CHARACTERISTICS OF COMPLEX SOCIO-TECHNICAL SYSTEMS AND GUIDELINES FOR THEIR MANAGEMENT: THE ROLE OF RESILIENCE

Tarcisio Abreu Saurin[1], Angela Weber Righi[2], Éder Henriqson[3]
[1,2]. Federal University of Rio Grande do Sul (UFRGS), Av. Osvaldo Aranha, 99, 5. Andar, Zip code 90035-190, Porto Alegre (RS), Brazil
saurin@ufrgs.br
angelawrighi@yahoo.com.br
[3]. Pontificia Universidade Católica do Rio Grande do Sul, Porto Alegre (RS), Brazil
ehenriqson@pucrs.br

Abstract

Resilience engineering (RE) has been widely promoted as a safety management paradigm particularly suitable for complex socio-technical systems (CSTSs). However, the reasons for that assumption have been often taken for granted. This paper contributes to the identification of the links between RE and the nature of CSTSs, by discussing three questions: (a) how do the characteristics of CSTSs affect the system´s resilience? (b) how does the guideline of creating an environment that supports resilience interact with other guidelines for managing CSTSs? (c) how are the characteristics of CSTSs affected by actions aimed at creating an environment that supports resilience?

1 INTRODUCTION

An increasing number of studies on resilience engineering (RE) have been undertaken, mostly in sectors widely regarded as complex socio-technical systems (CSTSs), such as healthcare and aviation (Hollnagel et al., 2011). Nevertheless, while RE has been promoted as a safety management paradigm that fits the nature of CSTSs, the reasons for that assumption have been often taken for granted. This lack of understanding may encourage ill-thought out applications of RE, since complexity is a multidimensional and elusive construct (Perrow, 1984). For instance, it may be wondered why it is necessary to engineer resilience into a CSTS if resilience is an intrinsic property of a true CSTS. Moreover, the idea of engineering resilience may be at odds with the self-organizing nature of CSTSs, which are resistant to centralized control. Another possible source of misunderstandings arises from the difficulty of measuring complexity (Cilliers, 2005). Due to this fact, it may be tempting to believe that RE is equally applicable and useful to any CSTS, since complexity is always present to some extent.

In this article, three questions concerned with the links between RE and complexity are investigated: (a) how do the characteristics of CSTSs affect the system´s resilience? (b) how does the guideline of creating an environment that supports resilience interact with other guidelines for managing CSTSs? (c) how are the characteristics of CSTSs affected by actions aimed at creating an environment that supports resilience?

2 RESEARCH METHOD

In order to answer the three questions previously mentioned, it was necessary to identify both thecharacteristics of CSTSs and guidelines for their management. The number of characteristics that define a CSTS and their descriptions vary substantially across authors and disciplines. In this paper, the set of characteristics identified by Saurin and Sosa (2013) is adopted as a basis, as they conducted a literature review of two kinds of studies: those that investigate complexity in socio-technical systems, taking it as a basis to question established management approaches (e.g., Kurtz and Snowden, 2003; Perrow, 1984); and those that emphasize complexity from an epistemological perspective, suggesting it as an alternative to the Newtonian scientific view (e.g., Cilliers, 2005).

The guidelines for managing CSTSs are those identified by Saurin et al. (2013), based on a literature review of: studies that have used insights from complexity theory for proposing management strategies compatible with the nature of CSTSs (e.g., Dekker, 2011; Hollnagel and Woods, 2005); reports on experiences of using complexity theory insights to support process improvement (e.g., Stroebel et al., 2005); and theoretical discussions on the use of complexity theory to improve dimensions of organizational design, such as decision-making (e.g., Snowden and Boone, 2007).

The three questions focused on this paper are discussed with the support of three concept maps: the first presents the relationships among the characteristics of CSTSs (it addresses question "a"); the second presents the relationships among the guidelines themselves (it addresses question "b"); and the third presents the relationship among the guidelines and the characteristics of CSTSs (it addresses question "c"). The first concept map was originally presented by Saurin and Sosa (2013), and it is re-interpreted in this study from the perspective of question "a". The second concept map was originally presented by Saurin et al. (2013), and it is re-interpreted in this study from the perspective of question "b".

3 HOW DO THE CHARACTERISTICS OF CSTSS AFFECT THE SYSTEM´S RESILIENCE?

Figure 1 presents the characteristics of CSTSs identified by Saurin and Sosa (2013).

