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PROCEEDINGS

5TH REA SYMPOSIUM
MANAGING TRADE-OFFS

Resilience Engineering Association

FINAL 28/2/2014

Edited by

Ivonne Herrera, Jan Maarten Schraagen, Johan van der Vorm and David Woods

PROCEEDINGS

5TH SYMPOSIUM ON RESILIENCE ENGINEERING

MANAGING TRADE-OFFS

Colophon

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Editors	Ivonne Herrera, Jan Maarten Schraagen, Johan van der Vorm and David Woods
Publisher	Resilience Engineering Association, http://www.resilience-engineering-association.org/
Full title	Proceedings 5th Symposium on Resilience Engineering, Managing trade-offs
Editing date	February 2014

Preface

The Resilience Engineering Association continued its tradition with the 5th Symposium, organized with TNO, bringing together 140 researchers and practitioners from diverse disciplines, multiple industry sectors and about 20 countries. It focussed on Resilience Engineering: Managing Trade-offs. Our increasingly interconnected world is producing new forms of complexity as individuals, groups, and organizations seek ultra-high performance and safety across the energy, transportation, and health care sectors.

A major portion of the program, see page XIII, addressed current challenges organizations face, why resilience is needed to address those challenges, and how Resilience Engineering can be put into practice. Examples include reverberations of extreme weather, preparing for the unexpected, brittle automation, proactive safety, business continuity, and others; and adaptive responses are examined across multiple systems levels from operational to organizations to industry wide. The symposium program highlighted the latest developments in Resilience Engineering: new techniques, concepts, models, and measures. The program has been set up to facilitate putting the techniques and new developments into action to help organizations manage the trade-offs created by new capabilities, new performance pressures and new forms of complexity. The goal is to stimulate discussions and innovations across organizations and across research and practice so that Resilience Engineering continues to flourish and grow in impact.

By publishing this proceeding the Resilience Engineering Association wants support on developing knowledges, exchange vision and to share practices implementing resilience engineering. For more information including papers of all symposia organized so far, please visit: http://www.resilience-engineering-association.org/.

I enjoyed the energetic 5th Symposium particulary the Young Talent Program designed to assist “young” students and researchers develop their thesis projects through discussions with a panel of leading professors and experienced practitioners in Resilience Engineering The extensive industry participation will help future synchronization of R&D opportunities with industry capabilities, trends, and priorities. I look forward to the cross-fertilization from this dialogue.

The complexities of today’s world create trade-offs for organizations. Resilience Engineering points the way to overcome the risks of brittleness and help navigate the trade-offs. Together, in this Symposium and in our continuing collaborations, we are building the means to outmaneuver complexity. I thank all participants for contributing their energy and imagination to further develop and spread the means to build resilience with the REA family.

David Woods, Chairman of Symposium programming Commmittee

February, 2014

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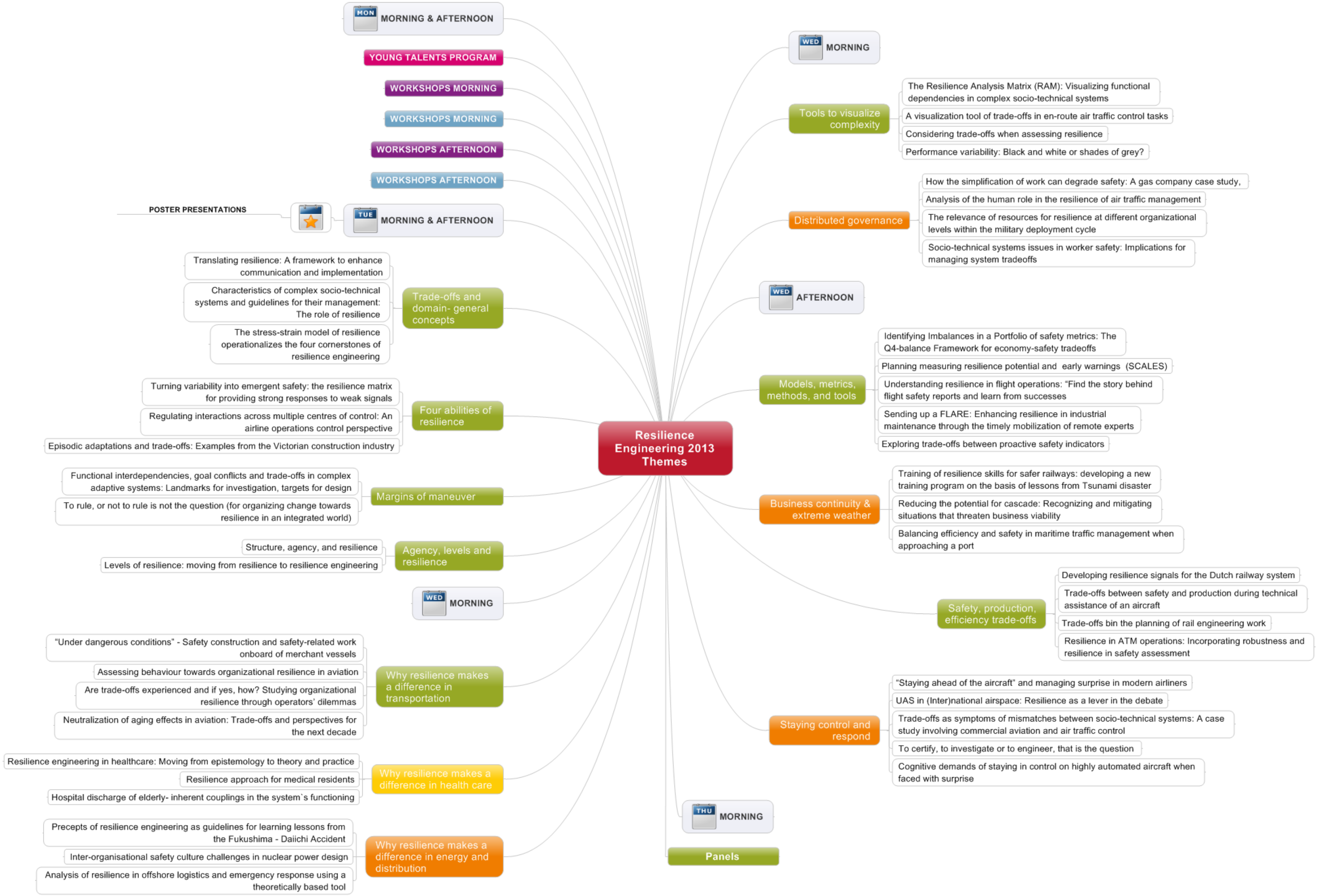
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Translating Resilience: A Framework to Enhance Communication and Implementation

Patricia H. Longstaff [a1], Thomas G. Koslowski[b] and Will Geoghegan[c]
[a].Newhouse School of Public Communications, Syracuse University, NY, USA,
phlongst@syr.edu
[b].Institute of Computer Science and Social Studies, University of Freiburg, Germany,
koslowski@iig.uni-freiburg.de
[c].Whitman School of Management, Syracuse University, NY, USA,
wjgeoghe@syr.edu

Abstract

The proposed framework enables a more holistic understanding the various fields of resilience research and makes communication across several domains more productive by placing the discussions into four types of resilience that are broad enough to facilitate discussion but specific enough to allow for the translation of resilience into specific policies, practices and outcomes.

1 INTRODUCTION

Translate: To bear convey, or remove from one person, place or condition to another; to transfer or Transport, Oxford English Dictionary

Most of us are familiar with the translation of languages. Many have been surprised at how a word or concept from another language gets converted by translation software or even professional translators who are proficient in both. Sometime words carry with them the culture and/or conceptual orientation of the speaker that are not shared by the listener. Misunderstanding is almost certain in such cases. But centuries of dealing with people who speak other languages or speak the same language but come from other cultures have given us some tools for managing the potential confusion and misconstructions. Interdisciplinary and international problem-solving is hard work and there are often communication errors so it is important to know what level of translation matters for the problem at hand. Does the problem require the participants to share broad definitions or to agree on very precise ones? We think there is another way. And while the definitional framework proposed here does not solve all problems it allows us to make progress in areas that are critical to human and technical systems now.

The increasing complexity of today's inter-connected social systems has resulted in calls for greater understanding and development mechanisms for coping with turbulence and uncertainty (Longstaff, 2005, Weick and Sutcliffe, 2007). Resilience has been studied and described by various academic disciplines as a potential answer to move beyond survival and even prosper in the face of challenging conditions (Carpenter, et al, 2012). These disciplines include: ecology (Holling, 1996, Walker an Salt, 2012), psychology (Masten, 2001), socio-technical studies related inter alia to safety management (Hollnagel et al., 2006), disaster research (Norris et al., 2008) and a broad range of organizational studies (Lengnick-Hall and Beck, 2005, McCann and Selsky, 2012, Sheffi, 2007, Weick and Sutcliffe, 2007). Publications concerning the concept have increased dramatically.

The concept of resilience has emerged relatively recently in the scientific debate. The number of publications dealing with resilience is strongly increasing over the last years. Taking into account a general increase in publications per year (about doubled since 1995), scientific articles containing the keyword resilience grew more than ten-fold since 1995, corresponding to a larger application of the resilience concept and a wider diffusion to other scientific areas. Picture 1 shows the number of publications dealing with resilience in all

[1] Corresponding author: phlongst@syr.edu

scientific disciplines. Searching for the keyword "resilience" in only scientific articles on the scientific database web of knowledge (www.webofknowledge.com) yields 9,272 results (Sept. 2011).

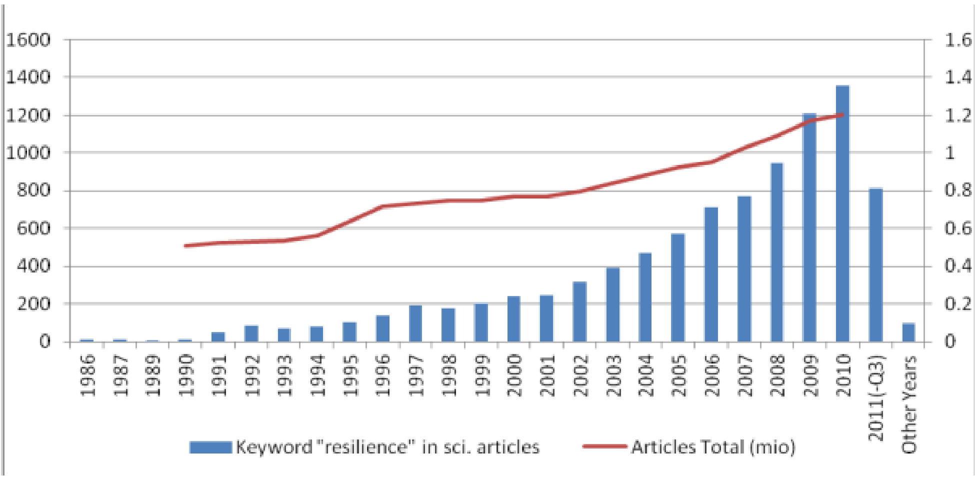

Figure 1. *Resilience Publications (1996-2013)*

The increasing popularity of the term 'resilience' has caused some (e.g., Lorentz 2010; Strunz 2012) to believe that resilience is in danger of becoming another linguistic fashion or buzzword with little or no meaning or validity. While there may be some transient fashion involved, the increased popularity of resilience also signals an alternative focus to the challenges of uncertainty and variability that arise from the increasing complexity and interconnectedness of modern systems. This has led to new worldwide efforts to recognize and deal with systems that cross traditional academic boundaries and corporate and governmental regulatory divisions. For example, the Resilience Alliance has developed an interdisciplinary "Resilience Thinking" as a framework for understanding change in social-ecological systems (Walker and Salt, 2012) (http://www.resalliance.org). An emerging community of engineers from a variety of subspecialties is developing 'Resilience Engineering' as "a new way of thinking about safety" (http://www.resilience-engineering.org/).

Against the backdrop of varied conceptual usage across multiple fields, it is not surprising that extant resilience research is surrounded by diversity and ambiguity of definitions, scope conditions, antecedents and outcomes e.g. Lorenz (2010) and Norris et al. (2008). Is resilience a metaphor, a capacity, a capability, a strategy, a goal, a guiding principle, a philosophy, a measure or a behavior? Although an elastic notion of resilience may facilitate communication across disciplines (or even divergent lines of research within a discipline (Brand and Jax, 2007, Strunz, 2012), a lack of clarity confusion may hinder operationalization in specific contexts and lead to unclear or even contradicting evaluations of results. A definition that is too broad would also hinder empirical research results and even cause some to question the relevance of the concept (Strunz, 2012, Suddaby, 2010). As Suddaby (2010) states, a clear construct might not only facilitate communication between scholars, it also "enhances researchers' ability to empirically explore the phenomena" and further enhance outcomes by "allowing managers to redefine problems in ways that are more amenable to resolution" (p. 352).

Unfortunately, a holistically agreed upon definition will be difficult and problematic in the short term. And the world cannot wait for the perfect definition before it begins to tackle the dangers and uncertainties from which we must bounce back. Fortunately, a variety of definitions can exist as long as they are acknowledged (Strunz, 2012) and there are people who can translate between them. The skills for translation between academic disciplines and between the academy and practitioners will almost certainly need to happen for productive discussions between ecologists, engineers, physicists and psychologists (who have all developed their own definitions and lexicon) in order to build new approaches to the complex problems facing many organizations and all governments. (Le Coze and Dupre 2008)

The framework proposed here will help begin the process of translation and this will help identify the modi operandi (strategies and mechanisms used) that are more likely to allow a system (such as a community or a technical system) achieve resilience. The four perspectives are broad enough to allow for differences in situations but concrete enough to allow for the discussion of how and to whom resources for recovery or adaption are allocated (Baker, 2009) and help identify other trade-offs with regard to the arsenal of resilience mechanisms and policies that are employed.

Notwithstanding some substantial communalities among the disciplines, substantial distinctions of the concept exist with regard to (1) the level of complexity that is assumed (reductionism vs. holism orientation) and (2) the degree of normativity included in the perspective (descriptive vs. normative orientation). After analyzing these meanings, we will discuss the applicability of our conceptual framework as a blueprint for facilitating real-world problem solving and cross-disciplinary resilience research by giving options for re-contextualizing the appropriate resilience type to the respective object of investigation. This allows for the concept of resilience to continue to evolve as disciplines begin to talk to each other and as practitioners discover new mechanisms for systems to recover from shocks they cannot avoid.

That does not mean that there is one best way to accomplish resilience, at least not at the moment. That is unlikely to be the immediate outcome of international, interdisciplinary, and inter-organizational efforts to deal with a wide variety of uncertainties. The first step in managing such an effort is to acknowledge all the potential opportunities and all possible difficulties. The next steps are to make the goal clear in each case, decide how success will be judged, and determine how (or if) the lessons learned in one place can be translated into another place or knowledge domain.

2 A BRIEF WALK IN THE DEFINITIONAL THICKET

Resilience: The action or an act of rebounding or springing back; rebound, recoil. 2. a. Elasticity; the power of resuming an original shape or position after compression, bending, etc. b. The energy per unit volume absorbed by material when it is subjected to strain; the value of the elastic limit. …. 5. The quality or fact of being able to recover quickly or easily from, resist being affected by, a misfortune, shock, illness, etc.; robustness; adaptability. Oxford English Dictionary

The English word “resilience” is derived from the Latin words resilire and salire, meaning to leap back, recoil, spring and spring again, re-flow, et cetera. Although, in general terms, resilience is often said to reflect any system’s response to change or forces outside itself, the evolution of the term across different disciplines and fields of application leads to a diverse and sometimes confusing definitional lexicon. An extensive review of the literature reveals that the word resilience has been used to indicate a metaphor, a capacity of a systems and a strategy to cope with uncertainty (Norris 2008). Several conceptual and review papers have been written to clarify resilience in various fields: Klein, Nicholls, and Thomalla (2003) review resilience in natural hazards, Brand and Jax (2007) in sustainability science, Norris et al. (2008) in community resilience, and Strunz (2012) has applied resilience into the vague/ precise concept debate in philosophy of science).

After looking at the definitions of resilience from a wide variety of disciplines one can see that they almost always contain the basic idea of bouncing back from challenges or dangers that the individual or system could not resist (stop from happening). It involves the survival or persistence of something over time even if there is a change, a surprise and/or uncertainty. In this section we give readers a brief look at how the word is used in several disciplines.

For materials scientists, resilience is an expression of how a material responds to external force by either bending or breaking. A material is either ductile or brittle. A resilient (or ductile) material can bend when force is applied and return to its original condition once that force is removed. The material will exhibit “stretching” along with unfolding and refolding at the molecular level. This is referred to as “reversible unfolding. The more tightly bound a substance is at the molecular level the more brittle it is.(Campbell, 2008). The strength of molecular bond is measurable and so the ability of the material to bounce back is predictable.

But not all systems are predictable. Engineers have attempted to deal with complex organizational structures that are intended to develop complex technology with Concurrent Engineering methods that integrate design, manufacturing and downstream uses. But the uncertainties in this process has lead some to analyze it as a complex system that must deal with surprises. (Wolfram 1986; Efatmaneshnik 2007) They have noted that some technological systems have high sensitivity to small perturbations – a characteristic of many chaotic systems and conclude that Complexity x Uncertainty = Fragility. (Efatmaneshnik 2007) Others have concluded that these systems must avoid optimum solutions because this implies hypersensitivity to small perturbations and therefore fragility (J. Marczyk 2002). In fact, optimization may not be a meaningful term in complex and adaptive systems where order emerges from uncertainty – especially if one is trying to encourage adaptation or innovation. (Holland 1998) For some resilience engineering scholars a system's resilience is represented by the adaptations necessary to cope with the real world complexity. (Nemeth 2009; 2008) Engineered systems resilience might be measured by the time it takes to return to appropriate functionality. Sometimes this will be to bounce back to system specifications and sometimes this will mean bouncing forward to a new, adapted system that can cope with changed conditions. (Woods 2006, Mendonca 2008)

For ecologists associated with the Resilience Alliance (noted above), resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. A resilient ecosystem can withstand shocks and rebuild itself when necessary. Resilience does not mean the system will look exactly like it did before the forest fire or the flood but many of the same species and their place in the ecosystem hierarchy will be preserved. It will still be a forest or a prairie even if the mix of species has changed. The ecosystem depends on the ability of individual species to adapt.

Authors studying the resilience of human organizations and human-technical systems organizations refer to organizational survival when encountering unexpected, adverse conditions that result either from large-scale disturbances or the accumulation of several minor disruptions (Vogus & Sutcliffe, 2007, Woods and Hollnagel 2006). Initial work on organizational resilience was undertaken by Weick (1993) who analyzed the behavior of a group of smoke jumpers in the Mann Gulch disaster and drew conclusions on factors contributing to organizational resilience, including an ability to improvise, virtual role systems, organizational wisdom, and respectful individual and social interaction.

Further work by Weick and his colleagues focused on how organizations find ways to deal with challenging conditions as they occur and before their effects escalate, rather than trying to prevent them from happening (e.g., Weick and Sutcliffe 2007, Weick & Roberts,1993; Weick, Sutcliffe, & Obstfeld, 1999). Their research suggested that resilience is brought about by the underlying stability of organizations (i.e., mindful processes of understanding, detecting, evaluating, and revising unexpected situations), which is leading to their reliability. This definition emphasizes the ability of organizations to rarely fail and maintain their performance despite encountering unexpected events. (Linnenluecke 2010) In other research, the resilience mechanisms or dimensions identified remain tied to specific functions of the organization or sub-functions within it. For example, Lengnick-Hall, Beck, and Lengnick-Hall (2011) wrote of strategic human resources management. M, Sheffi (2007) cited supply chain management and Riolli and Savicki (2003) discussed resilience in an information systems context.

The reader will have noted that there are clearly ideas that are common among one or more of these disciplines. In fact, there is some evidence that resilience is most likely to be found in systems that:

- Build the right amount of diversity and robustness for increasing options and spreading risk
- Increase their range of knowledge for learning and problem solving
- Create opportunities for self-organization, including strengthening local functions, building cross-scale links, and building problem-solving networks
- Organize with the right balance of tight and loose coupling
- Increase resilience at the right scale. (e.g., Berkes, 2007; Woods 2006; Dorner 1996; Longstaff, 2005)

For human organizations that are good at dealing with uncertainty:

"The traits of resilience include experience, intuition, improvisation, expecting the unexpected, examining preconceptions, thinking outside the box, and taking advantage of fortuitous events. Each trait is complimentary and each has the character of a two-edged sword." (Nemeth 2008, p. 7)

Therefore there is hope for some sort of definitional structure that is broad enough to allow for translation between them all even as we allow for the particulars to remain at the disciplinary level.

3 MULTIDISCIPLINARY RESILIENCE FRAMEWORK

There are two main differences that must be bridged in translating resilience ideas between disciplines. First, the various disciplines differ with regard to their assumptions about their system's potential for stability and equilibrium. Some have a Newtonian outlook (everything can be counted and predicted) while others take complexity/unpredictability outlook (the system has so many dimensions or variables that it is mathematically intractable and/or emergent properties that make prediction difficult or impossible) (Kauffman, 1995; Lewin & Regine, 1999; Mitleton-Kelly, 2003). And second, the degree of normativity (resilience as a coping capacity vs. a desirable outcome). The framework presented below puts these two differences in a framework that allows us to make some distinctions that are broad enough to find commonality put narrow enough to recognize differences. It is the contention of this paper that these fields are not mutually exclusive and that a fuller understanding of resilience would encapsulate many (if not all) of these views.

We have also differentiated resilience that is seen as a capacity or a capability of the system. The choice of these terms is somewhat arbitrary but reflects (we think) the most commonly understood ideas behind those words.[2] We use the term capability to denote human/animal skills that can be brought to bear on a challenge. The term capacity is used for anything you can hold/ measure. There are obviously no bright lines between the two because you can sometimes measure skills. But the distinction is worth noting because it affects how disciplines look at the systems they study and how they describe and (sometimes) measure what they call "resilience."

The Multidisciplinary Resilience Framework outlines four applications based on the differing fields of study. The boxes on the left of the Framework focus on system's level of complexity. In the upper box, the state of the system and the impact of a disturbance are both predictable and measurable. In the lower box the system has multiple possible states due to high levels of complexity/non-linear behavior and there are often high levels of uncertainty. Measurement and prediction in the bottom box is thus more problematic.

The boxes on the top of the matrix focus on the level of normativity that is applied to describing the resilience of a system, that is, the extent to which humans determine how things should be, how to value the state of the system, and which strategies are good or bad. Normativity can be contrasted with Positivity which is generally described as producing factual statements that attempt to describe reality.

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[2] The terms capacity, capability and ability are often used interchangeably. There appears to be much ambiguity surrounding which is future orientated. Some say capacity if potential and the deployment of you skills to be successful. See 2 contrasting sources:
http://northtemple.com/journal/2008/08/18/beethovens-heiligenstadt
http://www.des.emory.edu/mfp/AbilityCapability.html

With regard to computing the term seems to support the single and multiple equilibrium i.e. capability for single (simple) and capacity for multiple (complex):
http://www.appro.com/blog/capability-computing-vs-capacity-computing-what%E2%80%99s-the-difference-does-it-matter/

Degree of Normativity / Level of Complexity	**Low: Descriptive** ***Perception of Deviation:*** *symptoms of change and strain* ***Conceptual Orientation:*** *Outcome and capacity*	**High: Normative** ***Perception of Deviation****: To be avoided/reduced symptoms of adversity and inefficiencies* ***Conceptual Orientation****: Process and capability*
Low: Reductionism ***Aspect of stability:*** *Single State* ***Environmental characteristics:*** *Short-term, Linearity and Predictability* ***Dominant Logic:*** *Bounce back (absorb and recover)*	**(I) Capacity to rebound and recover** • Elasticity (capacity to absorb deformation[1]) • Rapidity/rate (**time required** to return to pre-defined state/normalcy[2]; • Robustness (resistance against perturbation)[3].	**(II) Capability to maintain desirable state:** • Maintaining systems identity and functions[9]; • Ability to withstand and recover within acceptable parameters[10];
High: Holism ***Aspect of stability:*** *Multiple States* ***Environmental characteristics:*** *Long-term; Non-Linearity and Uncertainty* ***Dominant Logic:*** *Bounce forward (adapt and transform)*	**III) Capacity to withstand stress** • Magnitude of disturbances[4]; • Elasticity threshold[5]; Transition probability between states[6]; • Emergent system property[7]; • Balanced contingency between system and its environment by adjustments[8].	**(IV) Capability to adapt and thrive:** • Inherent and adaptive responses to disasters[11]; • dynamic process encompassing positive adaptation within the context of significant adversity [12]; • Degree of capability to self-organize, adapt and learn[13].

1(Timmerman, 1981; Wildavsky, 1988), 2 (Pimm, 1984; Zobel, 2011), 3 (Antunes 2011; Grimm/Wessels 1997; Zobel 2011), 4 (Gunderson/Holling 2002; Holling 1996), 5(Folke et al., 2004; Walker 2004), 6 (Holling 1973; 2001; Brock et al., 2002), 7 (Boin/McConnell 2007), 8 (Lorenz 2010), 9 (Cumming, 2005; Walker/Salt 2006), 10 (Aiginger 2009; Aven 2011); 11 (Rose 2004), 12 (Luthar 2007), 13 (Carpenter, 2001 ; Folke 2006; Walker et al. 2002).

Figure. 2. *Multidisciplinary Resilience Framework*

Type I Resilience: The Capacity to rebound and recover (low complexity/low normativity): The systems/disciplines that fall in this box see resilience as a purely descriptive measure of elasticity against perturbations and the rapidity of the recovery to a pre-defined (usually intended) state. Resilience can be seen as a system property or measure of stability. This view of resilience is predominantly adopted in traditionally engineered and other designed systems. It is most feasible in situations where the normal system state is assumed to be a reliable (if not necessarily optimal) state for the system or the adaption of the previous system state toward an alternative state is too difficult in terms of time and/or costs.

Type II Resilience: The capability to maintain a desirable state (low complexity/high normativity) This is described in systems/disciplines that have a low level of complexity and focuses on the maintenance of some predetermined state or equilibrium that is judged to be either a desirable outcome or as a process of positive adjustments that leads the system back to that predetermined, desirable state. (Luthar et al., 2000; Matson & Gadgil, 2007). Predominantly employed in business, psychology and other social studies; resilience in these systems is regarded as something positive and bouncing back to an approved equilibrium proves the existence of resilience.

Type III resilience: The capacity of the systems to withstand stress The disciplines in this box often describe resilience as the relationship between the current system state and a potential system shift that will flip the system into a different state often called a "regime shift." The focus is on persistence thresholds. The distance between the current state and a potential flip is a measurable indicator of resilience levels. High resilience implies sufficient robustness and buffering capacity against a regime shift and/or the ability of system components to self-organize and adapt in face of fluctuations. If resilience is low, the system loses its original identity and moves toward a new regime or "basin of attraction." None of the potential system states or regimes is preferable to the system itself since it cannot make good/bad distinctions.

Type IV Resilience: The capability to adapt and thrive Resilience in social systems and psychology is often conceptualized as skill that an individual or group can bring to a disturbance that will allow it to reach a level of functionality that has been determined to be "good." Human beings and human systems have high complexity and a determination of what is good or "adaptive" in these systems is often highly high normative. The disciplines in this box acknowledge the existence of multiple possible states, but also explicitly call for a successful adaption before or after a disturbance occurs. This contrasts to Type II resilience, which focuses on a successful return to an assumed normal state. Hence, a positive adjustment can involve different desirable states ranging from a worse, but acceptable level to an even better post-disturbance state. Managing resilience as a normative activity or outcome involves human capabilities such as anticipation, sense-making and learning.

4 USING THE FRAMEWORK FOR TRANSLATION

The categories in the descriptive boxes of the framework will allow participants to ask questions about how the other participants see the level of complexity/ predictability of the system(s) they are trying to deal with. The framework will also help them discuss how they see the role of shared norms. A discussion of the four Resilience Types will further identify shared or differing goals (e.g., bounce back or bounce forward). So, for example, people in government are likely to be in category II with a high degree of normativity about outcomes and a seeking short-term, linearity and predictability for their actions. Engineers at the table may be less sure of predictability for anything that requires a human interface but less interested in the norms that applied to outcomes so they would be in category I or category III. Ecologists may be more comfortable with designing systems that can adapt so might be in category IV.

Once the similarities and differences have been identified the next steps are to make clear what the goal is in each case, how success will be judged (or measured), and how (or if) the lessons learned in one place can be translated into another place or knowledge domain. Does the problem require a capacity or a capability? Does the system have to be maintained as it is or should it be capable of adaptation? How will that adaptation be judged? Can the adaptation be designed in advance or will it have to emerge from the conditions that are presented? Once these questions are answered the group can narrow down its search for definitions and mechanisms that are found in similar systems to the Resilience Type they are dealing with.

Of course there is the possibility (and in some cases a likelihood) that a particular problem will involve multiple types of resilience. In those cases the role of translators becomes critical as two stems attempt to work in consort toward resilience for both without unanticipated harm to the other system. If the resilience of one requires the rules of the other to be ignored for a time how does that get decided and by whom? If action by one or both is called for in response to some danger (or opportunity) does this require the measurement of something that they measure differently? This does not require that the two systems (or disciplines or organizations) respect each other’s methods but it does require agreement on the goals and that they actually understand what the others are saying.

5 CONCLUSION

It seems certain that the need to find ways to make things bounce back will only continue to grow. The groups who come together to deal with these issues will only become more diverse. The framework proposed here allows researchers and practitioners from various disciplines and/or economic sectors to communicate and concentrate their efforts on specific types for resilience goals by allowing broad definitions where that is possible and identifying where specific definitions are necessary to deal with the issues at hand. The words used to designate these efforts will undoubtedly adapt, splinter into subgroups, and go in and out of fashion. Translation and translators will only become more important.

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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.

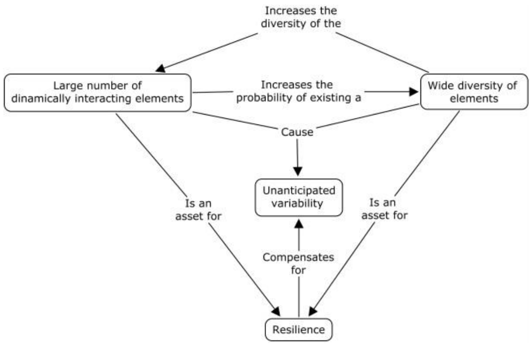

Figure 2. *Relationships among the characteristics of CSTSs (Saurin and Sosa, 2013)*

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).

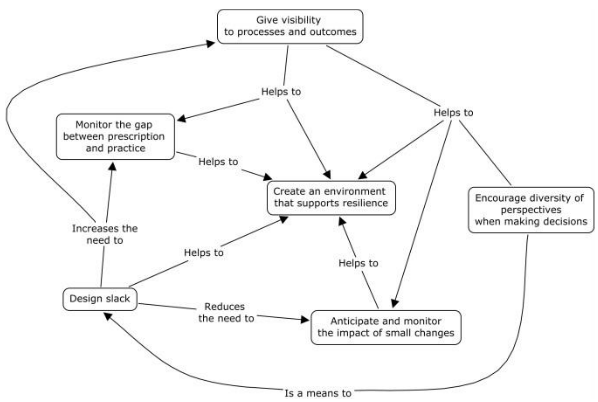

Figure 4. *Relationships among the guidelines for managing CSTSs (Saurin et al., 2013)*

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.

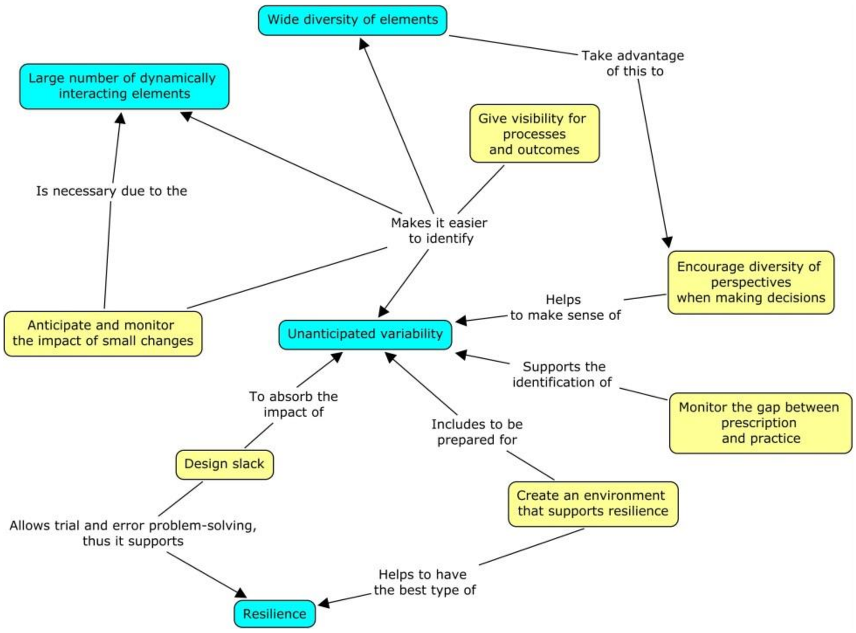

Figure 5. *Relationships among the guidelines and the characteristics of CSTSs*

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.

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The Stress-Strain Model of Resilience Operationalizes the Four Cornerstones of Resilience Engineering

David D. Woods,[1] Yong Jie Chan[2] and John Wreathall[3]
[1] The Ohio State University, Columbus OH, USA
woods.2@osu.edu
[2] Defense Science & Technology Agency, Singapore
cyongjie@gmail.com
[3] The Wreathwood Group, Columbus OH, USA
john@wreathall.com

Abstract

This paper presents the latest results on the Stress-Strain model of resilience and shows how the model provides a means to operationalize the four cornerstones of Resilience Engineering as proposed by Hollnagel and utilized in the Resilience Analysis Grid. The Stress-Strain model of resilience, originally proposed by Woods and Wreathall in 2006, addresses one of the original goals for Resilience Engineering -- how to assess brittleness of an organization or system. The model is based on a representation, in the tradition of plots of adaptive landscapes, that captures the relationship of demands or challenge events (what variations and events place stress on the system) and the ability of the system to draw on sources of adaptive capacity to respond to challenge events. The Stress-Strain model provides a framework for analysis to answer the key question -- how does a system stretch to handle surprises?

1 INTRODUCTION

One major family of approaches to Resilience Engineering defines resilience as the opposite of brittleness, or how to bring 'extra' adaptive capacity to bear in the face of potential for surprise (Woods, 2005; 2006). This approach juxtaposes brittleness versus graceful degradation and bases analysis of systems on the question: how do systems stretch to handle surprises. Without some capability to continue to stretch in the face of events that challenge boundaries, systems are more brittle than stakeholders realize. And all systems, however successful, have boundaries and experience events that fall outside these boundaries - surprises. Being prepared to adapt to handle surprise arises because there is always some rate and kind of events that occur to challenge the boundaries of more or less optimal. or more or less robust performance. Ironically, attempts to expand this envelope of base adaptive capacity (or competence envelope) shifts the kinds of events and the dynamics of events that will occur to challenge the new boundaries.

