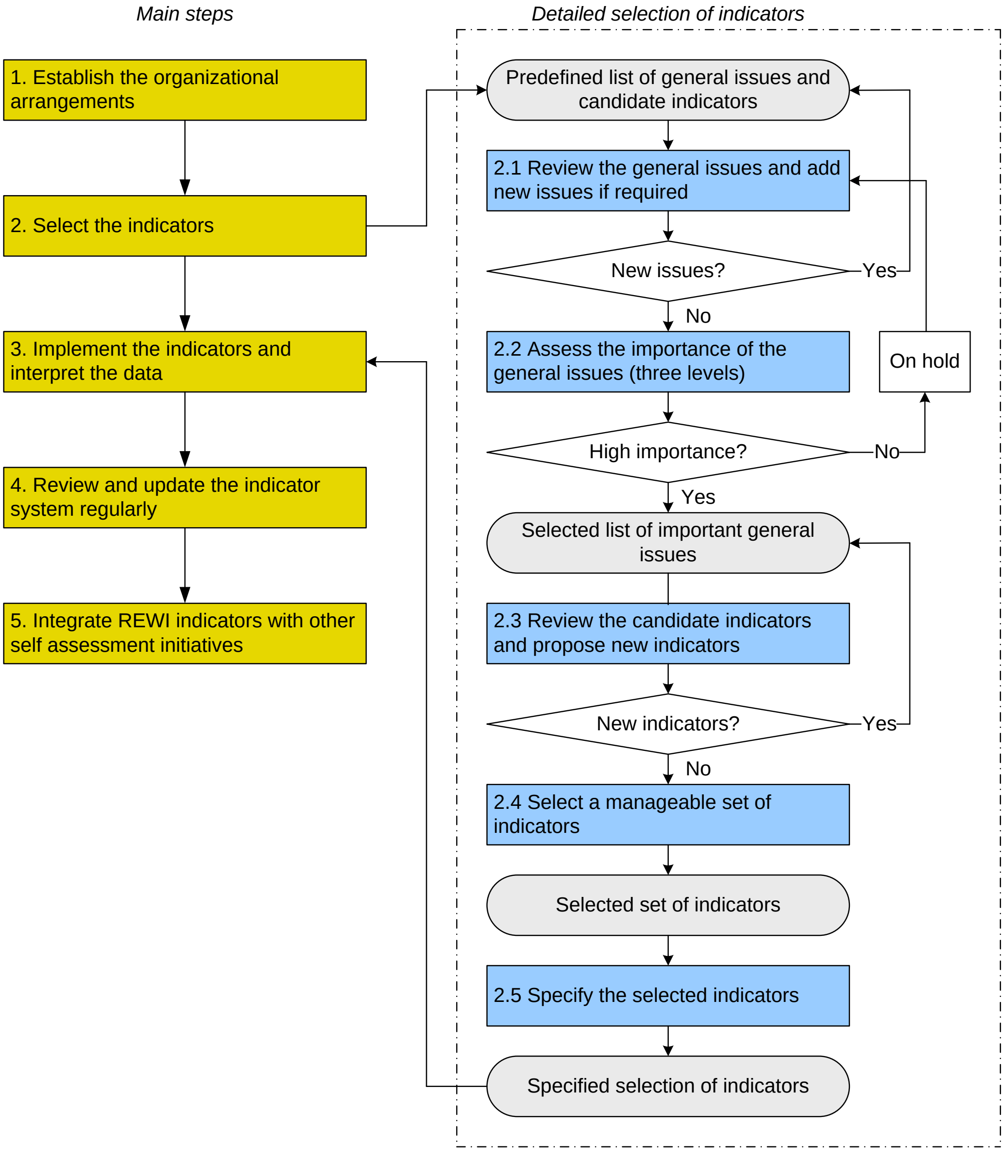


Figure 2 Overview of the REWI method

The overall goal of the method is not simply to collect data, but to improve organizational safety and resilience and thus the organization’s performance in the long run. Dialogue is essential to create a collective sense-making of how the system, plant, or unit can improve with respect to the eight factors of resilience.

Part 2: Contributing success factors (CSFs) – general issues – indicators

Contributing Success Factors (CSFs)

The CSFs are based on some key literature sources (e.g., Woods, 2006; Woods and Wreathall, 2003; and Tierney, 2003), and was tested in an empirical study on successful recovery of high-risk incidents (Størseth et al., 2009). The empirical study supported the selected set of CSFs. The CSFs are shown in Figure 3.

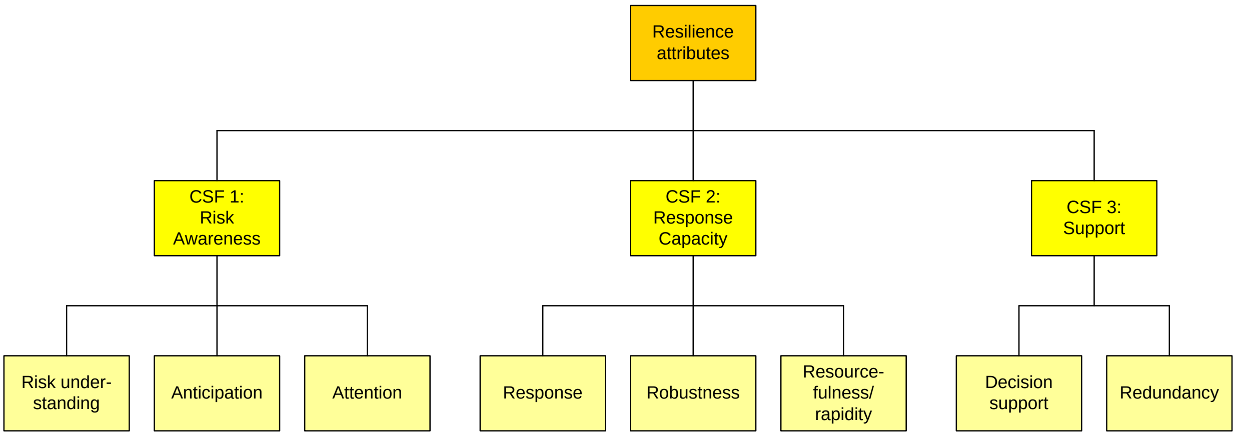


Figure 3 Contributing Success Factors (CSFs)

There are two levels of CSFs; overall and detailed. The CSFs at the overall level are:

1	Risk awareness	Make sure that risk awareness is maintained (avoid under-estimation 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

The CSFs at the detailed 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 level of the method is the general issues connected to each of the CSFs.

General issues

The general issues represent the second level in the method. An overview of the predefined general issues is shown in Figure 4 (green boxes). Descriptions of each of the general issues are provided in Appendix A.

