SAFETY SCIENCE Monitor

Issue 2 2010 VOL 14

Article 6

RESILIENT RECOVERY FACTORS: EXPLORATIVE STUDY

FRED STØRSETH
SINTEF Technology and Society, Safety Research, Trondheim, Norway Phone: +47 735 93 582, Fax: +47 735 92 896, e-mail: fred.storseth@sintef.no (corresponding author)

EIRIK ALBRECHTSEN
SINTEF Technology and Society, Safety Research, Trondheim, Norway

MAREN HELENE RØ EITRHEIM
IFE Institute for Energy Technology, Industrial Psychology, Halden, Norway

ABSTRACT

The present study was aimed at exploring how elements of resilience could contribute to early recovery of high risk incidents. Based on theoretical studies of resilience, Resilience Engineering and improvisation, a specific operationalization of resilience is suggested to explore the dynamics involved in successful recovery. The aim of the study was to explore how a set of resilience based 'Contributing Success Factors' (CSFs) could contribute to early successful recovery of high-risk incidents in development. Three resilience based factors were hypothesized (each with sub-dimensions): Risk awareness, Response capacity, and Support. The paper reports a first empirical testing, performed by means of in-depth research interviews regarding recovery of high-risk incidents in the offshore petroleum industry. Each interview was centered on one specific case of successful recovery: 'the rig sectioning incident', 'the piping system incident', and 'the simultaneous operations incident'. The results revealed that although each case had their own unique path of scenario development, they shared an interesting common feature in terms of being short of elements that resilience prescribes. Based on these case-based interviews the potential contribution of the resilience based CSFs are discussed. It is argued that the CSF operationalization of resilience appear promising, both for studying cases that has happened (post hoc analysis), and as part of a proactive effort to expose implicated risk hubs in new scenarios, e.g.. consequences of new technology and new ways of organizing work.

Key words: improvisation, incidents, offshore petroleum industry, Resilience Engineering, risk, successful recovery.

1. INTRODUCTION

Ideas revolving around the concept of resilience have solid momentum in current safety science and management. Resilience is a rather loose term in that it holds a variety of theories and definitions. There is however no doubt in that resilience as debated within safety science is heavily flavored by the Resilience Engineering (RE) approach (e.g. Hollnagel and Woods, 2006). According to Erik Hollnagel and colleagues, resilience refers to the ability of a system to adjust its functioning, 'prior to or following changes and disturbances, so that it can sustain operations even after a major mishap or in the presence of continuous stress. Resilience is therefore both reactive and proactive' (http://www.resilience-engineering.org/faq2.htm). The aim of the current study was to focus primarily on the reactive part of resilience by asking: how does resilience come into play during successful recovery of incidents? *Incidents* are here defined as situations of loss of hazard control in a system, resulting in a potential for hazard exposure of personnel, environment and material assets (Kjellén, 2000). The paper reports how a set of resilience based 'Contributing Success Factors (CSFs) were operationalized and explored in terms of their possible contribution to early recovery of incidents in development. Although the operationalization of resilience includes elements from RE (Hollnagel et al., 2006), the resilience factors as suggested here are based on theoretical studies that are broader than RE as such, including additional interpretations of resilience as well as elements from improvisation theory.

Looking at incidents is by no means a novelty in safety work. Reporting and analyzing incidents have been part of the remedial tool box for quite some time. It is also well recognized that there are lessons learned to be found in incidents and near-miss cases. It is however also acknowledged that there are challenges attached to this approach. Here, the inescapable aspects of blame and liability enter the safety equation with full force. The possibility of ending up as the scapegoat is a real threat for establishing a culture willing to report and reveal errors, mishaps, near-misses and incidents. In addition to the justified fear of finger-pointing, another challenge to focusing on incidents is the almost pre-programmed feeling of relief when "nothing serious happened". As "nothing happened", these cases seldom receive the attention and scrutiny that are given to accidents. This is in line with the response sets of accidents. According to Hale (1997), incidents are typically met with the same response set as accidents, although in a less traumatic form: (1) the hunt for scapegoats, (2) the wish to understand what happened, and (3) the want to learn from what happened as it must never happen again. For incidents, there is often a forth response as well: (4) the feeling of relief that nothing worse occurred, trying to forget it fast, and moving on. With this last response in domination, the possibilities of lessons learned are lost.

Acknowledging the importance of safeguarding against this forth response, the intention of the current study was to look into the processes of incidents that were successfully recovered.

The study explored how a set of predefined factors could be "mapped on" to cases of successful recovery. The study can be thought of as a first, explorative validation of a set of factors assumed to be contributory in a risk scenario of successful recovery. The factors were intended to mirror key elements from the theoretical contributions pertaining to resilience. In psychology, the term resilience refers to a characteristic of the individual. A resilient individual manages to cope with severe strain and stress. In psychological terms then, resilience refers to an ability to both endure and "bounce back from" strain. Similarly, a resilient organization can be thought of as a system that possesses stress tolerance abilities. According to Hollnagel (2006), "the essence of resilience is (…) the intrinsic ability of an organization (system) to maintain or regain a dynamically stable state, which allows it to continue operations after a major mishap and / or in the presence of a continuous stress" (Hollnagel 2006, page 16). In other words, the resilient organization is able to both endure and *successfully recover* from severe strain. RE is literally 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).

Based on theoretical studies and literature reviews of resilience and RE contributions, a set of contributory variables were identified. The theoretical basis for these variables is presented in the following.

The underestimation of risks is a significant factor in producing drift towards failure. Accordingly, making sure that risk awareness is maintained when facing high pressure situations is an important stepping stone for an organization to become resilient (Woods and Wreathall, 2003). Adaptation is an important element in RE. The capacity to adjust and adapt comprises knowledge in terms of Anticipation (what to expect), Attention (what to look for), and Response (what to do). These three elements (A-A-R) are not positioned such that anticipation precedes competence, which in turn precedes response. Rather, all three should be continuously applied and kept active. This constant alertness is made possible by a constant updating of knowledge, competence, and resources (Hollnagel and Woods, 2006). Based on the above, the following variables were hypothesized as potential contributors for successful recovery: *Risk understanding; Anticipation; Attention; Response.*

In relation to the adaptation process of A-A-R, it was interesting to look into how aspects of *improvisation* would tie in with these three elements. Improvisation quickly becomes a controversial topic in scientific contexts, perhaps even more so in a safety context. Be that as it may, it is here to be argued that improvisation is embedded in the resilience approach. In RE a resilient system is characterized with watchfulness towards the constantly changing environment. This attention is related to any act / operation, i.e. anywhere in the system (organization) where actions and decisions are taken. This alertness describes certain abilities in terms of performance.

Adaptation (A-A-R) is a clear example here. The process of A-A-R is dynamic, intertwined and ongoing. Furthermore, it suggests the handling of exceptions beyond day to day routine operation. Considering the resilience focus on constant change, the need for this flexible coping ability is ever more evident. In other words, adaptation is a necessary means to face and cope with change and unexpected events. Adaptation (A-A-R) denotes being ready for the next surprise. As this preparedness represents a way to meet unexpected (non-routine) situations, the handling / response may well also be outside of procedure. In other words, the process of adaptation includes aspects of improvisation.