The field of Resilience Engineering needs to provide integrative models that can be used to analyze and track how an organization is functioning as an adaptive system. The Stress-Strain model of resilience (Woods and Wreathall; 2006; 2008) is one and is arguably the most complete. All of the key concepts, including the basic trade-offs (Woods, 2006; Hollnagel, 2009; Hoffman and Woods, 2011) and the four cornerstones of Resilience Engineering as proposed by Hollnagel (2008) and utilized in the Resilience Analysis Grid (Hollnagel, 2011) -- can be expressed in the notation and visualization the Stress-Strain model provides. The framework specifies anticipatory monitoring focused on the boundary area in the adaptive landscape, three forms of adaptive capacity to be called into action when events challenge boundaries, and two learning processes that should go on in parallel after organizations experience an adaptive shortfall. The Stress-Strain Model also provides a visualization for generating and tracking data about how an organization performs the four cornerstones of Resilience Engineering.

In the tradition of plots of adaptive landscapes (e.g., McGhee, 2007), the Stress-Strain model provides a representation that captures the relationship of demands or challenge events (what variations and events place stress on the system) and the ability of the system to respond to challenge events (Figures 1 and 2). As a landscape, the Stress-Strain model for a particular organization captures the split between its base and extra adaptive capacities and the potential for adaptive shortfalls to arise where responses cannot match the demands of challenge events that fall near or beyond the boundary area of the base envelope (the borderlands). The plot then captures how the system in question brings to bear extra adaptive capacity to handle events near or outside the boundaries of 'normal' functioning and allows systems to continue to respond to changing demands and meet some goals to some degree. The analysis shows how a system is capable, in advance, to handle classes of surprises or challenges (e.g., Finkel, 2011). Sources of resilience undergird this capability and providing and sustaining these sources has its own difficulties that arise from the need to manage fundamental trade-offs. This paper shows how the latest results on the stress-strain model of resilience provide a means to operationalize the four cornerstones of Resilience Engineering (Hollnagel, 2008).

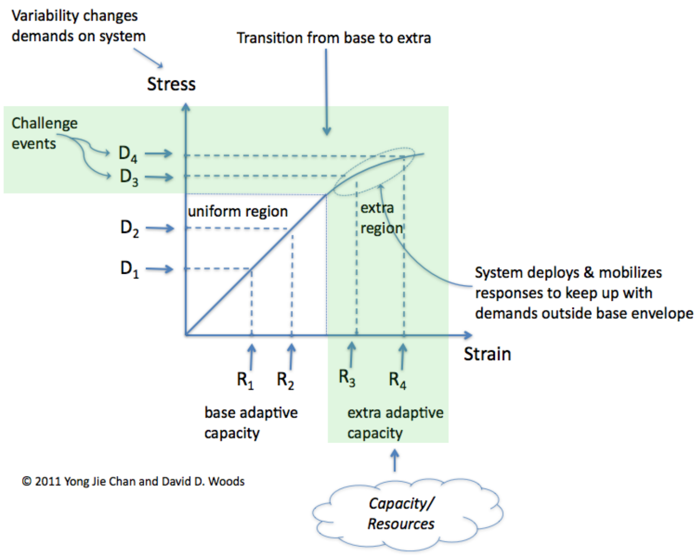

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Figure 1 *Adaptive Landscape Representating the Stress Strain Model. Basics of notation: Demand/Response relationship defines fitness; base and Extra AdaptiveCapacities regions are delineated.*

2 OPERATIONALIZING THE FOUR CORNERSTONES

2.1 The Cornerstones of Anticipation and Monitoring

One fundamental finding is that resilience (defined as stretching at and beyond boundaries) is based on the ability to anticipate potential bottlenecks or shortfalls ahead. Limits on the ability to do this means the system risks falling into one of the basic patterns of how adaptive systems fail. In particular, the ability to anticipate potential bottlenecks or shortfalls ahead is related to how a system exhausts its capacity to respond as challenges cascade or build -- as defined in the decompensation pattern of adaptive system failure (Cook and Rasmussen, 2005; Woods and Branlat, 2011).

The need to anticipate in order to keep up with changing patterns of demands and challenges provides a way to focus an organization's monitoring resources at the borderlands (Figure 2) between the organization's base adaptive capacity and its ability to bring extra adaptive capacity to bear to stretch performance in the face of smaller or larger surprises (see Woods, in preparation). Monitoring at the borderlands in an adaptive landscape representation of an organization's base and extra adaptive capacity provides a means to understand potential adaptive shortfalls.

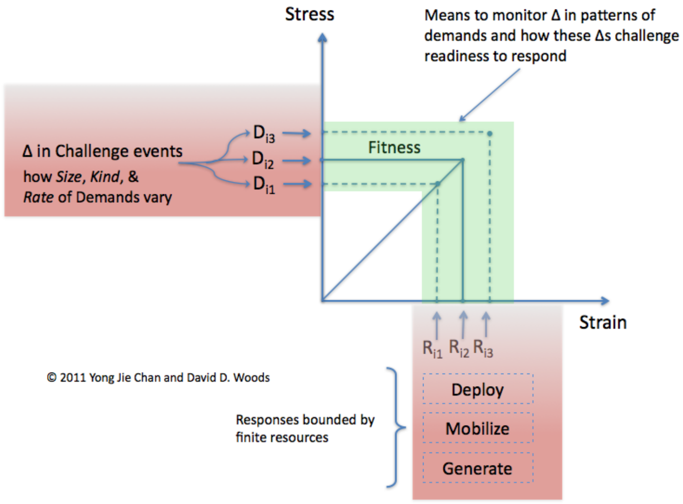

Figure 2. *Monitoring the Boundary area between Base and Extra Adaptive Capacities. This is a transition region since the boundary is neither crisp nor well understood (shaded area represents 'Borderlands' in the Fitness space). In the borderlands the potential for surprise (challenge events or variations that fall outside base capacity) could generate adaptive shortfalls (breakdowns in the ability to deploy/mobilize/generate responses to meet those challenges). The stress-strain landscape represents fitness as the ability to deploy, mobilize, or generate responses to keep up with changing patterns of demands.*

2.2 The Cornerstone of Responding

One of the cornerstones is -- Responding. The stress-strain model operationalizes this in terms of three processes -- how does the system deploy, mobilize, and generate responses to stretch to keep up with changing demands (Figure 2). Each of the three operates at different time scales and is poised to match resources (and therefore resource costs) to the expected rate of surprise. Settings with high expected experience of surprise (e.g., the emergency department or urban fire fighting) invest resources to be able to deploy extra adaptive capacity rapidly as situations present and cascade. Lower rates of experience of surprise may lead an organization to prepare to be able to mobilize resources to produce the needed capabilities to match challenge events (e.g., how hospitals in an area plan and prepare to handle mass casualty events such as the Aurora CO shooting victims). When the ability to track the shape of surprises to come is low, an organization may invest in the ability to generate new kinds of capabilities to match new kinds of challenges which are unanticipateable in advance while at the same time it is certain that future challenges will not match current base adaptive capabilities and even current capabilities to deploy extra adaptive capacity (Cook and Nemeth, 2006; or see the 1940 case of how George Marshall prepared the US Army officer core for the demands of future operations - Ricks, 2012).

2.3 The Cornerstone of Learning

Another of the cornerstones is -- Learning. The stress-strain model operationalizes this in terms of two parallel learning processes or loops. One learning loop concerns how the organization learns to expand base adaptive capacity given how it experiences an adaptive shortfall event and defines the experience of that shortfall (Figure 3). The very same experience of an adaptive shortfall event should also trigger a parallel learning loop that examines how extra adaptive capacity was brought to bear to try to continue to stretch function despite the shortfall (Figure 4). This learning loop looks at re-calibrating distant perspectives to better understand the shape of surprise in the borderlands, what the system actually draws on as sources of resilience when stretching at the borderlands, and the limits revealed about the ability to deploy or mobilize extra adaptive capacity for future challenge events. The two learning processes go on in parallel after organizations experience an adaptive shortfall. Supporting both learning loops is critical to avoid the situation where an organization can undermine, inadvertently over time, their own sources of resilience (e.g., as in the lead up to the Columbia accident) and inadvertently reinforce the risk of falling into one of the three basic patterns of adaptive system failure (Woods and Branlat, 2011).

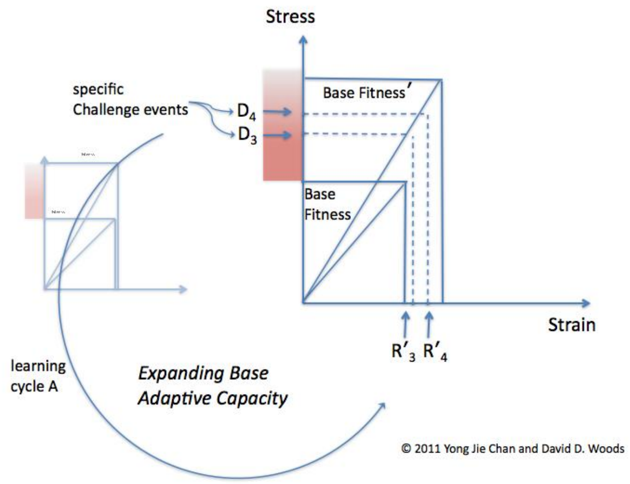

Figure 3. *Learning from Specific Surprises: Cycle A - Expanding Base Adaptive Capacity. Specific surprise events should trigger learning and change. In the figure specific new demands have been recognized outside previous base capacity, and new responses added to the base of plans to meet those new demands. Note, the new response capability, in this case, required new resource investments.*

3 SUMMARY

The Stress-Strain Model operationalizes the four cornerstones as:

- Monitoring at the borderlands in an adaptive landscape representation of an organization's base and extra adaptive capacity provides a means to understand potential adaptive shortfalls.
- Responding to kinds of surprise events, which are experienced as adaptive shortfalls, calls into action extra adaptive capacity. How extra capacities were deployed or mobilized provides a means to understand what capabilities need to be resourced and sustained to handle future surprise events.
- Learning from the experience of a smaller or larger, more or less critical adaptive shortfalls can lead to reframing of models of (a) actual base adaptive capacity, (b) the changing shape of surprise at the borderlands, and (c) reveals how extra adaptive capacity is brought to bear.
- Anticipation of risks of adaptive shortfalls and adaptive failures comes from feedback on the above three, in combination.
- The Stress-Strain Model, as a kind of representation of an adaptive landscape, then provides a visualization for generating and tracking data about how an organization performs the four cornerstones of resilience engineering.

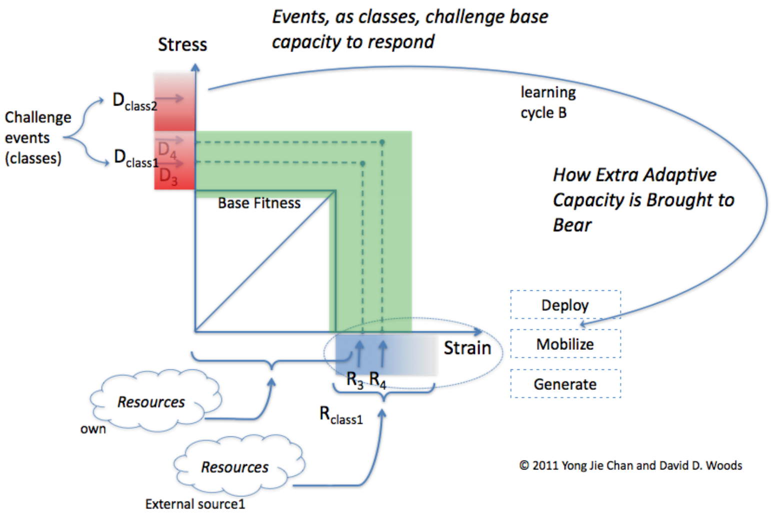

Figure 4. *Learning from The Shape of Surprise: Cycle B - How Extra Adaptive Capacity is Brought to Bear to Stretch to Accomodate Changing Demand. Responses to past challenges in the borderlands informs assessment of how the system brings extra adaptive capacity to bear relative to classes of challenges. This provides the basis to re-examine how the system develops, enhances, and sustains the ability to bring extra adaptive capacity to bear to handle surprise.*

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Turning Variability into Emergent Safety: the Resilience Matrix for Providing Strong Responses to Weak Signals

Fabrizio Bracco[1], Tommaso Francesco Piccinno[1] and Giorgio Dorigatti[2]
[1] DiSFor, Dept. of Educational Sciences,
Unit of Psychology - University of Genova, Italy
fabrizio.bracco@unige.it
piccinnotommaso@gmail.com
[2] Ormes Consulting srl
Genova , Italy
dorigattig@ormes.it

Abstract

Resilience is the ability to provide strong responses to weak signals. Weak signals are uncertain information that could be read as a warning of future changes, both mishaps and opportunities. They could be the first symptoms of a big change, but they are embedded in a variability that is hidden in normal operations and difficult to distinguish from random occurrences. We propose a model, the Resilience Matrix, which could help systems cope with these weak and potentially resonant signals by means of a cyclic information transfer along the system. Front-line operators should be able to notice weak signals, understanding how the current variability is a threat that is not mitigated by available procedures and barriers. This information should be shared and managed at the group level and then, if necessary, it should be transferred at the organizational level, where procedures and barriers should be formally redesigned according to the new information. These procedures should then be tested for their effectiveness at the group level and transferred as new skills for operators by means of training. This cycle is aimed at empowering people, groups and organizations, helping them to turn variability into a source for resilience.

1 INTRODUCTION

Resilience is usually defined as a system's ability to react and recover from a major mishap, safely continuing the core task of operations (Westrum, 2006). In this paper, we will focus on the proactive nature of resilience, considering it as the ability to pay attention to the ordinary variability of the system's components. The monitoring of this performance variability can prevent what Hollnagel (2004) defined as functional resonance, i.e. an unwanted outcome emerging from uncontrolled sources of entropy. We ground this proactive point of view on the ability to provide strong responses to weak signals (Weick and Sutcliffe, 2001). By weak signals we mean unclear information, hidden in the "normal" variability of system's elements, which could be considered as a warning of future resonance. Weak signals are sources of variability and could be read in foresight as the first signs or symptoms of a relevant change, while in hindsight they would be interpreted as unambiguous factors that triggered the accident causal chain. However, weak signals are not always clues about future events, and here is one of the main trade-offs of system's managers at every level: how to notice and cope with those signals that are most likely to evolve into a functional resonance? A second trade-off concerns who is in charge to act upon these signals: at which system level should the actors respond? A third trade-off is related to the adaptation to the cultural background of the system: how radical should be the cultural change imposed to system to enhance its resilience? If it were too drastic the system could trigger a counteraction, if it were too mild the system could not develop any resilience.

2 THE RESILIENCE MATRIX

Here we present a model of Organizational Resilience called the Resilience Matrix, combining both the category of signals trade-off, and actors trade-off. It is a 3x3 matrix that can be sketched on an orthogonal plane having "signal variability" on the y axis and "actors that should provide a response" on the x axis (individual, group or organization). The plane can be divided into nine sectors each of which representing a different response a system could provide, taking into account the specific signal and the actor. We argue that system resilience could emerge from the proper information flow along all these sectors. Taking into account the Resilience Matrix, we can see along the y axis the continuum of signal's variability and tractability. As stated by Hollnagel (2012, 14) "in order to do their work, people – individually and collectively – must therefore adjust what they do to match the conditions”. This means that practitioners’ performance will change according to the kind of signals they are dealing with. We propose to match the Skill-Rule-Knowledge (SRK) hierarchy by Rasmussen (1983) with the tractable-intractable continuum by Hollnagel (2004). Either single workers or groups or the organization, could be engaged in the management of these tractable or intractable signals.

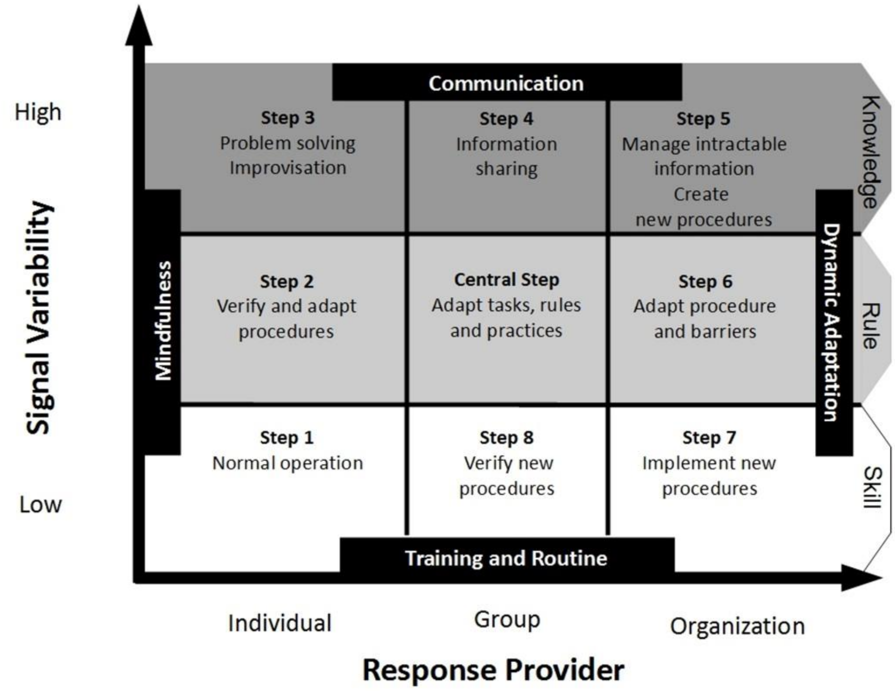

Figure 1. *The Resilience Matrix*

When the signals to be managed are tractable, known, and predictable, it is sufficient to carry out the well-learned and automatized procedures at the Skill level. In other circumstances signals are variable but also containable within the ordinary performance, their variability is predictable and the procedures can be effective in damping down on it. This condition could be performed at the Rule level. When the signals are intractable, operators should perform more complex cognitive processes, in order to activate the adequate problem solving strategy for the novel and unpredicted situation. In this third kind of situation we are at the Knowledge level. Those involved in the management of the signals (whether persons, groups or the whole organization), should find a balance between a fast, efficient, rigid, and automatized Skill-based coping, and a resource-demanding Knowledge-based level, where the flexibility is necessary to cope with the signals’ variability and intractability. This balance has been well described with the Efficiency-Thoroughness-Trade-Off (Hollnagel, 2009), where the very nature of complex systems requires the operators to be aware of their position in between these two extremes. As will be described later, this balance is the core of the first trade-off: how to respond to those weak signals that will probably develop into a functional resonance, without wasting resources in chasing every kind of signal? It is trivial to say that everybody want to save resources when possible.

The X axis is concerning the actors involved in the management of the signals. They could be single operators, or groups or the organization itself. Each actor has a different perspective on the system, different power of action and functions. At the single operator level, the front-line practitioners notice weak signals sooner than at the other levels. They are the most sensitive “detectors” of variability, but they are also limited in their power of action and they could cope with the intractable events just in the current situation. If a stronger and more accurate response is needed, they must move the signal management at the group level. The team is able to analyze and discuss about signals variability, and it could modify internal procedures, rules and activities, in order to take into account the new source of variability. However, the group is limited in its power of action if the resonance control requires a higher management, at the organizational level. At this further level the information concerning weak signals is deeply analyzed and it is possible to provide even big structural changes. However, it has the limit to be slower than the other levels to provide a response and it cannot process every kind of signals. This means that individuals and groups should be trained to report to the organizational level just those signals that they consider to be potential threats that they cannot manage at their level. This is the core of the second trade-off we presented: who is in charge to act upon these signals? How should they process it? The proper response provider should intervene according to the kind of signal, single operators for quick and easy management, groups for deeper revision of procedures, the organization for wider changes that require a broad view over the system's dynamics.

At this point, we can describe the nine steps that, in our view, characterize the cycle for enhancing safety along the matrix. The beginning of the resilience cycle takes place at the single operator's level, performing skill-based control of tractable signals (step 1). The complex system is characterized by unpredictable variety, but this could be tractable within the available procedures. Therefore the operators could move to the Rule-based management of variable but tractable signals (step 2). If the signals become more and more intractable, the single operator will be able to move from the Rule to the Knowledge level, when facing intractable and variable situations (step 3). This will need a good capacity to notice the unpredicted source of variability and its potential functional resonance with other elements in the system. Practitioners could cope with them looking for a solution by themselves, but it is generally better to share this information with the other actors of the system (step 4). At this point the group should decide the right path. If the signal variability is concerning work-group procedures and habits, it is possible to adapt tasks, rules and practices to the new information (central step) and move to the implementation of the new procedures in the everyday practices (step 8), going back to Skill-based management of now tractable signals. Otherwise if the group acknowledges that the intractable signal involves procedures, tasks and resources that can be controllable only at a higher level, it will move the information to the organization (step 5). Here the organization is involved in the management of new and intractable information coming from the group and it needs to devote resources to accomplish this. The effort is high and the organization cannot endure too much at this level, since it needs to find new barriers (physical, normative, technological) and constraints adapting the procedures or creating new ones. This lets the organization move from the Knowledge to the Rule level (step 6). When the procedures have been enriched in order to cope with the weak signals, the organization can move to the Skill level and monitor the implementation of these solutions (step 7). Here the group will provide feedbacks about the manageability of the solutions, the possibility to transfer them into the skills of the workers (step 8). The resilience cycle ends when the new variety is embedded into the barriers, procedures, and practices, it is normalized and will become part of the operational skills of front-line operators. These are the nine steps of Resilience Matrix: the eight steps turning around the central step. The rationale of the Matrix is that a real resilience is an emergent property of a system where all the actors are involved in the right way, acting upon the right kind of signals. Every actor is part of an information flow along the system, enabling it to eventually provide strong responses to weak signals.

3 TRADE-OFFS, BLAME CULTURE AND RESILIENCE

In this paper we propose a model to cope with several trade-offs. First of all, the system is engaged in the dilemma concerning what the “right” weak signals are, i.e. how to recognize those signals that could develop into a functional resonance. Escaping the hindsight bias, righteousness concerns the signals that are collectively considered potentially resonant, given past experiences and system properties. This collective mindfulness is only achievable by means of trust and open information sharing among the group members. Nothing but shared experience, reflection about practices, open discussion stimulating the requisite imagination can allow people to become sensitive to potentially resonant signals. A resilient system should adopt an analysis method able to take into account this complexity in order to provide strong and effective responses. This is the only way to prevent mishaps.

A resilience culture will enable the system to cope with another trade-off: which actor should intervene in a certain situation? Complex systems should be able to cope with different signals and to identify the correct actors to provide a response. The sharp end is where variability can be detected, but the group and the organization levels are where these signals should be treated and mitigated. There are several factors that could block a free movement from the single to the group and the organization level. For instance, a lack in the Informed Culture, a bad communication among group members could inhibit a free sharing of information concerning weak signals, and this will decrease the capacity of the group to foresee threats. A rigid and bureaucratic organization could impair the development of the decision making process from the group to the organization level. This will affect the Learning and Flexible Culture. The movement along the steps in the Resilience Matrix is promoted by the Just Culture, enabling a shared responsibility, an effective information circulation, a Reporting Culture and a flexible adaptation of barriers and procedures to prevent the functional resonance. In a resilient system there should be no fear to be punished, both economically and socially, and people would share their information and openly communicate. In this way, it would be possible to move, on the X axis of the matrix, from the individual level to the group level and to cope more effectively with intractable events.

A third trade-off is the one between the new culture we wanted to enhance and the traditional Italian work culture, biased by blame and hindsight, together with a legislation which is oriented to the search for individual responsibilities. In cultural anthropology, there is a difference between the shame society and the guilt society (Benedict, 1947). The shame culture has typical traits of eastern countries and, in some way, of Anglo-Saxon and north-European countries. It controls people's behavior by forcing them to protect their reputation and avoid the shame after some deviant or inappropriate action. It tends to promote a strong introjection of the norm and reinforce a sense of shared responsibility. This could be the proper cultural ground for Resilience culture to grow, based on mutual trust, openness, and commitment. The guilt society is grounded on the creation and the reinforcement of the expectation of a punishment after a specific forbidden behavior. The Italian cultural model seems to be closer to the guilt society, where the Blame Culture present in many organizations reinforces the search for a scapegoat. This work context makes people afraid of taking responsibilities, they try to do as little as possible because the less they do, the lower the probability to be blamed will be. Moreover, system safety is perceived as something depending on others, they do not feel in charge of taking care of it, they perceive safety as something to accomplish just to avoid punishment. After a mishap, this kind of culture will look for the scapegoat, there will not be any organizational analysis, it will provide more stringent rules directed towards the punishment of human errors and violations, making the system more rigid. As a consequence, these additional rules and rigidity will make it even harder to work. In order to promote Resilience Engineering in an Italian organization, it should be necessary to cope with a political, cultural and normative system that lead people to adopt the opposite behaviour, where the legislation and the organization of work and safety are almost incompatible with this new perspective. In our view, this is the major challenge to face in the promotion of Resilience Engineering in Italy.

4 PUTTING THE RESILIENCE MATRIX INTO PRACTICE

As a practical example of the implementation of the Resilience matrix and the coping with the three trade-offs we just described, we present a resilience engineering project developed in an Italian chemical plant department. The intervention was aimed at increasing the safety of the department without reducing its productivity and promoting operator's well-being. The project also wanted to enhance proactive behaviors towards weak signals in the three kinds of respondents: individuals, groups and organization. At the individual level we trained operators to notice and report weak signals in their operational context, discussing human performance variability, procedures and barriers effectiveness and developing the requisite imagination to foresee possible sources for resonance, looking at the variability from the sharp-end point of view. Moreover, we highlighted the importance of an internal locus of control about safety and we linked the increase of responsibility with the increase of power of action of every practitioner. At the group level we focused on reporting procedures, shared tutoring, providing tools and contexts for information sharing, and group's problem solving and decision making skills. We aimed at improving communication skills, we showed the biases of hindsight analyses of accidents and we discussed about the nature and effects of a blame culture. In addition, we tried to promote a group-based mutual support of practitioners, helping them to cope with stress and lack of motivation. At the organizational level, an intranet interactive platform was developed for collecting salient information to increase safety and a Resilience Engineering Program was planned to implement responses for the most relevant warnings. In addition, we linked safety and well-being, providing the organizational level with some hints about the development of a safety culture ad the decrease of the organizational cynicism among workers. The intervention is still in progress but operators' high involvement into the program and the positive feedbacks of operators and management are encouraging "strong" signals of a cultural change.

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Interactions across Multiple Centres of Control
An Airline Operations Control Perspective

Kenneth E. Igbo[1], Peter G. Higgins[1], Simon Dunstall[2] and Peter J. Bruce[1]
[1] Swinburne University of Technology, PO Box 218 Hawthorn VIC 3122, Australia
kigbo@swin.edu.au, phiggins@swin.edu.au, pbruce@swin.edu.au
[2] CSIRO Mathematics Informatics & Statistics, Locked Bag 10 Clayton South VIC 3169, Australia
simon.dunstall@csiro.au

Abstract

This paper elucidates the driving forces that shape a unit's choice of adaptive strategies. It is based on a two-stage field research conducted at four airline IOCCs. A total of 18 experts were both interviewed and observed across the IOCCs studied. In many aspects, the findings reiterate that human adaptive systems need a cooperative culture and structure in order to adapt formalised procedures across functions; particularly, in the face of myriad internal constraints and external pressures. On a rather interesting twist, evidence suggests that cooperative adaptation is not always preferred when managing trade-offs at the IOCCs. Building on the three locally adapted strategies proposed by Stephens and colleagues (2011) – cooperative, defensive and autonomous, we have found a fourth, *protective strategy*. The findings should be useful in advancing our understanding of trade-off dynamics that are context-specific and the ones that are shared across the broader human adaptive systems. Our position is that it is not whether adaptation is defensive, cooperative, protective or autonomous that determines its effectiveness. Rather, it is the extent that an adaptive strategy allows decision makers to effectively manage trade-offs to achieve a better overall outcome given prevailing circumstances.

1 INTRODUCTION

Strategies employ by individual actors and autonomous functions have been applied extensively in discourses relating to resilient modes of reorganisation (Cook, 2006; Cook & Rasmussen, 2005), management of risks and abnormal situations (Malakis, Kontogiannis & Kirwan, 2010; Woods & Wreathall, 2003; Reasons, 2008), and basic trade-offs in human adaptive systems (Hoffman & Woods, 2011; Hollnagel, 2009; Woods & Branlat, 2011). A recent study (Stephen et al., 2011) discusses a set of strategies—cooperative, defensive and autonomous—use by units in regulating horizontal interactions across multiple centres of control. This paper advances our knowledge of locally adapted strategies in human adaptive system by mapping these findings to the specifics of airline operations control. It delineates how specific events and the unique characteristics of the airline Integrated Operations Control Centre (IOCCs) shape a unit's choice of adaptive strategies. In particular, this paper examines external forces at play in the broader air transport system. The main intention is to elucidate how external pressures shape both horizontal and cross-scale (vertical) interactions at the IOCCs; at the same time, shed light on how resultant cross-scale interactions influence horizontal adaptive behaviours, particularly during *escalating situations* (Bergstrom, Petersen & Dahlstrom, 2011).

2 REGULATING INTERACTIONS ACROSS AIRLINE FUNCTIONS

Airline operations control, given its highly dynamic and distributed nature, is often characterised by goals that are dynamically changing or locally adapted across multiple centres of control. Governance is typically distributed across autonomous functions that possess specialised expertise in dealing with specific aspects of the operation (Clarke, 1998). Regulating interactions across functions presents interesting challenges because each centre possesses 'partial authority, partial autonomy and partial responsibility' (Ostrom, 1990) in relation to the extent they can adapt overall operational goals and activities. Complex interdependence between key resources controlled by the different centres further exacerbates the challenge to adapt planned operations, particularly in the event of unforeseen disruptions (see Abdelghany et al., 2008; Clausen et al., 2010). Clearly, managing such reciprocal dependency, often under severe economic pressures and time restrictions, necessitates that decision-making protocols reflect the intrinsic complexities of interactions across multiple centres of control.

This paper is based on a two-stage field research conducted at four airline IOCCs. The first-stage involved brief discussion and observation sessions and lasted approximately three hours for each study site visited. Second-stage visits involved in-depth exploration of themes put together from field memos and literature review in several 45-mins-interview and 2-hour observation sessions. A total of 18 experts were both interviewed and observed across the IOCCs studied. Their current roles and previous experiences span key functions including aircraft control (ops-control), crew control, dispatch, maintenance watch, passenger recovery, port operations, and senior management. As the centre of operations control, most part of this study focuses on interactions between the ops-controllers and other actors at the IOCC. The field notes and interview transcripts were coded inductively to identify the driving forces that shape the adoption of specific strategies at the IOCCs studied. The findings are linked deductively to the discourse on “locally adapted strategies” and “teamwork strategies” in human adaptive systems (Cook, 2006; Malakis, Kontogiannis & Kirwan, 2010; Stephens et al., 2011) to provide a broader explanation beyond the specific case studied. The following sections present key factors that exert influence on the adaptive style employ at the IOCCs.

2.1 Mutual Beliefs, Shared Intentions and Interdependent Resources

Autonomous units tend to show willingness to cooperate when there is interdependence between resources controlled by different centres. Based on our findings, decision-makers at the IOCCs broadly agree that it is rather a rule than an exception for units that control interdependent resources to sacrifice their local margin for an anticipated better global outcome. This consensus was linked to the belief that it is hard to extricate the performance of one centre from the system’s global outcome.

The willingness to cooperate has also been linked to one’s interpretation of and trust in other’s reputation (Ostrom, 2003), intentions and beliefs (Meggle, 2001; Tuomela, 1995). While internal beliefs are hard to capture in most cases, evidence suggests that the participants gained understanding of each other’s beliefs through *shared intentions* (Bratman, 1993). A specific event was observed that captures the interplay between interdependent resources, shared intentions and *mutual beliefs* (Colombetti, 1993; Tuomela, 1995). In this event, a crewing officer requested a 35-minutes delay so a reserve crew could be flown to another port to replace a sick crew. The ops-controller obliged without hesitation in spite of the obvious negative effect the request would have on current flight’s punctuality performance. The reasoning, as described by the ops-controller, was based on the belief that the borrowed margin was for the greater good of the system rather than for own benefits. By cooperating with the crewing officer, the ops-controller was able to avert cancellation of two flight legs and potential cascade of cancellations.

In airline operations, tight coupling of system resources leads to a high level of interdependent operational activities. A direct consequence of this tight interaction is that the interconnected web of activities makes it difficult to extricate one centre’s performance from the others. Therefore, we surmise that the tight coupling of system resources and the emergent socio-cognitive mechanisms of positive mutual beliefs and shared intentions promote *reciprocity* (Ostrom, 2003), which in turn encourage autonomous functions to adopt *cooperative* strategies.

2.2 Shared Referents and Clearly Defined Basis for Cross-Functional Adaptation

In order to maintain *situational awareness* (Endsley, 1995) of the state of the system, ops-controllers source and effectively make use of most current operational information across functions that are involved in tactical operations control. Nevertheless, as captured in the framework of generic competencies for handling complex and escalating events (Bergstrom, Petersen & Dahlstrom, 2011), autonomous units need more than just a means of sharing information to be able to cope amidst escalating demands. To guarantee readiness to respond as new information surfaces, autonomous functions need a common referent and clearly defined basis for negotiating and adapting plans (Hollnagel, 2011, pp. 284-287).

Decision-makers across functions were observed using explicitly defined criteria to create mutual understanding. Updates were periodically displayed on a whiteboard requesting all units to work towards a common goal. Themes that were displayed include “protect OTP” (on-time performance), “maximise slot allocations”, and “passengers first”. The need to have a common set of evidence as a basis for revising plans is also evident in the findings of the study that examine Swedish railway tunnel projects (Cedergren, 2011). Therefore, we posit that sharing common and explicitly defined referents fosters the creation of *common ground* (Klein et al., 2005) and a shift towards more *cooperative* strategies.

2.3 Lack of Time and the Dynamic Nature of Airline Operations

Airlines operate in a highly *fluid* and competitive business environment, which necessitates that fast and fiscally sound decisions must be deployed within a reasonable timeframe. A delayed decision may no longer be feasible at the time of implementation because the relationships between resources are constantly changing over time and space. Therefore, decision-making must be quick, pragmatic, responsive to change, and above all amenable to myriad conflicting constraints. Consequently, satisficing decisions, which could be easily iterated over time and space, are often preferred over “one-off” optimised decisions at the IOCC (see a related discussion in Hollnagel & Woods, 2006, p. 355).

While reflecting on the dilemma pose by the interplay between time criticality and the dynamic relationship between airline system resources, a participant used the term *command-and-control* to describe a strategy “…that gets the job done…” when there are too many variables to negotiate, particularly when time is critical. Although all participants did not explicitly share this position, there seems to be an implicit agreement, based on their reflections, that command-and-control does allow for quick, approximate solutions to be deployed, which are later iterated. Specifically, the more experienced participants tend to support the idea that command-and-control expedites decision-making processes. Some openly argue that command-and-control is probably a more attractive strategy to adopt during high-risk events or when a decision of ‘high importance’ is to be made within critical timeframe. Thus, we postulate that the interplay between complex decision variables, time criticality, and the dynamic relationships between system resources often influence higher-echelon governance to initiate a *command-and-control* procedure for horizontal adaptations.