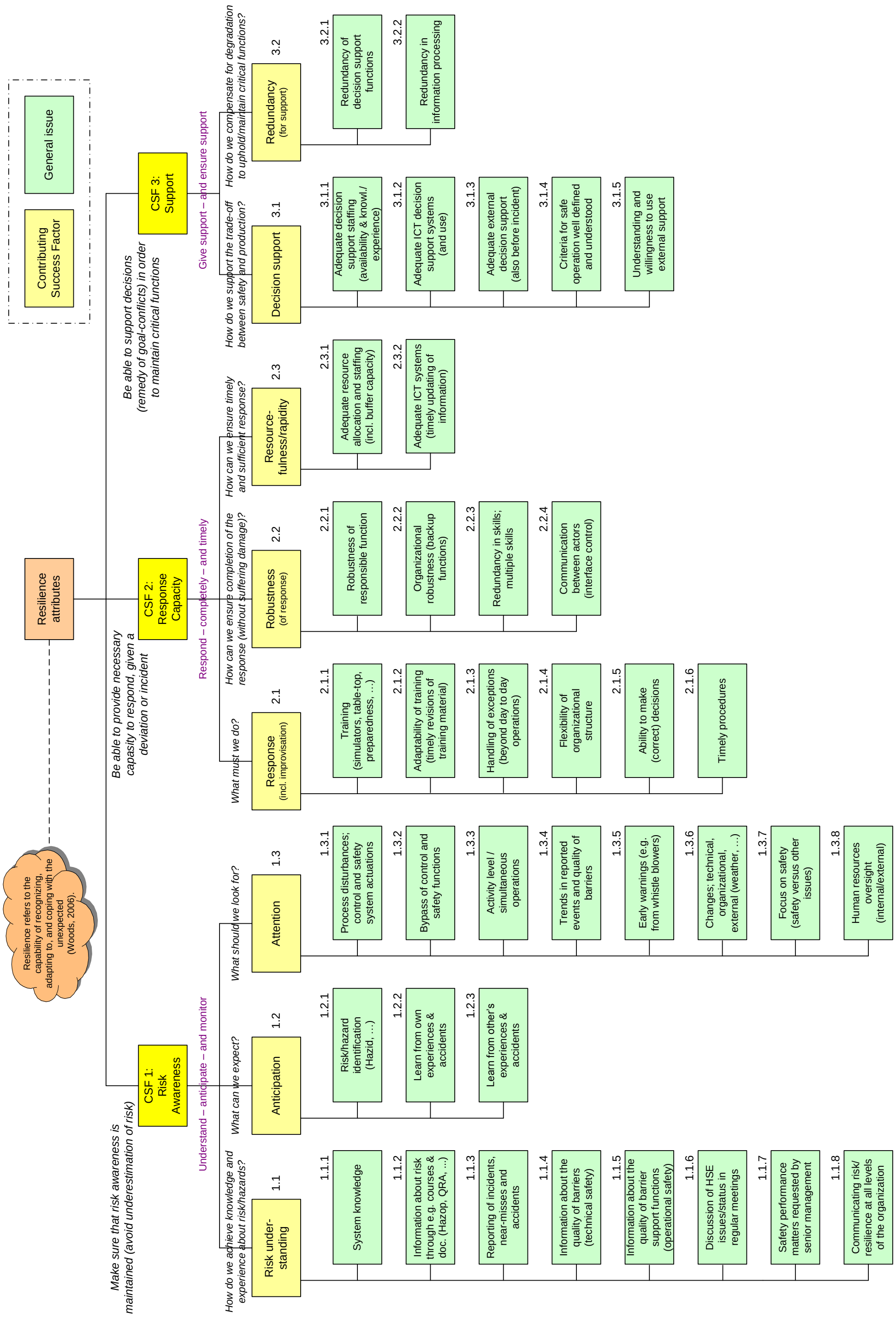


Figure 4 General issues (green boxes) for each CSF (yellow boxes)

Indicators

The indicators represent the final level in the method. The candidate indicators for the CSF 'Risk understanding' (1.1) and the general issues ‘System knowledge’ (1.1.1) and ‘Information about risk through e.g. courses & documents (HAZOP, QRA, etc.)’ (1.1.2) are presented in Table 1. The complete list of the indicators is presented in Appendix B.

Since there are actually two levels of CSFs in the REWI method (and one level of issues), the indicators are numbered using four digits, i.e.:

{CSF overall level, CSF detailed level, general issue, indicator}

Table 1 Candidate Indicators

No.	Name
1	Risk awareness (CSF 1)
1.1	Risk understanding
1.1.1	System knowledge
1.1.1.1	Average no. of years experience with such systems (e.g. offshore production 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)

SJA – Safe Job Analysis; 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 should be selected. This means that we can focus on the most important general issues, and we only need to define in detail the selected indicators.

Part 3: The REWI method steps

The REWI method steps - overview

The method consists of the following five main steps:

1. Establish the organizational arrangements
2. Identify and select the indicators
3. Implement the indicators and interpret the data
4. Review and update the indicator system regularly
5. Integrate REWI indicators with other self assessment initiatives

Table 2 shows the five steps of the REWI method.

Table 2 Overview of the REWI method's five steps

Main steps		Detailed steps
Step 1	Establish the organizational arrangements	1.1 Appoint a project manager
		1.2 Set up the implementation team
		1.3 Convene the team
Step 2	Identify and select the indicators	2.1 Review the general issues • Review predefined issues • Propose additional issues
		2.2 Assess the importance of the general issues
		2.3 Review the candidate indicators for the most important general issues • Review predefined indicators • Propose new more specific/relevant indicators
		2.4 Select a manageable set of indicators
		2.5 Specify the selected set of indicators
Step 3	Implement the indicators and interpret the data	Collect, review and interpret the data. Present results in reports and meetings. Decide on actions required.
Step 4	Review and update the indicator system regularly	Review the set of indicators and evaluate any need for changes/update of the indicator system
Step 5	Integrate REWI indicators with other self assessment initiatives	Integrate REWI findings/actions into already existing corrective action programs

The REWI method steps - details

0. Prerequisites

The initiative to develop and implement REWI indicators must have necessary management commitment.

The scope of the indicators, i.e. the whole organization, a site, a unit or a system, needs to be clear. Some clarifications may need to be sorted out with respect to interfaces with adjacent systems (both physical and administrative systems).

The team tasked with the implementation of the REWI indicators should possess a broad understanding of technical systems, human performance principles, health and safety methods, and organizational and administrative systems used in the organization.

1. Establish the organizational arrangements

Step 1	**Establish the organizational arrangements**	1.1 Appoint a project manager
		1.2 Set up the implementation team
		1.3 Convene the team

1.1 Appoint a project manager

A project manager is needed to promote and introduce the new system. This may be a responsible person from operations or a safety professional within the organization. The project manager must be sure that top managers or senior leaders are in agreement about what the REWI method is intended to do, how it should be done, how long it will take and who is involved. It could be useful to make a business case, i.e. identify the business benefits that can result from improved safety management through resilience based performance indicators ("what does it take and what do we gain").

Having senior managers supporting the initiative will also help in case others in the organization may need to be mobilized and/or appropriate resources have to be made available.

The project manager will be the owner of the indicator system also after the first implementation. Alternatively, this ownership is transferred to another person.

1.2 Set up the implementation team

The project manager (possibly together with a senior manager) set up an implementation team. The team may be independent from existing safety committees and should draw people from different operations, with particular emphasis on employees with direct knowledge of the systems and operations affected by the safety management/risk control systems measured by the indicators.

The team can typically consist of a project manager/facilitator, a secretary and 4-8 participants with diverse background and experience (operations, maintenance, safety, etc.).

An important function of the team is to enable exchange and dissemination of ideas within the organization through the sharing of a common approach to improve organizational safety and resilience (and a "common language" for talking about resilience and learning from success).

1.3 Convene the team

A workshop series or a set of meetings is recommended. As a minimum three to four meetings should be expected (two for the general issues and one or two for the indicators). It is recognized that not everyone will be familiar to concepts of organizational safety indicators and resilience, as well as that people with different backgrounds will look at things differently. Therefore some education may be in order. When everyone is familiarized with safety indicators and resilience, the process of selecting indicators may begin. Experience from other industrial projects has shown that it is not likely to get a perfect set of indicators from the first workshop(-s).

2. Identify and select the indicators

Step 2 Identify and select the indicators	2.1 Review the general issues • Review predefined issues • Propose additional issues
	2.2 Assess the importance of the general issues
	2.3 Review the candidate indicators for the most important general issues • Review predefined indicators • Propose new more specific/relevant indicators
	2.4 Select a manageable set of indicators
	2.5 Specify the selected set of indicators

This second step of the REWI method is a rather comprehensive part of the method, and it is not recommended to carry out all sub-steps in one workshop. As a minimum, it is recommended to have two workshops for the review of the general issues and one or two workshops for the review and selection of the candidate indicators.

2.1 Review the general issues

Once the implementation team has an understanding of the eight contributing success factors, the next step for implementing the REWI method is to review the general issues (see Figure 4 and Appendix A). These 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 or unit in question.

The general issues already included in the method serves an important role as a basis for identifying a 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. Dialogue is a key determinant of the overall process, nonetheless it is important to maintain a structured approach.

