Work 41 (2012) 2810-2816
DOI: 10.3233/WOR-2012-0528-2810
IOS Press

A program to support the construction and evaluation of resilience indicators

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Abstract. The main objective of this work is to propose a method and a tool to support the development of indicators able to inform an organization about the state of its resilience through a cyclical process of identifying its resilience factors, proposing resilience indicators, assessing its organizational resilience followed by assessing and improving the resilience indicators. The research uses concepts from complex adaptive systems and from resilience engineering to establish an initial set of indicators able to assess elements that contribute to organizational resilience, and structures them temporarily as a hierarchy. A software application to support indicator definition and structuring, questionnaire generation, and result assessment activities was built to assist in speeding up the experiment-adjust cycle. Prototype indicators were instantiated with helicopter operating companies in mind, and were reviewed by a domain expert.

Keywords: resilience engineering, indicators, complex systems.

1. Introduction

Modern socio-technical systems are increasingly complex, larger and more interconnected. In many fields, such as transportation, energy, and health care, dysfunctions may have catastrophic consequences. Much of the complexity of highly evolved technological systems found its way there as means to create robustness, but can itself be a source of new fragility, leading to “robust yet fragile” tradeoffs in system design [1].

The traditional safety and reliability engineering point of view considers the human operator as a source of operational uncertainty and the cause responsible for most failures in these systems [2], [3]. A symptom of this approach is the stop rule tacitly used in accident investigations, which cease looking as soon as the cause can be ascribed to "human error" [4]. Recent developments are trying to view issues of safety and reliability in terms of resilience, highlighting the objective of building organizations and systems able to self-monitor and anticipate developments within themselves and in their environment in order to preserve their reliable and safe operation even when unexpected events occur. There is a growing recognition of the role that people play at all levels of organizations and systems to maintain their function despite the numerous factors that could destabilize them.

What motivated this research and the proposed instrument for resilience indicators development was the belief that it should be possible to contribute toward more resilient organizations by providing them with resources for better perception of themselves, such as indicators that inform decision makers about risk conditions in which the organization is operating in relation to any item at any given time. Thus avoiding that those organizations make decisions without really knowing the circumstances in which these decisions are made, and without being able to assess their real effects [5].

The aim of this article is to propose a framework to indicate where the organization is located within the capabilities needed to deal with the disturbances that can affect it (the organization’s resilience level); to describe a method to evaluate the organization’s capabilities against the criteria defined by the framework; to define a set of indicators for the organiza-

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tion's stakeholders to monitor the evolution of their resilience building; and to build a tool to support the processes of indicators assessment and presentation of the results.

2. Method

From the literature on resilience engineering [6], [7] we develop a set of initial attributes capable of influencing organizational resilience in order to build a framework that allows us to express where an organization is located in the space of capabilities to deal with disturbances that can affect it (its resilience). In parallel, we describe a method to develop tools to assess the organization's capabilities in relation to the criteria defined in the framework. Finally, we develop a software system to support the processes of indicators definition and evaluation, assessment, record, and presentation of results.

2.1. Proposed steps

The method, presented in figure 1, was based on the PDCA cycle (Plan, Do, Check, Act), widely adopted in organizations responsible for complex socio-technical systems, implementing it in three interlinked levels: the level of identification and description of the elements that contribute toward an organization or system's resilience, the level of instantiation of instruments to assess these elements in a specific organization, and the level of performing the evaluation. The program developed provides functionality to operationalize the activities recommended by the method, such as the hierarchical organization of elements identified as contributing to resilience and the generation of evaluation tools (questionnaires) for them. The program records the evolution of these processes in a development database.