During (safety) critical events, improvisation may be crucial for a response operation as a way to complement and compensate for insufficient automatic security systems and unsuitable or lacking procedures (Cunha, Cunha, and Kamoche, 2002; Mendonça and Beroggi, 2003; Mendonça and Fiedrich, 2006). Mendonça and Fiedrich (2003, page 350) define improvisation as: …"a combined behavioural and cognitive activity that requires serial creativity under tight time constraint in order to meet performance objectives." The adaptation process in the RE framework suggests a level of creativity that enables the agent to both foresee and be aware of unexpected occurrences. This element of creativity is reminiscent of the capacity to improvise. Also, the response in the adaptation process (A-A-R), implies that both skills and creativity are matched on a level that enables the agent to "let go", to move outside of the procedure box; to improvise. Furthermore, as the elements in adaptation (A-A-R) are viewed as continuously active; they are simultaneously active elements of coping. The emphasis on thinking, interpretation, and action (response) as tightly tied activities is close to Cunha et al.'s description of improvisation as "thinking in action" (Cunha et al., 2002). In this line of reasoning, the current study hypothesized that improvisational aspects are embedded in the resilience adaptation process of A-A-R: *Improvisation is part of the adaptation process (A-A-R).*

The resilient organization has established support systems. That is, when faced with the tough decisions, some kind of (decision) help ought to be institutionalized and part of practice. Support in relation to what Woods and Wreathall (2003) called "sacrifice judgments" illustrates this point. According to Woods and Wreathall, a resilient organization must have a practice of decision support related to the production / safety trade-offs. Specifically, this implies that there must be specific guidance for when to reduce or stop production in order to reduce risk. These kinds of "sacrifice judgments" (i.e. when production demands are sacrificed to maintain necessary safety standards) must be supported (Woods and Wreathall, 2003). *Decision support* was thus hypothesized as a contributor for successful recovery.

Tierney (2003, page 2) defines resilience as "the capacity for both physical and social systems to withstand forces and demands generated by disaster events (e.g., earthquakes, hurricanes, human induced events) and to adequately cope with such events through employing effective response and recovery strategies". Both physical and social aspects of resilience can be further specified as being comprised of *robustness*, i.e. ability to withstand stress / demands without suffering damage, degradation or loss of function; *redundancy*, i.e. the extent to which elements, systems, and other units of analysis exist that meet functional requirements in the face of disruption, degradation, or loss of functionality; *resourcefulness*, i.e. capacity to identify problems, establish priorities and mobilize resources to avoid or cope with damage or disturbance; and *rapidity*, i.e. capacity to meet priorities and achieving goals in time (Tierney, 2003). Accordingly, these variables were hypothesized as recovery contributors: *Robustness; Redundancy; Resourcefulness / rapidity*[1]

Having identified a set of contributory variables, the next step involved categorizing the variables into a hypothesized dimensional or factor structure. This classification process emulates the initial steps of a confirmatory factor analysis, i.e. predefining theoretically generated dimensions. However, the focus in the current study was to explore how these operationalized resilience elements could be mapped on to recovery cases.

2. RESILIENT RECOVERY FACTORS

Based on meaning, the resilience elements were classified into a structure of three dimensions, or Contributing Success Factors (CSFs) for incident recovery and prevention. See Table 1.

[1] As Resourcefulness and Rapidity both revolves around the ability to prioritize they were collapsed into one hypothesized variable.

Table 1
Hypothesized set of Contributing Success Factors for recovery and prevention of incidents (CSF's)

CSF1 Risk Awareness
Risk understanding (CSF1.1): Knowledge / competence to identify something as a risk. Risk understanding is thus the composite of experience and knowledge that risk perceptions are based upon.

Anticipation[1] *(CSF1.2):* Knowledge in terms of what to expect related to future developments, threats and opportunities

Attention[1] *(CSF1.3):* Knowledge in terms of what to look for, monitoring what is or can become a threat or an opportunity in the near term.
CSF2 Response capacity
Response[1] (CSF2.1): Knowing what to do – how to respond to regular or irregular disturbances either by a planed set of responses or by adapting normal functioning to the situation

Robustness[2] (CSF2.2): Ability to withstand stress / demands without suffering damage, degradation or loss of function.

Resourcefulness / rapidity[2] *(CSF2.3):* Capacity to identify problems, establish and meet priorities, mobilize resources to avoid or cope with damage or disturbance; and achieving goals in time.

CSF3 Support
Decision support[3] (CSF3.1): For an organization to be resilient there must be a practice of decision support; e.g. related to production/safety trade-offs, this involves guidance for when to reduce or stop production in order to reduce risk. These kinds of "sacrifice judgments" (when production demands are sacrificed to maintain necessary safety standards) must be supported.

Redundancy[2] (CSF3.2): The extents to which elements, systems, and other units of analysis exist that meet functional requirements in the face of disruption, degradation, or loss of functionality. Human resources and organizational redundancy falls into this category.

[1]Based on Hollnagel and Woods, 2006.
[2]Based on Tierney, 2003.
[3]Based on Woods and Wreathall, 2003.

Looking at content and meaning of the CSFs and their respective sub-dimensions, it is obvious that they can be interpreted as "muddled blend" of premises, functions and abilities.

For instance, what is CSF 1.1 Risk understanding referring to? Is it a kind of premise embedded in the system, which allows its members to understand risk? Is it an established system function, handled by its players? Or is it the actual knowledge of an individual worker, or group of workers? It is here to be argued that each question can be answered with "yes". In other words, the CSFs are operationalized in a way that prepares for examining different organizational layers, levels, and focal points. Another CSF example illustrates this logic: CSF 2.2 Robustness. This may well trigger associations in the direction of individual stress tolerance; e.g. the individuals' ability to handle demanding experiences. However, the robustness theme may equally pertain to some overall organizational robustness or stress tolerance, i.e. more as a premise or function.

It is here to be argued that the rationale for this approach is at core of the resilience idea. A hallmark of the resilience idea is the interplay and interchange between different system (organizational) layers, levels, and focal points. The notion of a resilient organization is based on a set of premises that suggest both intra- and inter-layer dynamics within an organization. Based on this argumentation, the CSFs are not specified in terms of what analysis level they are defined on; i.e. individual, group, or organizational level.

The hypothesized CSFs were applied to explore how resilience attributes could contribute to early successful recovery of high-risk incidents in development.

3. METHOD

3.1 Participants and research design

Two pilot interviews were carried out as a preliminary test of examining recovered incidents. The interviewees, both male, had long experience from the petroleum industry. The results of the pilot interviews served as input for the interview guides for the main study. The interviews had an open structure, as the primary aim was to explore how it would work out to gain information regarding incidents in 'real time', i.e. during the interview. The pilot interviews were executed as telephone interviews (approximately 1 hour each). The interviewees were invited to participate based on their industry experience. The interviews were performed in February 2008.