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

2.2 Assess the importance of the general issues

A screening process, through a structured brainstorming session, is suggested in which only the most important general issues are considered for the development of indicators. The structured screening should be carried out starting from the left in the themes and issues diagram (see Figure 4), and consider general issues for each CSF at the time (starting from the top of the list of issues).

A simple three level assessment is suggested:

Importance level 1: Most important issues
Importance level 2: Important issues
Importance level 3: Less important issues

The importance is related to the issue's contribution to prevent major accidents, based on the participants' subjective view. The importance level is decided based on a consensus among the participants. It may also be a combination of individual assessments followed by a consensus agreement. An example is illustrated in Appendix C1.

Only the general issues on importance level 1 are considered for identification of indicators. (The identification of indicators for the issues on importance level 2 and 3 are put "on hold".) However, this initial assessment may be changed in the review and updating in Step 4.

This first screening is mostly based on a relative comparison of issues within each separate CSF. The overall importance assessment, comparing across the CSFs, is carried out in a second screening in Step 2.4.

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 (see Table 1 and Appendix B). 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 or unit in question than the existing candidate indicators.

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

This process may be repeated in new workshops and with 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. At this point it is also useful to have an overview of the existing safety performance indicators in the company. (However, in order to facilitate a creative process, it might be useful to have a first discussion about issues and indicators without too much focus on the existing indicators.)

There are some questions that might help in developing indicators for newly identified issues (see also Appendix C2):

- What would tell me that we are doing well (or have problems) with issue 'x'?
- How well (or bad) are we doing with issue 'x'?

Also, existing indicators for other issues might be adapted or might prompt ideas on how to create the new ones.

2.4 Select a manageable set of indicators

When the indicators have been processed, 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, 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.

This constitutes the second screening in which the issues and indicators are compared across the CSFs. An example is illustrated in Appendix C3 and C4. This second screening also allows for the possibility to consider interdependencies between issues/indicators, such that even less important issues may be selected.

The selection of the final set of indicators also includes the consideration of how to distribute the indicators between the contributing success factors (CSFs) and the general issues. Each of the three top-level CSFs should have at least one indicator allocated, to ensure that all resilience dimensions are covered. An example is illustrated in Appendix C5.

As part of the final selection of indicators it should also be logged (for later review and updating) why some issues and indicators are considered more important than others.

Research and experience provide some criteria to judge the best system, plant or unit specific indicators. The indicators should be, e.g.:

- *Valid at face value*. The indicator is easy to understand and relates directly to the issue in question.
- *Objective and reliable*. The value of the indicator can be observed without significant degree of judgment or perception (that could be influenced by political interests).
- *Quantitative*. It is possible to trend the values of the indicator to be aware of changes taking place.
- *Easy to use*. The indicator is compatible to other programs and data gathering efforts may already be taking place. This will reduce cost of data collection.

The initial selection of indicators to be implemented may be changed during the review and updating in Step 4. Some or all of the selected indicators may be replaced at regular reviews. Do not strive to get a perfectly balanced set of indicators from the first workshop(-s). It is far more important to get started, than it is to be overly concerned about the predictive validity of any individual indicator.

2.5 Specify the selected set of indicators

The selected indicators need to be specified in detail. This includes e.g. name, definition, description, data sources, responsible persons, calculation, qualitative evaluation, references, revision date, etc.

The data should be collected approximately monthly in order to provide reasonable quarterly data. Clearly, not all issues will change during a month; however, if there is no change over a long period of time (half a year or a year) it should be considered to remove this or these indicators.

3. Implement the indicators and interpret the data

Step 3	**Implement the indicators and interpret the data**	Collect, review and interpret the data. Present results in reports and meetings. Decide on actions required.

The ultimate goal of the project is not simply to collect data; the goal is to provide early warnings to avoid major accidents and to improve the organization's resilience through structured dialogue and intervention.

When the selected indicators have been specified in sufficient detail, implemented and used, some adjustments in an initial trial period must be expected. This includes definitions of indicators, but also how and who is responsible for extraction of data, quality assurance and presentation format of the results.

One issue that is often raised is whether to use trends or absolute thresholds. The focus should be on trends, at least until enough experience has been gained to suggest robust threshold values.

The collected data has to be translated into meaningful information about current conditions to help finding ways of improvement. Quarterly meetings of the implementation group and senior management should be mandatory. Shorter time frames will not be able to detect changes and will bias toward shortsighted attention.

The project manager should prepare a draft report for the meeting on the REWI data to be followed by a discussion. In preparing this report the project manager should contact persons that have information pertinent to the conditions that will be discussed (e.g. indicators showing *negative trends* on which improvement actions are proposed, or indicators showing *positive trends* on which lessons from success should be learned). Write stories relating to operational issues identified and/or let the subject present them at the meeting. Summarize the performance data in a single sheet by showing the overall, most important trends, possibly with the use of color codes (green, yellow, red) or "smiley/sad faces".

Since interpreting the data is not trivial (e.g. local situations vary) no foregone conclusions can be offered about how to interpret them. The indicators provide first of all a potential "alarm" about the situation, which then needs consideration (analysis) in order to identify both causes and necessary actions.

Some questions might help focusing the project manager initial report and the workshop discussion:

- What changes appear real as opposed to simply being noise in the data?
- Can we account for the changes observed in terms of purposeful changes that we have made? Are there other reasons for the changes? Are we surprised?
- Subjectively, how do the changes in the indicators correlate with changes in overall performance on the REWI issues? What is the story behind the changes observed?

- Is there any relationship among the changes that would indicate that something is going to happen? What might this be? Will we be able to react, and how?
- Overall, are we satisfied with the observed changes? If satisfied, do we want to continue as we are, or do we want to look elsewhere? If less satisfied than expected, do we think it is time to act?

Remember that learning from successes (i.e. positive trends) is equally important as learning from negative trends.

The final step in reviewing the data is deciding if action is required.

The outcome of this step is a document that summarizes the relationships between the CSFs, the system, plant, or unit progress during the evaluation period and any action deemed appropriate. Remember that this document aims at getting the big picture: potential alarms/early warnings and progress with regards to the CSFs, to resilience.

This document (not the database, the numbers, or the charts) is a key outcome of the REWI method.

4. Review and update the indicator system regularly

Step 4 Review and update the indicator system regularly	Review the set of indicators and evaluate any need for changes/update of the indicator system

The REWI indicators (as any other leading indicators) are not static and cannot be subject of straightforward statistical evaluation. REWI indicators are not "cast in stone" but evolve over time. Therefore the indicator's performance will most likely change over time, and it is recommended to review and update the indicator system regularly (e.g. once a year). New issues and indicators may be identified, either through a regular review or a systematic assessment that takes into account changes in current conditions, e.g., by checking whether accidents or incidents that have occurred are covered by the indicator system.

One reason for change in current conditions/safety performance 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. Consider also the collection process by reviewing the indicators for accuracy, reliability, responsiveness and collection costs.

As already mentioned, issues/indicators that do not change (no variation in the data) over a long period of time should be considered removed. Similarly, issues that have been raised as a concern by someone (managers, unions, whistle blowers, etc.) should be considered included for follow-up in the indicator system in order to possibly confirm the concern.

It should also be considered to keep track of the indicators no longer being monitored, including an evaluation to what degree the corresponding issues are attended to in other parts of the safety management system.

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.

5. Integrate REWI indicators with other self assessment initiatives

Step 5	**Integrate REWI indicators with other self assessment initiatives**	Integrate REWI findings/actions into already existing corrective action programs

The REWI method is 'an indicator system' based on resilience theory and Resilience Engineering. 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 quarterly document should be considered part of the company's self assessment and corrective action program. Establishing a place for the REWI method in already existing programs will strengthen its presence.

Epilogue

The eight contributing success factors (risk understanding, anticipation, attention, response, robustness, resourcefulness/rapidity, decision support and redundancy), being the backbone of the method, are based on a literature study including more recent developments in resilience theory and Resilience Engineering.

The goal of the method is to provide early warnings to avoid major accidents and to improve organizational safety and resilience and thus the organization's performance in the long run.