Categories of characteristics	Key aspects
A large number of dynamically interacting elements	- The system changes over time - The interactions are non-linear, which means that small changes in the cause imply in dramatic effects in the outcomes - The interactions take place among tightly-coupled elements (e.g., interdependence in terms of tasks, teams, production sequence), which allow for the quick propagation of errors and create difficulty in isolating failed elements
Wide diversity of elements	- The elements are differentiated according to a number of categories, such as hierarchical levels, division of tasks, specializations, inputs and outputs - The nature of the relations among the elements exhibits variety, in terms of aspects such as degree of co-operation, degree of shared objectives and degree of information exchange
Unanticipated variability	- Uncertainty, which is a result of the richness of the interactions between the elements as well as from the fact that elements receive information from indirect or inferential information sources, especially in highly automated systems - Complex systems are open, which means that they interact with their environment, which is in itself a major source of variability - Emergence is a well-known manifestation of unanticipated variability. An emergent phenomenon arises from interactions among the elements, independently on any central control or design
Resilience	- It is the systems´ ability to adjust their functioning prior to, during, or following changes and disturbances, so that the system can sustain required operations under both expected and unexpected conditions - Performance adjustment means filling in the gaps of procedures, whatever their extent and reason, such as under specification for an expected situation or inapplicability for an unexpected situation - Performance adjustment is guided by feedback, both from recent events and from the earlier organization´s history. The assumption is that the past of a system is co-responsible for its present behavior - Self-organization, which enables a complex system to develop or change internal structure spontaneously and adaptively in order to cope with their environment

Figure 1. *Characteristics of CSTSs compiled by Saurin and Sosa (2013)*

Figure 2 presents the map concerned with question (a), stressing relationships between the four categories of characteristics of CSTSs. Resilience is argued to be a functional characteristic of a CSTS, which benefits from two other characteristics of those systems. A large number of dynamically interacting elements is an asset for resilience as it tends to provide more alternatives for the adjustment of performance. A wide diversity of elements, especially if there is diversity of complementary skills, is an asset for resilience as performance adjustment is likely to be more precise if decisions and actions are based on a deeper understanding of the context (Saurin and Sosa, 2013).

Figure 2 also indicates that resilience compensates for unanticipated variability, in order to maintain operations when procedures are no longer sufficient. It is also worth noting that resilience can contribute to reduce the incidence of unanticipated variability, even though this possibility is not clearly shown in Figure 2. Indeed, provided that performance adjustment includes the reduction of unnecessary interactions, elements and diversity (i.e., waste), the incidence of unanticipated variability is also likely to decrease.

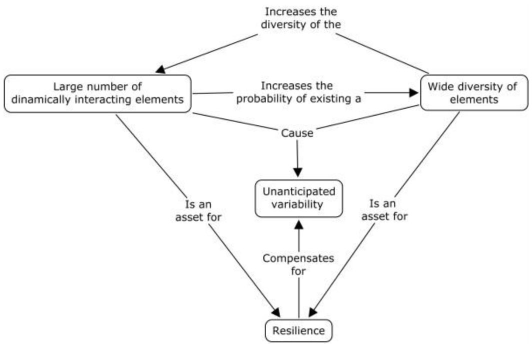

Figure 2. *Relationships among the characteristics of CSTSs (Saurin and Sosa, 2013)*

In fact, the characteristics of CSTSs seem to reinforce each other. If the system is truly complex, the more one of its characteristics is intensified, the more the others will be. In other words, complexity generates more complexity, and therefore, more resilient performance. Nevertheless, we contend that some complexity and resilience is unnecessary, as it only exists because of waste in the system.

4 HOW DOES THE GUIDELINE FOR CREATING AN ENVIRONMENT THAT SUPPORTS RESILIENCE INTERACT WITH GUIDELINES FOR MANAGING CSTSS?

Figure 3 summarizes the six guidelines identified by Saurin et al. (2013).

Guidelines	Dimensions of the guidelines
Give visibility to processes and outcomes	Systems should make both problems and complexity visible Visibility should be given to informal work practices, which over time may be considered as part of normal work Privacy may be important for adapting and innovating
Encourage diversity of perspectives when making decisions	Diversity of perspectives may help to tackle uncertainty Agents involved in decision-making should hold complementary skills Some requirements for the implementation of this guideline are: high levels of trust, reduction of power differentials and identification of apt decision-makers
Anticipate and monitor the impact of small changes	Each organization should define what counts as a small change The impacts of small changes may be large, due to non-linear interactions As small changes happen all the time, they offer frequent opportunities for reflection on practice Small changes may be either non-intentional or intentionally self-initiated by the organization (e.g., through kaizen) as well as originated from external sources (e.g., a client changes its order)
Design slack	Slacks reduces tight-couplings in order to absorb the effects of variability Slack may take a number of forms, such as redundant