The main study consisted of six research interviews. Six interview candidates were selected based on recommendation. The candidates were contacted and invited to participate by the oil and gas company that had recommended them. In the invitation, the candidates were informed about the study and asked to prepare for the interview by recollecting experiences involving incidents with successful recovery. All six candidates accepted the invitation and agreed to participate. The interviewees were all male, each with relevant background from the petroleum industry, ranging from the late 1960s up until today. Their experiences covered a wide range of the petroleum industry, from offshore operational work to onshore top management.

The study was designed as a three-part research interview: The *first* part was open in form. There was no structure or guideline beyond attaining an understanding of the interviewees working experiences and history within the industry, as well as discussing incidents. The interviewees were asked to identify one incident they had experience were successful recovery had occurred. The *second* part of the interview was designed to pursue the successful recovery incident identified by the interviewee in the first part in more detail. This more focused part of the interview was centered on mapping out the sequence of the incident as it happened; as well as identifying key actors that were involved. This was attained by plotting the incident in a STEP-diagram (Sequential Timed Events Plotting (Hendrick and Benner, 1987) in collaboration with the respondent. Details on the STEP-methodology and how it was applied are presented in a separate section below). In the *third* part of the interview, the interviewees were asked structured questions from a CSF questions battery that was developed specifically for this study. The interviews were administrated by two researchers, with one focusing on the interview / dialogue, the other on taking notes. In addition, a doctorate candidate with observatory status was present. Interviews were set up with a maximum of 2 hours per interview. The interviews were executed in May 2008. The current study is based on the results of three of these interviews.

The interviewees had close relation with the described incidents as they had been part of the sequence of incident either as an operator discovering the event and/or handling the incident or as a line manager close to the incident. For case no.1 (rig sectioning, happening in 1990) presented in the next session, the interviewee was part of the operation department at the installation as an operation superintendent. As a part of the operating team at the installation, the interviewee closely followed the progress of the incident. The second case (piping system incident, happened in 1999), the interviewee explaining this incident was part of the commissioning group that became aware of and handled the incident. The interviewee describing case no. 3 (simultaneous operations incident in 2004) was the offshore field manager for the installation the incident happened at plus two other installations at the same field, thus following the incident closely All interviewees had long experience in offshore operation at different installations and fields.

The incidents could have been explained differently by other actors involved in the incident at different part or levels of the organizations. For example, for case no1, the view of the interviewee is of course biased from the perspective of the operation team; the causal chain could have been explained differently by an actor from the project organization involved in the same incident. However, the objective of the interviews was not to get a precise, correct picture of the incidents, but to shed light on factors contributing to successful recovery. The aim was to explore how a set of predefined factors can be mapped to cases of successful recovery as a first explorative validation of this set of factors.

3.2 The CSF questions battery

For the structured part of the interview, a questions battery for the CSFs was developed. See Table 2.

Table 2
Contributing Success Factors Questions battery

CSF1 RISK AWARENESS

1.1 Risk understanding
1.1.1 How do you perceive risks in these kinds of incidents? (before, during, after)
1.1.2 What triggers risk awareness in these scenarios?
1.1.3 At what stage is risk assessed in such incidents?
1.1.4 How do such incidents affect subsequent assessment of risk?

1.2 Anticipation (knowing what to expect)
1.2.1 In the given event, did you know what to expect?
1.2.2 How do you consider the relevance of experience from previous incidents or training scenarios?

1.3 Attention (knowing what to look for)
1.3.1 In the given event, did you know what to look for?
1.3.2 How did the event correspond to relevant procedures?

CSF2 RESPONSE CAPACITY

2.1 Response (knowing what to do)
2.1.1 In the given event, did you know what to do?
2.1.2 To what extent were overall emergency principles applied?
2.1.3 How did you manage to approximately continue normal operations when responding to the event?

2.2 Robustness
2.2.1 How do you experience these kinds of incidents? (Key words: stress, fear, worry).

2.3 Resourcefulness/rapidity
2.3.1 How would you rate your ability / capacity to handle these kinds of incidents?
2.3.2 How do you rate your (organisation's) capacity to recombine previous experiences and knowledge to handle unexpected incidents?
2.3.3 How do you rate your (organisation's) capacity to adapt existing procedures on the spot?
2.3.4 How do you rate your teams'/organisation's ability to attune individual actions?
2.3.5 How would you rate your capacity to prioritize during these kinds of incidents?
2.3.6 Are there any conflicts in terms of how / what you should prioritize during such incidents?

CF3 SUPPORT

3.1 Decision support
3.1.1 How does the management/onshore provide decision support during / in relation to such incidents?

3.2 Redundancy
3.1.1 To what extent is it an overlap in terms of competence, tasks, and responsibilities (related to these kinds of incidents)?
How do you rate the willingness to:
3.2.1 Exchange information?
3.2.2 Give feedback?
3.2.3 Reconsider decisions made by yourself / others?
3.2.4 Intervene to recover erroneous actions?

3.3 STEP methodology

STEP (Sequentially Timed Events Plotting) was developed as an accident investigation method (see Hendrick and Benner, 1987). The method involves the detailed mapping out of a scenario (accident) by plotting the sequence of events / activities in a diagram. See Figure 1.

Successful recovery - figures

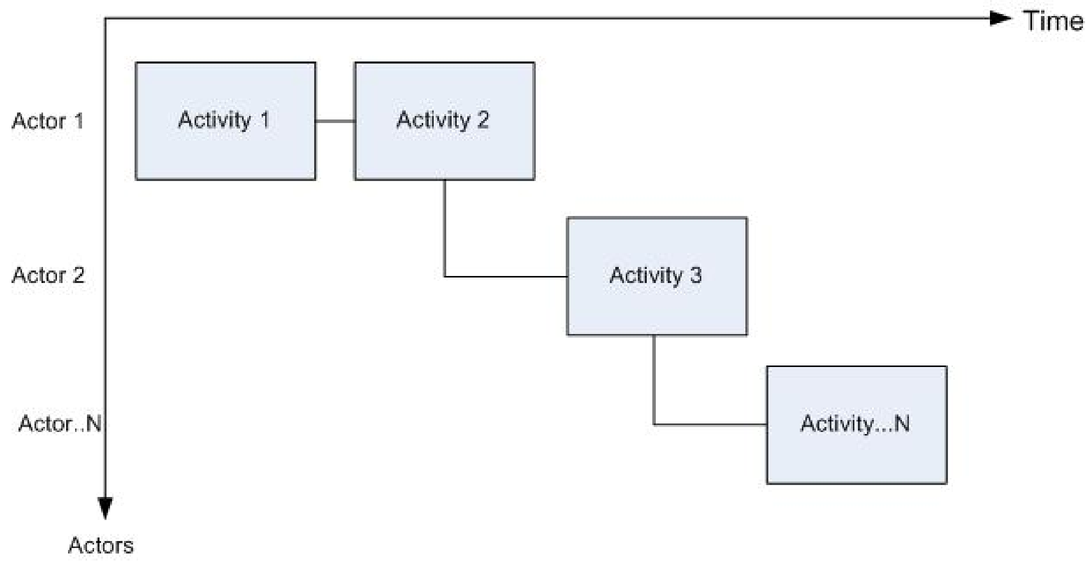

Fig. 1. Illustration of the STEP-diagram

Each actor is plotted vertically and is given one line within the STEP-model of which the activities are plotted sequentially. *Actor* in these respects is not restricted to being a person; it can be a technological aspect or some other item that in some way plays a part in the unfolding of the scenario. The horizontal line in the model indicates time. The lines connecting the activity boxes indicate the flow of activities.