Dialogue is essential to create a collective sense-making supported by data of how the system, plant or unit can improve with respect to the eight factors of resilience. Hence, an important benefit of developing leading indicators is the process that such an activity creates in the organization:

- It provides proactive monitoring and evaluation of safety critical activities over time
- It provides dialogue across departments, units and people on safety issues
- It provides a common language for talking about resilience and learning from success

References

Baker, III J.A., Leveson, N., Bowman, F.L., Priest, S., Erwin, G., Rosenthal, I., Gorton, S., Tebo, P.V., Hendershot, D., Wiegmann, D.A., Wilson, L.D., 2007. The Report of the BP US Refineries Independent Safety Review Panel.

EPRI, 2000. Guidelines for Trial Use of Leading Indicators of Human Performance: The Human Performance Assistance Package. EPRI (U.S. Electric Power Research Institute), Palo Alto, CA, 1000647.

EPRI, 2001. Final report on Leading Indicators of Human Performance. EPRI, Palo Alto, CA, and the U.S. Department of Energy, Washington, DC, 1003033.

Hopkins, A., 2000. Lessons from Longford. The Esso Gas Plant Explosion. CCH Australia Limited, Sydney.

Størseth, F., Tinmannsvik, R.K., Øien, K., 2009. *Building safety by resilient organization – a case specific approach*. Paper at the European Safety and Reliability Association Annual Conference (ESREL), 7 – 10 September, 2009, Prague, Czech Republic.

Tierney, K.J., 2003. Conceptualizing and Measuring Organizational and Community Resilience: Lessons from the Emergency Response Following the September 11, 2001, Attack on the World Trade Center. Disaster Research Center, Preliminary Papers, Nr. 329.

Woods, D.D., 2006. Essential Characteristics of Resilience. In: N. Leveson, E. Hollnagel, and D.D. Woods, Resilience engineering: concepts and precepts. Aldershot: Ashgate, pp. 21 – 34.

Woods, D., Wreathall, J., 2003. Managing Risk Proactively: The Emergence of Resilience Engineering. Columbus, Ohio University.

Øien, K., Massaiu, S., Tinmannsvik, R.K., Størseth, F., 2010. Development of Early Warning Indicators based on Resilience Engineering, PSAM 10. International Probabilistic Safety Assessment and Management Conference, 7 - 11 June 2010, Seattle, USA.

Øien, K., Utne, I.B., Herrera, I.A., 2011. Building Safety indicators: Part 1 – Theoretical foundation. Safety Science, Volume 49, Issue 2, 2011, pages 148-161.

Appendix A – General issues

The candidate general issues are described in Table A1.

Table A1 Candidate General Issues

No.	Name	Description
1	Risk awareness	Make sure that risk awareness is maintained (avoid underestimation of risk); understand – anticipate – monitor
1.1	Risk understanding	How we achieve knowledge and experience about risk/hazards
1.1.1	System knowledge	Knowledge about how the technical systems work and the interactions between systems, and knowledge about design assumptions and operational conditions. This knowledge provides insight in how systems may fail, and the potential consequences.
1.1.2	Information about risk through e.g. courses & doc. (HAZOP, QRA, …)	Risk understanding is enhanced by basic knowledge of the concept of risk, and by specific knowledge about the risk on the particular plant, installation, etc. described in various risk analyses. A certain level of basic knowledge about risk is required in order to utilize the risk analyses information and/or to perform risk analyses.
1.1.3	Reporting of incidents, near-misses and accidents	Information about real incidents and accidents gives knowledge about what have happened in the past, which also provides insight in what may go wrong in the future. An important aspect to measure is also the ability of the organization to elaborate a detailed and in depth description of all the contributing factors and conditions to the incident / accident occurrence so to avoid classic human error justifications.
1.1.4	Information about the quality of barriers (technical safety)	Information about the quality of barriers, e.g. based on test results or real demand, gives knowledge about how well the safe-guards / defences are protecting against accidental events. It provides insight in the technical systems that prevent the development of an accidental event.
1.1.5	Information about the quality of barrier support functions (operational safety)	Information about the quality of barrier support functions, e.g. preventive maintenance, by-passing, etc. including human and organizational elements, gives knowledge about the operational readiness of the safe-guards / defences. It provides insight in the operational support systems contributing to the readiness of the barriers.
1.1.6	Discussion of HSE issues/ status in regular meetings	Exchange and spreading of information about on-going HSE issues in regular meetings enhances risk awareness in the organization. In addition to regular meetings, the following aspects need also to be monitored; existence of HSE dedicated meetings, and inclusiveness of operators and first line managers in those meetings (not exclusively management oriented meetings).
1.1.7	Safety performance requested by senior management	When safety performance is requested by senior management it signals the importance of safety in general and the specific issues that are addressed in particular. It enhances the awareness of the importance of safety in the organization. Safety performance metrics (number, variety, detailed level, etc.) requested by senior management reflect also the level of importance given to safety aspects.
1.1.8	Communicating risk/ resilience at all levels of the organization	To obtain widespread risk awareness in the organization it is important that information about risk and resilience are properly communicated at all levels in the organization. This can be obtained through various channels, e.g. meetings, safety alerts, bulletins, etc. In order to be easily accessible to all levels in the organization common terms should be used as far as possible (i.e. reduce the use of specialized risk/resilience terminology).
1.2	Anticipation	What we can expect
1.2.1	Risk/hazard identification (HAZID, …)	Systematic risk/hazard identification is a prerequisite in order to anticipate what may go wrong. It expands on the repertoire of incidents/accidents that have been experienced.
1.2.2	Learn from own experiences & accidents	The most obvious source of information on what may go wrong (and how to treat such situations) is the experience from incidents and accidents in own

No.	Name	Description
		organization. It is a particular obligation to any organization to avoid the reoccurrence of events. Learning from success stories, e.g. "what went right", should also be included.
1.2.3	Learn from other's experience & accidents	The manifestation of potential events in real occurrences constitutes only a small percentage of the potential events. Therefore, it is important to learn as much as possible also from other's incidents and accidents. Today's accessibility of information makes organizational borders no excuse for learning from outside own organization. Learning from success stories, e.g. "what went right", should also be included.
1.3	Attention	What we should look for
1.3.1	Process disturbances; control and safety system actuations	Any process disturbance, in particular those leading to the actuation of control and/or safety systems, should be paid attention to since they may represent the initiation of accidental events.
1.3.2	Bypass of control and safety functions	If control and safety functions are bypassed, i.e. disabled, then these barriers provide false security. The safe-guards / defences are made ineffective against accidental events through these by-passes, and it is important to have full knowledge and overview, and keep track of any by-passes in the barrier systems.
1.3.3	Activity level/ simultaneous operations	The possibility that something goes wrong increases with the activity level in general and with simultaneous operations in particular. Unexpected interactions between activities can increase the accident risk. Thus, it is important to be particularly vigilant in periods with high activity / high number of simultaneous operations. (High activity may also be caused by absence of resources/personnel).
1.3.4	Trends in reported events and quality of barriers	Increase in reported events or negative development in the quality of barriers (including barrier performance influencing factors) are clear indications of the need to take action to remedy the situation.
1.3.5	Early warnings (e.g. from whistle blowers)	Early warnings provide information about potentially deteriorating safety before this is manifested in usual trends. It provides an opportunity to be proactive and take action at an early stage.
1.3.6	Changes; technical, organizational, external (weather, …)	Any changes, whether they are deliberate or not, may cause unintentional effects on safety. Close attention should be paid to changes with respect to potential negative effects.
1.3.7	Focus on safety (safety versus other issues)	Safety is often claimed to be first priority. This should also be reflected in the proportion of attention given to safety (e.g. in decision-making) compared to other issues such as production and economy.
1.3.8	Human resources oversight (internal/external)	Attention should not only focus on safety systems and factors directly affecting risk, but also on more remote factors such as human resources both within own organisation and external human resources.
2	Response capacity	Be able to provide necessary capacity to respond, given a deviation or incident; respond – completely – timely
2.1	Response (incl. improvisation)	What we must do
2.1.1	Training (simulators, table-top, preparedness, …)	Training on how to deal with potential scenarios is essential in order to know what to do, not only with respect to identical or similar scenarios as trained on, but also with respect to response to other (unexpected) scenarios. This includes the use of simulators, table-top exercises, emergency preparedness drills, etc.
2.1.2	Adaptability of training (timely revisions of training material)	The repertoire of training scenarios should be reviewed and adapted regularly based on experience from own and other's accidents, and the training material updated accordingly. The training should cover a sufficiently broad spectre of scenarios.
2.1.3	Handling of exceptions (beyond day to day operations)	The handling of exceptions provides hands-on experience in how to respond. Such exceptions may be experienced during commissioning and start-up of operations. Thus, it is valuable to have access to personnel with experience from commissioning and start-up, in addition to personnel experienced in the handling of exceptions during normal operation.