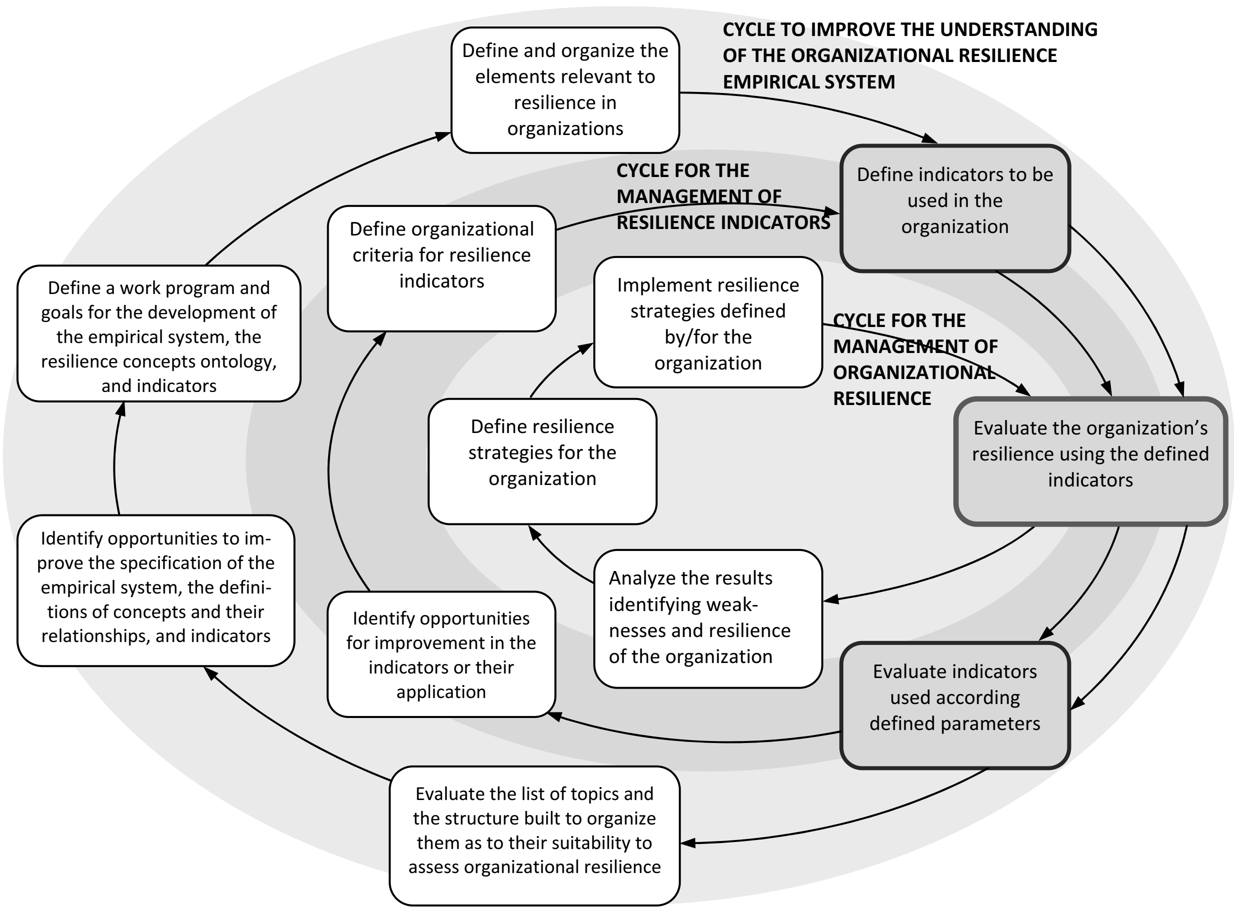

Figure 1 – Method to develop resilience indicators.

2.2. Model to think about resilience

To allow the development of resilience indicators and organize the factors and criteria related to resilience, we define a conceptual model for thinking about resilience in organizations. The model (fig. 2) has four dimensions that support the organization of elements that promote resilience.