It should be noted that a complete STEP-analysis was not performed in this case study. A comprehensive STEP analysis would comprise a more detailed investigation, e.g. regarding the lines / arrows that connect the activities, as well as identifying important safety problems for the given scenario. This was however not the purpose in the current study. Rather, the STEP methodology was used as a support tool for establishing a sufficient understanding of the incident at hand. Also, by developing the model in collaboration with the interviewee, we were able to attain an immediate quality control of our rendition of the incident.

4. RESULTS

Three cases are reported, each describing scenarios played out on offshore installations; each with an inherent potential of developing into a serious accident. The first case is referred to as the *rig sectioning incident*. Here, a consultancy company was hired to assist in finding suitable solutions for the necessary system upgrading for the installation. The second case is called the *piping system incident*, and refers to a situation of pressure shocks in the piping system on an offshore rig. The third case is called the *simultaneous operations incident*, and describes a scenario in which simultaneous work being performed without one being aware of the other.

The results are presented case by case, by means of (i) a case description, (ii) a STEP-diagram of the scenario development, and (iii) a results table from the CSFs questions battery.

4.1 Case 1: Rig sectioning incident

An offshore installation had a FAR-value (Fatal Accident Rate) assessed as too high. An extensive project was therefore initiated in order to reduce the FAR. The objective was to section the installation in order to reduce the release of oil and gas. The sectioning involved installing a number of valves; a system change that altered the shut down routines of the rig. A consultancy company was hired to find a suitable technical solution. A preliminary project was initiated in which the technical design was specified. The project was then implemented (this was coordinated with a maintenance stop). The work started approximately 6 months after project initiation and involved system upgrading, installation of valves, and implementation of data technical solutions.

During work, it was noticed that there were enormous amounts of hot work class A (welding) in certain areas of the rig. Welding habitats were not established (as one would do today). Hot work was being performed in classified areas - during production. The development division had limited offshore hot rig experience. The operational organization felt left out, and not heard by the development division. There was also a pressure from the production CEO. At this point, the operational organization was both pressured and seen as somewhat difficult. The operational organization explicitly stated that hot work class A had to be limited, and that components had to be prefabricated in secure areas. This was met with a “no” that was explained by the fact that this would slow down the project progression. The project came to a 3 week revision stop (in order to change valves and work on the control system). During restart after the revision stop, several system malfunctions were identified: Extremely high pressure on wrong places, valves that shut down / did not shut down on the wrong places, and a lot of banging noises. The control system was basically out of control. The operators repeatedly attempted to start up the system; but the malfunctioning ultimately made the operators refuse further attempts. The platform was shut down for 3 more weeks, with high pressure in tanks and separators that should not have any pressure. Trouble shooting (by the development division, consultancy company, and operational organization) identified that wrong valves were placed in wrong places. It was also established that the control system was designed by use of an erroneous logic.

Outcome: Old parts had to be retrieved from the garbage disposal (due to long delivery time for new parts). Case 1 is illustrated in Figure 2.

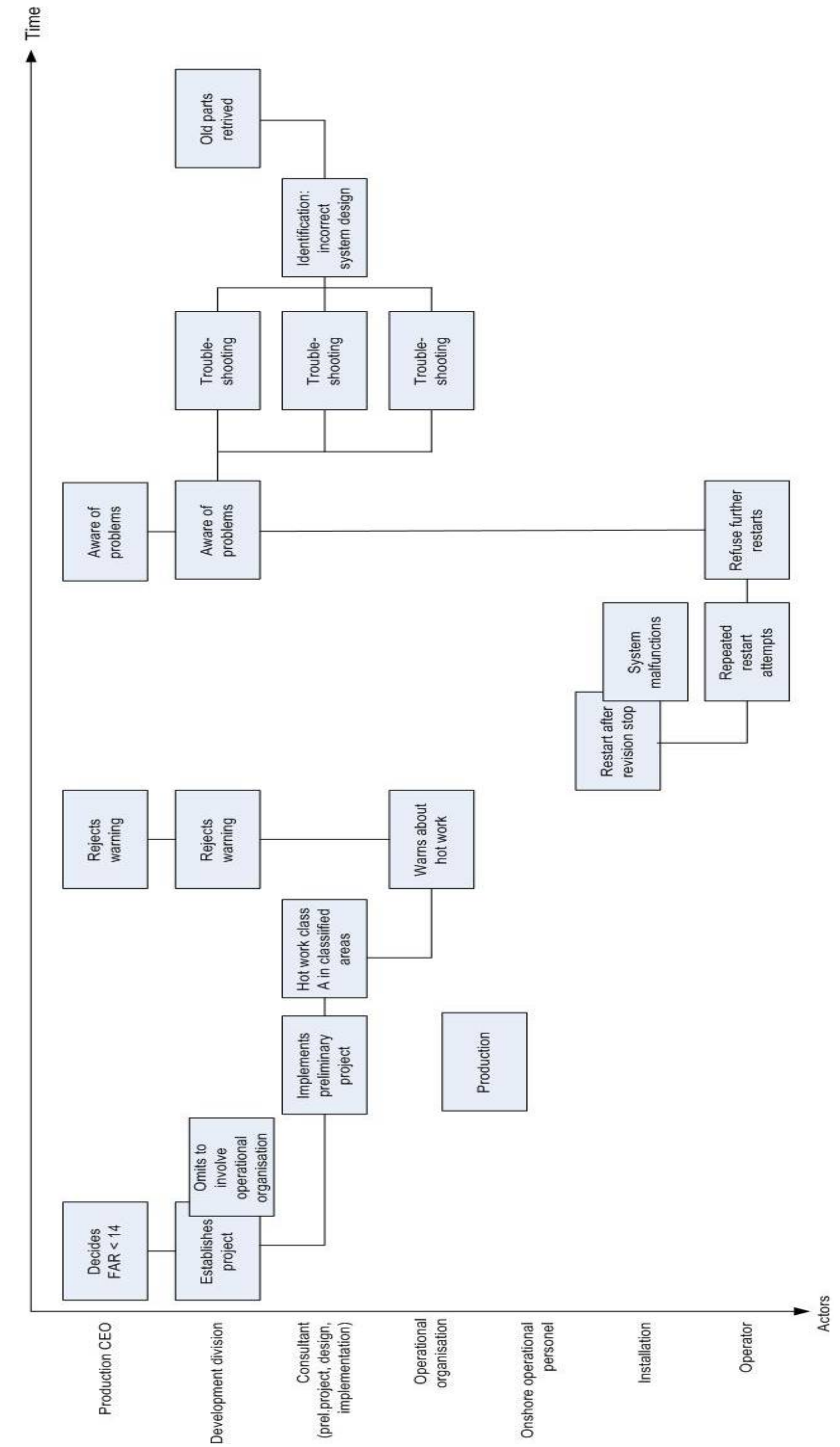

Fig. 2. Sequential model of Case 1 (rig sectioning incident)