2.4 Awareness of Risks and Commitment to Safety

Internal safety regulation was also found to be one of the driving forces that shape the choice of adaptive strategy across functions at the IOCCs. The role of engineering maintenance as guardian of maintenance schedules of aircraft necessitates a fully autonomous unit that has full authority to initiate and implement aircraft maintenance decisions and activities. Engineering maintenance is typically consulted when safety issues arise regardless of how trivial the case might seem (see Dekker, 2007; Hale & Swuste, 1998). Based on the needs to maintain a constant sense of unease (Hollnagel & Woods, 2006, pp. 355-356) and to remain sensitive to the possibility of failure in safety-critical systems (Hollnagel, Nemeth & Dekker, 2008), a maintenance engineer argues that it is indeed criminal for maintenance watch to base safety decisions on uncontested assumptions or be unduly influenced by other considerations. With this understanding, the engineering maintenance departments see themselves as internal regulators or “watchdogs” when balancing trade-off between safety and many other pressures at the IOCCs.

A specific case was recounted where a ground operator reported a supposedly scratch near the engine of an aircraft caused by collision with a fuelling truck. On chasing up this information, maintenance watch found that it was actually a dent that might have compromised the structural integrity of the aircraft. Consequently, maintenance watch grounded the aircraft for further assessment despite the lack of spare aircraft at the port to continue the operation. The participant further noted that issues of unplanned maintenance checks require an independent assessment of the risks involved with minimal influence from units that shoulder other responsibilities in addition to safety. In parallel, a maintenance engineer (at a different airline) highlights that maintenance units typically coordinate scheduled aircraft maintenance with strategic planning and operations control units. However, the participant emphasised that maintenance watch reserves the rights to ground an aircraft as long as is necessary until the aircraft is deemed fit for duty again.

The common denominator in the accounts narrated by both participants is that maintenance units largely exercise autonomy in their assessment of risks to safe aircraft operations. Therefore, we assert that the need to regulate risk-taking behaviours and to guarantee that an operational system is not drifting precariously towards its boundary of safe operation would often compel functions that exercise regulatory powers over others to lean toward *autonomous* strategies.

2.5 Pressure to Remain Competitive

In efforts to remain competitive following the deregulation of air transport industry, airlines devised a number of strategies for dealing with competitors and other organisations within the broader air transport system (Holloway, 2008; Williams, 1994). The expensive nature of resources and equipment needed for seamless operations often necessitates pooling of resources and reciprocal sharing of resources for mutual benefit (Pilarski, 2007). For example, airlines largely cooperate with other carriers for key services at out-of-station ports, including catering, check-in, maintenance and ground service operations (Wu, 2010). It is not uncommon for airlines to engage the services of other carriers during major disruptions to recover their crew and passenger schedules (Wu, 2010).

Nonetheless, the pressure to survive the extreme competitiveness of the industry often pushes airlines to adopt more *defensive* strategies (Williams, 1994). This is typically reflected in practices, such as hoarding landing/take-off slots and initiating policies and practices that favour local airlines over non-local carriers at home ports (Holloway, 2008). Anecdotal evidence suggests that during critical incidents, airlines often give priority to variables that has the potential to damage their reputation, whether they relate to safety, political or economic factors. In most cases, sacrificing decisions are made where necessary to protect a company's reputation.

Another event was recounted that depicts how a committee that reviews business strategies during critical incidents influenced an operational decision to continue flight operations into a region that has lost economic attractiveness at the peak of a political upheaval. Beyond imminent financial losses due to reduced passenger traffic, the committee identified potential risks to business relationship with the government. Also, the committee was compelled to void the decision to discontinue flights given the broader impact a damaged business relationship could have on the airline reputation in that region.

Protective strategy is frequently evident in the way airlines offer generous reimbursements and free flights in efforts to save their reputation and customer base after major incidents, such as computer glitches, booking system failures, union strikes, etc. (Park, Robertson & Wu, 2006). In resilience engineering parlance, a protective approach represents a situation where priority is given to chronic goals (e.g., long-term customer goodwill) over short-term gains (acute goal). Therefore, we posit that the pressure to sustain competitive advantage amidst high operating costs (Pilarski, 2007), as well as myriad political and regulatory factors often trigger a shift toward *defensive* and *protective* strategies.

3 DISCUSSION

This paper sheds light on the driving forces behind a unit's choice of adaptive strategies, with particular focus on how internal constraints (e.g., interdependent resources, time criticality and safety) and external drivers (e.g., regulatory, economic and political forces) shape the adoption of specific strategies. Collectively, both the specific events observed and the unique dynamics of airline operations control highlight the characteristics of these compelling factors when regulating both inter-organisational and intra-organisational interactions.

In many aspects, the findings reiterate that human adaptive systems need a cooperative culture and structure in order to adapt formalised procedures across functions; particularly, in the face of myriad internal constraints and external pressures. The tight coupling of system resources underscores a key motivation that compels functions to cooperate, in that it is hard to extricate one unit's performance from the performance of other units. Cooperative adaptation is more likely in units that share symbiotic relationships, where individual actors share mutual beliefs of one's positive affect towards the other (Meegle, 2001; Tuomela, 1995); and perhaps, shared intentions to cooperate as well (Bratman, 1993). On the contrary, units that share only unidirectional (one-way) interaction may likely lean toward autonomous or defensive strategies.

Nevertheless, having highly interdependent resources alone may not be enough to yield satisfactory results when teams cooperate toward a common goal. The need for quick reorganisation not only necessitates easily accessible means of acquiring, communicating and validating information (Bergstrom, Petersen & Dahlstrom, 2011), but also a clearly defined referent in order to guarantee readiness to adapt plans across functions in the face of surprises. Thus, our results give support to the postulation that cooperating functions need a common referent and clearly defined basis for activating responses (Hollnagel, 2011).

On a rather interesting twist, evidence was found to suggest that cooperative adaptation is not always preferred when managing trade-offs at the IOCCs. This twist reflects the necessity to implement a course of action under severe time constraints (Hollnagel & Woods, 2006, p. 355); particularly, when managing complex network of interdependencies relating to resources and performance variables controlled by different units.

More specifically, command-and-control has been found to expedite decision-making processes, when there are too many variables to negotiate; when time is critical; or when safety, regulatory or political issues are involved. It is also interesting to note that command-and-control strategy is mainly deployed during extreme or high risks negotiations between specialized units and traditional functions than during routine, horizontal resource regulations across traditional functions. The attractiveness of command-and-control strategy appears to go beyond the military and airline operations control. We found that command-and-control strategy is one of many coordination mechanisms use by the Australian Health Protection Committee for dealing with health related emergencies involving multi-party cooperation (pp. 6-7).

Likewise, autonomous adaptation appears particularly significant in airline operations control. Evidence suggests that autonomous modes of adaptation are well suited for internal safety-regulation purposes (Hale & Swuste, 1998). Units deploy autonomous regulation to checkmate a system-wide risk taking behaviours, particularly when there is a need to ensure a system is not drifting precariously towards its boundary of safe operation. Given the need to remain sensitive to the possibility of failure in aviation (Hollnagel, Nemeth & Dekker, 2008), having an internal regulation mechanism or unit will likely improve a system's ability to monitor its position in relation to its boundary of acceptable performance. The structural relationship between safety-regulatory units and other units parallels what is obtainable in the financial world, where some agencies are set up to regulate transactions within the financial market.

By mapping the three strategies suggested by Stephens and colleagues (2011) into an airline operations control context, we have found a fourth, *protective strategy* (possibly, a variant of autonomous/defensive strategy), which decision-makers employ to reorganise their margin when faced with very tough choices that have broader implications than immediate operational losses. While defensive and protective strategies share a lot in common, protective strategy encompasses both restrictive and sacrificing approaches mainly tuned towards survival of the system in the long term. Perhaps it is more appropriate to describe protective strategies as damage control procedures, which are mainly activated when there is need to address critical issues that would otherwise impact negatively on an organisation's reputation. Defensive strategy, on the other hand, is deployed purely to create monopoly power (Holloway, 2008, pp. 157-161) or competitive advantage by restricting opportunities of others (e.g., competitors) to gain market share (Williams, 1994). Although there was not enough evidence found in this study to suggest that defensive strategy applies within airline functions, we suppose our inability to capture a defensive mechanism *in situ* may be linked to the limited access that was allowed for this study. Nonetheless, issues of mistrust have been a long-standing problem in the broader airline industry since deregulation (Congress of the US Senate, July 27, 2000). The presence of mistrust is clearly evident in subtle defensive approaches adopted by airlines, especially when responding to competitor's pricing and revenue management (see Holloway, 2008, pp. 125-190 for a detail discussion on these strategies).

4 A CONCEPTUAL CHALLENGE AND FUTURE RESEARCH

In general, we surmise that different modes of adaptation are best suited for managing different forms of trade-offs under different circumstances. The challenge for both researchers and practitioners, therefore, is to ascertain contextual mechanisms that support the effectiveness of specific modes of adaptation when managing specific trade-offs in varied contexts. Whilst the discussions might have suggested that the different adaptive strategies operate as discrete strategies, it is important to note that these strategies actually operate within a continuum. For instance, an adaptive strategy deployed by a unit would more likely encompass a mix of cooperative, autonomous, defensive or protective behaviours; at the same time, project one or more as prominent trait(s). Future research should aim to formalise the defining attributes and dimensions within each strategy. A conceptual challenge at the moment is whether command-and-control can be categorised as a separate strategy or whether it can be classified as an autonomous, defensive, cooperative or protective strategy.

The findings presented in this study should be useful in advancing our understanding of why units prefer specific kinds of locally adapted behaviours over others. They also elucidate common denominators that managing trade-offs at the IOCC may share with the broader human adaptive systems. Research is continuing to ascertain possible links between a unit's choice of adaptive strategy and the nature of trade-off. Such insights should provide a framework for delineating underlying structures, culture and practices that support decision makers to adapt formalised procedures *in-flight*, while managing many-to-many mappings across conflicting goals, roles, and responsibilities.

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Episodic Adaptations and Trade-offs: Examples From the Victorian Construction Industry

Manikam Pillay[1] and David Borys[1, 2]
[1] School of Health Sciences, University of Ballarat, Australia
pillay.manikam@gmail.com
[2] VIOSH, University of Ballarat, Australia
d.borys@ballarat.edu.au

Abstract

A central facet of resilience engineering involves adaptation which involves making temporal adjustments by responding, monitoring, anticipation and learning from disturbances and continuous stressors. This ability to adapt is inherent in the behaviors and actions of individuals and teams as they respond to regular and irregular threats in a manner such that work continues to operate as normal. Invariably, these adaptations also require trade-offs and sacrifices by individuals and teams. However, there is little published research that seeks to explain how such adaptations actually occur in construction works, especially where the duration of the works can be short. Recent research suggests that resilience manifests as episodic adaptations comprised of 'cluster of potentially dispersed activities,' which can be observed as 'pockets of order' and analyzed through the response-execution-leverage (REL) model. These adaptations can be understood in normal construction work by observing how workers react to respond threats. Apart from the REL model, these adaptations can also be analyzed using the four cornerstones of RE suggested by Hollnagel. This paper, based on observations undertaken as part of a broader doctoral research project examining resilience engineering in the Victorian construction industry, explores and analyses three such adaptations and trade-offs.

1 INTRODUCTION

While there is no uniform definition of Resilience engineering (RE), it has been suggested to be closely linked with adaptation (Chialastri & Pozzi, 2008), hence has been associated with the adaptive age of safety (Borys, Else, & Leggett, 2009). Such adaptations involve temporal adjustments by organisations as they respond, monitor, anticipate and learn from disturbances and/or continuous stressors (Hollnagel, 2009). According to McDonald (2006) this ability to adapt is inherent in the actions and behaviours of teams, individuals and organizations as they respond to regular, irregular, (Westrum, 2006), and to some extent unexampled threats (Epstein, 2008) such that work continues to operate as normal. Invariably, these adaptations also require those operating at the sharp and blunt end of risks to make trade-offs and sacrifices in favour of safety over production (Cook & Nemeth, 2006).

In the case of construction work, such sacrifices and trade-offs form part of the way operators deal with regular threats encountered by the industry as part of their normal work. These occur at micro-levels of the work activity; however, there is little published research that explains how such adaptations actually occur in construction sites. This paper seeks to make a small a contribution by exploring these facets of RE. It is based on an analysis of observations made as part of a recent doctoral research project completed at the University of Ballarat, Victoria, Australia.

The reminder of the paper is organized as follows. First, the construction industry as a context for RE research is introduced. Next, we propose episodic adaptations as a means of exploring resilient behaviour at team level. This is followed by a close examination of three construction activities involving (i) roof plumbing and tiling, and (ii) excavation and drains on domestic construction sites. How the teams doing these activities are explored by analysing the way they responded a regular threat, changing weather conditions.

2 SAFETY AND COMPLEXITY OF THE CONSTRUCTION INDUSTRY

On a global level, the construction industry is one of the most dangerous for workers as evidenced by the high number of injuries and fatalities. In the UK, one third of all work-related fatalities occur in construction; workers are six times more likely to be killed than employees in other sectors (Health and Safety Executive, 2003),with the industry incurring the largest number of fatalities and major injuries compared to other industries (Health and Safety Executive, 2012). In Australia at least one construction worker continues to die every fortnight (Fisher, 2008), with the industry experiencing a fatality rate of 5.6 fatalities per 100 000 employees, which is more than twice compared to other industries such as manufacturing (Australian Safety and Compensation Council, 2010).

There are a number of aspects of construction that sets it apart from other industries such as manufacturing. For example, construction work can be dispersed physically over several, sometimes distant, locations, with each site representing 'mobile factories' (Bakri, Zin, Misnan, & Mohammed, 2006). Upon completion of each project the 'factory' is disassembled and relocated to the site of a new or different project. However, the conditions at the new site might be completely different from the earlier site (Bakri et al., 2006). The construction working environments can also be very dynamic with frequent rotations of work teams, changing weather conditions, and a high proportion of unskilled, temporary and transient workers. As every construction site progresses, new hazards and risks may also develop. Outdoor operations, working at heights and sophisticated plant and machinery add to the risks faced by construction employees (Choudhry & Fang, 2008). The nature of the work, poor attitudes and behaviors, unsafe work practices, ignorance, pressure from budget cuts and time restraints can compound health and safety risks (Choudhry & Fang, 2008; Holmes, Lingard, Yesilyurt, & De Munk, 1999). Combined, these factors make construction a complex industry to work in (Choudhry & Fang, 2008; Howell, Ballard, Abdelhamid, & Mitropoulos, 2002).

One consequence of this is that improving safety in construction work can be more difficult than in a manufacturing facility. Existing contemporary approaches may not be sufficient in driving safety improvements beyond what has already been achieved. This makes it a candidate for RE (Pillay, Borys, & Else, 2011; Schafer, Abdelhamid, Mitropoulos, & Mrozowski, 2009). In RE, narrowing the 'gap between work as imagined and work as performed' requires making a number of trade-offs that involve balancing the goals of production and safety (Hofman & Woods, 2011). According to Hollnagel (2009), RE also requires organizations to anticipate, respond, monitor and learn from both success and failures. These four abilities provide one framework for examining RE in domestic construction work. The practical problem in terms of research, however, lies in being able to observe these abilities across a very short period of time that is normally allowed for doing domestic construction work. In such instances other frameworks for analysis become important.

2.1 Episodic adaptations

It has been suggested that resilience manifests as episodic adaptations (Grøtan, 2011; Grøtan, Størseth, Rø, & Skjerve, 2008). Such adaptations can be observed as 'pockets of order' and analyzed through the response-execution-leverage (REL) model. In a recent study Furniss, Back, and Blanford (2011) used case studies to observe a series of episodic adaptations in an Oncology Day Care Unit to understand the strategies that people adopted to balance risk and efficiency. The researchers concentrated on six episodes to explore resilient behaviors in normal work settings. It is our contention that such types of adaptations can be explored in construction settings by observing and analyzing how workers react to regular threats such as changing weather conditions.

3 RESEARCH FINDINGS

The paper is based on the results of observations conducted as part of research study aimed at exploring RE through the prescription and of safe work method statements in the Victorian construction industry. The aim of this research was to gain an understanding of the whether safe work method statements impede or enhance RE as a health and safety management strategy. Data for this study was collected in two domestic and one commercial construction sites through a series of one-to-one and focus group interviews held with sixty-four participants, review of documents and a series of observations. This paper is limited to an analysis of three observations, two involving working at heights and one involving excavation and drains.

3.1 Episode 1: Roof Plumbing on a Medium-Density Housing Project

The first activity involved roof plumbing on a medium-density housing project. Similar to most works in the construction industry, this work was outsourced to a subcontracted team of four people, one of who was a manager, an experienced tradesman and two apprentices. Over the course of two hours the researcher spent on the site, some slight changes in weather conditions were observed. There was a breeze, followed by a slight drizzle, with the wind picking up speed. Apart from a cursory glance at the sky, the team continued working work continued without a break. However, on an adjacent sit where similar woks were going on involving a different set of workers and unrelated to this research site, I observed the three people who had started the job stopped when the wind picked up speed.

It was noted that the Safe work method statement (SWMS) and Job safety analysis (JSA) used on our research site work did not mention changes in weather conditions as a potential hazard. Discussions with the team of roof plumbers revealed that such threats were basically treated as part of the norm, it was something they had learnt to continue working with; the threats were not high enough to put them in any form of harm. Because they were experienced plumbers, they relied on their experience to decide if and when the job had to be abandoned.

3.2 Episode 2: Roof Tiling on a Medium-Density Housing Project

The second activity involved roof tiling on a medium-density housing construction. During the course of our observations different degrees of changes in wind and rainy were experienced over the two days this work was done. On the first day there were slight drizzles and light breezes, with increasing speeds over the course of the day. Similar to the roof plumbers observed in Episode 1, the roof tilers did nothing more than give a cursory look at skies, and continued their work, even when the wind picked up some speed. However, as the wind became gustier, the team broke up early for 'smoko,' which also meant they left the site at around 2.00 p.m. (as opposed to 3.00 p.m. which was the norm).

However, on the second day it was windier, and wetter because of the rain that had fallen the previous night. As we joined the team at around 7.00 a.m., we observed this team were still on the ground. From the discussions they had another two days of work on that particular building, and were waiting for the weather to become better. The JSAs used for this job were also examined, and it was noted that 'wet weather, slippery top' and 'falling from height' had been added in black ink. The two partners indicated they would not normally add this on the JSA but had been advised to do so by the contract supervisor the previous evening, because of the 'OHS stuff that is going on!' They also provided that they would generally monitor the change in conditions and decide on the day if it was safe to work. Moreover, instead of relying on the JSA/SWMS they would use their previous experience to decide if it was safe to continue working.

3.3 Episode 3: Excavation and Drains on Domestic Housing Project

The third activity involved excavation and drains (plumbing) on a single storey housing construction. This work was done by a team of two people; an experienced drainer who was also doubled as an excavator operator, and an apprentice drainer. What challenged use was that fact that the apprentice stayed within an arm's reach of the bucket during the course of the excavation activity, literally 'close to the edge' where he could have been knocked out cold (if not dead) were the bucket to strike him. This practice of 'working in close vicinity of a mobile plant goes against the guidelines for doing such work safely. Excluding workers from areas of an excavator by bunting or fencing, a clearance of at least 0.5 metres between the any operating part of an excavator and persons, a high level of visibility and safe means of signalling between the excavator operator and any persons nearby are minimum requirements (Safe Work Australia, 2012). However, on this occasion, visibility and hand signalling between the plant operator and worker were used which, at least in my view, adequate in this high risk work context, for controlling the risks. In this instant there was a regular threat, in the form of the apprentice working in close vicinity of the excavator where he would have been subjected to series injuries from being stuck by the bucket or crushed by the excavator. However, the two workers continued work as normal by taking things in their stride (Cook & Nemeth, 2006). There were also decisions made, subtly, not to follow the typical 'rules' associated with mobile plant-pedestrian segregation laid down by the regulators. These rules, to this team at least, were deemed to be part of the 'low-order' goals according to the goal-means hierarchy; whilst completing the excavations and drains in a timely manner (i.e. production) was more necessary to achieve the higher-order goals of production.

This team's response to changing weather conditions was also observed. About an hour into work the winds picked up speed, followed by darkening of the skies. The workers glanced at these changing conditions but continued working, with a subtle increase in pace. At the sign of the first drizzle the excavator operator signalled 'thumbs down', a cue that resulted in his colleague starting to collect the boxes of PVA glues, joints and tapes for the job and moving it inside their ute. Within less than twenty minutes it started pouring heavily, causing the workers to stop work and move inside their ute.

4 DISCUSSION AND ANALYSIS

The response repertoire in the above three activities can be suggested to represent to forms of episodic adaptation in the form of small pockets of order (Grøtan, 2011; Grøtan et al., 2008). This adaptation can be analysed through the response-execution-leverage (REL) model (Grøtan, 2011). By subtly paying attention to the changing weather conditions (entry point) the three teams developed an anticipation of the risks; this targeted their risk understanding. The teams responded in an organised sequence, first by continuing to work and taking things in their stride (Cook & Nemeth, 2006), and later by stopping altogether to think of a new strategy when the weather worsened; this acted as the release chain. By stopping work altogether the teams responded to the changing degree of threats they faced.

At a minimum, these examples are illustrative of episodic adaptations that can occur in the construction industry, and demonstrated a form of resilience with production being sacrificed in favour of safety.

The three episodes can also be analyzed using the four cornerstones of RE suggested by Hollnagel (2009). By paying attention to changing weather conditions, the teams were able to monitor and remained aware of the changing nature of threats posed by increasing wind conditions and rainfall. They responded in one of two ways, by continuing to work or abandoning work altogether. By choosing to continue working In one case the team improvised on the job by including 'wet weather, slippery top' and 'falling from height' in their job safety analysis forms; in some ways this was about learning from success, because there had been no incident yet the team chose to take on board the learning's from the previous day.

The episodes also reveal different degrees of sacrifices being made on the construction sites, either for or against safety. In the first episode, subcontractors on our research site continued with their roof plumbing works by continuing to work when there was a slight drizzle, while on an adjacent site work stopped altogether. It could be suggested that there was some tendency on our research site to sacrifice safety in favour of production, while the adjacent site sacrificed production in favour of safety. Similar types of sacrifices were also made by the excavation and drains crew when they continued to use the mobile plant for excavating without the necessary level of segregation, and when choosing to abandon work when the site was impacted by rain.

The behaviours adopted by the participants in episodes 1 and 3, which included roof tiling, excavation and drains, were not stipulated in the formal documentation used on site, although both of them constituted high risk construction work according to the legal set of rules. The flexible use of rules in this instance can be suggested to have enhanced RE in these two contexts. In all three episodes previous successes could be suggested to play a role in the behaviours adopted in terms of how the three teams responded to changing weather conditions and environment stressor that is encountered as part of norm in construction work.

5 CONCLUSION

The types of episodes that were observed and analyzed above represent those that are part of everyday work in the industry. In the domestic and/or medium density construction trade-offs and adaptations such as the ones we observed are made regularly as part of normal work. Such trade-offs, in the form of episodic adaptations, could increase or decrease the gap between work as imagined and work as performed. Depending on whether they are aimed at sacrificing safety or production, and could therefore enhance or hinder RE as a safety management strategy in construction settings. This paper makes a small contribution to the RE literature by providing empirical evidence of the utility of the REL model for understanding episodic adaptations, by providing empirical evidence of how subcontracted construction workers make trade-offs amidst a regular, everyday threat in the form changing weather conditions, as part of their normal work.

Acknowledgements

The work reported in this paper is based on Manikam's PhD thesis which was supported by an Australian Postgraduate Award (2009-2012) and a University of Ballarat Publication Award (2013).

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To Rule, or not to Rule is not the question (for organizing change towards resilience in an integrated world)

Tor Olav Grøtan[1,2]
[1] SINTEF Technology and Society , Trondheim, Norway
tor.o.grotan@sintef.no
[2] NTNU Dpt of Production and Quality Engineering, Trondheim, Norway

Abstract

The paper is founded on the claim that exclusive emphasis on compliance to rules may pose a threat to progress in safety. Initially positioning compliance and resilience in a complementary relation, the dynamic nature of that relation is understood in terms of adding a dialectical relation that is based on the relation of hard thinking vs soft, abductive and conjectural thinking. Moreover, a shaping relation can be built from projecting the dialectical relation onto distinctive occasions of resilience, which in turn produces successive reconciliations between compliance and resilience. Based on a managerial reorientation to risk and organizing, rules can be "followed" in terms of their reconciliation with resilient capacities. Although the context of ICT-based integration implies an unresolved asymmetry, the overall approach is claimed to be generically applicable. The paper per se is an example of soft/abductive thinking that invites (and needs) a dialectical encounter.

1 INTRODUCTION

Deployment of ICT solutions transforms many industries. The magic word is integration. The founding motivation of moving from silo thinking to work process across disciplines and organizational boundaries is almost automatically superseded by ambitions of moving beyond the fixations of work processes into more generic capabilities (Rosendahl and Hepsø, 2012) of industrial actors to act in concert and with excellence, increasing the scope of control while presenting the actors as both lean and agile.

This development carries many possible futures, one of which could be the proliferation of ingenuity, diversity, emergence, adaptation and resilience in a brave new, "global industrial village" ecology of innovative and adaptive industrial actors. On the other hand, it might also be the foundation of a hyper-Tayloristic, strictly managed "continuous improvement" agenda, and as such be conceived as a "ready-to-go" whole concept of enterprise management and hierarchical governance that renders the motivations and foundations of (autonomous) resilience rather obscure.

A prime issue is thus whether the above integration context provides fertile grounds for organizing a process of change towards resilience. There is however an inherent asymmetry between compliance and resilience; the prevalence of safety by rule is institutionalized all the way from laws and regulations to the expectations of the individuals. Failed compliance seemingly always gets a second chance in the eye of the "critical" media as well the public opinion (the answer "we will revise our routines" often pre-empts any further inquiry), while successful resilience may pass unnoticed.

Resilience engineering presents itself with the intriguing question "why does it work" rather than the legacy orientation of "why does it fail". But the response to that key question is not necessarily the recognition and appreciation of adaptive practices as evidence of an undisclosed, autonomous and situated quality that need to be further nurtured and developed into resilience. The answer might as well be "excellence of execution in planning and/or management". A success story that obviously cannot be directly ascribed to such excellence might instead be interpreted as a spurious trace of some organizational "dark matter" that is usually infinitesimal and practically irrelevant for "normal" laws of the actual industrial universe, as a sign of waste of resources and unproductive redundancy, as a suspicion that that some other quality is unduly sacrificed without managerial consent, or, at best, a more or less random matter of circumstance that can be directly "learned" into the compliance regime.

Assuming that adaptive and resilient capacities will be unnoticed but present in a system surviving dynamic and complex environments, it is reasonable to fear that safety management may persist to promote a "rational façade" of organizations that actually are impermanent (Weick, 2009). Behind such façades, a crucial number of adaptive practices may be taking place without the attention of safety management principals and processes. The paper discusses how resilience thinking can be positioned as a complement to compliance by maintaining two key ideas; (1) that resilience may be comprehended holistically as an organizational effort that goes beyond the "patho¬genic" orientations and hierarchical imperatives of prevalent safety (compliance), and (2) that resilient practices may be infiltrated with compliance practices.

2 SCOPE AND APPROACH

On the above premises, this paper discusses a trade-off between compliance and resilience by means of three different relations between compliance and resilience;

- as a complementary relation in which resilience provides the means for the necessary "escapes" from a compliance-based "safe envelope";
- as a dialectical relation in which resilience is associated with communities of (situated) practice and "work as done"; and
- as a shaping relation in which resilience mediates the implications from system complexity that are normally hidden for the compliance regime, and drives a continuous process of reciprocity and reconciliation.

The three relations constitute a step-by-step generic analysis of the organizational trade-off between compliance and resilience, from which an impact from the integration context can be assumed. A managerial framework is introduced that is able to accommodate all trade-off relations in, but not limited to, the integration context.

3 TRADE-OFFS IN THREE DIMENSIONS (RELATIONS)

3.1 The complementary relation: setting the scene

Bieder and Bourrier (2013) see proceduralization of safety as part of a more general trend towards normalization of social interactions and practices, leading to the bureaucratization of everyday life. But the extended reach of proceduralization is also aiming "upwards" into voluntary regulation and social reporting, e.g. on "Corporate Social Responsibility".

Bieder and Bourrier (2013) however do not aim for a plea against proceduralization. They see rules and procedures as key features for an modern organization to function, and it is thus no surprise that especially in the safety management context, there seems to be an irresistible push towards a wider scope of norms, procedures and processes, "whatever the context implied". Proceduralization reflects the embedded nature of control and explication which can be used for brute enforcement of compliance towards subordinates and for deflecting safety issues into liability issues, but also as a formal explication of work practices that can be publicized and openly discussed. Procedures can be protective against arbitrary orders and inconsistent management, they can be comforting guidelines or tangible embodiment of successive lessons, they can bring comfort and reduce anxieties for newness and uncertainty and thus prevent exhaustion and fatigue, and they are the classical recipient of (highly important) technical knowledge. Despite their obvious progress and achievements in safety management, the exclusive and intensive use of procedures of today may however be a threat to further progress in safety.

Bieder and Bourrier urge the safety field to move beyond the belief that safety originates exclusively from reliable equipment, good procedures and processes, well-behaved operators and well-designed organizations. There are a number of cues and tracks to follow. Weick's (2009) intriguing description of the impermanent organization inflicts a potential mortal wound to the whole above ensemble of beliefs about organization and organizing. Besnard and Hollnagel (2012) mercilessly pin down a number of myths that prevalent safety management apparently wants to believe in. Hollnagel (2010) contrasts the relation between compliance to rules and resilience (engineering) in terms of the near dichotomy between "Theory W" and "Theory Z", the latter representing an, on its own premises convincing, theorizing of safety founded on human adaptation that is almost void of the aforementioned myths and beliefs, but not void of empirical merit and underpinning.

Although it is tempting to unmask the myths and to propose entirely different approaches that are no less logical than the more prevalent opponents, a more composite and less stringent approach is however needed for advancing with the purpose of organizing a process of change towards resilience. Bieder and Bourrier describe the shortcomings, but also the inevitability of proceduralization in the actual social and organizational contexts that safety management is destined to make its progress within. Myths are not "just myths", they reflect what the society at large, and thus the contexts for safety management, persist in with respect to beliefs, expectations and horizons of understanding. In such a context, the pragmatics of the safety management communication and discourse does thus not allow a clean cut competition between competing safety theories.

The complementary relation thus set the scene in which resilience is in "challenger" position residing in the contextual shadows of proceduralization and compliance. Theory W (Hollnagel, 2010) is recognized as an institutionalized deep structure for safety theory and practice. The contextual shadow signifies not only a restrictive context for exertion of resilience principles, but may also conceal the merits and achievement of any elusive and emergent type of safety (including resilience).

The contextual relation may thus be framed through the "Resilience In COntext" (RICO) approach (Grøtan, 2013a) which is designed for the promotion of a balanced mix of compliance and resilience based on the above premises, in five steps: (1) Initial positioning of resilience as an extended safety envelope in terms of a safety space outside the standard operating procedures (SOP), (2) "Hunting High" for organizational conceptualizations/holisms of resilience, (3) "Hunting Low" for demarcation lines between resilience and compliance in infiltrated, overlapping practices, (4) "Hunting High and Low" for identification of balanced, realistic and manageable reconciliations between resilience and compliance, and (5) addressing adaptive traps that may make (aspirations of) resilience more dangerous than helpful.

3.2 The dialectical relation: keeping the reconciliation vital and productive

Figure 1 illustrates the dynamics within the complementary relation. Two opposing imperatives are signified by the metaphors of pathogenesis and salutogenesis which refer, respectively, to "disease-creating" and "health-creating" processes and conditions (Grøtan, 2013ab). The notions of hard, soft and dialectical systems thinking are borrowed from Dahlbom and Mathiassen (1993), and the notions of ordered and unordered systems are borrowed from Dahlbom and Mathiassen (1993) and from Kurtz and Snowden, (2003). The notions of abductive thinking, conjectural paradigm and sensemaking are borrowed from Alvesson and Sköldberg (2009) Weick (2009), Perin (2005), Bieder and Bourrier (2013), Størseth and Grøtan (2011) and Pettersen (2013).

In Figure 1, the asymmetry of the complementary relation is reflected in the prevalence of the "rational façade" to the left, that is, the realm of "Theory W in action". The threat towards progress is paraphrased as a hesitation towards moving beyond the pathogenesis metaphor. On the right side, resilience thinking, as a (potential) representative of salutogenic thinking, generates new insights and prospects from the realm of emergence and impermanence behind the rational façade, unfolding in spite of its modest residence in the contextual shadows of compliance.

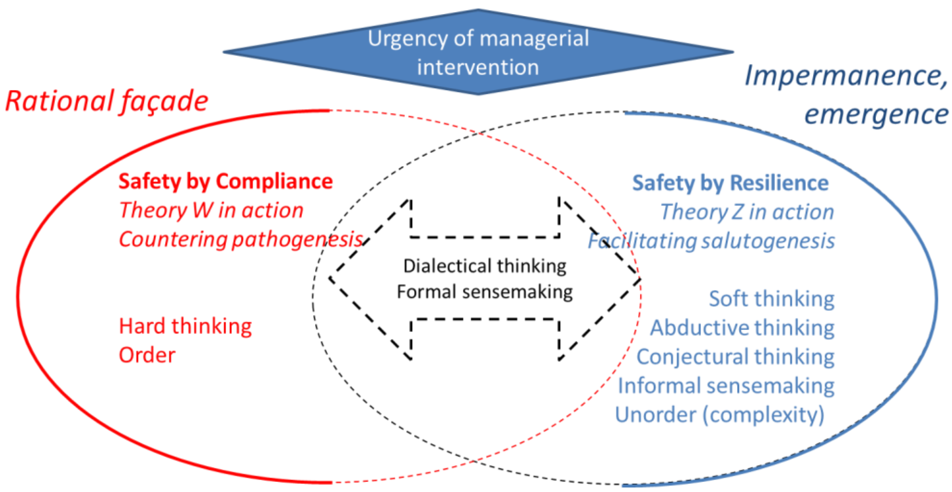

Figure 1. *The dialectical field and its constituents*

At the rational façade, bureaucratic and technical rationality and hard thinking prevail. That is, the belief that systems are out there, and that we build them, change them and improve them, by engineering. Hard thinking is ambitious, stretching its own premises not only to accommodate human failure per se, but also to capture the processes, conditions and organizational "pathogens" creating them (Reason, 1997).

At the right side, "Theory Z in action" is disclosed, encountered, explored and conceptualized by practitioners as well as the scientific community, resting on a quite different foundation. Soft thinking means recognizing that systems are in our minds, as perspectives that we change and improve by being confronted with other perspectives, by getting around in the world and experiencing and learning. We "see" systems as a result of our attempts to organize our experiences, beliefs and vision.

Abductive reasoning may be a trigger as well as companion to soft thinking. It is a combination of the scientific paradigms of deduction and induction, emphasising the forming and evaluation of hypotheses along an axis of meaning, sensitized by and seeking to make sense of puzzling events and facts. This is done by means of suggesting a world in which the cue or symptom may be meaningful. Not confined to individual thought, distributed abduction is thus a prospect for organizing in the face of unorder and complexity. The conjectural paradigm highlights the underlying link between faith, evidence and action which is the very foundation of inquiry - scientific or not. This requires constant sensemaking related to new cues, in terms of constant pending between order, interruption and recovery. A related example is anomaly handling, in which generation of hypothesis is a crucial activity (Woods and Hollnagel, 2006).