	equipment, underutilized space, excess of labor, generous time margins Slack may have side-effects, such as contributing to maintain problems hidden and disguising small changes
Monitor and understand the gap between prescription and practice	It is impossible for standardized operating procedures to cover all situations, thus inapplicability and need for adaptation should not be surprising Procedures may be of different types (e.g., goal oriented, action-oriented) and, for all types, the gap between them and practice should be monitored
Create an environment that supports resilience	All the previously mentioned guidelines support resilient performance As complexity cannot be fully eliminated, agents must have the skills to adapt to it (i.e., resilience skills) Resilience skills are defined as individual and team skills of any type necessary to fill in the gaps of procedures, in order to maintain safe and efficient operations during both expected and unexpected situations The use of resilience skills requires organizational support, such as granting authority to people self-organize as well as the provision of training

Figure 3. *Guidelines for the management of CSTSs (based on Saurin et al., 2013)*

Figure 4 presents the map concerned with question (b), stressing the relationships between the guidelines. Five guidelines have a key contribution to the implementation of the sixth guideline, namely the creation of a favorable environment to resilience. Saurin et al. (2013) report that: (a) the visibility of processes and outcomes tends to make it easier to identify when to adjust performance; (b) the monitoring of the gap between prescription and practice can provide measures of the amplitude and frequency of the adjustments, besides raising questions about why they happen; (c) the anticipation and monitoring of the impact of small changes helps to track how variability is propagating throughout the system, and thus how agents are adjusting to it; (d) the encouragement of diversity of perspectives when making decisions reduces uncertainty in terms of when and how to adjust performance; and (e) the design of slack makes processes loosely coupled, and thus it can provide time for the exploration of innovative solutions for adjusting performance (Saurin et al., 2013).

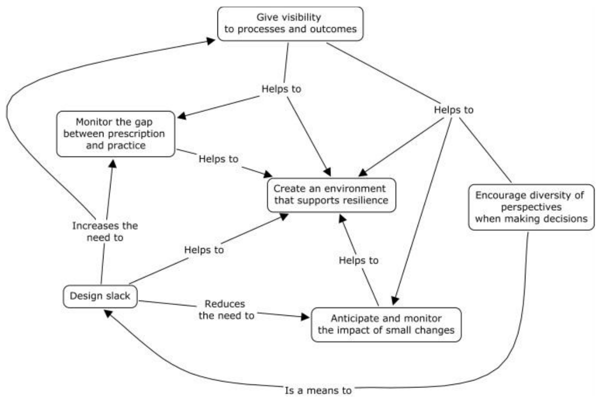

Figure 4. *Relationships among the guidelines for managing CSTSs (Saurin et al., 2013)*

Some trade-offs that are created by the guidelines include: (a) visibility given to processes and outcomes can be in conflict with the need for privacy, which may be important to adjust performance (Bernstein, 2012); (b) anticipation and monitoring of the impacts of small changes can generate information overload, creating a requirement for explicit criteria to define what counts as a small change (Saurin et al., 2013); and (c) as slack disguises and absorbs problems, it increases the need for monitoring the gap between prescription and practice, while simultaneously reducing the need for anticipation and monitoring of the impact of small changes (Saurin et al., 2013).

5 HOW ARE THE CHARACTERISTICS OF CSTSS AFFECTED BY ACTIONS AIMED AT CREATING AN ENVIRONMENT THAT SUPPORTS RESILIENCE?

Figure 5 supports the discussion of question (c). It points out that engineering resilience into a CSTS impacts mostly on unanticipated variability. In addition to stressing the need for giving visibility to unanticipated variability, the guidelines also emphasize the need for monitoring, absorbing and making sense of unanticipated variability. It is also worth noting that the guidelines do not necessarily create any trade-off between safety and productivity, which is consistent with the RE view that those two dimensions of business performance are inseparable. Even the design of slack does not necessarily imply in such a trade-off. An ideal amount of slack should exist, which at the same time absorbs the variability detrimental to both safety and productivity. Too much slack can reduce safety, because it adds unnecessary complexity and it may create new hazards; it can also be detrimental to productivity by creating the conditions that hide waste. Too little or no slack can be harmful for both safety and productivity, since it can make the system vulnerable even to normal variability. Even just-in-time systems, which are sometimes misinterpreted as zero slack systems, are known to maintain levels of slack compatible with the level of variability the system is exposed to.