Table 3
Case 1: Rig sectioning incident

CSF's and components	Yes	No	Explanatory info. from the interview
CSF1 Risk Awareness			
1.1 Risk understanding		X	Offshore personnel were left out of the design phase.
1.2 Anticipation		X	Could not anticipate, but became aware of problems when project started.
1.3 Attention		X	Things took more time, parts were returned onshore because they did not fit.
CSF2 Response Capacity			
2.1 Response (knowing what to do)		X	Although the need for action was recognized by the operational organization, this view was not shared by the superiors.
2.2 Robustness		X	A feeling of slow torture and constant anxiety. Relief when leaving the rig
2.3 Resourcefulness/rapidity		X	High risk and processes that continues over long time. Begin to feel alone due to the fact that no one seems to listen.
CSF3 Support			
3.1 Decision support		X	Totally absent.
3.2 Redundancy		X	Operational organization offshore was not to any extent involved in the project, or in any position to intervene or stop the work. There was a lack of knowledge of working offshore; and a lack of mutual understanding between different parties in the project.

4.2 Case 2: Piping system incident

Water in the piping system of an offshore installation had to be replaced to maintain corrosion protection. In order to save time due to a delay, a decision was made by a subsea group to use oil instead of water. Using oil would save time as it would be easier to start up again after replacing the water.

When the commissioning group started up the hot water system, they detected a high pressure in the riser[2], which is another system than the piping system the commissioning group was operating. Because of the high riser pressure, some system components had to be dismantled; and due to this, high pressure in the piping system was detected. There were periodical pressure shocks in the piping system. Operating personnel in the commissioning group were aware that the situation was developing into a critical incident. Something needed to be done fast. Recovery was attained by expanding the valves to release pressure. See Figure 3.

[2] In the Schlumberger Oilfield Glossary, riser is defined as: "A large-diameter pipe that connects the subsea BOP (blowout preventer) stack to a floating surface rig to take mud returns to the surface. Without the riser, the mud would simply spill out of the top of the stack onto the seafloor. The riser might be loosely considered a temporary extension of the wellbore to the surface". See: http://www.glossary.oilfield.slb.com/search.cfm

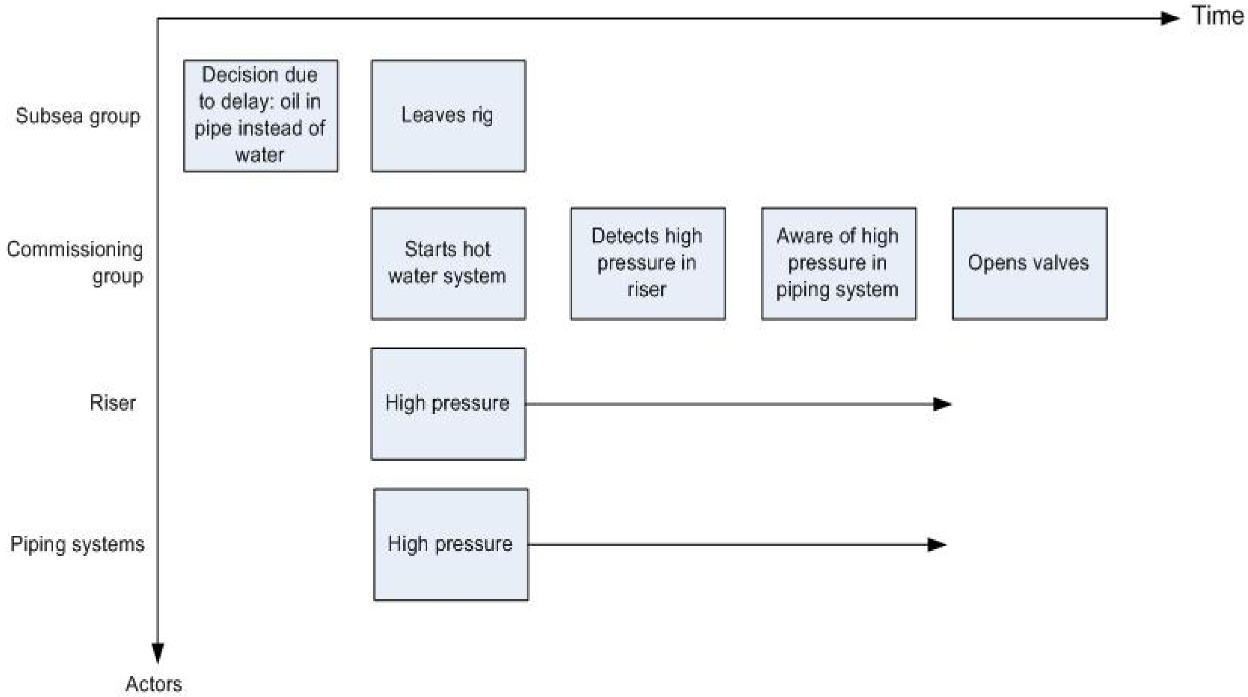

Fig. 3. Sequential model of Case 2 (piping system incident)

Table 4
Case 2: Piping system incident

CSF's and components	Yes	No	Explanatory info. from the interview
CSF1 Risk Awareness			
1.1 Risk understanding		X	Risk awareness was triggered (by coincident) by detection of pressure in another system (the riser).
1.2 Anticipation		X	It should have been possible to consider the chance of occurrence
1.3 Attention		X	Focus was on other operations / new equipment.
CSF2 Response Capacity			
2.1 Response (knowing what to do)	X		Interviewee refers that, although they did not know what to do when the pressure came, they trusted themselves and what they knew. That is the recovery focus.
2.2 Robustness	X		Interviewee refers that he rarely had had that kind of shiver/rush through his body. (But) not in a negative way, one has to trust oneself in such situations.
2.3 Resourcefulness/rapidity	X		The general competence on piping and commissioning was applied, as there was no previous experience from similar incidents. Interviewee knew thye were in a recovery situation. (There was) not a focus on procedure. (…) went outside of procedure. Pipe measurements were not part of the procedure.
CSF3 Support			
3.1 Decision support	X		Contact with leader group onshore, as the Subsea group had left the rig.
3.2 Redundancy		X	The need to exchange information was not recognized. Communication was not poor, but focus was on what had to be done. Sharing information takes time. There was an absence in overlap, however: The Subsea group had to use the system to test their systems and vice versa – in these respects there was overlap.