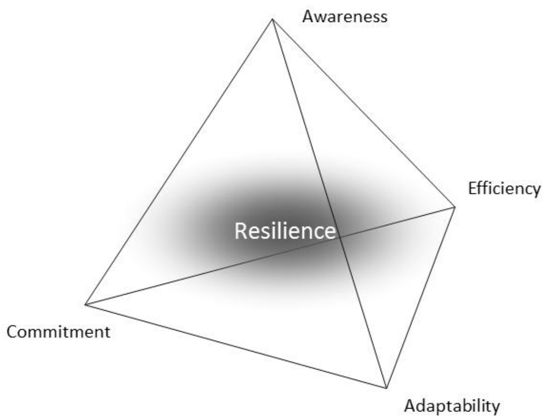

Figure 2 – Model to think about resilience.

At the bottom Efficiency (to do things with minimum resources) and Adaptability (to have spare or buffer capacities to deal with disturbances) are two conditions or behaviors usually associated with tradeoffs people make in organizations, which are usually adopted unconsciously [8]. It is the conflict between immediate benefits (efficiency gains) and uncertain benefits which only appear if a demand/disturbance occurs (resilience). More precisely stated, it is the conflict between easily visible benefits (quantifiable outcomes) and subtle (as yet hard to quantify) capabilities (inputs that provide latent benefits). These factors are connected representing the tension between them in the organization. Management models currently presume that these behaviors (stability and efficiency, adaptability and dealing with uncertainties) are antagonistic, that is, that is to have one it is necessary to relinquish the other, which is not necessarily true. The interpretation of the dynamic environment usually depends on the willingness of the organization to see a marked changeability, interspersed with moments of stability, or stability punctuated by exceptions. This polarization is such that it is possible to speak of paradigms, or organizational myopia, which inhibits the capacity to see things from another perspective, as exemplified by Gomes and colleagues [9], describing sacrificing decisions made by helicopter pilots.

This organizational myopia can be minimized through a proper awareness of the situation. Awareness is shown connected to the Efficiency/stability Adaptability/uncertainty "axis", indicating that it changes how organizations balance Efficiency and Adaptability and the ways they pursue efficiency and pursue adaptability as they conduct their activities.

Awareness is another element of resilience that is represented as a vertex in the model, making clear that just being able to adapt is not enough to make an organization resilient (a common mistake). To be resilient it must be able to adapt (latent capability) and be able to change its behavior to focus on adaptation (manifest behavior) when this is necessary.

The last factor in the model is the commitment to macro-factors previously covered, and changes the way of representing the relationships between and among these factors and resilience.

The geometry adopted, a tetrahedron, introduces some issues that deserve explicit mention of advantages and warning of risks. An advantage of this representation is to be regular, carrying a notion of comparable importance among the resilience factors represented. Another advantage is the direct interconnection between all vertices, which combats the tendency toward a mindset of duality or opposition between the factors included.

Each vertex of the tetrahedron corresponds to a position of primacy of the subject associated with that vertex, and the plane opposite it corresponds to a situation of total subordination to the other three resilience factors represented. This does not mean, however, that the subject is missing or has a zero magnitude on that plane. The evolution of the "greatness" of each subject over the corresponding height of the tetrahedron between the vertex and the center of the opposite side should be considered as having been normalized, so that the central region of the tetrahedron represents a volume where Resiliency is heightened.

The use of a geometric figure to represent the themes adopted can give tempt one to equate "issue" with "dimension". Throughout the preceding discussion we used the terms "factor", "element", and "theme" to avoid calling awareness, adaptability, efficiency and commitment dimensions of resilience. However, with due care to avoid the inherent pitfalls, treating them as dimensions of resilience can be useful for the intuitive understanding of their contribution to resilience. The most important caution is to remember that while they enjoy a relative autonomy from each other these issues are not independent from each other, and that together they do not exhaust the demand for explanatory factors of resilience. Like any model, this one favors some aspects at the expense of others. The decision of what to include and what to exclude is always present. The emphasis this model accords to the issues of commitment, awareness, adaptability, and efficiency reflects an evolution in modeling resilience for the management of organizations, adding dimensions to the previous models of Woods (which includes only one dimension in the stress X strain plot) and Rasmussen's drift into failure model [10] (with 2 dimensions). Our model was based on recent literature [11], [12], [13], [14], [15], [16], [17], [18] review reflecting the current moment in the trajectory of understanding the fundamentals of resilience. As this model has expanded over previous models that have adopted a smaller number of subjects, there will be models that adopt a larger number or a broader selection of themes. The cultures of justice and learning, preparation or readiness, and conflict resolution are examples of topics relevant to resilience, but not explicitly included among the major themes in this model, because they are relative newcomers and still lack a uniform enough meaning . The search for efficiency, on the other hand, is already so widespread and so developed that, despite being represented in the conceptual model and in the composition of resilience indicators the same way as commitment, awareness, and adaptability, it is treated summarily in the proposed resilience indicators development process, which recommends the adoption of existing indicators used in the organization to represent efficiency.

