Resilience Engineering and Indicators of Resilience[i]

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Introduction

The concept of 'resilience' has emerged in a variety of fields and the concept's proliferation has resulted in many interpretations and perceptions. A recent worldwide systematic literature review identified more than 300 definitions of resilience (DARWIN, D1.1). Within Resilience Engineering, resilience is more precisely defined as "the intrinsic ability of a system or organization to adjust its functioning prior to, during, or following changes, disturbances, and opportunities so that it can sustain required operations under both expected and unexpected conditions" (Hollnagel, 2014). Since its inception, the development of resilience engineering (RE) as a concept and a field of practice has made it clear that the scope of safety management must be expanded from being concerned with failure to include everyday functioning of a system or an organization. (Hollnagel, 2015; Nemeth & Herrera, 2015).

Traditionally, most of the safety and risk indicators are reactive related to malfunctions, failures or 'after the fact' information. Thanks to the consistent use of methods based on after the fact information, major accidents are extremely rare in ultra-safe systems (Amalberti, 2001). Therefore, in the everyday performance of most of the safety-critical industries, nothing goes wrong and positive outcomes are the norm. In this context, it is a questionable strategy to focus exclusively on potential risks and to look only for failures and malfunctions because effective everyday management cannot be based on something that is infrequent or unpredictable. Proactive indicators based on RE check the 'vital signs' of the system and identify areas for continuous improvement of the core business process. These indicators are intended to complement traditional approaches supporting the ability to monitor current performance influenced by the context and to assess how well the systems and organizations are prepared to handle potential challenges, opportunities and continue operations. Looking forward in addition to looking backwards will contribute to an improvement of the overall system.

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Resilience engineering basic terms

In the literature resilience terms are found to be common across several domains e.g. nuclear, transportation, electricity and health-care. This section presents a selection of the most commonly used resilience engineering terms:

Adaptive Capacity: The ability or potential to adjust activities, resources, tactics, and strategies in the face of kinds of events, variations, demands, and uncertainty to regulate processes relative to targets and constraints. This is a simple extension of an old definition for skill and expertise, the ability to adapt behavior in changing circumstances to pursue goals (Woods lecture on Resilience Engineering, 2015).

Brittleness describes how rapidly a system's performance declines when it nears and reaches its boundary conditions (Woods, 2015).

Graceful extensibility is a positive capability to stretch near and beyond boundaries when surprise occurs. Systems and organizations need graceful extensibility as a separate kind of capacity to our everyday performances when the system is far from the boundary conditions (Woods, 2015).

ETTO Principle - Efficiency-Thoroughness Trade-Off: people (and organisations) have to make a trade-off between the resources they spend on preparing to do something and the resources they spend on doing it. The trade-off may favor thoroughness over efficiency if safety and quality are the dominant concerns, and efficiency over thoroughness if throughput and output are the dominant concerns (Hollnagel, 2009a).

A resilient system or organization is characterized by dependent abilities (introduced as cornerstones Hollnagel, 2009b, 2015):

- The ability to **learn** addresses the use of experience, “dealing with the factual”. It includes what went well as well as what went badly. It is not only about information available in databases. This includes how the system learns and share stories e.g. what makes the system work.
- The ability to **anticipate** relates to the understanding of how the situation at hand develops, whether into single events, or through parts interacting and affecting each other. Anticipation relates to threats and challenges, as well as opportunities. It “addresses the potential” looking for possible future events, conditions, or changes that might affect the system positively or negatively.
- The ability to **monitor** relates to actively looking for signs of what might happen in the near future in terms of opportunities and threats. It “addresses the critical” looking into system´s own performance and external conditions focusing on what is essential to continue operations.
- The ability to **respond** corresponds to be prepared to respond, having resources and capacity to respond to regular, irregular variability, disturbances and opportunities in a flexible manner. It addresses “dealing with the actual” event (which can be expected or unexpected).

Sustained adaptability offers new ways to manage interdependencies across scales. It refers to the ability to manage adaptive capacities of systems (organizations) that are part of a layered network.

Objectives

Today´s systems and organizations adapt and function to demands in rapidly changing environments under different degrees of uncertainty. Thus, the question is to assess the ability of a system to remain resilient, how well systems and organizations cope with expected and unexpected changes. Hence, the overall objective of this chapter is to present methods and tools to identify and use resilience indicators developed within Resilience Engineering. These indicators support early identification and response to potential opportunities and problems ahead to meet demands, constraints and changes in a specific context of operations.

How to improve the ability of a system to remain resilient

Resilience refers to a quality, to something that the system does rather than to something that the system has; so it is highly unlikely that it can be represented by a single or simple measurement. Systems and organizations operate constrained by their design envelope. Resilience is required when systems or organizations are challenged due to conditions that were not imagined during design or when they operate outside, or at the boundaries of the design envelope. Thus, systems and organizations are required to enhance their adaptive capacity. Indicators of resilient performance are related to how the system anticipates and adapts to different kinds of disturbances (expected and unexpected). Woods (2009) argues that it is not possible to measure resilience per se, but the potential for resilience. These indicators are not derived from experience of resilience, but indicate potential to remain resilient when challenging events occur (these indicators are more related to feed forward and leading indicators). The following are examples of approaches and tools that have been proposed to identify and use indicators of resilience potential:

The ***Resilience Analysis Grid*** **(RAG)** (Hollnagel, 2011) includes a set of questions to provide a measure of a resilience profile in relation to resilience abilities (monitor, anticipate, respond and learn). The "RAG profile for an ability" shows how well a system does on each of the four abilities. There is also a RAG profile for the four abilities summarizing the balance among these abilities. Consequently, it can be used to determine improvements in relation to a specific ability or to re-establish a proper balance. The RAG is proposed as a process measure since it provides information about the actual situation. Hence, this measure should be updated on a regular basis.