4.3 Case 3: Simultaneous operations incident

Hot work (welding) needed to be performed on an offshore installation. The supervisor authorized the activity, and a welding habitat was established. In parallel to the welding, the supervisor had also authorized implementation of electrical work on the power supply providing the welding activity with electricity. One day, the compressor that fills the habitat with air shut down. The metal was still hot. If there had been gas – there would most certainly be a fire. Nobody was aware of the fact that there was an ongoing "*simop*", i.e. a simultaneous operation of welding and electrical work. The welder immediately became aware of the compressor shut down, and stopped. See Figure 4.

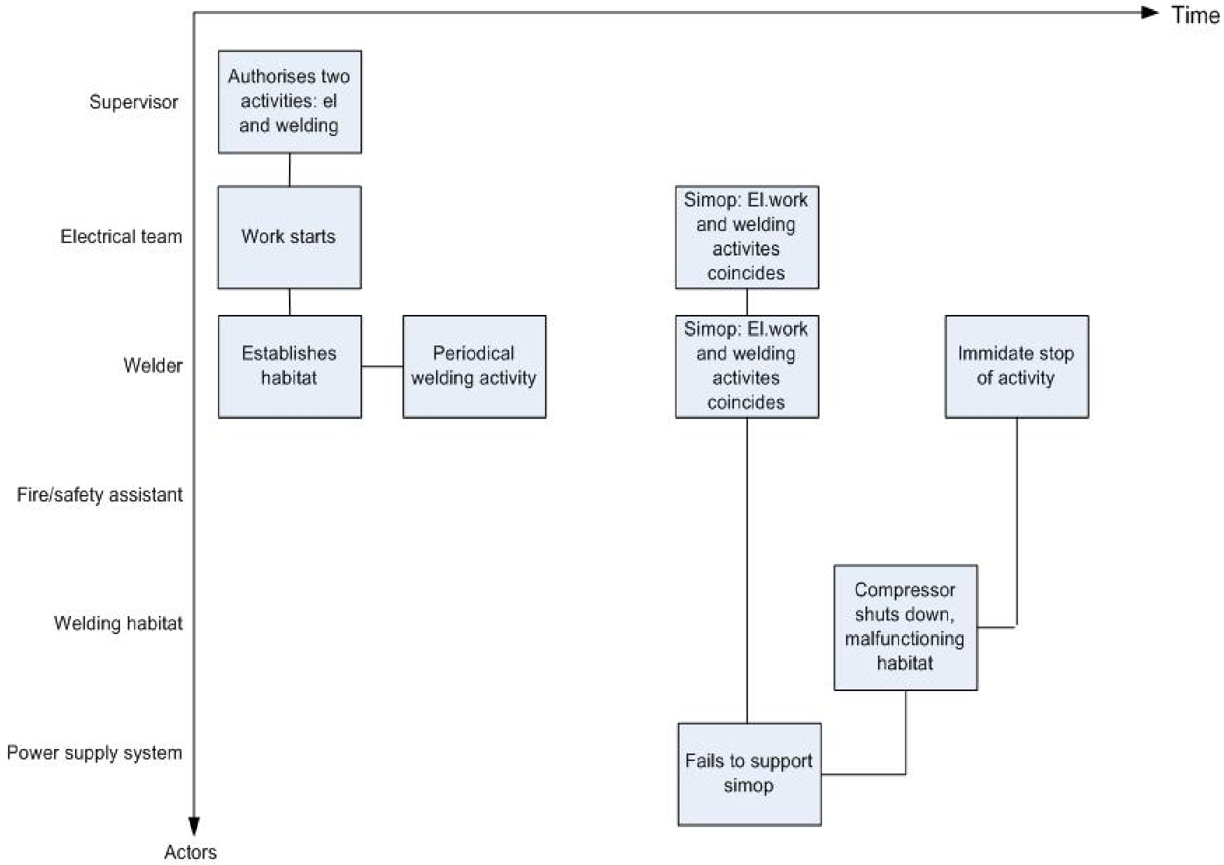

Fig. 4. Sequential model of Case 3 (simultaneous operations incident)

Table 5
Case 3: Simultaneous operations incident

CSF's and components	Yes	No	Explanatory info. from the interview
CSF1 Risk Awareness			
1.1 Risk understanding		X	Interviewee comments on what was lacking regarding this incident: (Not being) aware of exporting risks (…); (not realizing that) their neighbour have risks that may affect their own activities.
1.2 Anticipation		X	There was no exchange of information (see 'redundancy' in CSF3).
1.3 Attention	X		-
CSF2 Response Capacity			
2.1 Response (knowing what to do)	X		-
2.2 Robustness	N/A	N/A	-
2.3 Resourcefulness/rapidity	X		Interviewee refers to the aftermath of the incident and comments: (…) we learned a lot (concerning) coordination of these kinds of activities (simultaneous operations)
CSF3 Support			
3.1 Decision support		X	Not much support (from onshore), (…) there was not a strong organisation yet.
3.2 Redundancy		X	Different cultures – not too much willingness to share.

5. DISCUSSION

5.1 CSF contribution

A key characteristic of Case 1 was the timeline of the incident. It could be said that the incident already began at the stage when project decisions were taken; and continued throughout the planning and implementation. The incident, being that a hazardous project was allowed to progress and put into operation. The CSF results revealed that none of the resilience variables in the three CSFs (Risk Awareness, Response Capacity, and Support) effectively came into play. This does however not imply that the themes of the resilience variables were irrelevant. In fact, revisiting the case development, the *potential* for the resilience themes can be identified in the scenario as it developed. In terms of *Risk Awareness* (CSF1), the possibility for risk understanding (1.1) was initially precluded as the operational organization offshore was left out of the design phase. The same holds for anticipation and attention (1.2, 1.3), as the operational organization was kept out of the loop. As the scheme rolled out however, offshore personnel became aware of problems and risks involved in the project. In this way, one can say that Risk Awareness was triggered or activated; it did not however come into play as the superiors onshore did not acknowledge the risks.

Response Capacity (CSF2) can be looked at by a similar logic. As the operational organization offshore became aware of the potential problems at hand, they immediately informed the onshore organization. These warnings were however not heard. Thus, although Response Capacity (2.1 knowing what to do) was activated, it failed to come into efficient play due to a discrepancy between the operational organization and superiors onshore in how the situation developed. Furthermore, it is reasonable to assume that the results on 2.2 and 2.3 (robustness, resourcefulness / rapidity) are linked to the superiors' disregarding of the needs for action. Regarding robustness (2.2) the interviewee described being on the rig as slow torture, feeling anxious, and a state of relief when leaving the rig. The interviewee also emphasized frustrations related to the combination of having identified the problem (resourcefulness / rapidity, 2.3) but not being heard. In other words, the *potential* for resourcefulness / rapidity was there, it was activated. But, the discrepancy in perception (as referred to above) closed the option of adequate priorities and action. The dynamics revolving around Response Capacity reveals more of this divergence in perception between onshore and operational organization offshore. The need for action was recognized offshore, thus the potential contribution of CSF2 Response Capacity was there. This potential was however not realized as superiors onshore failed to perceive the risks involved. As for 2.2 (robustness) the interviewee reported being worried; a natural reaction, knowing what was at stake. Finally, regarding *Support* (CSF3), decision support (3.1) was missing, and so was redundancy (3.2), as offshore personnel were neither included nor heard. The absence of redundancy is evident in the lack of both knowledge regarding offshore work and understanding between different parties involved.