2.3. Development of resilience indicators

During this work we developed a preliminary set of elements that contribute to organizational resilience and of relations between those elements, sampled in table 1. In the table, levels of abstraction are arranged from left to right from more general to more specific, and the columns rank the assessment elements. The labels used in the column headings reflect to some degree word usage found in the field (note the use of "Dimension" in spite of caveats) as well as form ("Questões" stands in for both "Questions" and "Issues" in Portuguese, the original language used in this work).

Due to a complexity containment strategy adopted in this iteration of the process of developing the indicators, the relationships are represented as a tree, where each element of resilience assessment contributes only to one other higher ranked (more general) element. As the method proposed here is instantiated in real organizations the need for a more sophisticated representation of the relationship between resilience assessment elements will become manifest and the tree representation will soon give way to directed acyclic graphs.

For example, a new path connecting the "*How well information provided reflects the reality of operational states*" assessment element may be used provide clues about the organization's commitment to issues such as safety or resiliency, in addition to the path in the table showing this assessment element providing clues about the organization's awareness through the question "*Do the operators monitor the state of the system to determine the operating mode to maintain or adopt?*".

Table 1 only presents some of the initially instantiated elements for resilience assessment and some of their possible relations; we suppressed the remainder to preserve clarity. The entire initially instantiated set of elements and relations was represented in the database of the software tool developed to support the application of the method. Based on this structure a preliminary set of questions that can be used as a starting point for developing resilience indicators in any organization was defined.

Table 1
Relationship among elements to define resilience indicators.

Objective	Line	Dimension	Criterion	Question or Issue	Item Assessed
Resilience	Commitment	Search for improvement	Conflict management	How does the organization see itself in relation to its workers?	
				How does the organization deal with divergences between itself and its workers?	
			Construction of reference, culture	How does the organization access its culture?	
			Others…		
		Others …			
Resilience	Awareness	Knowing what behaviors to reinforce to deal with the efficiency-adaptability tradeoff	Awareness	Do operators monitor system status do determine what operating mode to maintain or adopt?	Sources used for information to asses the current state of operations
					Frequency with which information about the current state of operations is updated
					How well information provided reflects the reality of operational states
				Do operators know the possible system configurations and the processes that determine them?	
				Do operators recognize weak signals?	
			Assessment and planning horizons		
			Values		
		Proactive verification of operational conditions	Measures to identify and avoid recurring errors	Does top management seek to identify and solve problems regularly?	Frequency of the organization's operational status reviews
			Others …		
	Adaptability	Capacity to adapt according to the situation	Resource availability	Are there buffer capacities (time, people, tools) to be used during disturbances?	Existence of resources available for deployment in case of disturbances
				How are buffer capacities stipulated and controlled?	Existence of explicit policies of reserves to maintain
			Change willingness		
			Change readiness		
		Ability and capacity to respond to situations beyond project scope		Are there plans to deal with vulnerabilities?	
				Is the usability of response tools taken into account?	
	Efficiency	Left to other management controls			

Fig. 3 presents the main working screen of the software tool developed to support the method, showing a tentative set of labels to refer to the ranks of resilience assessment elements (as used in table 1) as well as placeholders for a column to provide an explanatory text (reason or justification) and another to provide grading scales and criteria to support the assessment of each indicator.