Perin (2005) note that abductive reasoning and sensemaking is useful not only as a framing of scientific inquiry on safety. It is also an appropriate description of what "sharp-end" operators actually turn to when being confronted with strange signals or puzzled situations in which procedures are rendered inadequate or ambiguous. Scientists and practitioners thus share a common challenge in making the outcome of their abductive reasoning credible and applicable. Under the contextual shadow of the rational façade, the urge will not be only to make the pieces fit into a(ny) whole, but also to translate their experiences and findings into an encounter with the standards of hard systems thinking which emphasises instrumentality and economy of implementation. Hard thinking pursues a kind of safety that result from plans and deliberations, rather than emerging from some previously unknown territories of knowledge. Such encounters may pose embarrassment, and reconciliations are not ready at hand. But we are now at the crux of the matter – or put differently, in the middle of Figure 1. Compliance and resilience must meet, fit together, work together in reciprocity and meaningful reconciliation, and thus be infiltrated in each other (Grøtan, 2013a). The different cultures of control (Perin, 2005) have to strike a balance between an axis of (ordinary) function, definition and closure, and an axis of meaning related to situated experience of change, variability, exceptions, ruptures and surprises. Hard thinking is like photographing, soft thinking is like teaching, but they have to meet in dialectical thinking which is more like political action and struggle. Dialectical thinking will also have to rest on abduction and sensemaking, but in a politicized context of conflicting interests. Dialectical thinking should help to attend to contradictions in order to understand, explain and control the system's adaptive history, precarious present and resilient future (Branlat and Woods, 2010). These are key issues for a safety management process that want to take up the challenge from Bieder and Bourrier (2013), as well as for scientific inquiry.

The dialectical relation must be maintained with a proper "distance" in order to be maintained. If abductive thinking escapes the shadows and is left unattended, it may "dry out" or degrade because it loses touch with opposing views, and is never tested for broader application. If abductive thinking aligns too close with the terms of hard thinking, it may be "abducted" in a very literal sense and loose its distinctive characteristics. Referring to the fundamental dialectics of prescription and practice (Nathanael and Marmaras, 2008), it can also be argued that the dialectical safety management resembles the anatomy of resilient practices per se at a more "micro" level (Grøtan 2011), in which episodic adaptations unfold across similar dialectical fields across a stratified organization. Hence, it is necessary to recognise that resilience and its inherent dialectics unfolds at different scales.

3.3 The shaping relation : "follow that rule!" into complex landscapes

In Figure 2, a model of practical drift is shown, drawing on Snook (2000) and Dekker (2011). The key issue is that practical drift not necessarily end up in failure, it might also end up in success. First, the drift from "engineered" into "applied" might be just necessary, and be interpreted as a manifestation of resilience per se. Second, drift from "applied" into a less relaxed (more tightly coupled) situation also signifies a chance for resilience to show what it is worth. If successful, the new situation may in turn demand an updated reconciliation between compliance and resilience. The need for such reconciliation may also be triggered by external events like accident reports, technology shifts and industrial reconfiguration. These events will drive a "shaping circle" in which resilience is the prime mediator of a complexity that may hide itself behind practical drift, and which may employ parts of or the full range of the RICO framework (Grøtan, 2013a). The result may be an extended safe envelope comprising SOP and additional margins of manoeuvre beyond. Hence, rules must be "followed" also in terms of their process of mutual constitution with the margins of manoeuvre.

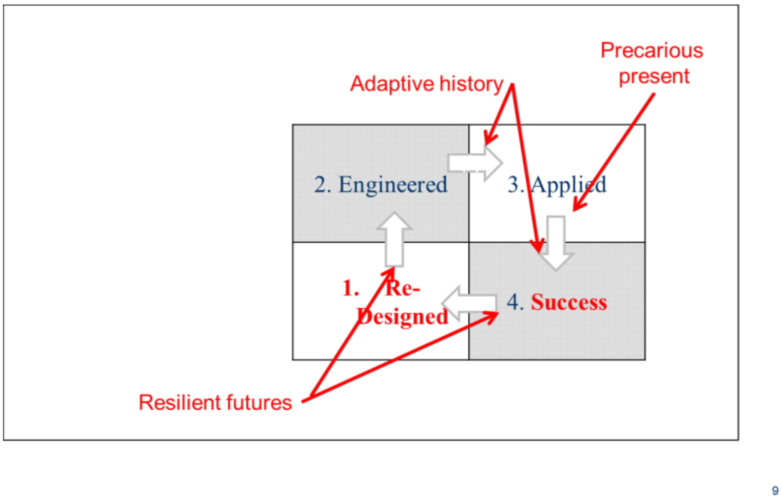

Figure 2. *The pulse of the shaping relation.*

But "drift into success" will not come for free. It will require a constant focus on resilience in terms of making sense of the occasions of, e.g., adaptive history, precarious present and resilient futures. The pulse of this shaping circle is set by the distinctive moments, each of which following a trajectory from soft, abductive thinking that grasp complexity along an axis of meaning related to change, variability, disruption and surprise, into a dialectical encounter with hard thinking that insists on grasping the very same complexity along an axis of function and definition. The merits of such a shaping circle will deviate from what may be expected from the rather common "total quality management" approach.

4 ELECTRONIC IMPERATIVES FROM THE CONTEXT OF INTEGRATION

Prevalent conceptualizations of ICT impact in organizations do not escape classical critique, e.g. as by Dahlbom and Mathiassen (1993) and Roszak (1994) which position ICT mainly as supportive of hard thinking.) Moreover, the side-effects of ICT-based integration is a complexity that "reboots" itself (Hanseth and Ciborra, 2007). Lilley et al (2004:76) forwards the view of ICT as a technology of re-presentation; that the appearance of detached representations is productive of a new form of power that enable a view of the world as a table top ruled by the human hand and eye. The attempt to trap all uncertainty tends towards an overarching and closed system. As a result everything is dragged closer together and made smaller, is displaced and abbreviated in order to facilitate remote control. The deployment of ICT thus holds out the dream of grasping the uncertainty created by its own dispersal.

Although the representational powers of ICT are most easily associated with hard thinking, Grøtan and Asbjørnslett (2007) points at a certain potential for deliberately turning the edge and power of the very same technology into the realm of situated action, thus actively supporting abductive thinking. When combined with the principles of Joint Cognitive Systems (Hollnagel and Woods, 2006), the embodiment relation and the hermeneutical relation could be a foundation of communicative devices for exchange of artefacts associated with the abductive and dialectical process (Figure 1).

5 A MANAGERIAL FRAME TO ACCOMMODATE THE TRADE-OFFS

Safety management should nurture both compliance and resilience on their own (different) terms, but at the same time respond to the urgency for managerial intervention and participation when and where the two defy each other and ensure a proper dialectical distance. Reconciliations must reflect actual capacities of the organization at the time. This would benefit from a reorientation from risk and decision into risk and organizing, based on an emphasis of organization of attention, formal/institutional sensemaking and capacity to re-organize (Grøtan, 2013b).

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Structure, Agency, and Resilience

Garth S Hunte[1], Robert L Wears[2,3] and Christiane C Schubert[4]
[1] University of British Columbia, Vancouver, Canada
garth.hunte@ubc.ca
[2] University of Florida, Jacksonville, FL, USA
[3] Imperial College London, Paddington, UK
wears@ufl.edu
r.wears@imperial.ac.uk
[4] Vanderbilt University, Nashville, TN, USA
christiane.c.schubert@vanderbilt.edu

Abstract

Giddens' structuration theory is a practice theory widely used and adapted in analyzing social and sociotechnical systems, but has not been applied to the notion of resilience in systems. Discourses on resilience have tended to focus either on agency or structure. Structuration theory gives a different view, of structure and agency as mutually constitutive. This view helps clarify the tradeoffs that often arise pitting stability against change, procedure against innovation, or standardization against contingency, by viewing them as inseparable and dependent aspects of a duality.

The view from any given observation point simultaneously reveals and obscures.

D. D. Woods

1 INTRODUCTION

Discourses about resilience tend to emphasize actions of agents in complex, adaptive, sociotechnical systems – how they anticipate or detect threats (or opportunities), and how they take action to forestall (or facilitate) them. Woods describes this as "... responsible people step[ping] into the breach of otherwise brittle systems to overcome adaptive shortfalls" (personal communication). This is a natural view of resilience, given that human actors are the most adaptable elements of any system, and will always be the 'last resort' when other elements or properties are falling short.

However, two potentially misleading ideas can flow from this view. The first is an attribution bias, the tendency to express critical events in the form of heroic narrative. This tendency, combined with people's inability to articulate their tacit knowledge, can give resilient interventions and the agents enacting them a magical, mythical quality – divinely inspired 'bolts from the blue' – that fails to illuminate supportive resources, or the conditions evoking them, much less providing guidance on how to ensure these capabilities.

The second is an implication that systems of work are implacable and unevolving, which, by viewing people as the only malleable resource, limits notions of what is possible. This is often true over short time spans, but it ignores the role of constraints as causes (Vicente, 1999), as shapers of behaviour, and thereby narrows the 'workspace' for resilience engineering.

While the resilience literature shows a sensitive awareness of the role played both by agents' knowledge (tacit and explicit understandings of situations, constraints, goals, means, threats, opportunities, *etc*) and their context (physical, technical, social, and historical) in performance, the role of structure tends to be unarticulated with respect to that of agency. Le Coze raised this question indirectly in his criticism of a model of resilience dynamics (Wears, 2011), noting that the model 'has no people in it' (personal communication). The remark led to an exploration of the reflexive relationship between structure and agency and the importance of acknowledging the reciprocal determination of both structure and performance.

In this paper, we draw on Giddens' structuration theory (Giddens, 1984) to highlight the dynamic relationship of structure and agency in resilient performance, and argue for the value of adding this viewpoint to enhance the prospects for resilience engineering.

2 STRUCTURE AND AGENCY

2.1 Sociological Roots

Giddens' notion that social phenomena are the result of a dialectic relationship between social structure and human action is rooted in a long history that he carefully explores. Since the beginning of social theorizing two major traditions put forth competing perspectives of social systems. Structural sociology emphasizes the importance of the social whole over its individual parts. Explanations of social behavior highlight the structural conditions that shape human action predominantly in the form of constraints (Giddens, 1984). The explanation of causal relationships between social structure and behavioral outcome favours a deductive approach in which objectivity becomes a prime concern.

The interpretive tradition argues that, "the study of human behaviour is the study of human lived experience" (Prus, 1996, p. 9). Rooted in Dilthy's hermeneutical approach but also drawing on the Weberian notion of *verstehen*, interpretive sociology highlights the importance of self-reflexivity -- the subjective understanding of peoples' meanings, interpretations, activities and interactions. From this perspective, social behaviour is best understood when looking at the actions and motivations of individuals rather than considering the effects of social-structural constraints. Approaches associated with this paradigm are largely inductive and as such capable of capturing the subtle nuances that provide insight into the multi-perspectival nature of social life and human inter-subjective experience.

With two traditions this fundamentally different Giddens (1984) set out to "put an end to these empire-building endeavours" (p. 2) to prioritize neither the individual actor nor the structural-functional aspects of the social whole. Instead, Giddens considers their dialectic relationship. As a result, structuration theory proposes that human action as a continuous flow of conduct, or a *duree* (p. 3), is intertwined with the reproduction of the structural conditions that support social activities to become social practices, which are maintained across space and time as routines.

Offering a complex and intriguing conceptual framework, albeit with little methodological direction, structuration theory has been celebrated in the field of sociology for nearly 30 years. It has also gained traction in other domains including information systems research (e.g. Greenhalgh & Stones, 2010; Rose, 1998) and healthcare (e.g. Hardcastle, Usher, & Holmes, 2005; Beringer, Fletcher, & Taket, 2006).

2.2 Elements of structuration theory

Giddens' structuration theory of social action is one of a body of practice theories (Nicolini, 2013; Schatzki, Knorr-Cetina, & von Savigny, 2001) which claim that society is better understood in terms of a recursive duality of structure and agency. Within this recursive duality, human actors perform intentional actions and have the power and "the capacity to make a difference to a pre-existing state of affairs or course of events" (Giddens, 1984, p. 14). Being able to affect transformation and change people produce social systems employing rules and resources (structures) during interaction (agency), knowingly or unknowingly reproducing these structures in practice by routines that are generally taken-for-granted (Hardcastle, Usher, & Holmes, 2005). Giddens (1984) argues that social systems as reproduced social practices exhibit what he calls "structural properties" which, if maintained over long periods of time and space become the foundations of institutions. As Bellah et al. (1991) so eloquently describe, "we form institutions and they form us every time we engage in a conversation that matters" (p. 12). Crucial to the notion that social reality is actively and intentionally produced and reproduced is the presence of a recursive relationship where neither structure nor action can exist independently (Giddens, 1984). The argument we present here is that the articulation of this mutually constitutive and dynamic relationship between agency and structure forces trade-offs and fosters brittle/resilient action.

2.3 An Analogue from Biology

An example from biology may make the duality of structure and agency a bit more easily grasped. Observers of social insects had to explain a 'coordination paradox' – by what means are the complex social, behavioural and physical manifestations of insect societies organised, controlled, and regulated, give the severely limited cognitive facilities of their constituent individuals? Grassé developed the concept of *stigmergy* – artefact-mediated collaboration to explain this (Grassé, 1959). For example, an ant returning to the nest with food lays down a pheromone trail (different from the one she produced on the outward journey), thus modifying the environment. Other ants noting this in their wanderings are led to the food, and reinforce the trail on their return, eventually leading to coordinated action to retrieve food. As the food items are diminished, the pheromone production stops, the trail decays, and the ants resume their apparently aimless wandering.

The concept of stigmergy has been progressively expanded beyond its relatively limited origins in insect societies, and applied to higher order coordination in economies and human societies as well (Doyle & Marsh, 2013; Susi & Ziemke, 2001). Fundamentally, stigmergy illustrates the recursive nature of structure and action – people take actions based on existing structure; by those actions, structure is reinforced and/or modified, and by those reinforcements / modifications, future actions are influenced.

2.4 An Example from Healthcare

An illustrative example of the generative potential of structure and agency as a duality is the problematic surrounding access block in emergency departments (EDs). Timely response to the acutely ill and injured is the *raison d'être* of an ED. However, this capability is chronically challenged by limited access to system resources. Thus, ED resources are often unavailable to incoming patients because previously admitted patients are "boarding" in the ED. The only available space is often a hallway or waiting room (Scheuermeyer *et al.*, 2010).

Although the provision of ED care in waiting areas is controversial (Wears & Cook, 2010), the alternative is potentially worse. In one ED, the emergency physicians changed their practice to mitigate risk for unseen patients by attending to waiting patients wherever they were, to assess, triage, and initiate treatment. However, because waiting areas were not monitored, the emergency nurses felt uncomfortable administering medication in a way that did not meet their practice or negotiated standards.

Here, in the liminal space of a waiting room, the political dimension of 'safety' played out. Nurses perceived the risk of patient harm as an act of commission — administering a medication without adequate monitoring, while physicians perceived the potential of patient harm as an omission — not attending to an unstable patient in a timely way. Both groups attempted to mitigate risk within the constraints of their respective structures (rules and resources). Hence, their *bricolage* was different. While physicians had more power to innovate, nurses exerted power through resistance. Following a cluster of waiting room deaths, an urgent dialogue produced a collective change in process and led to the development of rapid assessment zones, a diagnostic treatment unit, and an organizational overcapacity protocol (Hunte, 2010). These novel structures allow for more timely assessments and interventions, a greater margin of manoeuvre, and improvement in patient flow through the ED.

3 DISCUSSION

3.1 Relation to resilience

While structuration has found acceptance, it has not been linked to resilience — the ability of a system to handle unanticipated disruptions and variations that fall outside its integral adaptive mechanisms or models (Hollnagel, Woods, & Levenson, 2006). Moreover, structuration theory is absent from the literature that describes the complex and uncertain work environment of emergency medicine as a resilient system (Wears, Perry, Anders, & Woods, 2008), save for a single exception (Hunte, 2010).

The concept of structuration, a theory of recursive production and reproduction of social practice, expresses the mutual interdependence of structure and agency in both constraining and generative senses. Agents are empowered by structures, both by the knowledge that enables them to mobilize resources, and by the access to resources that enables them to act. Structure is therefore dynamic, not static; it is the medium and outcome of the reproduction of practice, the continually evolving outcome and matrix of interaction (Sewell 1992), manifest in material time-space rules, resources, and memory traces that orient action. Practices, not roles, constitute the mediating moment of reproduction and change in the recursive articulation between actors and structure.

Changes in formal and informal structures have (un)intended consequences for work routines (practice), the capacity to act (agency), and the meaning of work. Work systems cannot match their environments completely; there are always gaps in fitness and a need to adapt. Any system (ecological, economic, engineering) that remains viable over time must be able to cope with unexpected change. It must be able to revise and replace policies and procedures (structure), for variation not only contributes to progress, but also to stability (sustainability) in a changing environment. Although bureaucratic structures are often coercive and inflexible (brittle), they also enable work performance when they provide guidance and clarify responsibilities without squashing innovation and creativity.

The *bricoleur* works (or plays) within the possibilities (margin of manoeuvre) of a finite system, always negotiating trade-offs between structure and performance. The science of the *bricoleur* is a 'science of the concrete' (Lévi-Strauss, 1962, translated 1966), obliged to work within the elements at hand, and to cope with the inherent resistances and constraints in *travaillant de bric et de broc* (ragtag work). The set of constraints and resources channels the set of possible innovative and evolutionary paths. Therefore, resilient organizations appreciate local practice variations as a potential trove of unique innovations and commit resources to their development in order to support and enable adaptive action.

Whereas variable practice is instrumental in maintaining stability amidst perturbations, stable mechanisms and limits enable adaptability by providing the background and memory for identifying the unexpected. Effective bureaucracy facilitates the transfer of scarce attention and resources from routine to non-routine tasks by fostering trust, reducing uncertainty, and providing a framework for emergent action (Farjoun, 2010). A systemic and collective approach facilitates adaptation by promoting coordination, channelling work in productive directions, and guiding and promoting innovation. The duality perspective of practice theories therefore offers insight into how exploitation and exploration intertwine in the messy world of practice (Powell, 1996). It reflects a tension that can never be resolved, but must be actively managed (Greenhalgh, Potts, Wong, Bark & Swinglehurst, 2009).

4 LIMITATIONS

Structuration leaves room to consider practices as activities of individuals guided by rules, and only reaches its potential as an innovative view of social action when the locus of analysis moves from individuals to practices.

5 CONCLUSION

To think about "tradeoffs" from a structuration or recursive practice perspective helps us move beyond the problematic dualism of structure and agency and guides our understanding of interdependencies and margins of manoeuvre. Moreover, a recursive lens illuminates new approaches to designing resilient systems that are capable of coping with complexity in everyday practice.

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Levels of Resilience: Moving from Resilience to Resilience Engineering

Robert L Wears[1,2] and J Bradley Morrison[3]
[1] University of Florida, Jacksonville, FL, USA
[2] Imperial College London, Paddington, UK
wears@ufl.edu
r.wears@imperial.ac.uk
[3] Brandeis University, Boston, MA, USA
morrison@mit.edu

Abstract

In order to clarify the concept of resilience in systems, we propose distinguishing among three levels of resilient behaviours: 1) simple, homeostatic response; 2) second order response involving more novel adaptations; and 3) a third order response characterized by learning. This representation is useful in demonstrating how simple first order responses can be ultimately maladaptive (by consuming resources and decreasing the impetus for more fundamental change), and also by suggesting areas where resilience engineering might most productively be focused.

1 INTRODUCTION

The idea of resilient performance, and of engineering work systems to support it, has a strong attractiveness but a definitional imprecision. Woods has illustrated this by outlining 4 common understandings of the term 'resilience' (personal communication). In addition, it has grown increasingly popular in many different contexts (Taleb, 2012; Walker & Salt, 2006; Weick & Sutcliffe, 2007; Zolli, 2012), and this multiplicity has increased its conceptual fuzziness. Although resilient performance seems relatively easy to recognize and describe, moving from resilience to resilience engineering will require a greater clarity not just about what it is, but also how to get, maintain, preserve or enhance it.

In this analysis, we propose a hierarchy of behaviour patterns than can be (and have been) called resilient, and focus on the implications, for research and practice, of clarifying what we mean when we say a system is resilient or (better) acts resiliently.

2 THREE LEVELS OF RESILIENCE

We use causal loop diagrams to illustrate three proposed levels of resilience (Sterman, 2000); although the causal loop notation is convenient and expressive, the fundamental concepts are separable from this representation. In the causal loop notation, arrows indicate the direction of influences among variables; a '+' sign indicates one variable increases the value of another (over what it would have been otherwise) and a '-' sign the reverse.

2.1 Level 1

The simplest level is a simple negative feedback loop (Figure 1), with the system responding to reduce a deviation (ie, to mitigate a threat or address an opportunity). We might well label this Level 0 resilience, because many would not consider it resilience at all, at least in the sense commonly used in the resilience engineering community – after all, we would not ordinarily consider a thermostat or a speed governor an exemplar of resilience – but we use the numeral 1 to signify that resilience at this level is essentially a first order response to some disturbance. Using tried and true methods (often but not always codified in formal procedures), actors in a system deal with the 'normal, natural troubles' they encounter in a largely routinised way; they reach their goals in the context of their current mental models, but those models remain unchanged. Much of the work on resilience in ecosystems resides at this level; the feedbacks and systems are much more complex than illustrated abstractly in Figure 1, but are essentially about homeostasis, either as ordinary stability or as stable albeit hysteretic cycles (Bueno, 2009; Gunderson, 1999; Gunderson, Carpenter, Fowlke, Olsson, & Peterson, 2006; Holling, 1973).

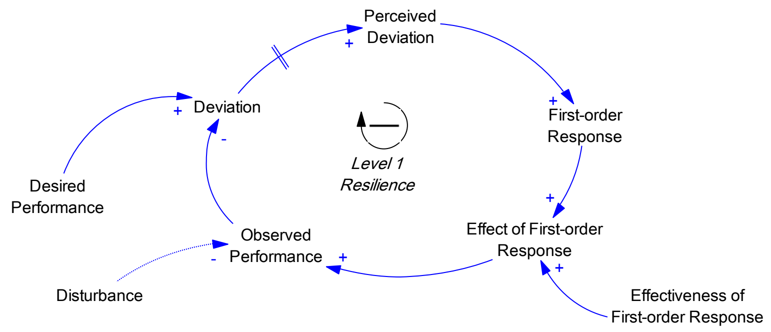

Figure 1. *Level 1 resilience, first order responding to counter a perceived deviation.*

Figure 1 shows a disturbance decreasing performance, ie, increasing deviation; after a time delay (indicated by the double lines) the perceived performance deviation then leads to increased responses, which if effective tend to improve performance and thus reduce the level of deviation from the desired level of performance. This creates in effect a negative feedback loop, tending to stabilize the system.

2.2 Level 2

Level 2 resilience is a second order response to a disturbance that is either unexampled, or not well-managed by first order processes. These responses are often variations on, or novel applications of, well-rehearsed procedures. Here, information from the world not only alters performance, it also alters the framings and mental models that influence performance. Case studies at this level of resilience are common in the resilience engineering literature (Pariès, 2011; Stephens, Woods, Branlat, & Wears, 2011; Wears, Fairbanks, & Perry, 2012; Wears, Perry, Anders, & Woods, 2008; Wears, Perry, & McFauls, 2006). These detailed, technically expert analyses have provided rich insights into the nature of resilience, but often fall short of providing insight into whence come these flashes of brilliance, much less how to enhance them. Resilience at this level typically involves goal tradeoffs, or 'sacrifice decisions'. Partly because of that, resilient activities are often hidden in the interstices of organisational life (since, officially, no goals can ever be admitted to have been sacrificed). This level of performance is roughly related to Argyris' concept of double-loop learning, although not specifically aimed at that notion (Argyris & Schön, 1974).

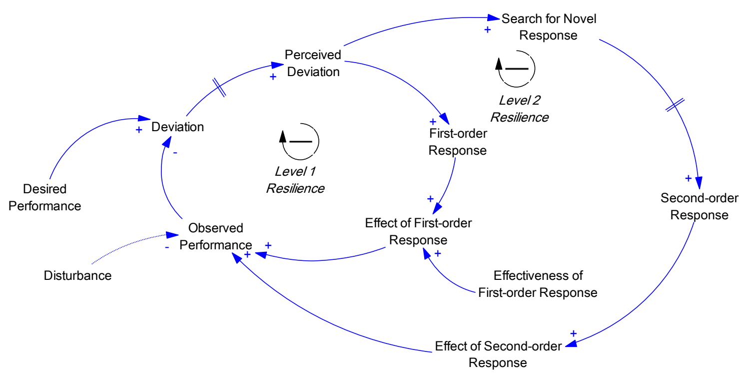

Figure 2. *Level 2 resilience. Second order response involves adaption, preparation for future similar disturbances (ie, anticipation and monitoring).*

Level 2 involves more than just responding, but also engages the activities of anticipation and monitoring, as a second order response is often aimed at preparing for the recurrence of a similar threat or opportunity. But, Figure 3 reveals a problem at this level (red arrow) – more effective first order responses lead to decreased second order efforts precisely because they are effective, and so reduce the strength of the deviation signal. Thus, fundamental problems tend to persist in the system, because they seem to be easily mitigated. This pattern can be seen in the common tendency to focus on first order responses (eg, fixing 'errors') at the expense of understanding what continues to produce those 'errors' (Dekker, 2011).

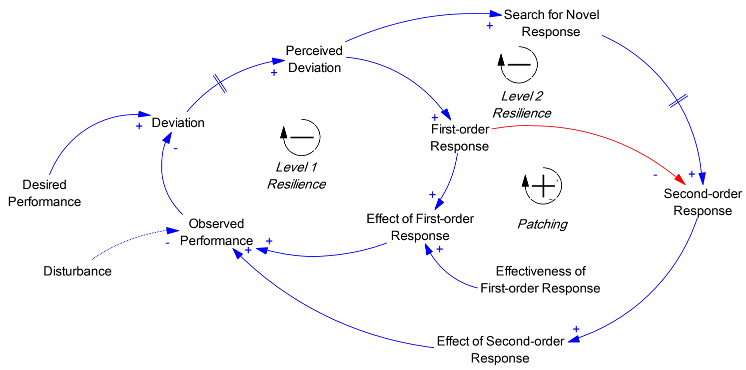

Figure 3 *But, effective first-order response reduces second-order response (red arrow).*

Figure 3 shows that this behaviour involves both positive and negative feedback loops; this makes the performance of the system hard to predict, as it depends on the relatively strengths of those loops, and on the time delays involved in experiencing their effects.

2.3 Level 3

If a system has gone through enough second order experiences with appropriate and relevant feedback (March, Sproull, & Tamuz, 1991), it may then begin to learn how to do second order response well. This not only increases the effectiveness of second order responses, but also contributes to building 'margin' (Stephens, 2010) – a collection of informal buffers, resources, short-cuts, tradeoffs and procedures – a 'bag of tricks' – that can be called on in either impromptu or extemporaneous ways. We postulate that resilient systems are characterized by their skill at capturing and learning from these experiences; which, paradoxically, may be dependent on their relatively frequently experiencing them (Farjoun, 2010). Figure 4 illustrates this more complex system, with an additional negative feedback loop.

3 DISCUSSION

3.1 Implications

This analysis of resilient performance indicates where we should be focusing attention, where resilience can become resilience engineering. We can certainly learn from Level 2 events, but they are not common, present some risk, and are often trivialized in heroic (deus ex machina) narratives. Resilience engineering should be about more than celebrating or understanding level 2 successes, important as that is. Rather, it should be focusing on Level 3 – understanding how build adaptive capacity; how and when to trigger it; how to control it, and by what types of control architectures; and how to husband it for future use (as opposed to squandering it on the everyday).

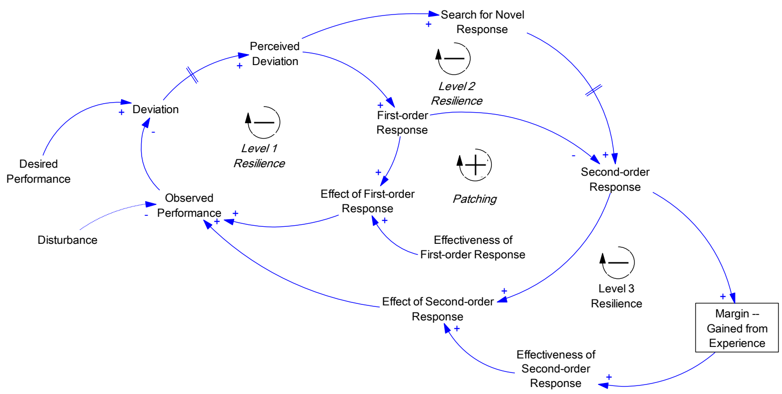

***Figure 4** Level 3 resilience, learning how to respond better; increasing the repertoire of possible responses.*

Figure 4 also identifies points at which specific resilience engineering efforts might be targeted in order to improve the system's overall ability to respond, to build the 'margin for manoeuvre' that can be called on against unexpected events. Note that the effectiveness of local, first order response negatively influences the 2nd order effort. This suggests that organised efforts to enhance second order response even when the local response is successful are not only useful but necessary to keep a system from getting trapped in a vicious cycle of temporary success from first order response that hides its growing vulnerability due to inadequate margin.

It is important to note in this analysis that the negative feedback is not always desirable, nor positive feedback always undesirable. Rather, they are rather dampening or amplifying, respectively; positive feedback is important to amplifying novel, desirable adaptation, especially after severe disruptions.

3.2 Tradeoffs

Finally, this analysis suggests that systems contain internal tradeoffs regarding the sorts of issues to which their control structures should attend. Given that attention is limited, there will be a tension among focusing on level 1, 2, or 3 responses. Level 1 responses are immediate and demanding, and so tend to dominate, in particular, reducing through their apparent success attention to level 2 responses. But for the system to be able to adapt and thrive over a long time, some attention must be shifted to level 3 responses, even though that must inevitably decrease attention and effort at levels 1 and 2.

3.3 Limitations

These levels of activity may roughly correspond to structural levels in an organisation, but there is no necessity that they do so. The value in this conception comes from looking at multiple levels simultaneously, and particularly how they relate to one another. Similarly, although the three levels tend to emphasize particular sets of the cardinal resilience activities (Level 1, responding; Level 2, monitoring and anticipating; and Level 3, learning), there is no presumption that they are so clearly separable.

4 CONCLUSION

By more specifically articulating the level of resilient behaviour that is the focus of a given discussion, we should be able to communicate more precisely, and to more directly identify opportunities for system design and improvement; that is, to move from simply describing resilience to engineering resilience.

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"Under dangerous conditions" – Safety construction and safety-related work onboard of merchant vessels

Gesa Praetorius and Monica Lundh
Chalmers University of Technology, Department of Shipping
and Marine Technology, 41296 Gothenburg, Sweden
gesa.praetorius@chalmers.se;
monica.lundh@chalmers.se

Abstract

The following paper presents findings from a qualitative study conducted on board of two merchant vessels. Interviews and observations have been used to obtain insights in how safety is defined and promoted by the personnel working on board. The merchant vessel, the crew and the single mariner are identified to be part of a socio-technical system displaying three levels of system aggregation; person-centred, crew-centred, and vessel-centred. The common ground of a crew, an overlap of the individual mariners' experience and knowledge, is identified as a basis for trust and predictability of action on board, which is a necessity to be able to conduct work safely. Furthermore, the results also show how storytelling is used to transform individual and organisational experiences into knowledge that can guide safety-related work on board. The stories told among the crew often exemplify how mariners, both on an individual, but also on a crew-centred level of system aggregation, balance safety and efficiency in the light of increasing production demands.

1 INTRODUCTION

The shipping domain is one of the oldest domains in transportation. For about 5000 years goods have been transported all over the world with the help of merchant vessels. Safety-related work within the shipping domain has in general been regulated by international guidelines, regulations and recommendations. As a consequence, an exhaustive legal framework has been created through the past 30 years. Nevertheless, most of these rules and regulations have been stated as a reaction towards accidents, such as the International Safety Management Code (ISM) (IMO, 2010) introduced after the capsizing of the Herald of Free Enterprise. This demonstrates the overall reactivity of the domain's stakeholders when it comes to safety-related work conducted on board.

Furthermore, the majority of research within the maritime domain has addressed the human element as the erroneous factor, accounting for between 60-80% of the causes for accidents and incidents (Dhillon, 2007; Schager, 2008), within the system emphasising on technical advancements, simulator studies or the development of training courses (Hockey, Healey, Crawshaw, Wastell, & Sauer, 2003) to reduce and mitigate risks. As highlighted by amongst others Hetherington, Flin, and Mearns (2006), Grech, Horberry, and Koester (2008), and Chauvin (2011), this perspective shows a limited understanding of the complex interactions between human operator, technology and the work environment. There is the need to shift the perspective from the *human error* towards an understanding of the complexity of the socio-technical focusing on how the system acts at large and how its performance can be kept within the limits of the so-called performance envelope without drifting towards failure (Dekker, 2011).

This paper presents results obtained through a qualitative study of mariners' safety-related work on board of merchant vessels. The aim of the study has been to gain insights in how crewmembers define, relate to, and promote safety within the settings of their daily work. This paper therefore wants to emphasize the positive impact of the professional crewmember in the promotion of safety aboard. Concepts derived from Cognitive Systems Engineering (CSE) and Resilience Engineering (RE) are used to discuss the findings of the study, and to emphasise the gain of shifting from *human error* to *resilience* when trying to understand the work on board a merchant vessel.

2 JOINT COGNITIVE SYSTEM (JCS), CONTROL, AND RESILIENCE

This article approaches the work on board a merchant vessel with theoretical concepts derived from Cognitive Systems Engineering (CSE) and Resilience Engineering (RE). CSE emerged in the early 1980s as a theoretical framework to analyse the performance of socio-technical systems within safety-critical domains, such as aviation and the nuclear power domain. Within the framework of CSE and RE, socio-technical systems are identified to be so-called Joint Cognitive Systems (JCS) (Hollnagel & Woods, 2005).

JCS is a system that consists of two components of which at least one is a cognitive system (Hollnagel & Woods, 2005). A cognitive system is a system, which can modify its behaviour based on past experience to achieve specific goals even under disruptive influences. JCSs are in control of a process or an environment, and act in complex situations, in which multiple goals need to be balanced to meet the demands of the context. Feedback control is applied by the JCS to react on differences between the actual and a desired state. Feedforward control is applied to operate in situations where time and/or information is limited, and supports the JCS to act upon an expected change or deviation before it happens (Hollnagel & Woods, 2005).

RE strives to understand how large socio-technical systems cope with the complexity of daily operation. The focus is on examples of the positive, meaning that resilience is concerned with how a system succeeds by adapting its performance to the demands of the environment, not on a failure to do so (Hollnagel, 2006). It can offer an explanation for how the system makes trade-offs between multiple goals to meet the demands of the context in real world situations. The system adjusts its performance to the demands of the environment, which enables it to achieve its goals under a large variety of operational conditions (Hollnagel, 2011). Within the settings of the maritime domain, the goals to balance are to operate safely at the same time as shipping is a trade-based industry, meaning that the overall efficiency, i.e. to operate cost-efficient, should not be endangered by how crew and vessel at large perform.