In the energy sector, indicators using the ***stress-strain analogy*** are proposed to identify how well the system copes with different kinds of demands. It plots the adaptive capacity of the system by looking at general situations and selected unexpected situations (Lay, 2011).

Weak signals occur every day because they reflect the adjustments of the people working in complex systems (e.g. air traffic controllers 'they get the work done'). Indicators that are related to weak signals draw data from the performance variability of humans (e.g. overload reports, quality of communications), technology (degraded system modes) and the organization (Leonhardt & Licu, 2015).

The concept of ***Margin of Manoeuvre*** is derived from the theories about complex adaptive systems. For organizations and systems to maintain control in the face of changing situations, they have to actively create and maintain an adequate margin of manoeuvre internally and in coordination with other systems and organizations - a cushion of potential actions and additional resources that allows the system to continue functioning despite unexpected demands. When this margin shrinks, or is lost, so is the ability to control the system when unexpected disrupting events begin to occur. Systems and organizations that fail to manage and maintain sufficient margin of manoeuvre fall into maladaptive traps that lead to systems failures (Hofmann et al., 2011; Woods et al., 2011).

The ***Functional Analysis Method*** (FRAM, Hollnagel, 2012) aims to capture the dynamics of complex socio-technical systems by modelling the non-linear dependencies and variability which the functions experience. A FRAM analysis assesses the potential variability of each function, defines the functional resonance based on possible dependencies amongst functions and potential for functional variability. The method has been applied to real-world problems (e.g. transportation, healthcare). The method provides qualitative results e.g. proposal for increasing wanted variability or damping unwanted variability, ways of monitoring variability.

Q4-Balance framework (Balancing Economy-Safety Trade-offs) proposes visual and conceptual basis to support effective decision-making by developing and utilizing a balanced portfolio of indicators. Performance indicators fall into a space defined by two dimensions: reactive-proactive and economy-safety. The structure reveals an emergent pattern where indicators can be grouped into four classes -- economy-reactive, economy-proactive, safety-reactive, safety-proactive. The Q4-balance framework is associated with the notion of ***safety energy***. This notion aims at qualifying efforts and resources the organization is devoting and at assessing its capability to be proactive in safety management. The notion emphasizes the fact that such resources are necessarily finite and that they are consumed by a variety of conflicting tasks (Woods et al., 2013).

SCALES Framework combines principles from Enterprise Architecture and Resilience Engineering proposing a tool prototype with a set of generic guidelines showing how resilience related indicators could be identified using different viewpoints. This prototype is developed as a semantic wiki to further support the analysis of the system from different views considering organizational, human and technological aspects. It includes a new resilience viewpoint integrated into the modelling prototype connecting resilience theoretical concepts into practical application. It combines resilience abilities to monitor, anticipate, respond and learn from changes, as well as to more concrete resilience engineering themes such as flexibility, cross-scale and cascades. This represents advancements on practical representations for resilience analysis. The web-tool includes the application of the SCALES Framework to four cases (delivered open source to promote its use, Herrera et al., 2016, SCALES, D1.3 and D1.4).

Saurin (2015) argues for the concept of ***slack*** as important for resilience engineering (RE). His argument, is that slack can be seen as a source for dealing with both expected and unexpected varying conditions. This concept is described as the pool of resources in an organization that is in excess of the minimum necessary to produce a given level of organizational output. It relates to means available spare resources, of any sort, which can be called on in times of need. A distinction between slack-as-imagined (SAI) and slack-as-done (SAD) to identify indicators is proposed as a parallel with the distinction between work-as-imagined as work-as-done, proposed by Hollnagel (2012). Both the imagined and actual slack should be checked against expected and actual deployed, respectively. This may help to identify effective ways to manage resources.

Indicators for resilience potential

Resilience indicators can be related to essential abilities to anticipate, monitor, respond and learn. The following terms are associated with resilience indicators across the resilience engineering literature: graceful extensibility and sustained adaptability, margin of manoeuvre, buffering capacity including redundancy and resourcefulness, flexibility, cross–scale interactions, communication, coordination, timing and synchronization (Mendonça et al., 2015).

Conclusion

The examples above illustrate ongoing efforts to develop approaches and tools for revealing, assessing and managing resilience when facing expected and unexpected challenging conditions. Resilience Engineering addresses the need for better tools for forecasting, change and crisis management and collective action within and across different systems and organizations at different stages before, during and after everyday operation and crisis. The approaches and tools mentioned above are still in an early phase and further developments are needed and expected in particular concerning their practical use.

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