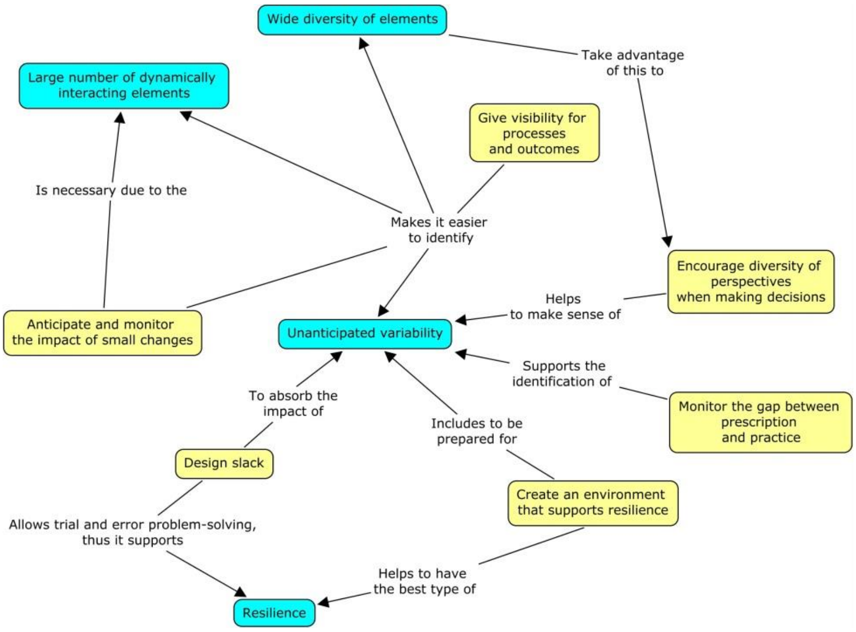

Figure 5. *Relationships among the guidelines and the characteristics of CSTSs*

6 CONCLUSIONS

This study helped to clarify the links between RE and complexity by:

(a) identifying two characteristics of CSTSs that are assets for proactive resilience: a large number of dynamically interacting elements and a wide diversity of elements. Since these characteristics can be designed, to some extent, the design should focus on the identification of the optimum number of elements and on the appropriate kind of social, technical, and organizational diversity. This study also identified unanticipated variability as a characteristic of CSTSs that encourages the emergence of reactive resilience;

(b) identifying that, without an effective system design, resilience can be limited to compensating for variability that could be avoided by using established good practices;

(c) identifying design guidelines that support the emergence of resilience as a characteristic of a CSTS.

REFERENCES

Bernstein, E. (2012). The transparency paradox: a role for privacy in organizational learning and operational control. *Administrative Science Quarterly*, 57, 2, 181-216.

Cilliers, P. (2005). Complexity, deconstruction and relativism. *Theory, Culture & Society*, 22 (5), 255-267.

Dekker, S. (2011). *Drift into Failure*: from hunting broken components to understanding complex systems. London: Ashgate.

Kurtz; C.; Snowden, D. (2003). The new dynamics of strategy: sense making in a complex and complicated world. *IBM Systems Journal*, 42, 3, 462-483.

Hollnagel, E.; Paries, J.; Woods, D.; Wreathall, J. (2011). *Resilience Engineering in Practice*: a guidebook. Burlington: Ashgate.

Hollnagel, E. Woods, D. (2005). *Joint Cognitive Systems*: foundations of cognitive systems engineering. Boca Raton: Taylor & Francis / CRC.

Perrow, C. (1984). *Normal Accidents*: living with high-risk technologies. Princeton: Princeton University Press.

Saurin, T.A.; Sosa, S. Assessing the compatibility of the management of standardized procedures with the complexity of a sociotechnical system: a case study of a control room in an oil refinery. *Applied Ergonomics*, 2013, in Press. http://dx.doi.org/10.1016/j.apergo.2013.02.003.

Saurin, T.A.; Rooke, J.; Koskela, L. A complex systems theory perspective of lean production. *International Journal of Production Research*, In Press, 2013. DOI: 10.1080/00207543.2013.796420.

Snowden; D.; Boone, M. (2007). A leader´s framework for decision making: wise executives tailor their approach to fit the complexity of the circumstances they face. *Harvard Business Review*, 69-76.

Stroebel, C.; McDaniel, R.; Crabtree, B.; Miller, W.; Nutting, P.; Stange, K. (2005). How complexity science may inform a reflective process for improvement in primary care practices. *Journal on Quality and Patient Safety*, 31, 8, 438-446.