There are four basic *system abilities* that a system needs to possess in order to be resilient: it must be able to *learn* from past events; to *anticipate* future opportunities, challenges and demands; to *monitor* the environment and its own performance for possible threats; and to *respond* to regular and irregular situations during daily operation (Hollnagel, 2011).

3 METHODOLOGY

This study has aimed at exploring and understanding how crewmembers define and promote maritime safety as part of their daily work on board. This is why a qualitative design using interviews and observations was chosen for the data collection.

31 semi-structured interviews with crewmembers of two vessels were conducted. 9 of the interviewees were part of the bridge-team serving as Masters or navigating officer, while the remaining 21 respondents represent crewmembers in various positions ranging from engine room personnel to mates and stewards.

The interviews conducted were semi-structured and followed an interview guide with up to 15 questions depending on the interviewees' working position on board. Of the 31 participants 24 provided their consent for a recording. These interviews were transcribed verbatim, while the other interviews were analysed with the help of notes taken during the time of the interview.

To complement the data gained from the interviews, two observations on board of merchant vessels were conducted. Five days were spent on each vessel. Crewmembers in various positions on board, e.g. bridge officers, mates, and engine-room personnel, were observed during their work. The observations were coupled with contextual inquiries during which the informants were asked why and how they would conduct certain tasks to gain deeper insights for how the subjects related the tasks performed to the overall concept of maritime safety.

The analysis of all data collected was conducted as an iterative process inspired by grounded theory (Corbin & Strauss, 2008). All aspects the informants related to their definition, promotion and understanding of maritime safety in the interviews and contextual inquiries were assembled and coupled with actions observed on board. In a second step, levels of system aggregation of a JCS of a merchant vessel were identified and assembled. In a last step, the actions of the JCS on various levels of system aggregation were identified with the help of concepts derived from CSE and RE.

4 RESULTS AND DISCUSSION

Three levels of system aggregation of the socio-technical system of a merchant vessel are identified through the analysis. The JCS of a merchant vessel incorporates crewmembers, both as individuals, but also as the crew as whole, technical artefacts, e.g. computerised safety management systems, and non-technical support, e.g. emergency procedures. Safety arises when the JCS is successfully balancing the multiple goals that arise from the increasing production demands in a vast amount of varying conditions of a vessel's operation. Three levels of system aggregation have been identified within this study: person-centred, crew-centred, and vessel-centred.

4.1 Person-Centred

The first layer of the JCS is person-centred and relates to the single crewmember and his/her tools, safety equipment and tasks that he/she is responsible for. Control at this layer of system aggregation mainly concerns conducting a task while mitigating the risk of injury as much as possible. As work on board of vessels is experienced as inherently dangerous, the informants emphasised that there is no way in which risks can be eliminated.

“If you stay on board it means that you are under dangerous conditions. You look around you and everywhere as something can come from anywhere which can damage your body” (crewmember)

Although the usage of safety equipment, such as goggles and helmets, can decrease the risk of injury, working on a vessel is considered as being inherently dangerous. Individual risk assessments at this level concern discussing whether a task can or needs to be conducted in the current situation and how the potential risk can possibly be mitigated. Nevertheless, the informants highlighted that some tasks are necessary to conduct. Safety equipment is one of the measures that can reduce, but not to eliminate the risks completely.

4.2 Crew-Centred

The second level of system aggregation, crew-centred, addresses the single mariner’s position as part of a whole, the crew. At this level of system aggregation coordination of tasks and communication are most important to be able to maintain control over the processes that the crew tackles as a whole. The quote below emphasises the importance of crew for the overall safety on board by using an analogy from the information technology domain as the informant identifies the physical vessel and its equipment as hardware, while the crew is the software that makes work safe.

“Most important for maritime safety is the software” (member of the bridge-team)

It is what people do, rather than the material they have to work with, that is important for safety. Activities steered on this level of system aggregation normally involve more than one member of the crew at once and require communication and coordination of tasks. An example for such an activity is loading and unloading a vessel. While a member of the bridge-team is planning the loading and unloading, the activity itself is conducted by the crewmembers in cooperation with a port’s operational personnel. Feedback on success or failure of an action or task execution on this level is slower than on the person-centred level, at the same time as the ability to anticipate and predict the system’s behaviour increases in complexity as there is a higher degree of uncertainty introduced by the dynamics of the environment.

4.3 Vessel-Centred

The third level of system aggregation is vessel-centred. Tasks at this level are concerned with monitoring the state of the vessel, including the technical and non-technical equipment, and the entire crew to fulfil the overall goal of transporting cargo safely from one port to another. More than one respondent in this study emphasized that especially technology, as well as the constant pressure to operate efficiently, has a large impact on the system’s ability to perform safely.

“Well, I have thought about maritime safety. It seems to be very important as long as it does not cost anything. Repairs and shipyard visits are postponed which has very negative influence on our working environment down there [in the engine room]” (crewmember)

The crewmembers often felt torn between safety and efficiency. As can be read in the statement above, what is considered to be safe for the vessel might not be what is promoted by the shipping company. The seafarers on board of vessels often felt the need to deal with the consequences of the financial pressure in the maritime domain as such. They generally stressed that several necessary improvements and reparations were postponed, which affected the system’s ability to work safely.

4.4 Common Ground as Basis for Resilience

Anticipation, learning, monitoring and responding are abilities that need to be present for a system to be resilient. Within the setting of the merchant vessel JCS, these abilities are found to be based on experience and common ground. Common ground in this study is identified as the overall of experience and knowledge of the individuals working on board. It is shaped by the experience of the single crewmember, but also builds on his/her knowledge and connects the crew to each other as it is constituted by overlaps in the members’ knowledge and experience as depicted in fig 1. These overlaps arise in situations where work is conducted in a team, where the work of one crewmember is depending on the work of another one, or when the crew is conducting drills and trainings. It is dynamic and highly depending on the individuals that constitute the crew.

As teams and tasks change, the common ground is either increasing or decreasing depending on the team size, the experience and the knowledge of the individuals aboard.

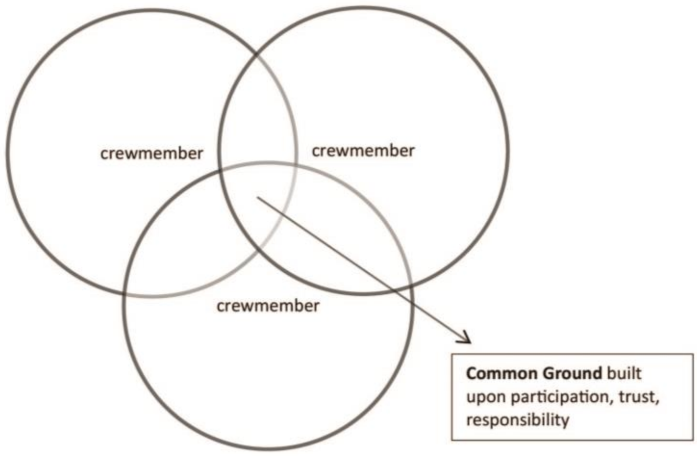

Figure 1*: Common ground constituted by the overlap of knowledge and experience of every crewmember on board a vessel.*

In a highly hazardous work environment, such as a vessel, each crewmember has to be able to trust into own and each other's competencies. Furthermore, similar to findings from Sanne (2008), the mariners part of this study displayed a high degree of pride within their professional roles, and storytelling among crewmembers was constantly used to confirm the norms and values of the profession, but also to emphasise importance of learning from each other. Crewmembers learn from each other's experience, and common ground and storytelling are used to transfer certain values and norms, as well as to show ways of balancing multiple goals and production demands. Many of the stories told from one crewmember to another contain essential information on how to work around conflicts within the operational work environment and the organisational environment.

4.5 Making Trade-offs

The results obtained show that the JCS faces several trade-offs between production demands and safety at each level of system aggregation due to the organisational environment constituted by the shipping company and the overall legal framework.

"(…) these books [SOLAS, MARPOL, STCW] can only say the roughly conditions and the most average conditions, you know, of the ship." (member of the bridge-team)

The seafarers interviewed in this study highlighted that the basics of safety are built upon an understanding and knowledge of current rules, regulations, recommendations and guidelines issued by either national administrations or international bodies, such as the International Maritime Organisation (IMO). Although these documents frame the options of available actions, safety itself arises from how these documents are interpreted and balanced with each other as regulations can state conflicting rules. It is therefore up to the crew themselves to decide which framework to prioritise. Further, due to increasing the regulating framework, a lot of new tasks have been introduced to the work of mariners. One example frequently named by the informants is the upcoming of checklists.

"I cannot find a checklist so important. As I told you before how I contribute to maritime safety is according to common sense and good seamanship practice."(member of the bridge-team)

The quote above shows that although checklists are present, they are not always considered meaningful. While they might be a good reminder, safety itself is promoted by applying experience and knowledge to deal with the variability of operating conditions met within the daily work settings. Overall the informants felt that checklists have only little to do with the actual work that needs to be conducted within a certain timeframe. When time is limited, the informants highlighted that experience is the key to getting work done in a safe manner. In addition to checklists, several of the informants also stressed the conflicting role of new technical equipment. While technology from a shipping company's perspective provides a clear cost and calculated benefit, it might not always support the mariners in their tasks. Often crewmembers experienced that equipment was just added without being properly integrated with already existing technology, rather increasing the overall workload than decreasing and supporting task execution.

6 CONCLUDING REMARKS

As outlined above, mariners face multiple trade-offs between production demands and safety as part of their daily job. The results have identified common ground, an overlap between knowledge and experience among the crewmembers, as an essential part of what makes the JCS resilient. Professional roles are assigned based on individual capabilities, but it is only on the crew-centred level where both common knowledge and individual capabilities are needed to keep the system within the limits of safe performance. Further, the importance of storytelling was highlighted in the results. Stories serve as guidelines of how to deal with the daily trade-offs between efficiency and safety in a highly hazardous work environment.

This study has been a first step towards a deeper understanding of how mariners relate to safety within their daily work. However, there is the need to look further into how both common ground and storytelling assist and support mariners' safety perception and construction.

Acknowledgements

The authors would like to thank the Fru Mary von Sydow, född Wijk, foundation, the Region of Västra Götaland, and the Swedish Mercantile Marine Foundation for funding this project. Further, without the willingness of our informants to share their views, opinions, and insights there would not be any results to present. Thank you!

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Assessing Behaviour towards organizational Resilience in Aviation

Michaela Heese[1], Wolfgang Kallus[2] and Christa Kolodej[2]
[1]Austro Control GmbH, Schnirchgasse 11, 1030 Vienna, Austria
michaela.heese@austrocontrol.at
[2]University of Graz, Universitätsplatz 2, 8010 Graz, Austria
wolfgang.kallus@uni-graz.at, christa.kolodej@uni-graz.at

Abstract

Traditionally safety management focuses on things that can go wrong (losses, harm, incidents and accidents) rather than on the positive side. Since Air Traffic Management (ATM) already is an ultra-safe industry with very high safety standards new safety management approaches may be necessary to keep standards high in light of future challenges such as managing increased automation and conflicting goals (capacity, cost, efficiency, environment, predictability and safety). This paper reports on the development and initial validation of an Inventory to assess Behaviour towards Organisational Resilience in Aviation (I-BORA) across three operational groups (N=282) within the aviation industry linked to a list of observable day-to-day behaviours on the job. Four dimensions underlying behaviour towards organizational resilience could be confirmed referring to *Goal directed/ proactive solutions*, *Flexibility*, *Improvisation* and *Availability of Resources*. Draft behaviours towards organisational resilience are presented in preparation for a validation in the simulator. Results are discussed with reference to current research and best practices promoting the resilience engineering perspective for management and staff to overcome system vulnerabilities for competitive advantage.

1 INTRODUCTION

Today aviation staff are required to adjust to rapidly changing processes and highly automated systems and juggle conflicting goals to ensure ever safe, efficient and environmentally friendly operations. Organisations within the aviation industry therefore have adopted a new approach to safety management which is widely known as “resilience engineering” in order to support their staff to cope with these new requirements. The concept of resilience was originally introduced in early childhood psychology referring to an individual's tendency to cope with stress and adversity (Mallak, 1998). Hopkins (2013) argues that the banner of resilience engineering is based on the theory of high reliability organisations (HRO) developed in the early 1980s, where commitment to resilience is one of five characteristics to manage the unexpected. In fact James Reason (2001) cleared the way for the resilience engineering perspective by recognising that it is the human variability, being able to adjust and improvise, that protects the aviation system in a dynamic uncertain world. Shortly after Sheffi (2005) presented the resilient enterprise demonstrating how organisations overcome vulnerability for competitive advantage. Since then the concept of business resilience and continuity has gained significant popularity.

Hollnagel (2006:16) defined resilience “as the ability of a system or an organisation to react and recover from disturbances at an early stage with minimal effect on dynamic stability”. Woods (2006) added to this definition four important properties of resilient systems highlighting buffering capacity (size/kind of disruption absorbed by the system without major breakdown), flexibility (ability to restructure in response to changes), margin (how closely a system operates relative to a performance boundary) and tolerance (how a system behaves near a boundary). Woltjer et al. (2013) recently suggested adding values such as “actual operational practices, procedures and techniques”, “goal trade-offs” and “human performance” in support of the Single European Sky Research Programme (SESAR). The European Organisation of the Safety of Air Navigation (EUROCONTROL, 2013) considers organisational resilience as a proactive approach to safety management focused on anticipating problems, accepting a wide range of variability, adapting to unstable and surprising environments and designing error-tolerant human/technical systems. By focusing on the things that go right (proactive), rather than the things that go wrong (reactive) resilience engineering takes a position, which fundamentally differs from traditional safety management approaches (Hollnagel, 2011).

1.1 Assessing resilience on organisational level

Hollnagel (2010:4) argued that "it is not possible to represent resilience by a single or simple measurement" and therefore proposed the Resilience Assessment Grid (RAG) assessing four cornerstones of a resilient organisation as potential solution. RAG looks at "the ability to respond to events, to monitor on-going developments, to anticipate future threats and opportunities, and to learn from past failures and successes alike. The engineering of resilience compromises the ways in which these four capabilities can be established and managed." (Hollnagel, 2011: Prologue). Completing RAG requires detailed knowledge on how an organisation operates and implicates that questions are tailored to match the characteristics of an organisation producing a relative rating of the resilience in an organisation. RAG offers a conceptual and methodological basis for engineering resilience on an organisational level. However, it does not provide any guidance on how this goal can be achieved on an individual or team level.

1.2 Assessing resilience on individual level

Human operators are at the sharp end of highly reliable systems ensuring safe operations even when systems fail. Mallak (1998) was one of the first to develop an instrument to assess resilient behaviour in the organizational context of the healthcare industry. He validated his resilience scales (compare Table 1) on a sample of 128 nursing executives producing acceptable values for internal consistency[3]. Sommers (2009) picked up on Mallak's scales to develop the Organizational Resilience Potential Scale (Table 1) tested on 96 public works directors. New developments (Kolodej, Reiter & Kallus, 2012:1) are motivated by the fact that resilient behaviour gets more and more important as a key qualification in the working life. The inventory of resilient behaviour at the place of work was constructed based on a sample of 132 working persons of no specific occupational group suggesting 12 underlying components. Overlapping components with previous research (Mallak, 1998 and Sommers, 2009) are listed in table 1 and form the base for the development of a tool to assess behaviour towards organisational resilience applicable to the aviation industry.

Table 1. *Comparison of overlapping components underlying organizational resilience*

#	Resilience Scales (Mallak, 1998)	Organisational Resilience Potential Scale (Sommers, 2009)	Inventory of resilient behaviour at the place of work (Kolodej et al., 2012)
1	Goal-directed solution seeking	Goal-directed solution seeking	Goal-directed solution seeking
2	Avoidance	Risk Avoidance	Avoidance/Scepticism
3	Critical Understanding	Critical Situation Understanding	
4	Role dependence	Ability to fill multiple roles	Improvisation, Flexibility
5	Source reliance	Reliance on information resources	Trust/Reliance on information resources
6	Resource Access	Availability of information resources	Resources

1.3 Assessing resilience on team level

Van der Klej, Molenaar and Schraagen (2011:2158) were the first looking at making teams more resilient by studying the effects of shared leadership behaviours on 105 students working on a naval demand and control scenario. They defined team resilience as "the ability of teams to respond to sudden, unanticipated demands for performance quickly and with minimum decrement of performance" and managed to design and test a training intervention to make teams more resilient.

[3] Cronbach's α (alpha) is a statistical coefficient of internal consistency, commonly used by psychologists as an estimate of the reliability of a psychometric test for a sample of examinees. Tabachnik & Fidel (2007) suggest a Cronbach's Alpha of .70 as acceptable level of internal constistency.

1.4 Training for organisational resilience

Basic unit and on the job training programmes in aviation traditionally aimed at building up skills and competencies for the operation of an aircraft or air traffic management system (Dahlström, Dekker, Nählinder, 2006). Although human factors and non-technical skills are long known to be one of the major contributing factors to aviation accidents and incidents, training to that respect still remains low level. Dekker and Hollnagel (2007:4) highlighted that "operational life contains situations whose subtle and infinite variations will mismatch the exact circumstances of training. It may contain surprises, situations that fall outside the textbook. Practitioners must be able to apply skills and knowledge acquired through training, to situations that even the trainer was unable to foresee." Knowing that resilience engineering expects organisations and their staff to bounce back from the unexpected quickly and resume normal operations, the right training approach seems to be even more relevant. Resilience requires management and front line staff to think outside the box and take an organisation or system way beyond the intended design. A recent aviation accidents and incidents review resulted in a rate of 4.2 accidents per million departures in Europe (ICAO, 2013) classifying aviation as ultra-safe industry. Hence, it is striking that stories of human heroes such as Captain Chesley Sullenberger who saved 150 passengers and 5 crew members on US Air Flight 1549 in 2009 by ditching an airbus A320 in the Hudson River are comparably rare. Media speculate that Captain Sullenberger was just lucky, while ambassadors of the resilient engineering perspective believe in remarkable skills to adjust to and compensate for the unexpected (Pariès, 2011). This paper is inspired by this new safety view focusing on human behaviours that make things go right, rather than the negative side.

1.5 Main research question

This paper reports on the development and initial validation of an Inventory to assess Behaviour towards Organisational Resilience in Aviation (I-BORA) across three operational groups within the aviation industry linked to a list of observable day-to-day behaviours on the job.

2 METHOD

This study is part of two year project looking at safety culture maturity, organisational resilience and proactive safety behaviour in aviation performed at the Austrian Air Navigation Service Provider in collaboration with the University of Graz to be completed by 2014.

The method consisted of the development and application of a questionnaire, execution of safety-related reconstruction interviews and behaviour observations (Kallus, Barbarino & van Damme, 1998) during live operations. Interview and observational data are still under analysis, so this paper focuses on presenting results from the initial validation exercise based on questionnaire data with an outlook referring to behavioural data.

2.1 Sample and procedure

The sample consisted of a total of 282 male and female operational staff spread across three different occupational groups (50,71% (n=143) licenced en-route and terminal ATCOs, 30,5% (n=86) air traffic safety electronics personnel (ATSEPs) as well as 16% (n=45) meteorologists, 2,8% (n=8) did not provide their occupational group) and eight different sites within Austria. For data anonymity reasons participants were not asked to provide exact age or gender. The minority of participants (9,4%) were under 25 years old. 33,3% of the participants were in the 26-35 years age-group, 31,1% in the 36-45 years group and 26,2% were above 45 years old. 15% did not select any age group. The majority of respondents (35,5%) had at least 15 years of experience within the organization. 12.1% also had a managerial role, 22.3% were supervisors and 40,3% trainers/instructors. Participation was voluntary during scheduled working hours and participants did not receive any other incentives.

2.2 Measures and Analysis

The Inventory to assess Behaviour towards Organisational Resilience in Aviation (I-BORA) is based on selected questions from the German Inventory of resilient behaviour at the place of work (Kolodej, Reiter, Kallus, 2012). I-BORA consists of 20 statements (translated into English language) regarding behaviour towards organisational resilience related to the past seven days and nights to be answered on a 7-point frequency scale from 0 (never) to 6 (always). For example: "I was able to cope with an unexpected situation without the help of managers." Based on empirical literature (table 1) the 20 statements were originally grouped to relate to four common resilience dimensions such as goal oriented solution-seeking, avoidance/scepticism, information resources and improvisation/flexibility. Data were transformed considering inverted answer formats and underwent principal component analysis (PCA) with Kaiser's criterion and Varimax rotation as well as reliability analysis using SPSS (Statistical Package for Social Sciences) Version 17.0. Missing values were excluded listwise (complete case analysis).

3 RESULTS

From the principal component analysis six factors could be extracted. The associated scree plot indicated a main breaking point after the third component, suggesting a three factor solution accounting for 42,16% of variance. A similar result was achieved when looking at the MET subsample (n=45) resulting in a three factor solution accounting for 53,27% of variance (Heese & Kallus, 2012). Table 2 shows factors loadings in the rotated component matrix.

Table 2. *Rotated component matrix (N=282) for 20 questions of the I-BORA*

	1	2	3	4	5	6
(1) … I was able to cope with an unexpected situation without the help of managers.				.711		
(2) … I was able to fill in for a colleague temporarily.				.788		
(3) … I exchanged ideas regarding improvements with my colleagues.	.692					
(4) … I tried to find alternative solutions for a problem.	.784					
(5) … I considered a problem as challenge	.779					
(6) … I made decisions, although I was not 100% sure.	.387		.456			
(7) … I actively avoided tasks/situations, because I felt overloaded.	.308				.626	
(8) … I searched for solutions to a problem together with my colleagues.	.671					
(9) … I worked on improving myself in my job.	.440					.447
(10) … I had sufficient knowledge to perform my tasks.		-.698				
(11) … I avoided any risk.					.707	
(12) … I relied on my intuition when faced with a difficult situation.			.813			
(13) … I achieved a good result by improvising.			.780			
(14) … I was sceptical in a new situation.		.401	.330		.396	
(15) … I knew who to attend to in case of problems.						.772
(16) … I adopted my way of working to the situation.						.581
(17) … I made use of informal contacts to solve a problem.		.564				.411
(18) … I actively avoided a situation that seemed chaotic to me.					.691	
(19) … I was not able to perform tasks as per procedure, because required resources were missing.		.755				

(20) … I was missing certain information to cope with a difficult situation.		.799				

Questions loading on one factor were clustered and underwent subsequent analysis of reliability. Eight Questions 6, 7, 10, 11 and 14-18 were excluded due to insufficient corrected item-total correlations <.35 and/or multiple factor loadings. The remaining 12 questions proposed for further use and validation are shaded in grey (Table 2).

Table 3 gives an overview of the four components extracted including Cronbach's Alpha values for internal consistency (reliability). Two of four components underlying organisational resilience (shaded in grey) demonstrated an acceptable level of Cronbach's Alpha = .70 according to Tabachnik & Fidell, (2007). The remaining two components just missed the cut-off point.

Table 3. *Cronbach's alpha values for internal consistency (reliability) of the latent variable behaviour towards organizational resilience (N=282)*

Component Name	Total item count	Item reference*	Cronbach's alpha
Goal-directed/ proactive solutions	5	3, 4, 5, 6, 8, 9	.787
Flexibility	2	1, 2	.633
Improvisation	2	12, 13	.671
Availability of Resources	3	19, 20	.708

*Note. Items 7, 10, 14-18 were excluded.

4 DISCUSSION

This paper adds significant value to empirical research and best practices within the Aviation industry by proving four components underlying behaviour towards organisational resilience as stable across three different occupational groups. Although two of four components just missed the .70 cut-off for internal consistency (Tabachnik & Fidell, 2007) it can be concluded that results confirm previous research (Table 1). One reason for the insufficient Cronbach's alpha values is the small number of items used to assess the associated two components. It is therefore recommended to include additional items based on the Inventory of resilient behaviour at the place of work (Kolodej et al., 2012) in a second validation. Previous work (Heese & Kallus, 2012) recommended excluding the component *flexibility* due to insufficient reliability. However, in view of Woods (2006) considering *flexibility* as one of the major resilience principles and in light of linking the behaviours to day to day operations, it was decided to keep *flexibility* as standalone the component.

Reason (2001) argued that human variability makes dynamic systems safe. Lessons from the Hudson (Pariès, 2011:15) identified "a very fast overall operational comprehension of the unexpected situation" going along with "a highly dynamic (re)planning capacity" and "some sense of improvising and adapting to the required emergency procedures" as behaviours supporting organisational resilience. Further, Pariès (2011) highlighted that controlling stress, as well as training and experience was a key factor contributing to the miracle of the Hudson. Woltjer et al. (2013) warned from prescribing normative behaviours towards organisational resilience claiming that depending on the situation/disturbance one behaviour maybe the right one, while in a different situation/disturbance it may be considered wrong. While this paper acknowledges this note of caution, there is a strong need from an organisational perspective to break down the resilience engineering concept to actual tangible behaviour that can be observed in every day operations. Executive managers want to know how to up-skill their staff to bounce back quickly after disturbances and handle unexpected situations. Recruiters and trainers want to know what skills to look for to create future heroes and finally operational staff wants to be reassured that their performance ensures safe and efficient operations.

Recent literature offers a broad range of theories and models focusing on engineering resilient systems (Hollnagel et al., 2011), but only little focus is placed on "engineering" the individual or teams. Understanding why things go right in every day operations and identifying which behaviours compensate for disturbances is therefore considered key to overcome vulnerabilities for competitive advantage.

5 OUTLOOK

Following the initial validation of I-BORA it was attempted to derive actual behaviours towards organisational resilience that can be observed on the job. Safety-related reconstruction interviews based on the integrated task analyses approach (Kallus, Barbarino & vanDamme, 1998) were used to find out how operational staff handles expected and unexpected situations. Table 4 presents a draft list of resilient behaviours linked to validated components including examples from the ATCO group to facilitate understanding of the reader.

Table 4. *Draft behaviours towards organisational resilience in day-to-day aviation operations*

Component	Resilience Principle (Woods, 2006; Woltjer et al., 2013)	Behaviour	Example from the air traffic control operations room
Goal-directed/ proactive solutions	Goal trade-offs	Trades conflicting goals (capacity/efficiency/cost)	ATCO proactively offering an earlier slot, direct routes/ taxiways
	Coordination	Anticipatory planning/coordination	ATCO caters for alternative options (plan B and C)
	Timing/Pacing/ Synchronisation	Takes conditions of colleague into account	ATCO waits until work step is completed before interrupting
Improvisation	Approximate adjustments	Bends standard operating procedures for safety/ efficiency/ capacity purposes (use best judgement)	ATCO hands-over aircraft earlier to the next sector
	Actual practice/ techniques	Invents work around procedure	ATCO referring to use cases for known system bugs
Flexibility	Buffering capacity, margins, tolerance	Actively increases safety buffers (defensive controlling)	ATCO providing additional separation for inexperienced pilots
	Adaptive capacity	Takes on a colleagues' s responsibility temporarily	ATCO covering for 2nd position temporarily
Availability of Resources	Complexity/ Procedures	Consults written/printed documentation (manuals, procedures)	ATCO referring to route charts for alternative waypoints
	Underspecification	Looks up electronic/ information online	ATCO consults current AIP online

In addition operational staff was asked to rate the previous shift using a 50-point Subjective Critical Situations (SCS) rating scale (Kallus, Hoffmann & Winkler, 2008) from 0=routine situation to 50=critical incident as well as assessing Taskload, Efficiency and Safety Buffers (TEST) (Kallus, Hoffmann, Winkler & Vormayr, 2010). Interview and behavioural data are still subject to analysis and will be reported and interpreted in context with the data from the rating tools.

In view that controlling stress was identified to be a key factor in handling unexpected situations (Pariès, 2011) results will finally be validated in the simulator investigating whether behaviour towards organisational resilience remains stable under stressful versus non-stressful conditions.

In conclusion this paper provides a wide range of methods and tools to be used to assess behaviour towards organisational resilience in aviation hoping to have contributed to making the new resilience engineering approach more tangible and relevant for organisations and staff.

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Are trade-offs experienced and if yes, how? Studying organizational resilience through operators' dilemmas

Dimitris Nathanael, Vassilis Tsagkas and Nicolas Marmaras
ErgoU, National Technical University of Athens, Greece
dnathan@central.ntua.gr, vtsagkas@central.ntua.gr, marmaras@central.ntua.gr

Abstract

In the present paper we report on a field observation study in a commercial aircraft maintenance organisation. We present cases where technicians face dilemmas on alternative courses of actions and take decisions during the performance of scheduled maintenance tasks. The aim of the study was to analyse in fine detail the technicians' decision frame in each particular case, and moving upwards to investigate how these decision frames are influences by higher level organizational trade-offs.

1 INTRODUCTION

Traditionally, deviations from prescribed work are treated as violations, i.e. as a symptom of risky behaviour and a sign of compromise in safety. They are thus managed through thorough control of deviating acts and/or through adding amendments to procedures. This strategy is both intuitive and effective up to a certain level of complexity. However, it is grounded on a techno-centric conviction i.e. that the lived reality of work can in due course be fully deciphered and become totally predictable. This strategy eventually leads to a vicious cycle of more prescription, resulting to more deviations and vice versa (Leplat, 1998). For example, in the domain of safety management Reason (1997) observed that safe operating procedures often become overwhelmingly exhaustive by continuous amendments to prohibit actions that have been implicated in some recent accident or incident. Through time such "additions" to the rulebook become increasingly restrictive, often reducing the range of permitted actions to far less than those necessary to get the job done under anything but optimal conditions (ibid). As Charles Perrow (1984) has demonstrated almost thirty years ago, organizational oversize leads to interactive complexity, and over systematization to tight coupling; the result is unpredictability; and unpredictability calls for resilience (Woods & Hollnagel, 2006).

Indeed, even in highly formalized work domains, workers often face ambiguity in their day-to-day conduct and find themselves in the midst of countless dilemmas that call for action. To resolve dilemmas, workers need to evaluate situations, make assumptions, take decisions and develop certain modes of action in order to get the job done. Actual work practice will necessarily deviate from prescription (Nathanael & Marmaras, 2008a). As an example, in the domain of air maintenance schedule pressures, unavailability of tools or spares, confusing manuals, or fatigue call for many situated decisions and diverse compensation strategies (Chang & Wang, 2009).

In the present paper we report on a field observation study in a commercial aircraft maintenance organisation. Specifically, we analyse cases where technicians face dilemmas and take decisions during the performance of scheduled maintenance tasks. Such decisions may or may not result in deviating from prescribed procedures. The aim of the study was to analyse in fine detail the technicians' decision frame in each particular case, and moving upwards to investigate how these decision frames are influenced by higher level organizational trade-offs.

2 THEORETICAL BACKGROUND

In order to enhance resilience, organizations must be able to adapt or to absorb disturbances, disruptions and change (Woods and Hollnagel, 2006). In this line of thought it has been suggested that organizations should provoke a constant dialectic between what is prescribed and what is actually done (Nathanael & Marmaras, 2008b; Kontogiannis & Malakis, 2012). In other words, in order to enhance organizational resilience, one needs to acknowledge the mute confrontation between what is actually experienced (i.e. contextual distinctions and community descriptions) and what is prescribed (i.e. procedures and written rules). It is by accepting this confrontation and uncovering it (i.e. through a dialectical process) that ultimately an organization gains in ability to absorb diverse threats and adapt accordingly.

One could maintain that the core of expertise, from the perspective of people actually performing work, is not so much exhaustive knowledge of and adherence to prescribed procedures, but rather the ability to perceive and distinguish between different types of situations and act accordingly when there is no clear path to follow. (Nathanael & Marmaras, 2008a).

Such situated judgements are generally not of the algorithmic type; more often than not, they seem to be experienced as dilemmas, i.e. as a confrontation and, often forced resolution of sets of partially conflicting determinants. Such conflicting determinants may sometimes lead to unmanageable situations or otherwise unavoidable deviation. In other cases, mutually reinforcing or conflicting determinants may also lead to local or novel opportunities for optimizing practice.

The notion of conflicting dualities is growing among authors in Human Factors related disciplines. The latest thinking in resilience engineering posits that safety is not an independent system quality, i.e. for given level of system resources, safety cannot be drastically improved unless productivity goals are at least partially compromised (Hollnagel, 2009). In the same vein, it has also been acknowledged that chronic goals tend to get sacrificed to acute goals. These observed antagonisms between productivity and safety have been formulated as the Efficiency-Thoroughness trade-off (Hollnagel, 2009) and the Acute-Chronic trade-off (Woods, 2009). Hoffman and Woods (2011) go as far as to propose five fundamental trade-offs for what they call “macro cognitive work systems”. These are: Optimality-Resilience trade-off, Efficiency-Thoroughness trade-off, Acute-Chronic trade-off, Specialist-Generalist trade-off and Distributed-Concentrated trade-off. These so called “fundamental” bi-poles of opposing tendencies can indeed be recognized in many work situations, and do provide an important framework towards a dialectical approach to organizational resilience. However, to become operational, such generic trade-offs also need to be considered (i.e. understood) at the level of concrete human experience and action.

In the present communication we concentrate on this critical part of day-to-day practice i.e. situated judgments and choices. We suggest (i) that many deviations from prescribed procedures, or other decisions aiming at contextual optimization, are experienced as dilemmas and (ii) that these dilemmas can be effectively represented in the form of flat sets (bi-pole, tri-pole etc.) of mutually confronting factors. These sets, at the level of operator’s experience, we term dilemmatic webs. Dilemmatic webs may then be associated to what we term systemic contradictions of a particular work domain. Systemic contradictions are inspired from materialist dialectics (Ilyenkov, 1977). They are essentially of the same nature as the fundamental trade-offs in the sense of Hoffman and Woods (2011) but are dependent of problem definition thus of a narrower scope. Systemic contradictions can be specific to a particular work-domain (or an established practice). We advocate that a systematic bottom-up analysis of empirically informed dilemmatic webs can be coupled with a hermeneutically inspired analysis of systemic contradictions as in the phenotype – genotype mapping. Such a two level analysis can help us get insight to the probable causal relation of both proximal (dilemmas) and distal (systemic contradictions) factors lying behind the observed deviating actions.

3 METHOD

The field of study is a commercial aircraft maintenance organization (MO) in Greece. In this particular MO there are 30 authorized Aircraft Maintenance Technicians (AMTs), 10 assistant (non-authorized) technicians and 14 aircrafts. At the time of the study, technicians had a broad range of in-house experience that ranged from 6 months to 25 years. All cases were observed during scheduled or unscheduled maintenance checks of four types of passenger aircrafts.

One researcher carried out field work, including systematic observations and interviews with the personnel. The field work lasted in total 3 months, 4 days per week, 5 hours per day. Prior to going to the workshop, the researcher spent an 8 month period in the MO’s various departments in order to become familiar with the MO and the regulatory environment as well as the supporting procedures for the AMTs work (internal quality procedures, schedules, technical procedures etc.). Time was spent at the engineering/planning, quality, airworthiness departments and in the Maintenance control centre (MCC) of the MO. Apart from the above, a familiarization period at the maintenance workshop preceded the actual field work period, in order to become as native as possible to the work team, according to standard ethnographic practice.

During the observations period, the researcher was closely following and observing the actions of one of the AMTs per task, checking the task instruction being carried out. Hence, only a proportion of the total actual maintenance actions were observed. The observations were enough, though, on our pursuit of decisions / dilemmas. AMTs were probed to verbalize and justify their actions. The researcher tried not to distract the technicians during the performance of maintenance acts, and only asked questions in idle periods, after work or during breaks. Any data collected during the field work was recorded by non-intrusive means (pen and paper). Following the field work, the researcher exhaustively studied all the manuals (manufacturer’s and organization’s) concerning the maintenance actions observed.