None of the resilience variables came actively into play (and are therefore checked "no" in Table 3). In spite of this, key variables within Risk Awareness and Response Capacity (CSF1, CSF2) were activated. The operational organization offshore became aware of the risks involved and recognized the need to act. Action was however impossible as superiors onshore did not share their perceptions. Although the study provides no empirical data to support it directly, it is tempting to suggest that this perceptual divergence is tied to the deficiency in the Support variables (CSF3).

A key feature in Case 2 was how risk was detected. *Risk Awareness* (CSF1) was triggered by coincidence. All variables in CSF1 were checked "no". That is, there were no risk understanding (1.1), no anticipation (1.2), and no attention (1.3). In spite of this however, Risk Awareness was subsequently triggered; by fluke. The irregularly high pressure in the piping system was noticed via the detection of pressure in the riser. When Risk Awareness had been activated, immediate actions were taken. As indicated by what the interviewee reported, all variables in *Response Capacity* (CSF2) were activated and contributed positively in the recovery process. In terms of *Support* (CSF3), the interviewee reported that decision support (3.1) was provided. Redundancy (3.2) was however not contributory for recovery.

Ignoring the fact that risk was noticed by coincidence, the recovery process in Case 2 suggests how the three CSFs may be linked together. When risks were noticed (CSF1), they were responded to (CSF2). What is more, the response activities were backed by onshore decision support (variable 3.1 in CSF3). Redundancy was on the other hand not part of the process. Again, as for Case 1, the results for Case 2 do not provide information to single out variables that ascertained successful recovery. Nevertheless, it is argued here that looking at what was absent suggests how recovery in this scenario could have been more accurate. Although Support was present (in terms of decision support), redundancy was not part of the picture. Redundancy was missing in terms of not recognizing the need to exchange information, and a lack in knowledge overlap. Holding the lack of information / communication up against the fact that Risk Awareness was activated by coincidence, it is not far fetched to presume that active contributions from redundancy (e.g. in terms of overlap in information / communication) would help activate Risk Awareness during the initiation of an incident. It is impossible to ignore the fact that recovery begins with Risk Awareness. Strengthening the foundation for Risk Awareness is thus an asset by implication.

In Case 3, the critical element was the parallel work that was going on without one being aware of the other. In addition to the welding activity, authorization had been given to perform electrical work on the rig. These parallel work operations went on until the power supply failed to support the simultaneous operations. Regarding *Risk Awareness* (CSF1), the authorization suggests that neither risk understanding nor anticipation was active on the management side (1.1, 1.2). In terms of *Response Capacity* (CSF2) however, the personnel knew what to do (2.1). Concerning *Support* (CSF3), there was not much decision support from onshore (3.1).

Furthermore, the interviewee reports that there was not much willingness to share (knowledge / information), i.e. no redundancy.

How could this incident have been detected earlier on; or better yet, avoided all together? It is hard to overlook the lack of sharing information / knowledge in these respects. It is reasonable to presume that if sharing of information / knowledge had been an integral part of everyday practice, this would have substantially increased the probability of detecting the hazards involved in simultaneous operations.

5.2 Elements of improvisation

As all variables in the CSFs in Case 1 came out with "no", it may be derived that there were no room for improvisation. As have been argued above, the dynamics in Case 1 is related to the perceptual discrepancy between onshore and offshore. The results revealed that although the CSFs were "activated" on the offshore side, they never came into play as the onshore organization failed to acknowledge the risks at hand. One way to see this is that the potential for improvisation was present and activated on the offshore side, as they wanted to stop the project and engage in actions that were outside of the defined procedures (i.e. the project). This potential was however cut off due to the lack of knowledge on the onshore side of things. The capacity to improvise is related to knowledge, experience, and skill. Thus, it may be suggested that the incident could have been stopped / recovered earlier if the onshore organization had acknowledged the need to break from the established routines. When the pressure in the piping system was detected in Case 2, the personnel responded (CSF2 Response Capacity). As the situation was outside of procedure (they did not know what to do at first), it is reasonable to suggest that the response phase had an element of improvisation. As emphasized by the interviewee, "you trust yourself and what you know". In this quote we find the very foundation for any improvisational activity: sufficient levels of knowledge and skills. In the response phase then, facing a new and surprising scenario – necessary actions were taken. In other words, improvisation was contributory for the successful recovery. In Case 3, improvisation was not part of the scenario.

5.3 Limitations

The current study does not possess sufficient data material to be considered a validation study. This is fully recognized and acknowledged in the title of the paper, by calling it an "initial test". Further testing and validation is necessary. As described in the method section, the explanations of the incidents are colored by the interviewees' roles in the sequence of events. The present-at-hand explanations provided by the interviewees are "stripped of context, situation, configuration, relational meaning and particulars, which means it has some combination of generality and simplicity but lacks accuracy" (Weick, 2009:40). Nevertheless, for the explorative study presented in this paper, the possible skewed present-at-hand explanations, give indications on the validity of the CSFs which justify further empirical studies on the CSFs.

Another limitation is the fact that the CSFs were not specified in terms of what analysis level they are defined on; i.e. individual, group, or organizational level. Although this represents a methodological challenge, it was nevertheless done intentionally. Basically, the CSFs were defined as dimensions that could play out on any level, as this is true to a hallmark of the resilience idea: the interplay and interchange between system level features and operational / agency level features. Thus, although it does represent a methodological challenge, it is here to be argued that the "inter-level resilience jumps" provides an interesting possibility to specify, and study the interfaces and influence between layers and levels. However, questions regarding the dynamics involving individual, group, and organizational level are at the core of what must be further specified in further work involving the CSF resilience factors.

5.4 Implications and further application

Although the three cases are unique in terms of scenario development, they do in fact share interesting common features. Specifically, three variables (CSF1 1.1, CSF1 1.2, and CSF3 3.2) came out with "no" in all three cases, see Table 6.