SINTEF

No.	Name	Description
2.1.4	Flexibility of organizational structure	The organization handling disturbances, incidents and emergency situations should be clearly recognized by all personnel. The transformation from normal operation to an emergency situation and back to normal operation should be clearly defined and trained for. The organization also needs to be flexible and able to adapt to the development of the situation, including substitution of injured or otherwise inaccessible personnel.
2.1.5	Ability to make (correct) decisions	Authority, support and training in making critical decisions, including decisions with potentially large economical effects.
2.1.6	Timely procedures	Response should also cover the capacity to provide relevant operational procedures in a timely manner, even if the situation may call for updated or new procedures on a short time notice.
2.2	Robustness (of response)	How we can ensure completion of the response (without suffering damage)
2.2.1	Robustness of responsible function	Endurance of critical functions to complete the response. This includes personnel in charge of critical tasks as well as the upholding of critical infrastructure systems (e.g. main safety functions).
2.2.2	Organizational robustness (backup functions)	Even if single persons are unavailable for some reason the critical functions should be ensured through pre-planned back-up, e.g. by deputies given the same training as the main responsible persons.
2.2.3	Redundancy in skills; multiple skills	Redundancy in skills and multiple skills provide the organization with means to back-up critical functions. This goes beyond what is foreseen or pre-planned.
2.2.4	Communication between actors (interface control)	Response is often dependent on information from other actors. It is essential that the (local) information and communication systems are available throughout the duration of the situation until control has been regained. The information itself needs to be understandable for all actors involved (including use of common language).
2.3	Resourcefulness/rapidity	How we can ensure timely and sufficient response
2.3.1	Adequate resource allocation and staffing (incl. buffer capacity)	Sufficient number of persons attending to critical functions, including back-up personnel in case of additional needs, unavailability of personnel or exchange of personnel. Duty schemes enabling adequate mobilization to provide timely response are needed.
2.3.2	Adequate ICT systems (timely updating of information)	Timely response requires timely updating of necessary information about the situation and the need to communicate this between the involved actors.
3	Support	Be able to support decisions (remedy of goal-conflicts) in order to maintain critical functions; give support – ensure support
3.1	Decision support	How we support the trade-off between safety and production
3.1.1	Adequate decision support staffing (availability & knowledge/ experience)	Adequate decision support staffing, either locally or remotely, implies staffing being available when required with necessary knowledge, experience and authority to provide/suggest decisions/actions. This may also concern goal-conflicts.
3.1.2	Adequate ICT decision support systems	Decision support requires adequate (remote) ICT decision support systems in place. This also includes adequate support for the ICT systems themselves, i.e. availability of ICT personnel. It is crucial to avoid breakdown or malfunction of these systems during a critical situation.
3.1.3	Adequate external decision support	A situation may require the support from outside own organization. Thus, the necessary external support, including accompanying ICT systems, must be available when required.
3.1.4	Criteria for safe operation well defined and understood	In order to understand when support is needed it is necessary that the criteria for safe operation is well defined and understood.
3.1.5	Understanding and willingness to use external support	Even if external support is available, those who should seek such support must be able to understand that they have such a need, and be willing to consult external resources.
3.2	Redundancy (for support)	How we compensate for degradation to uphold/maintain critical functions
3.2.1	Redundancy of decision support functions	Critical decision support functions, internal and external, should be redundant to ensure availability of support.

No.	Name	Description
3.2.2	Redundancy in information processing	Critical information systems should be redundant to ensure information flow necessary for decision support.

Appendix B – Indicators

The candidate indicators are listed in Table B1.

Table B1 Candidate Indicators

No.	Name
1	Risk awareness (CSF 1)
1.1	Risk understanding
1.1.1	System knowledge
1.1.1.1	Average no. of years experience with such systems (e.g. offshore production 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)
1.1.4	Information about the quality of barriers (technical safety)
1.1.4.1	Average availability of critical safety systems last 3 months
1.1.4.2	No. of red faces/traffic lights in the 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 (operational 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 the management system)
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	Discussion 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

No.	Name
1.1.7	Safety performance 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 management 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
1.2	Anticipation
1.2.1	Risk/hazard identification (HAZID, …)
1.2.1.1	Portion of operating personnel participated in (general) HAZID
1.2.1.2	Portion of affected personnel participated in HAZID for specific operation
1.2.1.3	Fraction of SJAs checked by independent person
1.2.1.4	Fraction of operational procedures that have been risk assessed
1.2.2	Learn from own experiences & accidents
1.2.2.1	(On hold)
1.2.2.2	(On hold)
1.2.2.3	(On hold)
1.2.3	Learn from other's experience & accidents
1.2.3.1	(On hold)
1.2.3.2	(On hold)
1.2.3.3	(On hold)
1.3	Attention
1.3.1	Process disturbances; control and safety system actuations
1.3.1.1	Average no. of persons monitoring the relevant control panels continuously
1.3.1.2	No. of alarms not acknowledged within 1 min during last month
1.3.1.3	No. of alarms disabled (without acknowledgment) during last month
1.3.2	Bypass of control and safety functions
1.3.2.1	Maximum no. of control and safety functions in bypass during last month
1.3.2.2	Maximum no. of control and safety functions in bypass to the next shift
1.3.2.3	No. of visual inspections of real or not suspended bypasses during last month
1.3.2.4	No. of unauthorized bypasses/overrides during last 3 months
1.3.3	Activity level/ simultaneous operations
1.3.3.1	Maximum no. of simultaneous operations last month
1.3.3.2	Maximum no. of work permits issued in the same time period last month
1.3.3.3	Maximum no. of hot work permits issued in the same time period last month
1.3.3.4	Total no. of hot work permits issued last month
1.3.3.5	No. of instances where hot work permissions have been checked against QRA
1.3.4	Trends in reported events and quality of barriers
1.3.4.1	(On hold)
1.3.4.2	(On hold)
1.3.4.3	(On hold)
1.3.5	Early warnings (e.g. from whistle blowers)
1.3.5.1	(On hold)
1.3.5.2	(On hold)
1.3.5.3	(On hold)