Decisions or dilemmas are of course subjective events and cannot be objectively identified as such by an observer. However, through the long observation period, a number of indirect triggers helped point at such phenomena, discuss them with the AMTs involved, and analyse the factors that played a role in each case. The most evident indirect sign of the existence of a dilemma or need for a decision is when resources for action are limited (e.g. not enough time, no available tool, lack of knowledge), or when something is recognized as unusual (e.g. a mismatch between maintenance manual illustration and actual a/c component). Such cases often trigger deviations from specified procedures or standard practice. Such deviations may be routine, infrequent or novel. Infrequent and novel deviations are almost direct indices of dilemmas or choices. Routine deviations may or may not involve decision making. In any case, they present entry points for further analysis and verification or not by the practitioner being observed.

4 ANALYSIS AND RESULTS

Overall 18 cases of dilemma or decision cases where identified and analysed. Dilemmas or decisions concerned both tasks carried out for the first time by maintenance technicians and tasks which have been repeatedly carried out by the maintenance team (*see* Table 1 for a summary of 3 out of the 18 cases analysed). The detailed analysis of each case let us identify specific factors that by large determined the concrete courses of action of maintenance technicians at the time of their decisions. These factors ranged from the most normative (e.g. the organization's pursuit of airworthiness) to the most contextual ones (e.g. personal comfort, schedule pressures etc.) (Tsagkas et al. 2013). We claim that combined, these factors pragmatically delimit the technicians' courses of action. In this particular work system, our attempt to group and generalise the various contextual factors, led as to five categories of determining factors.

The five categories of determining factors in the dilemmatic webs of AMTs choices / decisions identified are as follows:

- Schedule: schedule/time pressure related factors coming from outside the individual AMTs or team members of a particular task (e.g. pressure from the shift leader to finish task on time).
- Airworthiness (A/W): factors related to the perception that ATMs have as of the proper condition of the aircraft and its safety at flight after their work.
- Cost saving: all financial related factors that are perceived at the level of the AMTs to affect the organization (e.g. spare parts' costs, financial penalties).
- AMT Accountability: factors related to ATM's formal responsibility that might be traced back by an external entity after the task has been completed.
- Optimize AMT effort: factors related to the optimization / alleviation of either group, personal, cognitive or physical effort needed to perform certain actions.

For every case, each determining factor may take a positive sign, a negative sign or no sign (see last column in Table 1). A positive sign indicates that the particular determining factor influenced positively the action path taken. Conversely, a negative sign indicates that a particular factor was negatively influencing the action path taken. No sign indicates that a particular factor was not found to influence the action path taken. For example, in the third case of table 1, Schedule pressure and Personal effort optimization, combined with Airworthiness (due to the trust for the proper functioning of the new switches)influenced positively the AMT in his decision. Although, cost savings was a negative influence, they proved not powerful enough to compensate schedule pressure and personal effort optimization. Accountability in this case was not identified as a determining factor, and was therefore classified as neutral. In a similar manner, in case 5, Airworthiness, Accountability and Personal effort optimization, were classified as exerting a negative influence. Nevertheless, they could not compensate Schedule pressure, which was classified as the only positive influence, and the one that finally determined the AMT's decision. Cost savings were not identified and therefore were classified as neutral.

From the analysis of the 18 cases we identified that ATM effort optimization and schedule were the two most common factors influencing the action paths chosen (Table 2). Effort optimization was identified to affect the decision in 17 cases and schedule in 13. Airworthiness and Accountability follow determining the action path in 9 and 8 cases respectively. Cost played the least determining role in AMTs decisions, as it was identified in 4 cases. As of the positive vs. negative influence, Schedule proved the most salient determining factor having a positive/negative influence ratio of 12/1. Conversely, cost savings had the least positive influence with a respective ratio of 1/3.

The above analysis is indicative of the general influence that each factor exerts on the decided action paths if seen independently from the others. Such an analysis is limited

Table 1. *Example of three cases analysed*

Case description	Determining Factors
Decision to use a pressing tool instead of liquid nitrogen to accomplish a modification order. The AMT did not seek official advice or wait until liquid nitrogen was available. He was also aware that his choice could cause damages and affect the a/c's airworthiness overtime (A/W -). In addition, using a pressing tool is more tricky and laborious than the use of liquid nitrogen (optimize effort -). The AMT could also be traced back after an audit for his action (accountability -). Nevertheless, the fact that he was heavily pressed by the shift leader to accomplish the task on time (schedule +), determined his action path.	Schedule + Airworthiness - Cost Saving AMT accountability - Optimize AMT effort -
Decision to accept dents on the flap tracks instead of performing further inspections/maintenance or possibly seek official advice. Further inspection could lead to replacement of the flap tracks (optimize effort +). In addition, accepting the dents could affect the a./c's airworthiness (A/W -). Nevertheless, the fact that the AMTs had a heavy daily schedule (schedule -), combined with the fact that no one would probably trace back their action (accountability +), determined their decision to accept the dents and perform no further inspection.	Schedule + Airworthiness - Cost Saving AMT accountability + Optimize AMT effort +
Decision to install new overtemperature switches on the aircraft without inspecting the function of the removed ones. The manual instructions call for reinstallation of the removed switches if the check verifies their proper function. Installing new overtemperature switches ensures their proper functioning and airworthiness (A/W +). In addition, bypassing the check the AMT saves time and effort (effort optimization +). Also, shift leader was pressing for task completion (schedule -). The fact that the switches were thrown away after their removal results in cost increase (cost -).	Schedule + Airworthiness + Cost Saving - AMT accountability Optimize AMT effort +

Table 2. *Total influence of determining factors across all cases*

Influence	Schedule	A/W	Cost sav.	Account	ATM Ef.
positive (+)	12	3	1	4	13
negative (-)	1	6	3	4	4
neutral (0)	5	9	14	10	1
Total	13	9	4	8	17

in that it does not provide any information on how the various factors may mutually reinforce or be in conflict with each other in each particular case. Towards this end we conducted an analysis of the cross influence between factors if seen as bi-poles. Specifically we assigned the negative or positive influence of each factor in each one of the 18 cases with a minus or plus symbol, respectively. Then, for each one of the ten factor bi-poles, we counted them as mutually reinforcing (if they were found with the same sign in one particular case) or that they are in conflict (if they were found to be of opposite signs). We finally summed up the reinforcement or conflict of all factor bi-poles. The results of this analysis are presented in Figure 1.

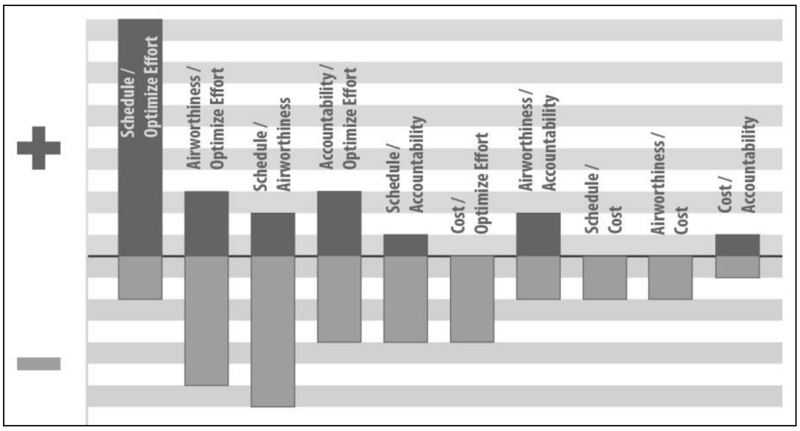

Figure 1. *Reinforcing / conflicting relations between bi-poles of determining factors*

One first interesting outcome is that the relation between factors is not stable. That is, in some cases factor A may have a reinforcing effect on factor B and on some other case the contrary. Nevertheless, some bi-poles demonstrate clear stability and some others not. For example the relation between Cost savings and optimization of AMTs effort was identified as conflicting in all four cases where the two factors were found together. In a similar manner, there seems to be conflicting relationship between Schedule and Airworthiness and to a lesser extent between Optimization of AMTs effort and Airworthiness respectively. On the contrary, the relation between Schedule (pressure) and Optimization of AMTs effort was found to be mutually reinforcing in 11 out of the total 13 cases where the two factors were identified together.

5 DISCUSSION

From the multitude of contextual factors identified as playing a role in the decisions taken we were able to identify five basic categories of determining factors. These categories were then analysed further as bi-poles of mutual influence, to reveal conflicting or reinforcing effects between determining factors.

For the majority of the bi-poles the most prevalent relation was conflict. This however is considered normal because conflict is inherent in the very nature of dilemmas. What seems to us of major importance in the above analysis is the frequency and relative stability (=/-) of the identified bi-poles. Such an analysis, if proven reliable, may provide an empirical basis for the study of the influence of organizational trade-offs on day-to-day practice. (or the uncovering of prevalent sets of trade-offs for a particular work system) The analysis however is more ethnographic than empirical. Observation data needs to be coupled with interviews and with an interpretative analysis of systemic contradictions as in the phenotype – genotype mapping. The choice of determining factors is still somewhat arbitrary so more work is needed in this respect. Nevertheless the method may eventually propose metrics or indices, on how the top-down analyses of organizational trade-offs influence the decision action paths in day-to-day practice.

Generic typologies of trade-offs may constitute a stable ground on which to base some form of comparative assessments between different work systems. On the other hand, in order for them to account for the plurality and particularity of conflicting forces in any concrete work situation, they may need to be complemented by bottom-up analyses and metrics as proposed in the present paper.

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Resilience engineering in healthcare: moving from Epistemology to theory and practice

Anderson, J.E., [1] Ross, A. [2], and Jaye, P. [2]
[1] King's College London, 57 Waterloo Road, London,U.K. SE18WA
[2] Simulation and Interactive Learning Centre, St. Thomas's Hospital, Westminster Bridge Road London, U.K.
Janet.anderson@kcl.ac.uk

Abstract

Few studies have taken a whole system approach to engineering resilience in healthcare. Doing so involves challenges in operationalising and measuring concepts, developing interventions and assessing their impact at a systems level. In this paper we have outlined a newly funded programme of work to operationalise key resilience concepts, develop and implement interventions to increase resilience, develop metrics to assess their effects and to make recommendations about how the insights of resilience engineering can be harnessed to improve patient safety. The results will provide evidence about the implementation and impact of four complex interventions in the areas of learning, responding, monitoring and anticipating, both singly and in combination, allowing future resilience interventions to be chosen based on knowledge of their effectiveness. The study will also yield an in depth picture of resilience engineering in action to inform the development of theory and the maturation of the approach.

1 INTRODUCTION

Traditional approaches to improving safety in healthcare are reactive and define safety as an absence of errors or adverse events (Woods et al., 2001; Sheps & Cardiff, 2009). Safety management practices are underpinned by a dominant technical/rational paradigm which is reductionist and based on linear causality (Wallace & Ross, 2006; Dekker et al., 2011). This approach does not take into account the complexity of healthcare systems, which can never be fully specified and therefore cannot be controlled via rigid procedures and rules (Dekker, Cilliers & Hofmeyr, 2011; Flach, 2012; Nemeth, 2011).

Resilience engineering represents a philosophical shift in safety science towards a proactive systems approach that addresses the need for organizations to adapt to changes in the environment in which they operate and to support workers to adapt safely when needed. Safety and harm are viewed as emergent properties of the system, (Flach, 1999; Rauterberg, 1996), both of which are caused by exogenous and endogenous variability. The focus is therefore on how to manage this variability safely and this is proposed to be achieved by four abilities; responding to threats and disturbances, monitoring organisational performance as it unfolds in real time, learning from past experience (both successes and failures), and anticipating changes in the future (Hollnagel, 2009).

Resilience engineering is at an early stage of development and although the epistemological basis is well developed the practical application of these ideas to building resilient organisations is not. Engineering resilience, rather than simply proposing how resilient organisations behave, poses difficult practical questions about how interventions, methods and measurements might be developed and tested in a complex system in the real world, with the requirement to demonstrate outcomes in line with specified safety objectives. In this paper we outline a funded programme of work which will extend the theoretical basis of resilience engineering by testing its operation in context.

1.2 AIMS AND OBJECTIVES

This research seeks to extend the theory and practice of resilience engineering by developing, implementing and testing interventions to improve organisational resilience. The overall aims are to identify how healthcare organisations can be engineered to be more resilient and to develop techniques to assess whether this has been achieved. The objectives of the research are to

1. Develop and implement multilevel tailored interventions to increase organisational resilience in different clinical settings
2. Evaluate their effectiveness, singly and in combination, in terms of quality and cost effectiveness, and a range of other outcome measures
3. Determine the relationship between resilience and other measures of quality and safety

4. Extend and develop the theoretical framework of resilience engineering, using insights from resilience in other domains and empirical evidence from the study

These high level objectives will be achieved by in depth work to

- Analyse existing data, model system performance and track it over time
- Develop measures of organisational resilience
- Examine aspects of resilient practice (eg. trade-offs and sacrifice judgements, gap between procedures and practice, organisational drift, sources of pressure) via ethnographic observations of clinical work
- Develop and implement, in collaboration with clinical teams multilevel (managerial and frontline) interventions to increase resilience
- Evaluate with mixed methods changes in system metrics, measures of resilience, staff knowledge, skills and attitudes and costs-benefits
- Synthesise results and develop an empirically validated model of resilience.

An overview of the research phases is shown in Figure 1

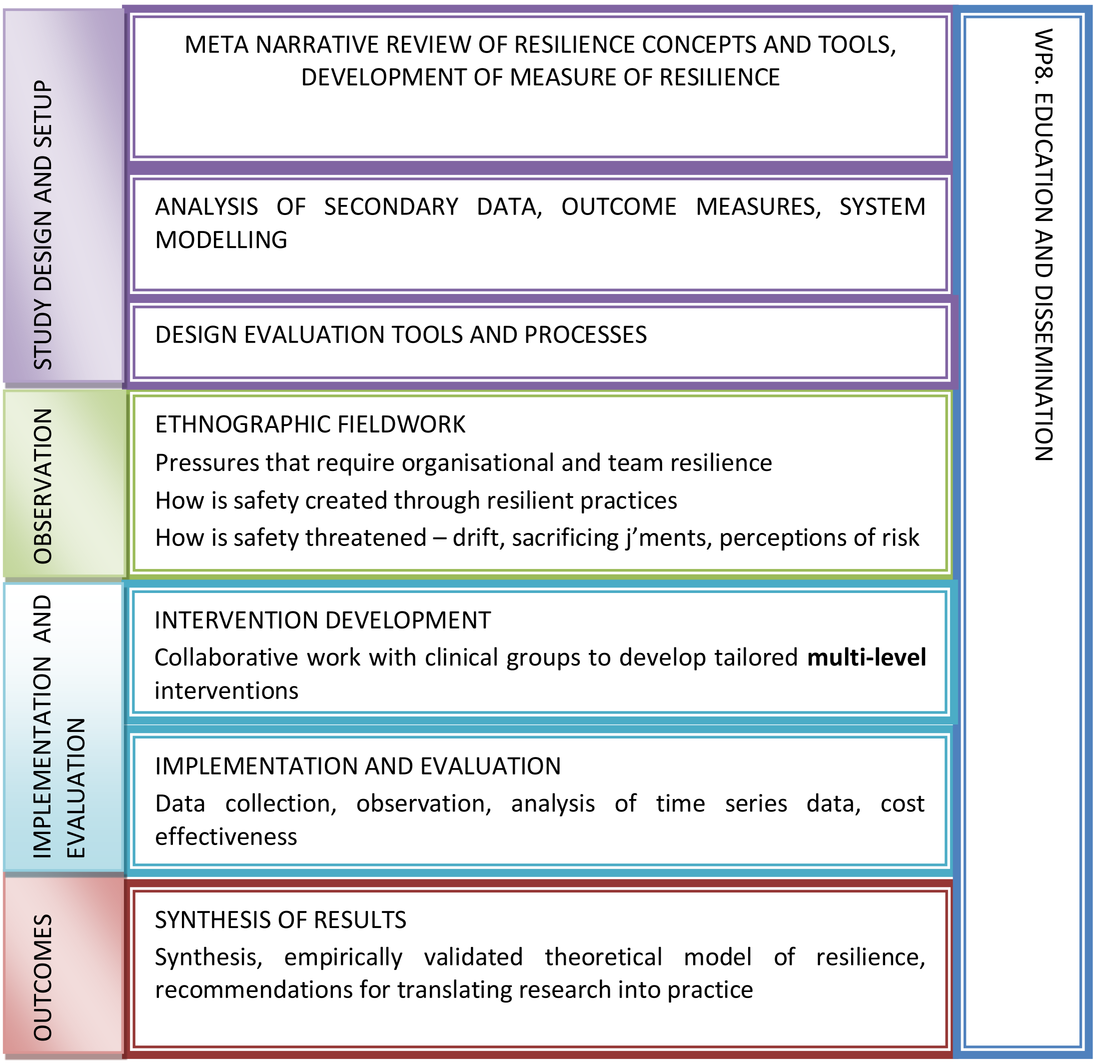

***Figure 1**. Overview of research design*

3 METHODS/DESIGN

3.1 Meta Narrative Review

Resilience is a concept being applied to diverse areas of human and organisational activity. It is grounded in different research traditions and has been applied differently depending on the context and the challenges faced in different areas of human activity. Although our research is based on the insights of RE we also intend to draw on developments and insights from other areas. To do this we are conducting a meta narrative review to identify how resilience has been conceptualised, operationalized and applied in 5 different disciplines – organisational/management, natural hazards and disasters, psychology, sport psychology and safety science/human factors. Meta narrative review (Wong et al., 2013) is a configuring or mapping approach to reviewing scientific literature. The aim is to identify how different research traditions have interpreted and studied the concept and to integrate these narratives into a meta narrative summary of the topic. The emphasis is therefore on how the concept was researched, rather than exhaustively summarising all the findings (Gough et al., 2013). The meta narrative review will inform all subsequent stages of the research.

3.2 Clinical areas

We intend to study two clinical areas in depth; an older person's unit providing specialist care and accident and emergency. The aim is to contrast and compare the different clinical environments in order to start to understand the influence of context on the theory and practical application of the RE. These areas were chosen because they differ in terms of patient acuity and needs, multidisciplinary team requirements, temporal demands and co-ordination requirements. We hypothesise that threats to resilience and strategies to increase resilience will differ depending on these factors. Data will also be collected from control sites.

3.3 System modelling

Assessment of the quality of care is currently based on tracking individual indicators such as numbers of falls or patient complaints. RE is a systems based approach that recognises that multiple aspects of system performance fluctuate over time, co-vary and interact. Therefore, the development of methods and metrics to understand and model system performance, rather than performance on individual variables, will be a key aim of the research. Leading and lagging indicators will be identified and modelled. Exploratory methods compatible with systems thinking (Byrne, 2002) such as trend analysis, cluster analysis, social network analysis and log linear modelling will be used to visualise and detect shifts over time, patterns, organizations and interactions. The unit of analysis will be the dynamic system as a whole rather than the individual atomised elements which make up the system. This system modelling work will underpin all later stages of the work and form the basis of our evaluation of the effects of resilience interventions.

3.4 Ethnographic fieldwork

The whole programme of work will be informed by in depth ethnographic and qualitative analysis to understand the realities of clinical work, sources of pressure and stress on the system, sources of resilience, the gap between procedures and practice, goal trade-offs and interactions between management and frontline staff. This formative work will ensure that the development of interventions, the system modelling and the evaluation are grounded in a deep understanding of the work environment. Data will be collected with qualitative interviews and non-participant observation of clinical work and staff meetings.

3.5 Measure of resilience

Starting with Hollnagel's definition of resilience as "the intrinsic ability of a system or an organisation to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions" (Hollnagel, 2011, p. xxxvi), we will develop a measure of resilience contextualised for healthcare. Taking a multilevel perspective, we will ask how this ability might manifest itself at different but interlinked organisational levels. We know that managers and frontline staff have different opportunities and potential to contribute to organisational resilience (Flin, 2006) and the interactions between these organisational levels are possible key determinants of resilience (Woods & Wreathall, 2006). The process for developing the tool will involve qualitative data collection from clinical staff and managers and will involve iteration and development throughout the research.

3.6 Interventions

Multi-level interventions will be developed in each of the four areas of resilience, co-created with clinical partners and implemented in a stepwise manner to assess their individual contribution to system performance. Clinical agreement with and commitment to changes intended to increase quality and safety is a key factor in their successful implementation (Firth-Cozens, 2001; Dopson & Fitzgerald, 2005) and so we will convene a series of workshops for researchers, clinicians and stakeholders to design the interventions, based on our findings from all the previous phases of the study. Co-development of the interventions will be underpinned by an on-going process of engagement with clinicians and managers at all stages of the research.

We argue that Resilience Engineering at present provides sparse guidance for the development of interventions. It is thus necessary to draw on more developed theories that are relevant for each dimension of resilience. For example, theories of organisational learning (Argyris & Schon, 1978) and absorptive capacity (Harvey et al., 2010) will be relevant for designing interventions to increase learning. Such theories can inform interventions to improve the acquisition, assimilation and application of knowledge to improve organisational performance. Likewise, interventions to improve performance monitoring will use data modelling and presentation techniques to present data, but will also draw on other theories to embed monitoring into organisational routines. For example, theories of sense-making in organisations (Carroll & Edmondson, 2002), groupthink,(Janis, 1982), and psychological safety (Edmondson et al., 1999) will inform our understanding of how the effectiveness of monitoring can be increased in the complex, multidisciplinary, political and hierarchical clinical environment. Interventions to promote the ability to respond to developing problems will involve simulation training with full video and audio playback and team debriefing. The training will aim to develop skills in dealing with and adapting to complexity, anticipating changes, prioritising and making sacrificing judgements, and identifying and responding to threats to safety. The design of simulation training will be informed by theories of learning and education including theories of cognitive skill acquisition (van Lehn, 1996) and social learning (Bandura & McClelland, 1977) to maximise learning and transfer to the clinical environment.

3.7 Modelling of resilience

We will develop a theoretical model of resilience showing relationships between key variables, including relationships between resilience as operationalized and traditional indicators of quality, and highlighting the most effective ways to increase resilience.

3.8 Education and dissemination

A key aim of this programme of work is to contribute to changing attitudes and practices in relation to risk and safety in the NHS in England. We aim to reduce the emphasis on incident reporting and procedural compliance for improving quality and safety, and increase knowledge of resilience engineering through discussions, education and dissemination of practical guidance. The outputs of the study will include detailed recommendations for implementing a resilience approach to safety in acute health care organisations.

4 DISCUSSION

A focus of the project will be processes of adaptation and trade-off in the context of a National Health Service pressured by large scale restructuring and budgetary constraints. It is known that staff face competing demands and inadequate resources across a variety of wards (Dixon-Woods et al., 2009). This paper argues that within the constantly fluctuating demands of the acute care environment we cannot completely specify what is safe and what is not, and seek to ensure that workers always adhere to a safe protocol. Although this approach will ameliorate some safety problems, a more powerful approach is to empower workers to safely adapt to the demands they face. This requires recognizing that workers in part will always have to set their own priorities. How they reconcile competing demands and what effect this has on safety and aspects of care quality such as patient experience and timeliness are empirical questions we will investigate in this study.

5 CONCLUSIONS

Improving safety in complex non engineered systems such as healthcare organisations requires a different approach. We need a change in emphasis from control of error and adverse events via arbitrary targets to a focus on proactive and adaptive processes and how they can be introduced, nurtured and sustained.

In this study, we propose an approach that involves developing and testing interventions in four areas;

1. Knowing what to do
2. Learning from past experience
3. Monitoring the work environment for changes and
4. Anticipating demands in the future.

Few studies have implemented resilience engineering interventions in healthcare. Doing so involves challenges in operationalising and measuring concepts, developing interventions and assessing their impact at a systems level. In this paper we have outlined a funded programme of work to address these challenges and to make recommendations about how the insights of resilience engineering can be harnessed to improve patient safety and care quality. The results will provide evidence about the implementation and impact of four complex interventions in the areas of learning, responding, monitoring and anticipating, both singly and in combination, allowing future resilience interventions to be chosen based on knowledge of their effectiveness. The study will also yield an in depth picture of resilience engineering in action to inform the development of theory and the maturation of the approach.

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Resilience Approach for Medical Residents

R.A. Bezemer and E.H. Bos
TNO, P.O. Box 718, NL-2130 AS Hoofddorp, the Netherlands
robert.bezemer@tno.nl

Abstract

1 INTRODUCTION

Medical residents (doctors in training to become medical specialists) are in a vulnerable position. While still in training, they are (partly) responsible for patient care. They have a dependent relation with their supervisor and have low decision latitude. In general, medical residents are committed and sometimes overcommitted to their job ('a vocation'). Furthermore, they frequently experience a double load in work and private life (e.g. starting a family). Previous studies show that this combination of factors poses medical residents at increased risk for burnout and drop-out of their training. Exhaustion increases the risk of making medical mistakes. Burnout, medical mistakes and quitting training might be reduced if medical residents are more resilient and work in a more resilient system (of processes, supervision and private life).

2 OBJECTIVES

The objective of this study was to develop and evaluate an intervention to increase resilience of individual medical residents, their environment, and the organisation around them. This was expected to lead to an increased system ability to promote individual resilience. The hypothesis is that resilience has an indirect impact on burnout, the intention to leave, and medical errors. To achieve the goals of this project, the following research questions were defined:

1. How can resilience be made operational at the individual (medical resident and specialist), team and organisational (hospital) level?
2. What is the 'Resilience Profile' of the pilot hospital?
3. How can the 'Resilience Profile' contribute to progress of programmes that promote resilience?

3 METHOD

3.1 Intervention Mapping

A resilience model for health care was designed, combining knowledge from individual resilience and system resilience literature. To increase individual and system resilience we focused on four abilities: responding (to the actual), monitoring (the critical), anticipating (the potential) and learn (from the factual). We used the Intervention Mapping (IM) protocol as a guideline. An approach was designed, consisting of four phases: problem analysis, selection of methods and strategies, implementation, and evaluation. In this study the first two IM phases were carried out.

IM is applied to prevent or solve a (health) problem, starting with the definition of a direction for a solution, or an ambition. Further, in all process steps active involvement of relevant stakeholders and users of an intervention is essential, e.g. through focus groups. Finally, IM is an interative process: the steps are repeated until an optimal intervention has been developed.

3.2 Population and Working Group

The intervention process was followed in close collaboration with the target group in a regional middle-sized general hospital, following an iterative and participative approach. Medical residents and medical doctors of many different departments were involved and the employees of the Academy, the occupational physician and the HR advisor. A broad working group was established, chaired by the Academy. The working group included external TNO-experts and convened four times during the project. A combined quantitative and qualitative approach was chosen for the evaluation study. At the start the medical residents and their supervisors filled out questionnaires on several key indicators of resilience and the outcomes (burnout, patient safety and intention to leave). These were followed by a literature scan, interviews and focusgroup meetings as a part of the development of the resilience intervention.

3.3 Questionnnaire

The questionnaire for residents consists of 39 questions and that for medical specialists consists of 34 questions. The questions were based on available literature and composed in dialogue with the working group. Some were subdivided into items, e.g.:

- Burnout (5-point Likert-scale, 5 items).
- Intention to leave (5-point Likert-scale, 2 items).
- Patient safety, focused on culture (5-point Likert-scale, 3 items).

After two weeks non-responders received a reminder. The data were analysed using SPSS. The reliability of the scores was tested through computing Crohnbach's alpha. Some results could be compared with those for the average Dutch working population in general and in the care sector.

3.4 Observations

Observations provide insight into daily activities of residents and specialists. There were three observations days at several departments: Emergency Care, Intensive Care, outpatient clinics and several wards. The observation reports were coded independently by four researchers and then discussed (peer debriefing). The results were utilised to define the interview items.

3.5 Interviews

A semi-structured protocol was written for the interviews, based on the questionnaire results. Four themes were included: learning & feedback, co-operation, patient safety, working hours. Six residents, six specialists/educators, the medical education co-ordinator and the occupational physician of the hospital were interviewed. Two researchers carried out the interviews. Interview reports were analysed in the same way as the observation reports.

3.6 Drawing up a Resilience Profile

The results from the questionnaires, interviews and observations together lead to a 'resilience profile' of the hospital. The combination of these information sources enables the use of quantitative and qualitative research methods (mixed methods).

4 RESULTS

In this study two kinds of results have been developed. Firstly, the results of the pilot study in one hospital in the Netherlands. Secondly, the resulting product "Health Care Resilience Approach" (HCRA).

The response among doctors and residents to the questionnaire was:

- Medical residents: N=47, 68% of the population in the hospital
- Medical doctors: N=69, 53% of the population in the hospital

4.1 Burnout, Intention to Leave and Patient Safety

Burnout

Burnout was investigated through questions about exhaustion, fatigue and general decreased functioning. The result is a score for burnout on a validated 5-point Likert scale (1 to 5). Medical residents have a higher average score (2.3) than medical doctors (1.9) and the average Dutch healthcare worker (2.1).

Perceived social support and autonomy are important determinants for the probability to develop a burnout (theory Job-Demand-Control model, Karasek and Theorell,1990). Perceived social support is a score on a validated 4-point Likert scale (1 to 4). The score is 3.3 for support from colleagues and 2.9 for support from supervisors. This is very close to the average Dutch healthcare worker.

Perceived autonomy is a score on a validated 3-point Likert scale (1 to 3). Residents have a much higher average score (2.3) than supervisors (1.4), close to the average Dutch healthcare worker (2.4).

Another important determinant of burnout is emotional load as a consequence of work. Emotional load is a score on a validated 4-point Likert scale (1 to 4). Residents and specialists have an equal average score (2.8), higher that the average Dutch healthcare worker (2.0).

Intention to leave

Both medical residents and specialists have been asked one question about the intention of residents to leave their training and education. Of the residents, 94% seldom or never seriously considers leaving the training. Of the specialists, 79% seldom or never gets signals that a resident seriously considers leaving.

Patient safety

Medical residents and doctors have been asked about the (perceived) extent of feedback that residents receive following errors and mistakes, with the aim to prevent them in the future. The extent of feedback is a score on a 5-point Likert scale (1 to 5). Residents (score 2.9) perceive less feedback and discussion than specialists (3.3).

The perceived level of patient safety is a score on a 5-point Likert scale (1 to 5). Residents (score 3.5) perceive patient safety to be better than specialists (2.6).

4.2 Resilience Profile

Five dimensions together give an indication of resilience among medical residents and specialists in the hospital, their teams and organisation, as visualised in Figure 1. These dimensions are discussed in this section.

Figure 1. *The Healthcare Resilience Profile is constituted of five dimensions*

Feedback and Learning Culture

Among residents, 60-75% of the respondents is positive about the role of his/her supervisor in stimulating a positive learning culture. The supervisor listens, stimulates own thinking and making choices, and has confidence in the resident's abilities. However, only 28% states that they are informed about errors and mistakes in their department, and only 52% states that team discussion takes place to prevent errors and mistakes from reoccurring.

Work Schedule and Life-Work Balance

Residents have a formal contract for 44 hours per week on average. 74% of them work structurally more than their formal contract and 23% incidentally. In the interviews they state that they perceive this situation as normal and have no problem with it. However, the managers who are responsible for their education and work, do not support this. Further, residents feel very responsible for their work; 13% of them reports that they regularly go to work even when they feel ill.

Multidisciplinary Co-operation: Information sharing

Information sharing between colleagues upon shift changes is adequate, according to 65% of the respondents. However, relevant information often gets lost if a patient is transferred to another department, according to 65% of the respondents. Departments have contacts with other departments only if there is a 'natural' relation.

Social Capital and Autonomy in Work

Social support and autonomy are positive resources. The contacts with colleagues are positive. The workload is reported to be high, but this is not seen as a problem. Some residents relate this to good personal contacts. Colleagues are helpful, interested and friendly, according to more than 90% of the residents. Supervisors are interested, promote working together, and pay attention to residents' ideas and initiatives, according to more than 85% of the residents. Co-operation within the team is good (more than 75%) and errors/incidents are not used personally against residents (more than 65%).

In the interviews several residents state that they are reluctant to take sickness leave when they are ill, because this puts a burden on their colleagues, who have already a high workload.

Autonomy heavily depends on the field of work: about 60% responds that they can regularly decide how to do their work, but only 26% is regularly free to define how fast and 41% can regularly define the order of activities.

Individual Resilience and Emotional Load

More than 95% of the residents states that intensive thinking and focused attention is often required (cognitive stress). 33% of them states that the work is often emotionally demanding. About 15% of them often feel emotionally involved (emotional load). From literature it is known that this 'professional friction' is required to increase resilience.

Questions were included about the confidence that residents had in 11 aspects of their personal efficacy regarding task performance and teamwork in stressful or threatening situations. Less than 5% has a score below 5 (1 = no confidence to 10 = full confidence). The average is 7 to 8. Quote from an interview: "Successful will be those who are flexible, structured and have social skills. To increase personal resilience, it is important to create back-up options together with colleagues." The results of these five dimensions are summarised in a so-called 'resilience profile' of the system in which medical residents operate. This 'resilience profile' allows resilience to be expressed in five dimensions. These dimensions were found to be the most closely linked to resilience and we hypothesize that these dimensions predict resilience in the specific work context. This helps medical personnel to make resilience operational in daily practice. The pilot hospital prioritizes 'multidisciplinary co-operation' and 'feedback and learning culture' as the key domains for their own situation. Policy of the hospital will focus on these two dimensions in the next years.

4.3 Healthcare Resilience Approach

This pilot study shows that this Healthcare Resilience Approach (HCRA) can support individual, team and organisational resilience programmes through the use of a Resilience Profile. This approach distinguishes four phases:

- Drawing up a Resilience Profile
    - Questionnaire for medical residents and medical specialists
    - Interviews and observations at different workplaces
- Participatory phase in order to develop a plan
    - Individual: mindfulness, reflection
    - Academy of the hospital: facilitating intervision
    - Organization: Connecting strategic aims
- Performing the plan and monitoring progress
- Embedding and connecting
    - Connecting to existing (learning and consultation) structure

5 MANAGING TRADE-OFFS

The work environment of medical personnel in a hospital is very dynamic. Patients might need urgent attention, work hours could be longer than anticipated. Decisions are often complex, especially with the increasing number and fragility of elderly people with multiple problems. Medical specialists and also residents have many trade-offs to deal with on a daily basis:

- Daily busy schedules and urgent (unforeseen) patient needs hinder enhancement of individual and team resilience through e.g. learning, reflection and sharing;
- Patient needs have high priority and personal attention for patients is important to improve patient safety. However, as a consequence there is often not much room for personal or private issues: eating

and drinking during work, pausing, getting rest, and social activities outside work are regularly postponed or skipped. This has a negative impact on resilient behaviour.
- Individual resilience grows as one goes through stressful and traumatic events, if followed by reflection and sharing of experiences. However, it takes resilience to get through such episodes.

These trade-offs are almost paradoxical, and are often difficult to handle for medical residents. These situations need critical attention by supervisors and the education department.

6 CONCLUSION AND DISCUSSION

6.1 Conclusions

Resilience is a valuable concept in the medical domain, but not easy to be translated to practical tools. Five dimensions of resilience were defined that reflect relevant areas of improvement. This 'breaking down' the concept of resilience is important to enable people to work with it in a complex and sometimes chaotic work environment. This helps them to develop tools to practically evaluate their situation (diagnosis, monitoring) and improve it (treatment). It appears that these five resilience dimensions might be readily applicable in other hospitals. In sectors outside healthcare this might be different – this was however not part of this investigation.