Table 6
Common features across the cases

	CASE 1		CASE 2		CASE 3	
	Yes	No	Yes	No	Yes	No
CSF1, 1.1 Risk understanding		X		X		X
CSF1, 1.2 Anticipation (knowing what to expect)		X		X		X
CSF3, 3.2 Redundancy		X		X		X

Risk understanding (1.1) and Anticipation (1.2) were absent in all three cases. In other words, Risk Awareness (CSF1) was not activated in the initial stages of the incidents. In Case 1, the interviewee emphasized that the operational organization was excluded from the project, i.e. there was no redundancy (CSF3, 3.2). The possibility for Risk Awareness was obstructed by this lack of redundancy. A similar dynamic seemed to be playing out in Case 2, as the need for communication / information was not recognized. This lack of redundancy is reasonably pointed out as related to the lack of Risk Awareness. In Case 3, the interviewee reported that there was a lack of willingness to share information (again, lack of redundancy, 3.2); and pointed to cultural differences as contributory to this fact. Thus, in all three cases, it is plausible to suggest that Risk Awareness (CSF1) could have been triggered earlier (and possibly contributing to adequate action), if redundancy (3.1, in CSF3 Support) had been sufficiently integrated.

On a more general level, the absence of Risk Awareness and Support in the three cases makes a strong point for paying attention to links between organizational level features and operational / individual level action / performance. The CSFs as operationalized and examined here appears promising as a way to systematically look into dynamics of this character.

This brings us to the question of how the CSF approach can be further applied and developed. The current study can be viewed as proposing a process approach that involves examining how key principles of resilience can be used to understand recovery processes, and by this endeavor identify ways to strengthen abilities of early identification and recovery. The CSFs should not be considered as a finished product. Rather, it is here to be advocated that the weight should be placed more on form rather than content. The *form* is here to be understood as the application of resilience principles that creates possibilities to specify paths of influence between every organizational layer. This is akin to the event analysis method “SOL” (Safety through Organizational Learning, see Falbruch and Wilpert, 1997), of which the focus is to standardize the process rather than the entire content.

Hopefully, the content side (i.e. CSF dimensionality and forms of interaction) can become more established by further studies. It should be noted that the issue of *organizational learning* lies at the heart of this study. The question is how we can learn from incidents. How can experiences of such scenarios be utilized? The idea behind the resilience based CSFs was the assumed value of establishing an approach in the pursuit of learning about what contributes to recovery. A relevant quote here is that “the act of learning implies comparison” (Freitag and Hale, 1997, page 11). In other words, one possible way to further examine the potential for CSF is to develop statistical measures that subsequently are put to empirical testing by statistical validation (e.g. by means of factor analysis).

However, we should not be tied up in statistics alone; it is equally important to further pursue validation by mapping the variables to cases similar to the ones in this study. With a more solid base of validity, it should be possible to apply the CSFs as a tool in order to look backwards to understand what happened, *and* to look forward, i.e. use the CSFs as an approach to derive risk hubs embedded in new and coming forms of organizing work.

The development towards Integrated Operations (IO) in the Norwegian oil and gas industry is a promising area for a proactive use of the CSFs. IO introduces new technology; new ways to organize work; and increased automation in petroleum activities mainly based on implementation of information technology and increased bandwidth in the digital infrastructure. IO encompasses a diversity of needs and agendas, not least because at the current time it aims at how future operations will look like.

A majority of actors at the Norwegian shelf emphasize rate of change as an important feature in itself, and the importance of staying at the leading edge (OLF, The Norwegian Oil Industry Association, 2006). This development of IO establishes new, tight operational collaboration between various actors in the industry, and spurs substantial changes in work patterns on the continental shelf, as well as in the onshore support services. Development of IO also facilitates the transfer of functions from offshore to onshore, thus a number of onshore activities gain increased importance for operational safety at offshore installations. The development also introduces new challenges for preventing and handling unwanted incidents as the operative socio-technical systems are in continuous change and become more complex (Grøtan et al., 2010). Looking at future developments of IO organizations, the CSFs are relevant for identifying safety challenges and opportunities as well as suggesting how to facilitate safe operations.

The results suggest resilience flavored CSFs as a promising means to specify areas to build the capacity for early identification of risk; as well as developing the capacity to respond effectively in order to intervene and stop the incident from developing further.

Acknowledgements

The work in this paper has been carried out as part of the research project 'Building Safety in Petroleum Exploration and Production in the Northern Regions'. Financial support from the Research Council of Norway and Eni Norge is gratefully acknowledged.

REFERENCES

Cunha, M.P, Cunha, J.V, Kamoche, K., 2002. Organizational improvisation: What, when, how and why. In: K. Kamoche, M. P. Cunha, J. V. Cunha (Eds.), *Organizational improvisation*. Routledge, London, pp. 96-137.

Falbruch, B., Wilpert, B., 1997. Event Analysis as Problem Solving Process. In: A. Hale, B. Wilpert, M. Freitag (Eds.), *After the Event – From Accident to Organisational Learning*. Pergamon, Oxford, pp. 113-130.

Freitag, M., Hale, A., 1997. Structure of Event Analysis. In: A. Hale, B. Wilpert, M. Freitag (Eds.), *After the Event – From Accident to Organisational Learning.* Pergamon, Oxford, pp. 11-22.

Grøtan, T.O., Albrechtsen, E., Rosness, R., Bjerkebæk, E., (2010). The Influence on Organizational Accident Risk by Integrated Operations in the Petroleum Industry. *Safety Science Monitor. Vol 14, Iss.1*

Hale, A., 1997. Introduction: The Goals of Event Analysis. In: A. Hale, B. Wilpert, M. Freitag (Eds.), *After the Event – From Accident to Organisational Learning.* Pergamon, Oxford, pp.1-10.

Hendrick, K., Benner, L. Jr., 1987. *Investigating Accidents with STEP*. Marcel Dekker, New York.

Hollnagel, E., 2006. Resilience – The Challenge of the Unstable. In: E. Hollnagel, D.D. Woods, N. Leveson (Eds.), *Resilience Engineering – Concepts and Precepts.* Ashgate, Aldershot, pp. 9-17.

Hollnagel, E., Woods, D.D., 2006. Epilogue: Resilience Engineering Precepts. In: E. Hollnagel, D.D. Woods, N. Leveson (Eds.), *Resilience Engineering – Concepts and Precepts*. Ashgate, Aldershot, pp. 347-358.

Kjellén, U., 2000. *Prevention of Accidents Through Experience Feedback*. Taylor & Francis, London.

Mendonça, D., Beroggi, G.E.G., Wallace, W.A., 2003. Evaluating support for improvisation in simulated emergency situations. *Proceedings of the 36th Hawaii International Conference on System Sciences (HICSS'03),* track 8, 229b.

Mendonça, D., Fiedrich, F., 2006. Training for Improvisation in Emergency Management: Opportunities and Limits for Information Technology. *International Journal of Emergency Management* 3(2006), pp. 348-363.

OLF (The Norwegian Oil Industry Association), 2006. *Potential value for integrated operations at the Norwegian continental shelf* (Norwegian title: Verdipotenisalet for Integrerte Operasjoner på Norsk Sokkel). OLF-report (www.olf.no).

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.

Weick, K.E., 2009. *Making Sense of the Organization. The Impermanent Organization.* John Wiley. Chichester

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