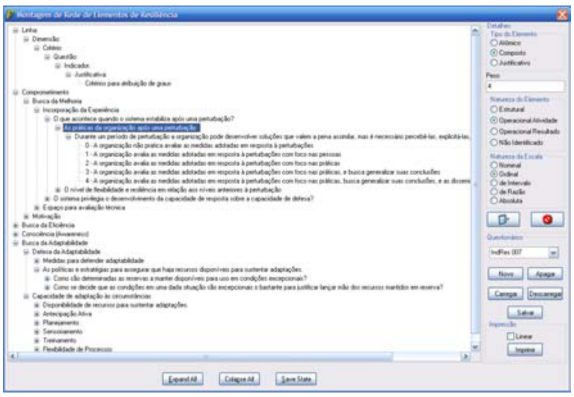

Figure 3 – Screen of the software tool.

3. Results and discussion

The method was tested in an air taxi company. Participants were company pilot trainers, with many years of activity in aviation and safety management in the sector of passenger air transportation to the offshore oil activity. Participants received a briefing and the prepared material (questionnaire) in a classroom session that lasted about five hours. The material was used to inform and stimulate discussions on various issues regarding resilience of the air taxi transportation system. The questionnaires were generated by the application using the initially defined indicators, and the assessments obtained were fed back into the developed application to generate the indicators and to manage the process of developing indicators.

The session was divided into two phases, the first to apply the indicators and the second for a review of the proposed method. The activities of phase 1 were answering the questionnaire for assessing organizational resilience, and assessing the indicators instantiated.

The Phase 2 activities included: identifying opportunities for improvement in the instantiation or application of the indicators, assessing the adequacy of the list of topics and the structure built to organize them, identifying opportunities to improve the specification of the empirical system, the definitions of concepts and their relationships and indicators.

Figure 4 shows one of the outputs of the process, a graph presenting the participants' assessment of five indicators related to contingency planning practices in their own organization as well as their perception of these same practices in the overall offshore oil air transportation system. The indicators presented (graph spokes) are related to the planning or change readiness criterion (graph title). Four questions connect the indicators to the criterion in this case. The types of disturbance covered and the types of measures recommended indicators respond to the "What is the predominant approach adopted in the contingency plans?" question. The questions are shown in the tree view but not necessarily on the graph so as to limit clutter. The middle layer of questions facilitates work in the management process responsible for instantiating indicators.

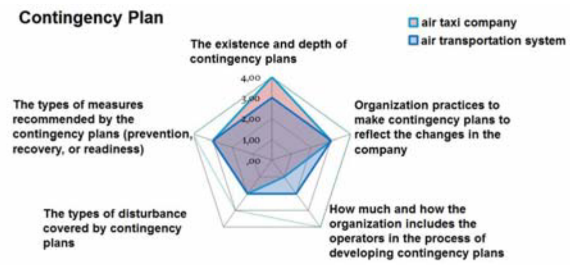

Figure 4 – Indicators of the organization's practices related to planning for dealing with disturbances.

4. Conclusions

In this research concepts related to resilience were organized enough to allow us to build a software tool that aims to be practical enough to be used by operators at all organization levels in different organizations. We present a method for developing resilience indicators with actions in three levels, to accelerate the process of improving the specification of the empirical system. The levels were: 1) the operators in the field, subjects of the resilience evaluation tool, 2) the managers of field operations, operating resilience and using the method and tool for instantiating the indicators that they believe are important, and 3) the researchers and system developers level, where managers can also act. In the experts' assessment of the air taxi company resilience application, the method and its division of activities into three levels resulted in activities compatible with the capabilities, interests and availability of those involved, and so was well accepted. The matched concept of hands-on development (a representative, participatory, iterative and interactive method) of resilience indicators was also well accepted and should tested in more work domains.

Acknowledgements

The authors gratefully acknowledge the support of the Brazilian Research Council (CNPq) and of Rio de Janeiro Research Support Foundation (FAPERJ).

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