The Health Care Resilience Approach is a promising approach for hospitals and medical personnel to express resilience in practical terms. This is especially helpful for personnel during their medical education (such as medical residents) and the system around them. Medical specialists, supervisors, nurses and education experts are part of that system. Succes factors seem to be the focus on both the individual and the system simultaneously and the strong participation of the medical residents.

- Patient safety: medical residents seem less involved than medical specialists in feedback and discussion of mistakes, but they perceive a better patient safety. The combination of these observations fits with a lower involvement of medical residents in patient safety.
- Intention to leave: Only a few medical residents consider leaving the education program.

6.2 Discussion

A point for discussion is the application of Intervention Mapping, which by definition is done in close collaboration with the target group. For medical personnel, including residents, patient related activities have almost always priority above anything else. Because immediate patient needs can hardly be anticipated, it is difficult to gather enough medical personnel for a productive meeting, focus group, or training. Therefore, the concept of Intervention Mapping in a medical setting should be adapted for the characteristics of daily work in hospitals.

Further research should focus on evaluation of the results of fully implementing the HCRA in the medical setting and adaptation of the HCRA for other health care professionals working in a complex environment, e.g. Intensive Care and Emergency Departments.

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Precepts of Resilience Engineering as Guidelines for Learning Lessons from the Fukushima-Daiichi Accident

Masaharu Kitamura[1,2]
[1] Research Institute for Technology Management Strategy (TeMS) Ltd., 6-6-40-403, Aramaki-Aza-Aoba, Aoba-ku, Sendai, Japan
kitamura@temst.jp
[2] New Industry Creation Hatchery Center, Tohoku University, 6-6-10, Aramaki-Aza-Aoba, Aoba-ku, Sendai, Japan

Abstract

Applicability of the precepts of Resilience Engineering as guidelines to derive lessons from the severe accident at the Fukushima-Daiichi Nuclear Power Station is assessed in this article. Two reports published by official investigation committees have been mainly analyzed as data sources for fact-finding. Through the analysis, the four main capabilities proposed by Resilience Engineering, i.e. responding, monitoring, anticipating and learning, are found to be extremely useful and cost-effective in preventing or mitigating nuclear power plant accidents. In addition, a sensible response to warnings is found to be critically important to ensure accident preparedness. The derived lessons are well-organized and systematized so as to be applicable to the prevention of accidents resulting not only from tsunamis but other trigger events as well. The observations obtained through the present analysis clearly highlight the applicability and effectiveness of Resilience Engineering in accident analysis and learning activities.

1 INTRODUCTION

The disaster of Fukushima-Daiichi Nuclear Power Station (NPS) resulted in tremendous damage in Japan and caused serious concerns about nuclear safety throughout the world. Accident investigations have been conducted by a number of organizations to identify the causes of the Fukushima nuclear accident and to propose effective countermeasures to prevent future accidents. The reports published thus far cover a wide variety of findings related to the accident and corresponding recommendations. Most investigations have been carried out based on a linear cause-and-effect approach, i.e., listing up adverse events experienced during the accident to identify the causes of each adverse event, with countermeasures then being recommended to eliminate the identified causes. A basic idea behind the cause-and-effect approach is that a high level of safety can be achieved by eliminating the causes of the accident. From a viewpoint of Resilience Engineering (Hollnagel, Woods, Leveson 2006; Hollnagel et al. 2011), the basic idea is equivalent to the traditional approach to safety, which is to pay attention to things that have gone wrong. Without doubt, the traditional approach has been widely employed in almost all investigations of the Fukushima-Daiichi accident.

It should be recognized, however, that the traditional approach tends to focus too much on the specific accident scenario experienced at the Fukushima-Daiichi NPS. As far as a huge tsunami is concerned, the recommendations might by quite sufficient (or possibly more than sufficient) to prevent another severe accident. But the triggering event of a future severe accident could be something other than a tsunami. A historical reflection of serious accidents in nuclear and non-nuclear industries indicates that every severe accident is unique as far as the identified cause-and-effect relationships are concerned. It is better to examine the specific accident scenario to derive generic lessons that can be applied to prevent or mitigate future accidents caused by a triggering event different from a tsunami. In addition, it would be worthwhile to reduce and organize the large number of various recommendations in order to obtain a systematic view of the recommendations. This paper describes an attempt to meet this need by applying the precepts of Resilience Engineering (Hollnagel, Woods and Leveson 2006; Hollnagel et al. 2011) to attain Safety-2 (Hollnagel 2013) rather than Safety-1.

2 TYPICAL RECOMMENDATIONS IN PREVIOUS REPORTS

Among various investigative groups, the Investigation Committee on the Accident at Fukushima Nuclear Power Stations of TEPCO (also called the Hatamura Committee), and The Fukushima Nuclear Accident Independent Investigation Commission founded by The National Diet of Japan, (also called the Kurokawa Commission) are regarded to be the most influential ones as they were founded by official organizations. Based on highly intensive field studies and interviews, these groups have published reports, which are herein called the Hatamura report (Hatamura 2012), and the Kurokawa report (Kurokawa 2012), respectively. The recommendations provided by the Hatamura report are listed below:

- Recommendations for a basic stance for safety measures and emergency preparedness
- Recommendations for safety measures regarding nuclear power generation
- Recommendations for nuclear emergency response systems
- Recommendation for damage prevention and mitigation
- Recommendations for harmonization with international practices
- Recommendation for relevant organizations
- Recommendations for continued investigation of accident causes and damages

The Kurokawa report provided a similar set of recommendations. It differs from the Hatamura report in that it places more emphasis on reforming regulatory bodies and laws related to nuclear safety. It should be noted that each recommendation in both of the reports consists of multiple sub-recommendations, and many of the sub-recommendations consist of multiple sub-sub-recommendations. Therefore, the number of corrective actions to be made is quite large. Actual implementation of the recommended measures would be extremely costly and time-consuming. As mentioned earlier, the purpose of these recommendations and measures is to eliminate each of the causes identified through the investigation of the accident. Within the framework of probabilistic risk assessment (PRA) (Kumamoto and Henry 1996), this approach to the elimination of the causes of the accident is practically equivalent to avoidance of occurrence of possible cut sets. An alternate approach, which is equivalent to the assurance of availability of path sets, is possible as well as reasonable. The applicability of the alternate, i.e., success-oriented, approach is examined in light of Resilience Engineering methodology.

3 GUIDELINES FOR LEARNING

The fundamental precepts proposed based on the framework of Resilience Engineering are briefly summarized below as guidelines for learning:

1. Safety-2 is more appropriate than Safety-1 fin ensuring the safety of socio-technical systems such as a NPS.
2. The four capabilities, i.e. responding, monitoring, anticipating and learning, are necessary for resilient systems.
3. Preparation and allocation of proper resources are critically important for resilient systems.
4. A constant sense of unease (Hollnagel 2006b) is necessary to maintain the resilience of systems.
5. Warnings must be carefully examined and proper sacrifice judgments (Woods 2006) must be made as necessary.

Precepts (1) through (4) can be understood as guidelines naturally derived from the basic knowledge of Resilience Engineering. Guideline (5) could be less obvious. However, it is a natural lemma of guideline (4). It is a well-known empirical heuristics that warnings are usually available if cautiously monitored. Examples can be found in the accident at Three Mile Island NPS (Leveson 1995; Kemeny 1979), and in well-known severe non-nuclear accidents such as the Titanic, Bhopal and Therac-25 (Leveson 1995). Although more precepts are available from the perspective of Resilience Engineering, the five precepts mentioned above are regarded to be the most important and basic ones.

4 APPLICATIONS

By applying the four guidelines to review of the accident, a set of observations has been derived as follows.

- Consideration of nuclear safety from the viewpoint of Safety-2 was practically absent. Since tremendous efforts had been spent on prevention of anomalies, which is equivalent to pursuing Safety-1, both Tokyo Electric Power Company (TEPCO) and The Nuclear and Industrial Safety Agency

(NISA) were unaware of the importance of severe accident management as an essential component of defense-in-depth.

- Among the four capabilities, the learning capability was particularly insufficient. The impact of external events such as earthquakes and tsunamis on nuclear safety had been widely recognized from the viewpoint of PRA (Kumamoto and Henley 1996). In addition, threats of tsunami and flooding were experienced in foreign countries. On December 27, 1999, an unexpectedly strong flooded the Blayais NPS in France, resulting in water damage of pumps and containment safety systems. Also, on December 26, 2004, the Sumatra tsunami attacked the Madras NPS in India, resulting in an emergency shutdown due to tsunami-induced damage to the seawater pump. The chance of learning had been available, but disregarded because of complacency and ignorance of Safety-2.
- Other capabilities, i.e., monitoring, anticipating and responding, were obviously poor because the poor learning capability overwhelmed the organization and, as a natural consequence, no attention was given to maintaining and enhancing these capabilities, which are critically important in managing severe accidents.
- Preparation of resources was obviously insufficient. Though TEPCO personnel at the Fukushima-Daiichi site struggled very hard after the station blackout to obtain electricity and fresh water, they were not successful. They actually collected and utilized batteries from trucks and personal cars to measure critical safety parameters such as the water level in the reactor core and pressure in the containment vessel. Such a desperate effort evidently indicates poor preparedness for severe accidents.
- Responses to warnings were also very poor. It is now clear that TEPCO and the NISA had received several warnings from reliable sources concerning the likelihood of the occurrence of a gigantic tsunami in Fukushima and adjacent prefectures. Nevertheless, the importance of such warnings was underestimated because of the misunderstanding that the probability of such a huge tsunami was practically negligible.

These observations can be transformed into lessons in a straightforward manner. For example, the first observation can be transformed into a lesson that greater attention must be paid to Safety-2 for upgrading the safety of NPSs. The second observation of insufficient learning capability can be simply transformed into a lesson that unusual events experienced in foreign countries and in Japan must be treated seriously. Other observations are also transformed into lessons without any difficulty. It should be recognized that the lessons derived from each of the observations are in essence related to ensuring certain success paths.

5 DISCUSSION

The observations mentioned above provide us with an organized set of lessons along with the guidelines from Resilience Engineering. Even a subset of the above-mentioned lessons can be sufficient to prevent the occurrence of a Fukushima-like nuclear disaster. In the official reports published in Japan, TEPCO personnel are criticized for not responding to the warnings because expected countermeasures such as a huge seawall, an extra high-performance diesel generator, etc. would have been too expensive. If TEPCO personnel had been aware of the importance of Safety-2 and of the precepts of Resilience Engineering, they might have tried to prepare some basic resources such as extra batteries and fire engines. Such resources are far less expensive than a huge seawall but would have been sufficient to significantly reduce the severity of the accident.

The author does not intend to criticize the official accident reports. Nor does he intend to claim advantages of the success-oriented lessons over other lessons and recommendations. Implementation of a large number of recommendations proposed by the official committees is definitely desirable for attaining an excellence of nuclear safety in Japan. The present approach has been conducted with the intention of providing an alternate practical way to achieve a higher level of safety in light of Resilience Engineering. As far as the widely acknowledged concept of Occam's razor (Rissanen 1978), also known as the law of parsimony (Akaike 1974), is concerned, out of two possible theories, the simpler is to be preferred from a scientific viewpoint. However, the exhaustive list of recommendations proposed by the investigation committees should be implemented in order to meet the public concerns (Kitamura 200).

Last but not least, consideration is given with the reference to the remarkable interpretation provided by K. Kurokawa, the chairman of the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission. He stated; "What must be admitted – very painfully- is that this was a disaster 'Made-in-Japan' Manmade accident". Then he continued that "Its fundamental causes are to be found in the ingrained convention of Japanese culture: our reflexive obedience; our reluctance to question authority; our devotion to 'sticking with the program'; our group-ism; and our insularity".

Japanese people would admit that the message from the chairman is to some extent valid. However, this interpretation can introduce significant side effects. One is the possibility of gradual neglect of the message in Japan. As the fundamental causes of the accident are so strongly attributed to Japanese culture, it is obvious that any attempt to eliminate the causes will demand tremendous efforts of various kinds. For any individuals and organizations, this would be too demanding, resulting in gradual neglect. Another is a possibility of neglect caused by the obstacle of distancing through differencing (Cook and Woods, 2006). If the fundamental cause of the accident is attributed to Japanese culture, people in other countries might feel that the cause is irrelevant to them. But such a view is absolutely wrong. The culture-oriented interpretation must be treated carefully by paying attention to commonalities rather than differences.

6 CONCLUDING REMARKS

The Fukushima-Daiichi accident must be studied in detail to prevent another severe accident. A large number of lessons leading to hardware/software improvements and organizational reforms must be seriously implemented. It is, however, certainly informative and desirable to look at the large number of improvements from different perspectives and try to restructure them in a systematic manner. The precepts of Resilience Engineering are highly effective to realizing this. It would be worthwhile to pursue improved safety of nuclear power plants and of other high-hazard processes as well on the basis of this recognition.

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Inter-organisational safety culture challenges in nuclear power design

Macchi, L., Pietikäinen, E, Savioja, P., Liinasuo, M., Wahlström, M., Reiman, T.
VTT Technical Research Centre of Finland
P.O. Box 1000 FI-02044, Finland

Abstract

This paper presents an explorative study of the inter-organisational safety culture challenges related to design activities in the nuclear power domain. Based on the analysis of in-depth interviews five major challenges have been identified. They reflect the need to balance between conflicting aspects during the design process.

1 INTRODUCTION

It has been long acknowledged that organisational safety culture needs to be taken into account and managed when operating and maintaining nuclear power plants. However, the fact that people designing the plants and their technological solutions are also influenced by cultural issues has not been given much emphasis. As design flaws have been identified as important contributors to serious nuclear power accidents, like the Fukushima nuclear accident in Japan in 2011 (e.g. Epstein, 2011), it is important to also start considering how safety culture affects the design activity and how the design work can be supported from this perspective. In this paper we describe an interview study that made an opening to this complex and understudied research area.

2 DESIGN IN THE NUCLEAR INDUSTRY

In the nuclear power industry the term “design” has been used to refer both to the process of designing and to the end product. Sharing the conceptions of Veland (2010 and Mark et al. (2007) in this paper we understand design as an iterative process composed by multiple steps that has an objective of creating an artefact to solve an expressed problem or a need. This process is an activity for inventing, creating, and implementing (technical) artefacts which combines analytical problem solving and innovative creation of new features based upon heterogeneous and uncertain domains of knowledge. Even if the resulting artefact cannot be known in detail in advance, the function(s) that the artefact should fulfil should be known and be specified already in the early phases of the process.

2.1 Special features of design in the nuclear industry

Nuclear power plants consist of several complex systems whose design, operation and maintenance requires special expertise and by nature requires collective effort that involves several stakeholders. The components designed for the power plants are usually tightly coupled, i.e., they come with several interfaces to other designed products. Four pivotal safety principles for design in the nuclear industry exist (e.g. IAEA, 2007):

1. *Defence in depth* meaning that components and systems should be designed in a way that if one of them breaks down, another defence layer still remains and takes over to protect the environment and population from radiation
2. *Redundancy* meaning that there should be several similar subsystems for carrying out one function and either one of them alone is sufficient for carrying out that function.
3. *Diversification* meaning that there should be several systems or equipment that carry out the same function but whose functioning is based on different principles or mechanism so that if one mechanism is failing due to some reason external to it, other mechanisms remain intact and functional.
4. *Physical separation* meaning that the parallel subsystems or equipment should be situated in distinct physical locations and are not connected to each other.

The people doing the actual hands-on design work can be in-house personnel of the power company but more often they work for a design organisation for which the power company has outsourced the design work. These design organisations may also provide services for other industries besides the nuclear power industry and they can not always be familiar with the nuclear industry context and its special requirements. Design in the nuclear industry is also highly regulated and the role of the regulator is more emphasised than what is typical to most other industries. The regulator sets requirements for the design process and follows whether they are met. The design process can therefore be understood as a complex interaction and negotiation process between different experts and organisations, the regulator being one of them.

Each (domain of design (e.g. mechanical, automation) can be expected to manifest its own unique characteristics in terms of particular skills needed. However, design activities are often associated with open problem spaces rather than closed ones. That is, design is a dynamic cognitive act where several different solutions to a problem might be possible. Veland (2010) argues that a core competence of a designer is a process skill, meaning that designers need to "think on their feet" when immersed in active, flexible, reflective exploration of the problem space. To navigate in an open and dynamic problem space involves dealing with uncertainty. Especially when design takes place in safety critical domains, there is an interesting tension between "conservatism" and "flexibility" in their work. Designers are creative innovators on the one hand , on the other hand they are demanded to strictly respect the limitations set by rules and regulations and the nuclear power specific technical design principles.

In the design for nuclear industry, transparency is often considered a good practice, but it could be challenging for a designer to continuously document what is happening in a design process. Firstly, because documentation takes time and may be perceived as unnecessary and disturbing. Secondly, there might be more uncertainty behind design decisions than a designer wants to reveal. In particular, both the public, the buyer and the regulator of a risk-sensitive system want to be sure that the designed end-product is safe. To be open about the uncertainties of the design process may therefore pose an additional challenge to design organisations.

3 SAFETY CULTURE IN DESIGN

Researchers at VTT Technical Research Centre of Finland (Reiman and Oedewald, 2009; Oedewald, et al., 2011; Reiman, et al., 2012) have stated six criteria for good organisational safety culture which can be further summarised into three easily communicable cornerstones of safe activities: mindset, understanding and organisational systems and structures (Figure 1).

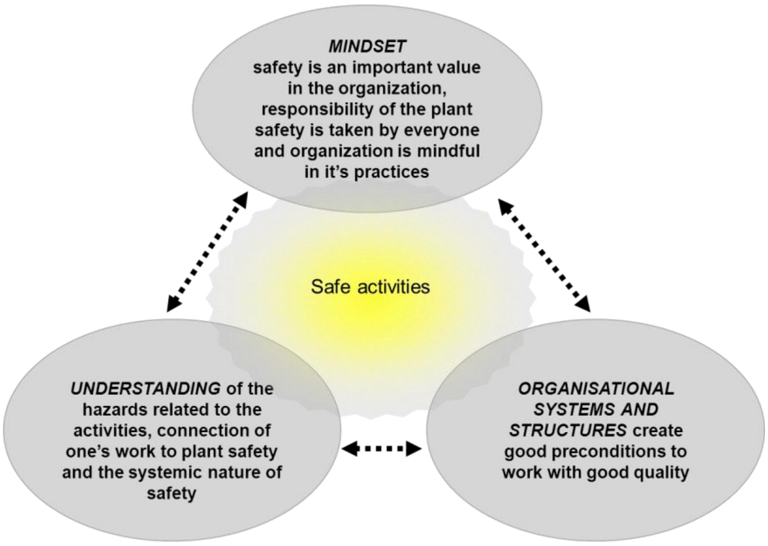

Figure 1. *Cornerstones of safe activities (Oedewald, et al, 2011)*

In this paper we have used these cornerstones to understand what good design safety culture is like.

4 EMPIRICAL STUDY ON THE CHALLENGES OF DESIGN

As part of a Nordic Nuclear Safety Research and Safir2014 study, 14 21 semi-structured interviews were conducted within the Finnish nuclear power community during 2011-2012. The interviews lasted from 45 minutes to 2 hours. In most of the interviews two interviewers were present. The interviews were audio recorded, transcribed, translated into English when needed and analysed in more detail. They represented different perspectives to design. The interviewees were all somehow involved in the design process. They represented different organisations (both power companies and the regulator) and different design disciplines from automation design to the design of whole new power plants.

Raw data was first roughly analysed for the extraction of challenges. Any expression that referred to a possible challenge for design from safety point of view was extracted from the interviews. These extracts were transformed into more general level statements in order to make comparisons and the formation of an overall picture possible. The identified challenge statements were then categorized into groups using a bottom-up approach. This grouping helped us to get acquainted with the data and to form an overall understanding of the large data set. However, it did not provide a meaningful overall structure as such. Thus the analysis was continued with a top-down analysis approach, where the statements were grouped into three groups based on the safety culture model depicted in Figure 1: mindset, understanding, and organisational processes and structures. The results of this analysis were presented and discussed together with two groups of nuclear power specialists (in two of the steering group meetings of the Finnish SAFIR nuclear safety research programme).

5 RESULTS

The safety related challenges that came up in the interviews that related to the fact that design is a complex process involving several different organizations are presented and discussed below.

5.1 Challenges relating to shared mindset

Many of the challenge statements related to valuing safety. It came up in the interviews that safety is not always the first and most important guiding value in the design process. Rather the different actors involved in the design process – including the regulators – are constantly balancing between safety and economics in their work. For example, when making contracts with design organisations, the power companies aim to make a good bargain, as any private company would do. There is quite understandably a temptation not to start the bargaining with explaining all the possible risks and complexities that relate to the design work. However, if this is not done already in the contract phase, it may be difficult to make demands later in the design process. This is how the issue was discussed in one of the interviews:

"There are commercial constraints between the supplier and the power company that sometimes are close to the limits of good safety culture […] you are trying to arrive at the cheapest possible price. You won't say there are all these special things. You try to buy the bulk of it and add to that later. […]. It would be fair to explain to the subcontractor which special requirements are included, that it will be included in a nuclear power plant et cetera"

From the interviews it emerged that also the regulator struggles to find sufficient time and resources to carry out detailed inspections and making demands while realising the strong commercial pressures the companies were struggling with. Also, the tension between safety and productivity was said to hinder the shared learning between different companies. One power company representative expressed it like this:

"In international forums, in my opinion it is quite superficial the discussion with no-one really willing to open up, necessarily."

5.2 Challenges relating to understanding

It is typical in the nuclear industry that the design work is purchased from design organisations outside the actual nuclear power industry. This can pose a challenge for designers since it may be difficult for them to correctly understand the context in which the designed artefact will be implemented and this may lead to dysfunctional designs. It was mentioned by the interviewees that, for example, some of the I&C designers have never been to an operating power plant and might thus not think of some relevant issues in their design work. Also, the interviewees pointed out that in some countries, the nuclear domain has been developed and in others recessed, so the level of designers' nuclear power specific expertise may vary depending on the country. Thus it was considered important that power company's personnel who guides the design work has solid understanding on functioning of the plant and can communicate this understanding to the designers.

Another challenge relating to understanding was that organisations do not always share the same safety philosophies and understand safety requirements in the same way. This is especially the case, if the organisations involved in the design process represent different national cultures - as is often the case in the nuclear industry. For example, it was mentioned in the interviews that the Finnish regulator emphasises the principle of continuous improvement much more than regulators in some other countries. If the designers don't understand this principle, they may not design enough buffers for the designed components. This is how one of the power company representatives described this issue:

"In some countries it is that when once approved for the operation, you don't have to do almost anything for that plant, unless very drastic and dramatic happens in a generic way, generic for that design. But in Finland (…) you really do have to have this spare capacity or otherwise you will end up with trouble."

Also safety philosophies and understandings of the safety requirements may differ between operating organisations and design organisations. Partly this may be due to their inherently different core tasks. For example, while operational personnel may emphasise conservative decision making, designers may focus more on quality issues of their work. The interviewees brought up that not only designers and operating personnel should understand the safety requirements, but the people doing the commercial contracts concerning the design process at the power companies as well.

5.3 Challenges relating to structures and processes

In terms of structures and processes it was found in the interviews that coordinating activities may be difficult between organizations that work according to different logics and understandings. For example, it was difficult to balance between the creative and iterative aspects of design process and the strict regulatory process. These two sub processes of the wider design process perhaps follow a different kind of time logics. It was brought up that there are constant discussions and negotiations between the power companies and the regulator on this issue. Also, the differences in national cultures came up in this respect. One of the power company representatives described the challenge of coordinating time-tables with the designers of a foreign company as follows:

"I must admit personally that the culture, working culture and how they negotiate and so on, it has been quite unclear, sometimes even confusing for me and that is also the learning experience, how to deal with those people. Because unless you don't understand how they feel, how they work, how they act, it will be quite difficult to cooperate with them in time schedule."

Distributing responsibilities and balancing roles between different stakeholders emerged as another challenge in the design process. In the interviews this was expressed by for example the following questions:

"If the design activities are purchased from several subcontractors, who manages the interfaces?"

"Should the regulator inspect subcontractors that carry out the design work or only the power company who is the licensee and who purchases the design work from the design organisations?"

"How should regulators balance between inspection and giving improvement suggestions in the design process?"

6 CONLCUSION AND DISCUSSION

The challenges found in the interviews are summarised in table 1 into five main points that connect to three different cornerstones of good safety culture

Table 1 *Summary of challenges in nuclear power design*

Mindset 1. Safety is not always the first and most important guiding value in the design process 2. Coordinating activities may be difficult between organizations that work according to different logics and understandings
Understanding 3. Understanding the context where the design will be utilized may be difficult for the designers and this may lead to dysfunctional designs 4. Safety philosophies may differ between organizations
Structures and processes 5. Distributing responsibilities and balancing roles between different stakeholders requires careful consideration

Many of these challenges are rather general. Similar challenges might be found for example in nuclear power maintenance activities, since both design activities and maintenance activities often involve several organisations working together in a tight network. However, some of the challenges reflect or are strengthened by the inherent requirements of the design work - the fact that the work is strongly future oriented and deals with an open problem space. For example, what comes to challenge number one, there may be an especially strong need to emphasise the financial aspects in the design process in order to avoid losing control over the budget exactly because the design process can sometimes be so unpredictable. Also, it may be both more important and more challenging for the designers to deeply understand the context for which they are doing their work than e.g. for welders or painters that carry out regular maintenance activities at the power plants. Also, as came up in relation to the structures and processes, it may be that the conception of time is somewhat different in design activities when compared to for example regulating activities or maintenance work. The iterative, future oriented creative thinking needed in order to design safe end-products might not easily follow the logics of other highly regulated nuclear power activities and this may cause problems. These challenges cannot be easily solved. Rather they are issues that need to be constantly considered and balanced with in the design process. For example, relating to challenge number 2, it will never be the case that all organisations would work exactly according to same understandings. After all, the benefit of bringing together the different actors comes from having different understandings and expertise. The identified challenges can be seen as reflecting inherent trade-offs of the nuclear industry design process. They are caused by the conflicting goals pursued in it. The identified challenges resemble the trade-offs identified in earlier literature (e.g. Hollnagel, 2004; Hoffman and Woods, 2011). For example, challenge number 3 relates to the specialist-generalist tension Hoffman and Woods (2011) have identified in their work as one fundamental tension in macro-cognitive systems. What is important in managing the challenges in practice – since they cannot be completely solved - is paying attention to them as they arise and taking them into account. As this study was an opening to a new research area, more work is needed to find systematic ways for doing this. In 2013 the study continues with more specific case studies that focus precisely on that.

Acknowledgments

We acknowledge the contribution of Ulf Kahlbom and Carl Rollenhagen to this research work. We also thank the Nordic Nuclear Safety Research and Safir2014 research program, the case study organisations, and especially all the staff that participated in the interviews.

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The Resilience Analysis Matrix (RAM): Visualizing functional dependencies in complex socio-technical systems

Jonas Lundberg [1] and Rogier Woltjer [2]
[1] Linköping University, Department of Science and Technology, Linköping, Sweden
jonas.lundberg@liu.se
[2] Linköping University, Department of Computer and Information Science
rogier.woltjer@liu.se

Abstract

RAM is a method for visualization to facilitate analysis of functional dependencies in complex socio-technical systems. The RAM facilitates the description of instantiations (as in FRAM) to model system behaviour in for example different situational circumstances or to model "work as planned vs. work as actually done". Instantiations can be traced through following a coloured line. Thereby the RAM can be used for retrospective (reconstructing the actual instantiations of an event) as well as prospective (possible instantiations in future behaviour of the system) analysis. Resilience characteristics (see e.g. Woods, 2006) can be analysed with a focus on functions and with a focus on paths/instantiations. Two cases are described to illustrate the points outlined above: a) The Swedish civil crisis response missions to the Asian Tsunami of 2004 and the Israel-Lebanon war of 2006 b) Attempted take-off from wrong runway accident of Comair Flight 5191, 2006.

1 INTRODUCTION

It is hard to visualize complexity without the visualization becoming overly complicated, thereby hiding the patterns, interactions, and emerging properties that the analysis set out to discover in the first place. A good visualization of functional dependencies in socio-technical systems should not merely illustrate complexity – it should provide an overview of analytical findings and facilitate the discovery of interdependencies of functions.

There are numerous analysis methods for complex systems available that also provide visual presentation and analysis techniques. Among these methods are Cognitive Work Analysis (Vicente, 1999), AcciMap (Svedung & Rasmussen, 2002), system dynamics (e.g. Senge, 1990), and various enterprise architecture frameworks (e.g. Johnson & Ekstedt, 2007). Application of the Functional Resonance Analysis Method (FRAM; Hollnagel, 2012) is done textually but invites for the visualization of analysis results in a loosely-defined manner, e.g. through illustrating instantiations.

The analysis of functional interdependencies and emergent (systemic) phenomena is a central capability of several of these analysis methods. Graphical representations of functional interdependencies and emergent phenomena generated by these methods suffer to varying degrees from difficulties to (1) facilitate the discovery of patterns, emergent properties, and interdependencies, or (2) communicate analytical findings. Nevertheless (and with varying success) both of these purposes are commonly pursued by analysts and scientists, likely because the representation of a problem affects its understanding and solution (e.g., Simon, 1996). Moreover, methods and visualization techniques that aim to aid in the analysis and communication of various systemic properties identified in resilient systems (e.g., buffering capacity, margin, flexibility, tolerance, and cross-scale interactions from Woods, 2006) are rare (although methods such as FRAM seem to be suitable for this purpose, see Woltjer, 2008). The present paper describes a method that aims to reduce these gaps.

2 THE RESILIENCE ANALYSIS MATRIX (RAM)

The purpose of the Resilience Analysis Matrix (RAM) that is proposed in this paper is to facilitate analysis of resilience and safety in complex systems. In RAM, we combine the matrix as a core organizing principle with the Matrix theory of graphics (Bertin, 2001) and basic information design principles (e.g. Tufte, 1990). A matrix is the core organizing principle used in frameworks such as the Design Structure Matrix method (Steward, 1981). The main advantage is that a matrix can present a fully connected function network – with every function being connected to every other function through both input and output – without becoming overloaded. In contrast, a visualization technique that connects functions only through lines quickly becomes overloaded when there are many connections between functions. A line-based technique may also give an illusion of complexity where none exists – comparable to how a chain if dropped on the floor may become entangled, in a complicated way, but still be a linearly connected chain of links.

We present an overview of RAM in Figure 1 and two RAM examples (Figure 2 and Figure 3). Above the lower red dividing line, there is a matrix of functions (Figure 1 to the left). Each function is presented both in a row, and in a column, with function output on the diagonal. On each row, inputs from (potentially all) other functions can be read. In each column, the output from a particular function to (potentially all) other functions, can be read. This means that even if all functions were connected to each other through input and output, the matrix can still be read, without clutter. Functions that do not have any inputs (that were not analysed further), are considered to be background functions. Those are placed at the top, above a red dividing line to differentiate them with other functions. They are placed at the top since they, in the analysis, will only affect functions below, and will not be affected by functions below.

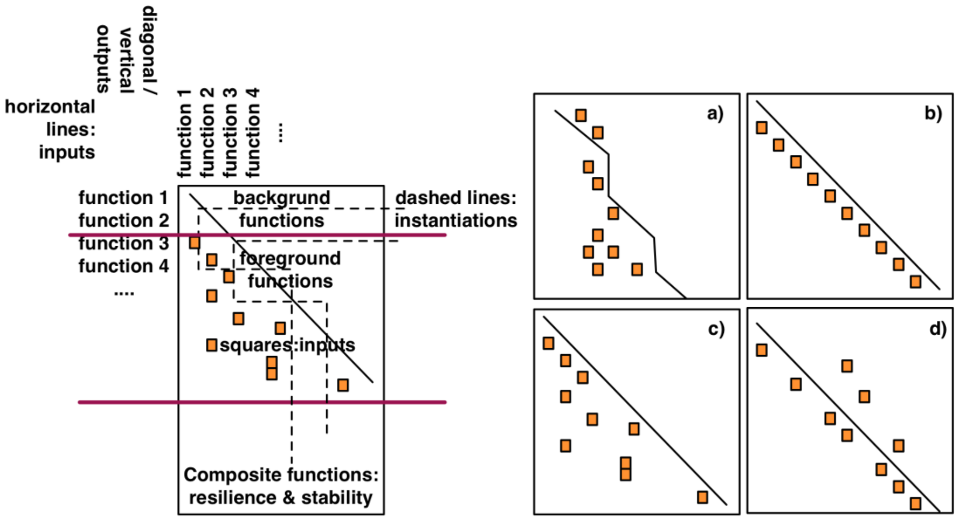

Figure 1. *Resilience Analysis Matrix: General layout and visual analysis patterns.*

In RAM, functions should be ordered following functional dependencies. As far as possible, functions should be placed below all functions that they receive inputs from. If there are no feedback loops in the analysis, then there will be no items above the diagonal. A visual inspection immediately reveals this to be the case in examples b and c (Figure 1). This also means that all feedback loops will be visible above the diagonal, making them stand out in a brief visual inspection (examples a and d, Figure 1).

RAM can be used with anything from plain input-output markings between functions, to textual descriptions, to use of for example SADT/IDEF0 notation, to FRAM notation. For this analysis, we have used the notation of different inputs from the FRAM method combined with textual descriptions: I) Input that triggers execution of the function, R) Resources that must be available during the execution of the function, P) Prerequisite functions that should be finished before the function starts, T) Time, C) Control input to the function. There is no need for a specific output symbol in RAM, since columns in the matrix represent outputs.

Instantiations (sets of couplings among functions for specified time intervals; Herrera & Woltjer, 2010; Hollnagel, 2012) of the function network are represented by lines drawn on top of the function network. The lines are created by drawing a line through all functions that are involved in an instantiation of the function network. This makes it possible to analyse upstream and downstream interactions for specific instantiations. By following the lines, the analyst can moreover compare instantiations. Differences and similarities between instantiations can easily be seen through visual inspection (see Figure 2 and Figure 3). As the next example (Figure 2) will show, it can also reveal how instantiations may affect subsequent instantiations of the network.

Below the lower dividing line, an analysis of instantiations can be written, facilitating a detailed comparison between the different instantiations. For each function that is activated, the effect (if any) on the outcome is written as an output in its respective column. This both highlights differences between instantiations with regard to what functions are activated, and with regard to what effect or non-effect the activation has.

3 APPLICATION

3.1 Case 1: Resilience and Vulnerability in Crisis Response

Figure 2 is part of the function network for adaptation of crisis response in the Swedish Civil Response of the Asian Tsunami of 2004 and the Israel-Lebanon War of 2006 (see Lundberg & Rankin, 2013). Over the top dividing line, two background functions are described. Both functions output “positive attitudes” (to taking improvised roles), an important pre-requisite for self-assigning and taking improvised roles.

Four instantiations of the function network are visualized in Figure 2 as coloured lines. They were derived from stories presented by crisis response personnel describing their experiences (see Lundberg & Rankin, 2013).