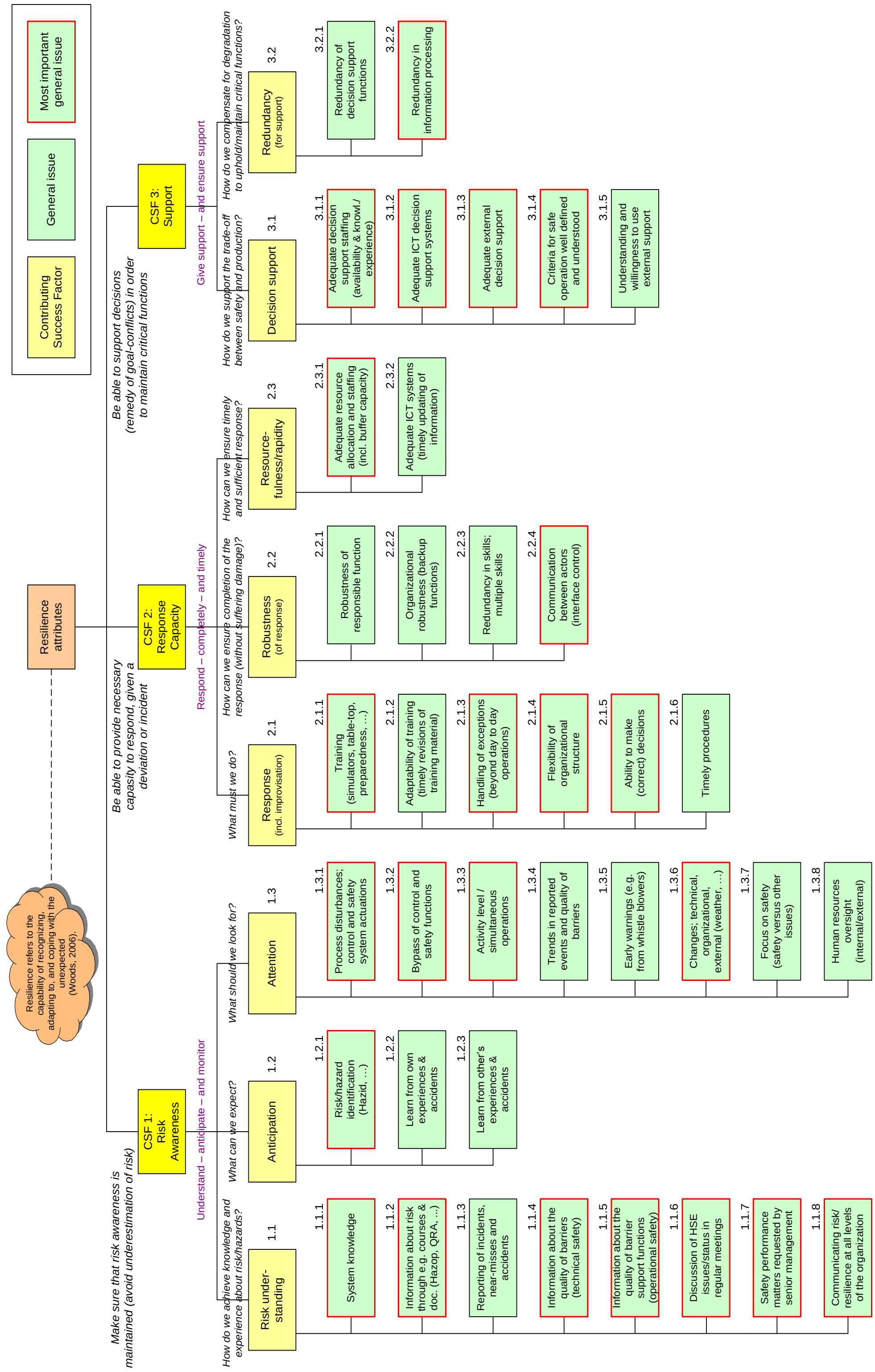
No.	Name
1.3.6	Changes; technical, organizational, external (weather, …)
1.3.6.1	No. of changes/modifications of technical equipment last month
1.3.6.2	No. of changes in process capacity last month
1.3.6.3	No. of organizational changes last 3 months
1.3.6.4	No. of instances where weather restrictions have been exceeded last month
1.3.6.5	Portion of decision processes not involving required functions
1.3.7	Focus on safety (safety versus other issues)
1.3.7.1	Fraction of action reports containing safety performance components
1.3.7.2	(On hold)
1.3.7.3	(On hold)
1.3.8	Human resources oversight (internal/external)
1.3.8.1	(On hold)
1.3.8.2	(On hold)
2	Response capacity (CSF 2)
2.1	Response (incl. improvisation)
2.1.1	Training (simulators, table-top, preparedness, …)
2.1.1.1	Average no. of exercises completed by operating personnel each month
2.1.1.2	No. of hours simulator training in total for operating personnel each month
2.1.1.3	No. of emergency preparedness exercises last three months
2.1.1.4	No. of different accident scenarios included in exercises last month
2.1.1.5	No. of hours IO training in total for relevant personnel last month
2.1.1.6	Fraction of SJAs included operator simulator practice/check
2.1.1.7	Fraction of work processes/procedures verified/tested in simulators
2.1.1.8	No. of process simulations of critical events last month
2.1.2	Adaptability of training (timely revisions of training material)
2.1.2.1	(On hold)
2.1.2.2	(On hold)
2.1.3	Handling of exceptions (beyond day to day operations)
2.1.3.1	No. of exceptions handled by operating personnel last month
2.1.3.2	(On hold)
2.1.3.3	(On hold)
2.1.4	Flexibility of organizational structure
2.1.4.1	Fraction of team-based responses to problems
2.1.4.2	Fraction of workers who are cross-trained
2.1.4.3	No. of cases with incorrect use/distribution of roles and responsibilities
2.1.4.4	Response time for selected critical actions
2.1.4.5	Fraction of responses that have led to organizational changes
2.1.4.6	No. of cases/responses in which experts have not been alerted or too late
2.1.5	Ability to make (correct) decisions
2.1.5.1	No. of cases in which a decision to respond has been delayed last three months
2.1.5.2	Average no. of available support functions/contacts during critical decisions
2.1.5.3	No. of exercises in which team performance has been suboptimal
2.1.6	Timely procedures
2.1.6.1	(On hold)
2.1.6.2	(On hold)
2.2	Robustness (of response)
2.2.1	Robustness of responsible function
2.2.1.1	(On hold)
2.2.1.2	(On hold)

No.	Name
2.2.2	Organizational robustness (backup functions)
2.2.2.1	(On hold)
2.2.2.2	(On hold)
2.2.3	Redundancy in skills; multiple skills
2.2.3.1	(On hold)
2.2.3.2	(On hold)
2.2.4	Communication between actors (interface control)
2.2.4.1	No. of cases in which communication between actors has been inadequate
2.2.4.2	Fraction of none native speaking personnel
2.3	Resourcefulness/rapidity
2.3.1	Adequate resource allocation and staffing (incl. buffer capacity)
2.3.1.1	Amount of overtime worked
2.3.1.2	No. of cases in which the response has been initiated too late last 3 months
2.3.1.3	No. of cases in which resources/staffing have been inadequate last 3 months
2.3.1.4	No. of responses closed in time last 3 months
2.3.1.5	Fraction of responses closed in time where the deadline has been extended
2.3.1.6	No. of cases where responses/actions have been transferred to next shift
2.3.1.7	No. of open action points at the end of each month
2.3.1.8	No. of occasions with deviation from the staffing plan during last 3 months
2.3.2	Adequate ICT systems (timely updating of information)
2.3.2.1	(On hold)
2.3.2.2	(On hold)
3	Support (CSF 3)
3.1	Decision support
3.1.1	Adequate decision support staffing (availability & knowledge/ experience)
3.1.1.1	Average no. of in-house persons available 24/7 last month
3.1.1.2	Total no. of positions available for decision support at end of each month
3.1.1.3	Portion of in-house support personnel practiced offshore last 6 months
3.1.1.4	No. of cases with inadequate decision support from onshore last 3 months
3.1.2	Adequate ICT decision support systems
3.1.2.1	Response time for critical ICT systems
3.1.2.2	No. of times critical ICT systems have failed or are inoperable/down
3.1.2.3	(On hold)
3.1.3	Adequate external decision support
3.1.3.1	Average no. of external experts available 24/7 last month
3.1.3.2	Total no. of positions available for decision support at end of each month
3.1.3.3	No. of cases with inadequate support/advice from external experts last 3 months
3.1.4	Criteria for safe operation well defined and understood
3.1.4.1	No. of criteria challenged during exercises last 3 months
3.1.4.2	No. of instances where criteria for safe operation have been exceeded last 3 M.
3.1.4.3	No. of simulations where criteria for safe operation have been exceeded
3.1.4.4	Fraction of simulations where operators have tolerated exceeding the criteria
3.1.5	Understanding and willingness to use external support
3.1.5.1	(On hold)
3.1.5.2	(On hold)
3.2	Redundancy (for support)
3.2.1	Redundancy of decision support functions
3.2.1.1	(On hold)
3.2.1.2	(On hold)

No.	Name
3.2.2	Redundancy in information processing
3.2.2.1	Availability of independent alternative communication channels
3.2.2.2	Average no. of tests or demands of the alternative communication channels
3.2.2.3	Portion of support decisions checked/verified by independent experts

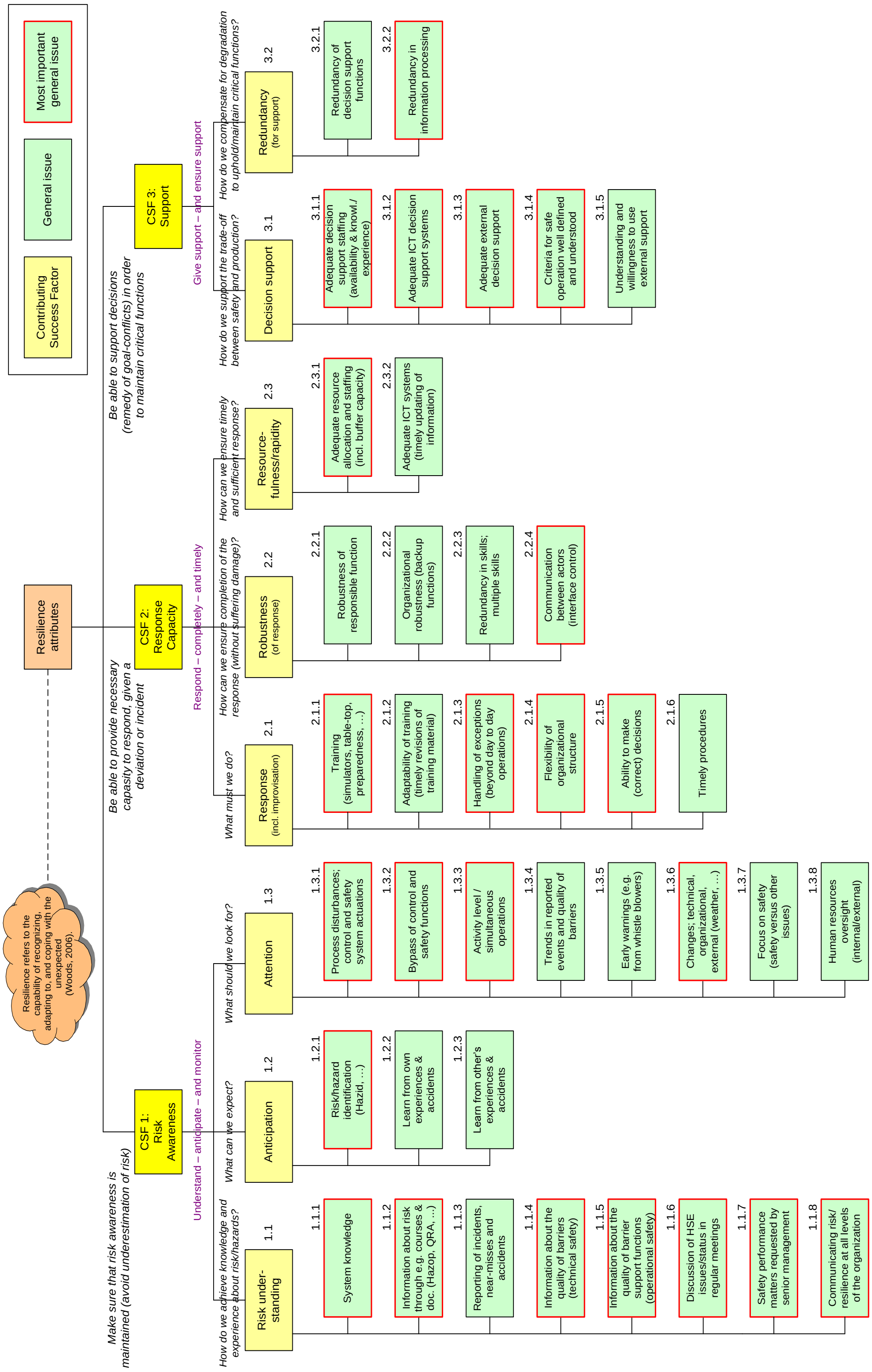
Appendix C – Illustration of selected method steps

C1 – Step 2.2: Assess the importance of the general issues

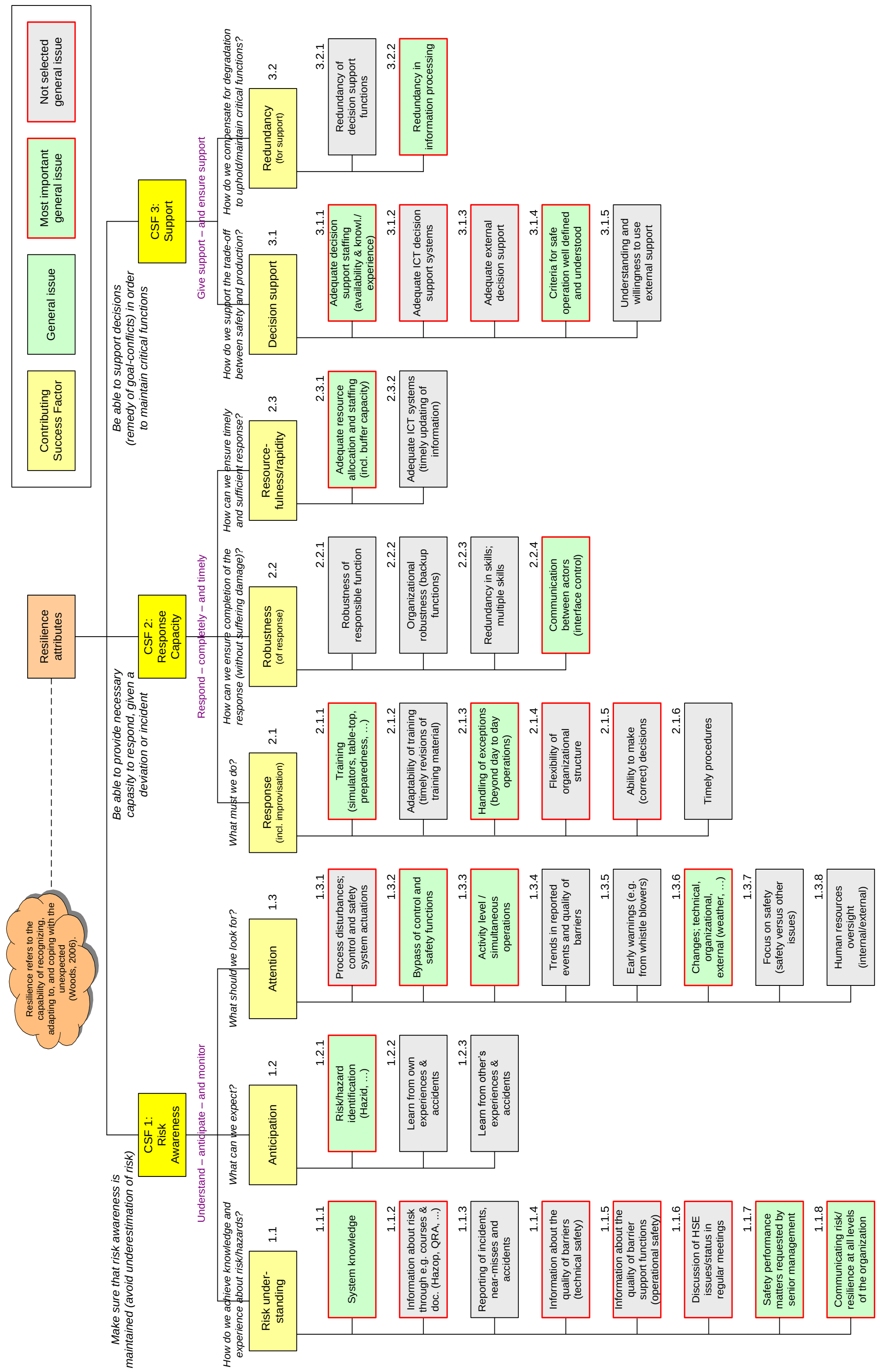


C2 – Step 2.3: Review candidate indicators for important general issues

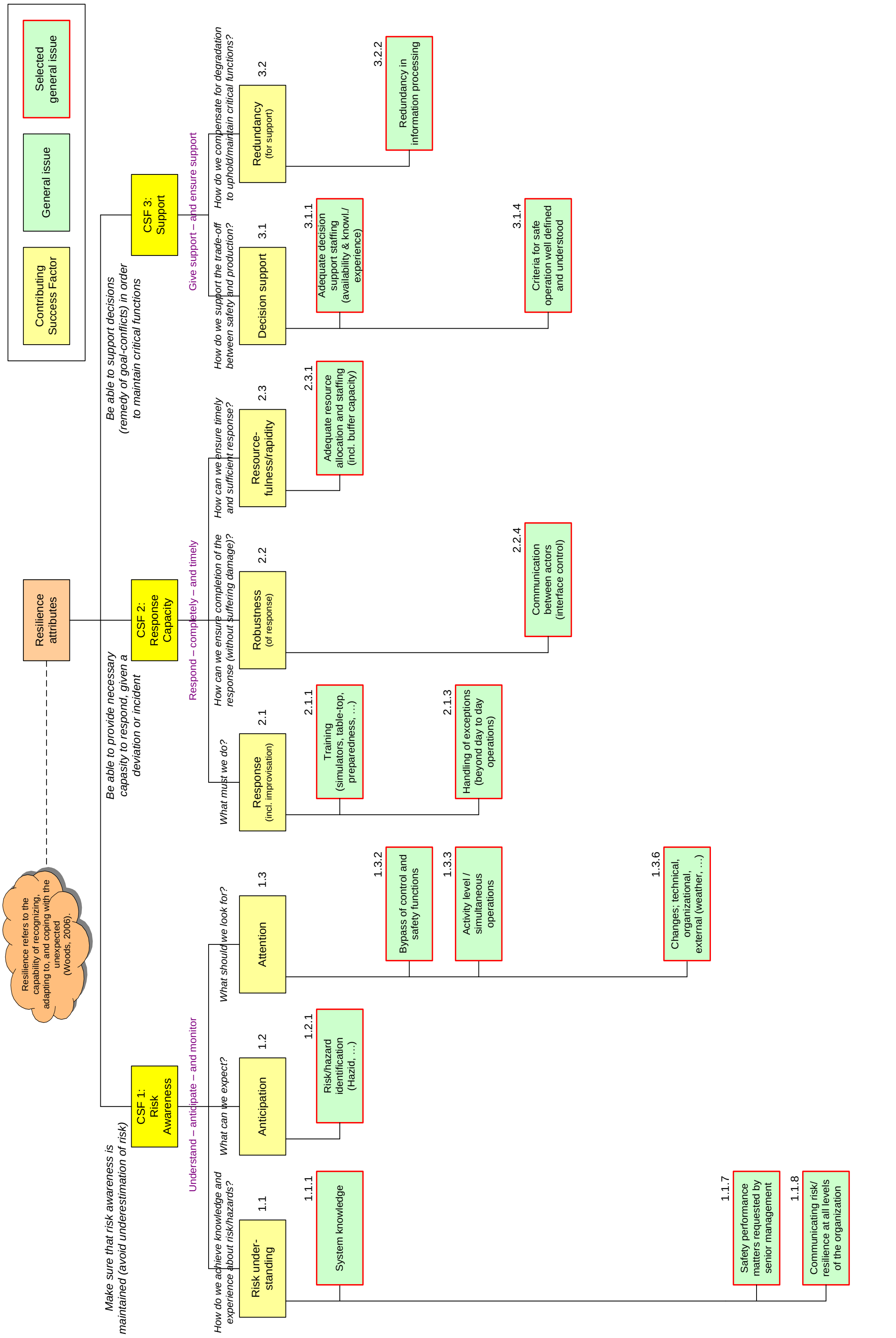
- What would tell me that we are doing well (or have problems) with this issue?
- How well (or bad) are we doing with this issue?



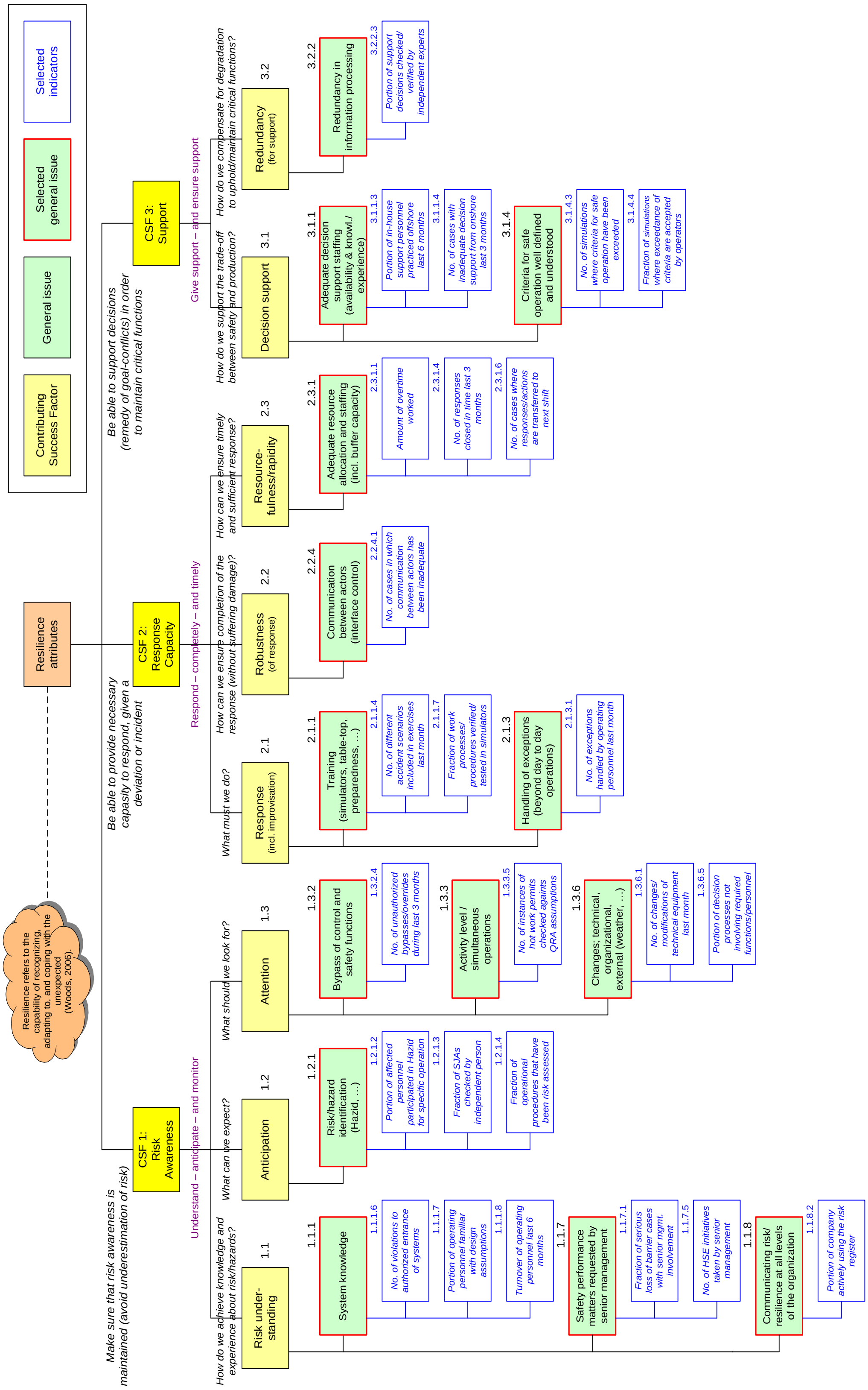
C3 – Step 2.4a: Select the most important issues (second screening)



C4 – Step 2.4a: Select the most important issues (continued)



C5 – Step 2.4b: Select indicators for the most important issues - overview



SINTEF

Technology for a better society

www.sintef.no