Looking at the lines going through the matrix, it is immediately clear from a visual inspection that there are minor differences in paths between the orange and brownish lines. To inspect the significance of the differences, the analyst may follow both lines and identify functions that are activated in one instantiation but not in the other. In this case, the difference lies in the execution of the “survey competences” function. The output from that function is “more optimal role assignments”. This is also reflected in the summary rows for both instantiations below the lower dividing lines. In the summary row, the “more optimal role assignments” are labelled as potentially increasing resilience in terms of increased margin of operations.

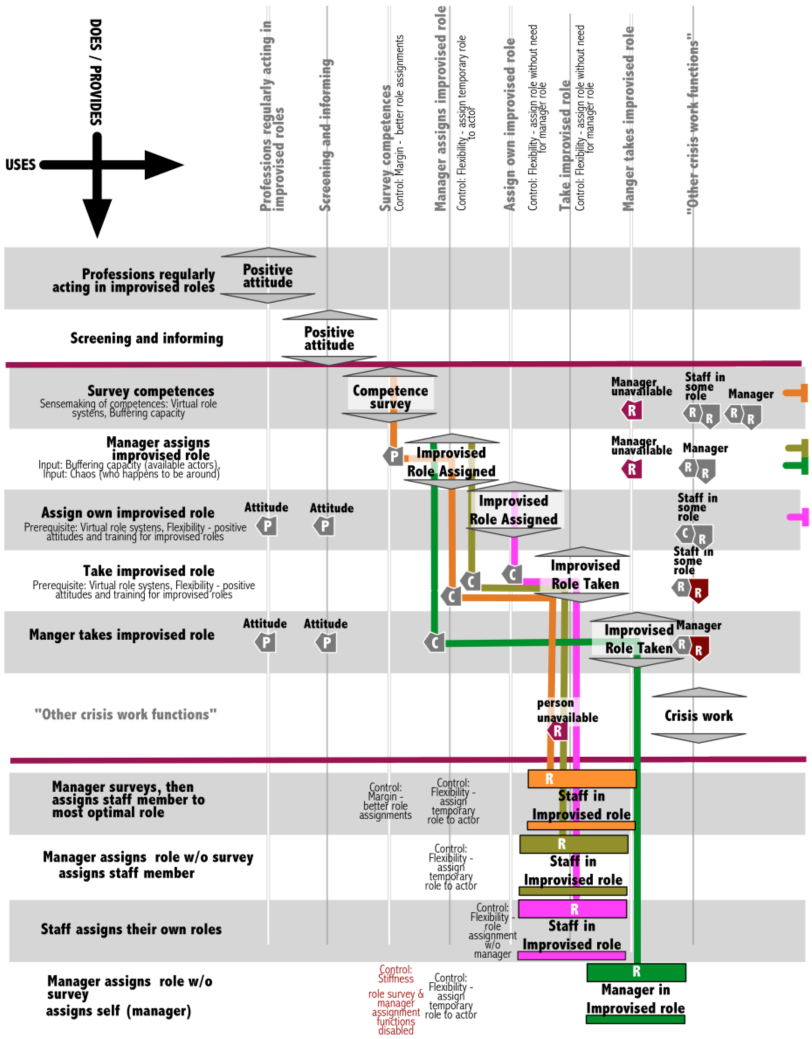

Figure 2. Resilience Analysis Matrix: Swedish Civil Response of the Asian Tsunami of 2004 and the Israel-Lebanon War of 2006

Looking the “survey competences” row we see that this function may be affected by a feedback loop (there are items to the right of the diagonal), represented by a red “R” in the network, which represents a resource necessary to carry out the function (the manager). The red “R” is placed in the “manager takes improvised role" column, identifying it is as the function that may cause this situation. Looking in that column, the analyst can see that "green line" instantiations will execute that function. The analysis thus reveals interactions between instantiations. In terms of resilience, it is represented in the row for the "green line" as "inflexibility by disabling role survey and manager assignments."

3.2 Case 2: Performance Variability in an Aviation Accident

Figure 3 visualises an excerpt from a FRAM analysis (Hollnagel et al., 2008) of the attempted takeoff from wrong runway accident of Comair Flight 5191, (NTSB, 2007). This example shows that RAM can be used to analyse traditional threats to stability as well as analyses of resilience.

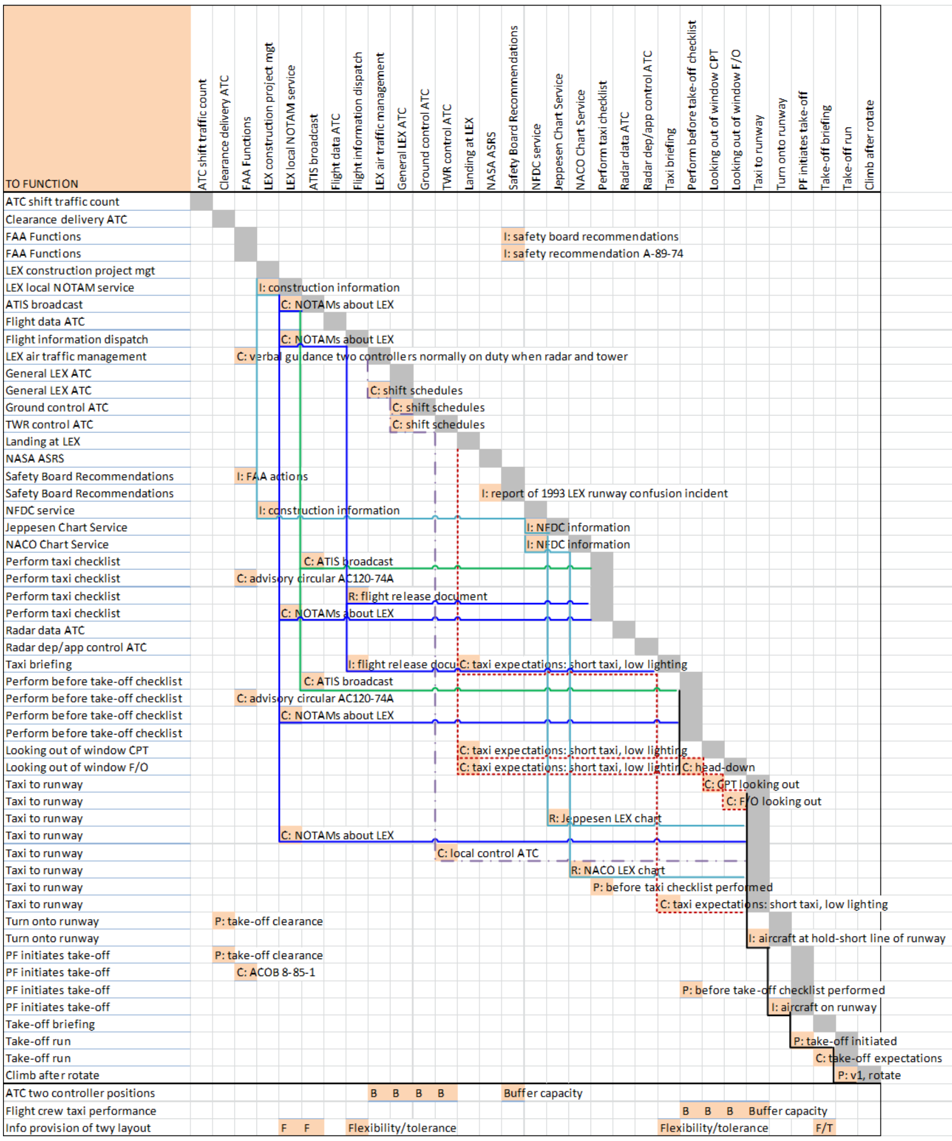

Figure 3. Resilience Analysis Matrix: The Lexington accident of 2006.

In contrast to Figure 2, in Figure 3, each row illustrates input from one function. This means that with input from several different functions, the input will cover several rows, potentially resulting in an imbalanced jagged line (Figure 1a). The jagged line in this case (Figure 3) represents the "Taxi to runway" function, which is immediately apparent from a brief visual inspection. The appearance of a "cliff" in the diagonal may indicate that the function is analysed in a too abstract level, implying that the analysis should be increased in granularity and "broken down" into several sub-functions. The RAM thus serves as a suitability check on the granularity of the analysis. Experience with the RAM moreover shows that it serves as a completeness and consistency check on functional models, as the matrix visualises potential couplings.

The analysis shows that roughly the same functions were performed in both the instantiation of performance as planned and the one of performance as actually done. The figure focuses on tracing the effect of combined performance variability by sketching trajectories through the functional network.

The solid coloured lines illustrate the effects of project management (turquois) information about taxiways being reconstructed and unavailable, having effects on NOTAM (blue) and ATIS (green) services, and production of charts (turquois ctd.), affecting checklists and briefings, eventually coming together (black) into the turning onto another runway than intended. The dashed (red) line illustrates part of the trajectory where landing at LEX the day(s) before built up expectations of a short taxi and low lighting levels that affected several functions such as briefing, taxiing, turning onto the runway and the take-off run. The dashed-dotted line (purple) illustrates the effects of a blunt-end ATC management function that affects one position of ATC being open and the controller being busy with other tasks. These trajectories, too, eventually come together (black line) into the turning onto the runway. The RAM thus visualises the effects of contributing factors.

Below the solid line several resilient system characteristics (Woods, 2006) are illustrated. These were intended but not realised in this instantiation, making function performance brittle. Buffering capacity is attempted to be established through several functions together, establishing two ATC positions during TWR/radar service. Similar buffering capacity would be available when both pilots can taxi looking head-up. Flexibility of adapting to changed taxiway construction circumstances and tolerance for conflicting information (e.g., charts, NOTAM) is shown in the third row. The RAM can thus visualise resilience characteristics of the functional system (actual or as intended).

4 CONCLUSIONS

RAM fills a need for visualizing complex systems and their dynamics. RAM overcomes some of the difficulties in current methods such as (1) facilitating the visual discovery of patterns and functional interdependencies, (2) providing an overview of analytical findings of complex systems analyses, (3) interdependencies between instantiations, such as intended vs. actual performance and actual performance over time, and (4) visually organising emergent properties of resilient and brittle systems. RAM is intended to be used by analysts in academia and industry to add a visual analysis approach to other established methods, for both retrospective and prospective analysis. Future research includes evaluating the benefits of using a dedicated tool, and evaluating the communicative power of the visualisations with industry.

Acknowledgements

This study was supported by the Swedish Civil Contingencies Agency (MSB).

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A Method for Visualizing Trade-OFFS IN En-route Air Traffic Control Tasks

Daisuke Karikawa[1], Hisae Aoyama[1], Makoto Takahashi[2],
Kazuo Furuta[3], Akira Ishibashi[4], and Masaharu Kitamura[5]
[1] Electronic Navigation Research Institute, 7-42-23 Jindaijihigashi-machi, Chofu,
Tokyo, Japan d-karikawa/aoyama@enri.go.jp
[2] Tohoku University, 6-6-11-907, Aramaki-Aza-Aoba, Aoba-ku,
Sendai, Japan makoto.toakahashi@qse.tohoku.ac.jp
[3] The University of Tokyo, 7-3-1-225, Hongo, Bunkyo-ku,
Tokyo, Japan furuta@sys.t.u-tokyo.ac.jp
[4] Safety Management Laboratory, 4-17-4, Nishishiba, Kanazawa-ku,
Yokohama, Japan captishi@safeaprch.com
[5] Research Institute for Technology Management Strategy (TeMS), 6-6-40-403, Aramaki-Aza-Aoba, Aoba-ku,
Sendai, Japan kitamura@temst.jp

Abstract

In Air Traffic Control (ATC) tasks, controllers face paradoxical demands for dealing with increasing amounts of air traffic while keeping (or enhancing) safety and efficiency. Controllers are required to handle the demands in uncertain and variable traffic situations. This paper proposes a visualization method of trade-offs in en-route ATC tasks, and conducts a tentative analysis of trade-offs in a high fidelity human-in-the-loop simulation using this method. The obtained results strongly imply that controllers are required to maintain a balance between the optimality of control strategies for an existing situation and the tolerance for the variability of the situation. Through this analysis, the basic effectiveness of the proposed visualization method was demonstrated.

1 INTRODUCTION

In Air Traffic Control (ATC) tasks, controllers face paradoxical demands for dealing with increasing amounts of air traffic while keeping (or enhancing) safety and efficiency. Controllers handle the demands in uncertain and variable traffic situations by making performance adjustments (Sperandio 1971, Fothergill 2008). In order to support appropriate management of trade-offs among contradicting demands, the detailed analysis for revealing the nature of the trade-offs is definitely required. However, how to visualize and describe the trade-offs for objective analysis is still an open issue in the ATC domain. The present research, therefore, proposes a visualization method of trade-offs in en-route ATC tasks with utilizing our process visualization tool of ATC tasks called COMPASi (COMPAS in interactive mode / COMPAS: COgnitive system Model for simulating Projection-based behavior of Air traffic controllers in dynamic Situations). The basic effectiveness of the proposed method is examined through a tentative analysis of trade-offs in a high fidelity Human-In-The-Loop Simulation (HITLS).

2 EN-ROUTE ATC TASKS AND TARGET SECTOR

En-route air traffic control is a part of ATC services provided for in-flight aircraft. The ATC tasks have two major purposes: they are to ensure safety and efficiency of air transportation. The primary goal is to achieve the maintaining of safety by assuring a minimum separation of 5 nautical miles (NM) horizontally or 1000ft vertically between aircraft. In the en-route control, a team of controllers takes charge of a divided airspace called a “sector”. The present research has adopted an actual sector, that is, Kanto-North (T03) sector in Japan, as the target sector. Figure 1 shows sector T03 that is the northern part of the Tokyo region. The size of sector T03 is approximately 120NM by 120NM. The small white circle and capital letters, that is, TLE, in Figure 1 indicates one of the geometrical points and its name used for aiding in air navigation.

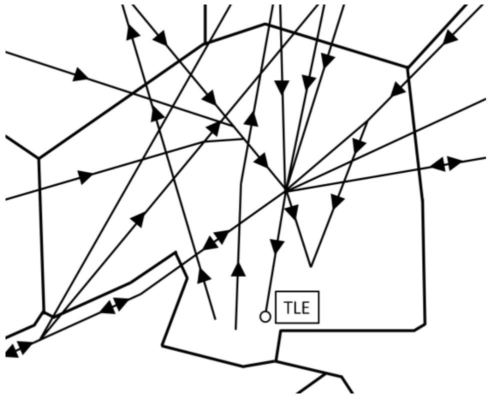


Figure 1. *Sector T03 and Traffic Flows*

Two hub airports, Tokyo (Haneda) International Airport and Narita International Airport, are located southward of sector T03. In addition, multiple smaller airports and air force bases are located in the surrounding areas of this sector. Furthermore, overflight aircraft between North America and East Asia pass through this sector in an east-west direction. Thus, this sector provides ATC services to various kinds of commercial and military flights. Regulations require the controller of sector T03 to achieve additional target altitude and separation of aircraft along with assuring minimum separation. For example, an aircraft arriving at Tokyo airport has to establish a 10NM in-trail separation from another aircraft arriving at the same airport and also has to reach 13,000ft by the TLE point (see Figure 1). In order to achieve the target states of aircraft, the controller can issue speed, altitude, and heading/rerouting instructions to the aircraft.

3 METHOD

3.1 COMPASi

COMPASi is a PC-based ATC simulation/visualization tool equipped with a kind of cognitive model of a controller called Situation Recognition Unit (SRU) that is capable of detecting ATC tasks in a given traffic situation. SRU models controller's situation awareness including realistic future projection with a certain safety margin for inevitable errors caused by situational uncertainty and variablility (Karikawa et al. 2013).

Figure 2 shows the conceptual diagram of COMPASi. Given the initial states of traffic (e.g., aircraft's initial position, altitude, indicated air speed, etc.) and the log of ATC instructions, the Air Traffic Simulator (ATS) simulates air traffic flow with continuous performance calculation of aircraft and automatic issuing of ATC instructions. The SRU analyzes the simulated air traffic situation and automatically detects ATC tasks in the situation. The detected tasks are classified based on Task Demand Levels (TDLs) shown in Table 1, which is an ATC task index for identifying ATC tasks and their execution states. Aircraft coming from an upstream sector have various TDLs ranging from Lv.1 to Lv.3+. By completing necessary ATC tasks in the sector, the TDL of each aircraft is expected to be reduced to Lv. 1 before it enters a downstream sector.

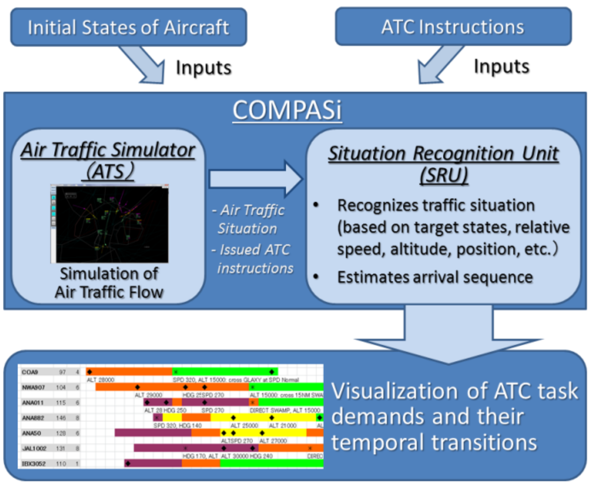


Figure 2. *Conceptual Diagram of COMPASi*

***Table 1**. Task Demand Levels (TDLs) (adapted from Aoyama et al. 2010)*

Lv.	Situation / Task Demand	Display Color on COMPASi
4	time-critical situation in terms of conflict resolution(s)	Red
3+	multiple separation assurances (conflict resolution(s) / in-trail spacing(s)) between the target aircraft and two or more related aircraft	Magenta
3	separation assurance (conflict resolution / in-trail spacing) between the target aircraft and one related aircraft	Orange
2	altitude change	Yellow
1	(ATC tasks are completed)	Green

As an output, COMPASi provides TDL of each aircraft in two forms: color codes of the flight number and of the lateral trajectory on a simulated radar display (see Figure 3), and a time series graph called Chart of ATC task Processing State (CAPS) (see Figs. 4 - 7). CAPS illustrates situation changes resulting from the instructions along the timeline, which is a visualization of the ATC task process. COMPASi also outputs flight distance and the number of instructions of/for each aircraft. The details of COMPASi was described in Karikawa et al. (2013).

3.2 Visualization of Tradeoffs in ATC Tasks

Using TDLs and other output data, COMPASi can visualize performance of ATC tasks from multiple aspects. As described in Section 3.1, the TDL of each aircraft is expected to be reduced to Lv.1 by completing necessary ATC tasks. Thus, reductions of TDLs reflect efficiency in completing ATC tasks (This performance aspect is referred to as “efficiency” in this paper). In addition, since greater levels of TDL, i.e., Lv.3, Lv.3+, and Lv.4, illustrate complex tasks such as conflict resolution and in-trail spacing, durations and accumulations of them indicate a potential intensive workload situation for a controller, which might compromise safety (Thus, this performance aspect is referred to as “safety”). Moreover, COMPASi records flight distance of each aircraft, which is a major factor affecting fuel consumption of the aircraft (referred to as “fuel economy”).

That is, by using TDLs and flight distances provided by COMPASi, trade-offs among safety, efficiency, and fuel economy can be visualized. Furthermore, through multiple simulation cases with varied simulation conditions, the performance tolerance of control strategies for situational variability can be examined.

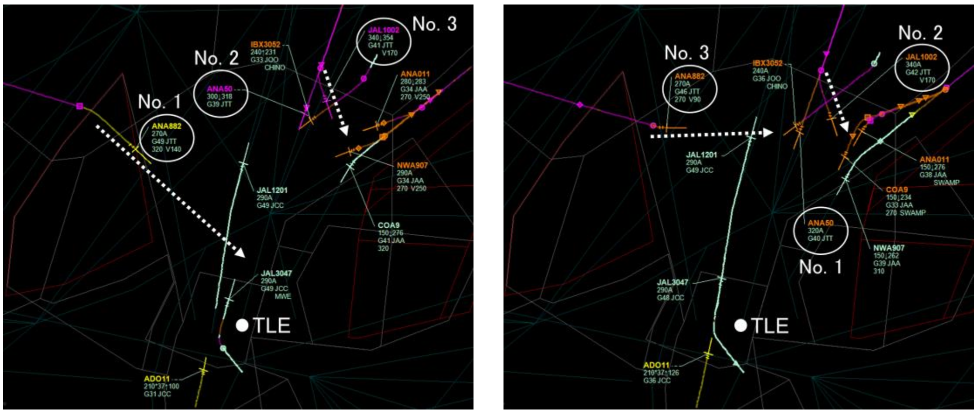
4 ANALYSIS AND RESULTS

In the present research, performances of two types of control strategies for a traffic scenario have been analyzed using COMPASi. The strategies were observed in the HITLS conducted in 2006 with 8 professional participants. This chapter describes a tentative analysis of the natures of tradeoffs in ATC tasks through visualization and comparison of performances of control strategies used by controllers.

4.1 Traffic Scenario and Control Strategies

Figure 3 and 4 depict a simulated sector, a traffic scenario, and control strategies analyzed in the present research. The target sector is sector T03 described in Chapter 2. Although there are several flights in those figures, the analysis in the present research focuses on arrival flights to Tokyo airport (that is, ANA882, ANA50, and JAL 1002). Based on regulations, the controller of sector T03 is required to achieve target states of those aircraft (that is, 10 NM in-trail separation and 13000ft at TLE), while continuously assuring the minimum separation from ADO11, a departure flight from Tokyo airport.

Two types of control strategies for this situation were observed in the HITLS. The first strategy (called Strategy A: ST-A) is depicted in Figure 3(i). The sequence of Tokyo-inbound flights in ST-A was ANA882, ANA50, and JAL1002. To achieve this sequence, following an ATC instruction, ANA882 took a shortcut in the direction of the TLE point as the first aircraft. The second strategy (called Strategy B: ST-B) is shown in Figure 3(ii). The arrival sequence in ST-B was ANA50, JAL1002, and ANA882. To achieve the sequence, ANA 882 was vectored to the east as the third aircraft to extend its flight distance.



(i) Strategy A (ST-A) (ii) Strategy B (ST-B)

Figure 3. *Control Strategies*

4.2 SIMULATION SETTINGS

For simulating the control strategies on COMPASi, two series of ATC instructions corresponding to ST-A and ST-B were extracted from recorded controller-pilot communication of the HITLS, and formatted as input files to COMPASi. Other necessary input data to COMPASi, that is, the initial state and performance data of each aircraft, were also prepared based on the recorded data of the HITLS. In addition, for evaulating the tolerance of the strategies for situational variability, two sets of simulation conditions summarized in Table 2 were prepared.

Table 2. *Simulation Conditions*

Simulation Conditions	Wind Condition	Control Strategies & Simulation Cases
Cond. 1 -Baseline Condition-	240 deg. at 80 knots at 40,000ft at 60 knots at 20,000ft	ST-A: Case 1A ST-B: Case 1B
Cond. 2	240 deg. at 80 knots at 40,000ft at 30 knots at 20,000ft	ST-A: Case 2A ST-B: Case 2B

4.3 RESULTS

Simulation Condition 1 (Baseline Condition) In Case 1A and 1B, simulation conditions and traffic situations of the HITLS were replicated on COMPASi. According to the simulation results, the completion time of required ATC tasks of the flights in question, which is indicated by the time when all TDLs of ANA882, ANA50, and JAL 1002 turn to Lv.1, are 14.5 minutes in ST-A versus 16.5 minutes in ST-B (see Figure 4(a) and Figure 5(a)). This result has demonstrated the higher efficiency of ST-A in completing ATC tasks. In addition, Lv.3 of TDL of ADO11, which indicates conflict between ANA882 and ADO11 in these cases, is not shown in each figure (see Figure 4(b) and Figure 5(b)). This fact points out that possible conflict between ANA882 and ADO11 was effectively prevented in both ST-A and ST-B. In terms of flight distances, the total flight distances of the target flights are 430 NM in ST-A versus 464 NM in ST-B. It indicates that ST-A has an advantage in fuel economy as compared to ST-B. From these results, it can be said that ST-A has better performance in efficiency in completing ATC tasks and fuel economy of aircraft than ST-B, although both strategies are effective in conflict prevention that can be a major factor in safety performance.

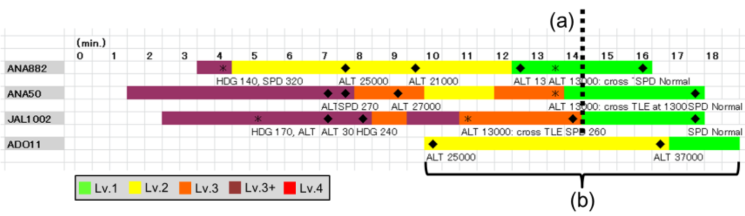


Figure 4. *CAPS of Strategy A (Case 1A)*

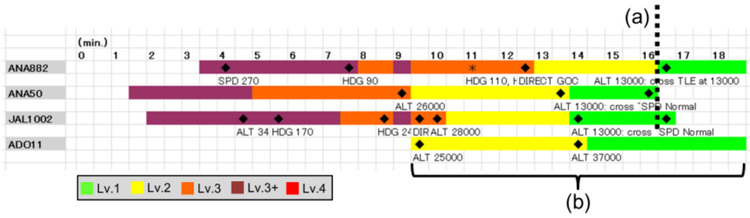


Figure 5. *CAPS of Strategy B (Case 1B)*

Simulation Condition 2 In Cond. 2, the wind condition was modified for simulating a situation where the wind velocity becomes weaker rapidly as aircraft descend, which is an example of situational variablity. Figure 6 and 7 show that, while any negative effects (that is, appearances of higher TDLs as compared to corresponding cases of Cond. 1) caused by change of wind condition are not shown in Case 2B, timeframes of Lv. 4 of TDLs of ANA882 and ADO11 are shown in Case 2A (see Figure 6(a)). It means that a conflict between ANA882 and ADO11 occurred in Case 2A. The cause of the conflict is that the geometrical point and the timing of the crossing of ANA882 and ADO11 shifted from those in Case 1A because weaker wind at lower altitude affected ground speeds of ANA882 and ADO11 and also the flight track of ANA882.

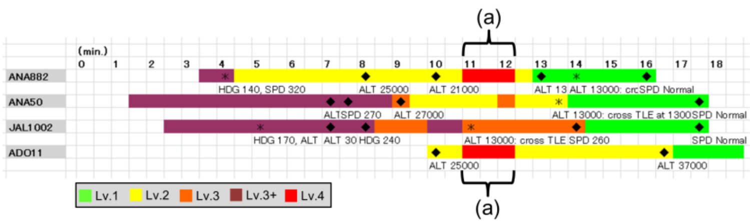


Figure 6. *CAPS of Strategy A (Case 2A)*

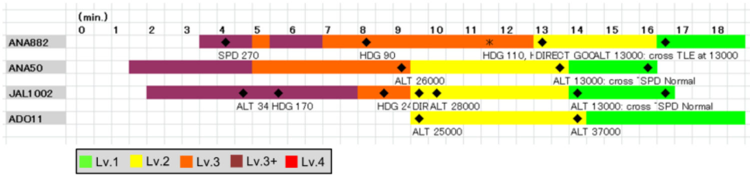


Figure 7. *CAPS of Strategy B (Case 2B)*

In the performance analysis described above, ST-A showed equivalent or higher performance both in safety and in efficiency as compared to ST-B under the baseline condition, whereas its safety performance was obviously decreased in the case that the simulation condition was modified for simulating the variability of the situation. On the contrary, ST-B showed the opposite performance: it was tolerant of the variability of a situation, while its efficiency was inferior to that of ST-A. Interestingly, despite good performance of ST-A in safety and efficiency under the baseline condition, ATC instructors have evaluated that ST-B can be more recommended even for less experienced controllers although both ST-A and ST-B are reasonable for dealing with the sample situation. This fact strongly implies that controllers are required to balance between the optimality of control strategies for an existing situation and their tolerance for the variability of the situation. The analysis described in this section has shown that COMPASi can be helpful for analyzing the natures of trade-offs in ATC tasks.

5 DISCUSSION

The present research proposed a visualization method of trade-offs in ATC tasks, which is essential for managing them. Since COMPASi can be used to visualize not only performances of control strategies in a certain situation but also their tolerance for the variability of the situation, we consider that it has potential applicability for estimating safety margins of controllers' activities. If simulations on COMPASi using realistic traffic situations and actual working processes reveal a potential tendency that controllers too often use working methods that are highly efficient in existing situations but less tolerant of the variability of the situations, the simulation results should be carefully fed back to controllers for sustaining their successful performance adjustments. In addition, for organizations, the results might be a sign that the controllers are exposed to high productivity pressures, and so the decision to sacrifice productivity might be required for ensuring safety. Now, we are developing an additional function of COMPASi called Variability-Tolerance Visualizer (VTV), which supports efficient analysis of tolerance of control strategies for situational variability. Further detailed analyses using VTV will be planned for revealing the nature of trade-offs in ATC tasks and controllers' management activities.

6 CONCLUDING REMARKS

The proposed visualization method using COMPASi has successfully visualized trade-offs in ATC tasks taking into account situational variability. It can contribute to accumulate objective data and knowledge concerning the trade-offs and controllers' management activities, which can be essential for supporting management of trade-offs. The visualization using COMPASi can also be useful for effective training of ATC trainees in order to enhance their ability to cope with trade-offs. Although the target domain of the present research is limited to ATC at this moment, we believe that the experience and findings of the present research might be useful for other industrial domains dealing with uncertain and variable situations.

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ConsideRing Trade-offs when assessing resilience

Eric RIGAUD and Christophe MARTIN
MINES ParisTech – CRC,
1 rue Claude Daunesse BP 207
06904 Sophia Antipolis Cedex, France

Abstract

This article describes the development of a prototype Resilience Analysis Grid for rail traffic management. The findings from testing of the initial model led to the identification of a set of potential vectors for improvement, in particular the need to integrate trade-offs. Based on Resilience Engineering trade-off theory this paper discusses how to integrate trade-offs into the system description and the impact of trade-offs on the four main resilience capacities.

1 INTRODUCTION

Resilience is an integrative concept that appeared in 21st century scientific thinking and encompasses two main ideas: recovery and the sustainability of systems in coping with stressful events (Reich et al., 2010). In Safety Science, resilience-based research aims to provide responses to the emergence of new and unanticipated threats that cannot be controlled by traditional prevention and protection practices. These threats are the consequence of changes in society and the emergence of vectors such as globalisation, increasing interdependence and complexity, the spread of potentially dangerous technology, etc. (Comfort et al., 2010).

The Resilience Engineering community aims to improve the control function of complex adaptive systems so that they are able to adjust their functioning prior to, during, or following changes and disturbances and can sustain the required operations under both expected and unexpected conditions (Hollnagel et al., 2011). Resilient processes aim to support the measurement of resilience factors, to monitor short-term developments and their consequences, to anticipate the emergence of long-term opportunities and threats and to provide adequate feedback loops from past events (Hollnagel et al., 2011).

A framework dedicated to the assessment and control of system resilience is currently under development (Rigaud et al., 2013). The framework is based on the Resilience Analysis Grid (Hollnagel et al., 2011) and aims to be able to define the resilience of a system, including: the definition and assessment of resilience factors and associated margins, the definition of a control scorecard and the definition of a list of improvement actions. Initial experiments established the need to be able to integrate trade-offs that may be the origin of performance variability.

This article discusses the issues raised by the integration of trade-offs into a resilience assessment and control process. The first part provides the foundation for the discussion that follows. It presents the initial Resilience Assessment framework developed for rail traffic management and the improvement vectors that emerged from initial testing. The second section offers some preliminary findings concerning the integration of trade-offs into the observation and description of a system and the causalities between trades-offs and resilience abilities.

2 THE RESILIENCE ASSESMENT FRAMEWORK

The first phase of the project was to formalise a generic Resilience Analysis Grid (RAG) in order to develop the capacity of systems to monitor their resilience performance. The grid was composed of a set of indicators that were related to the four capacities of a resilient organisation: the capacity to respond in an effective and flexible manner to normal, unusual and unanticipated situations; the capacity to monitor short-term developments and threats; the capacity to anticipate long-term threats and opportunities; and the capacity to learn from past events to correctly understand what happened and why (Hollnagel et al. 2001).

On the basis of this grid, focus groups were organised in order to develop a framework for the assessment of the resilience of rail management processes (Rigaud et al., 2013). The framework initially consisted of thirty-eight indicators related to the four resilience capacities (cf. Table 1), together with some introductory material about resilience performance and assessment guidelines and forms.

The resilience framework aims to monitor performance that is not captured by current assessment tools. Initial experiments identified both positive and negative outcomes and potential areas for improvement. Some indicators were difficult to understand and others were more or less relevant to the functions performed by an agent. The data collected was difficult to compare and aggregate and consequently it was difficult to use it as a basis for extracting relevant lessons and recommendations. Three areas for improvement were identified. The first concerns the refinement of indicators. The second is the integration of trade-offs into the framework, and the third relates to improvements to data collection and analysis processes.

Table 1. Example of an indicator

Indicator 2	The time required to provide resources needed to respond is appropriate to the situation	Capacity to respond
Indicator description Human and material resources required to respond have to be available and operational to provide an efficient response.		
Evaluation ***Insufficient.*** The availability and efficiency of resources does not receive particular attention. ***Average.*** Regular checks are made of the suitability of major resources. ***Acceptable.*** Regular checks are made of the suitability and availability of major resources. ***Satisfactory.*** Major and minor resources are exclusively dedicated to the response plan and their suitability and availability are regularly checked.		

2.1 Refinement of indicators

The aim of refining the four main capacities of organisational resilience was to make it easier to assess and control nuances. Starting with the four initial capacities, eleven key indicators were defined (cf. Table 2).

***Table 2**. Eleven abilities of organisational resilience*

Capacity	Key indicators
Capacity to Respond	Ability to respond to normal system and environmental variability
	Ability to respond to routine abnormal situations
	Ability to respond to unusual abnormal situations
	Ability to respond to unanticipated situations
Capacity to Learn	Ability to learn from unwanted situations
	Ability to learn from daily situations
Capacity to Monitor	Ability to monitor past safety performance
	Ability to monitor actual safety performance
	Ability to monitor potential future safety performance
Capacity to Anticipate	Ability to anticipate consequences of change
	Ability to anticipate consequences of innovation

2.2 Considering Trade-offs

Hoffman, Woods and Hollnagel have described how trade-offs are fundamental to human adaptive systems (Hoffman and Woods, 2011; Hollnagel, 2009). Their work aims to provide new concepts for modelling individual, collective and organisational behaviours and their impacts on system resilience. They identify five trade-offs: 1) optimality–fragility, 2) efficiency–thoroughness, 3) acute–chronic, 4) specialist–generalist, and 5) distributed–concentrated. These relate to different dimensions of a socio-technical system and can affect different aspects of resilience performance.

Taking trade-offs into account implies that:

- Agents perceive their environment relative to their own experience. An agent's perspective depends on factors such as culture, experience, aims or their unit's perspective.

- Strategy and plans designed to support an agent's performance may fail because of resource limitations (time, knowledge, information, human, technological, etc.).
- The system is divided into units. Each unit has its own goals, performance indicators and risks and responsibilities, which constitute the unit's perspective.
- Activities can depend on the joint performance of several units that can belong to independent systems.
- All the events that can occur in the system environment cannot be identified. Therefore resilience implies the implementation of relevant strategies for responding to known events and sufficient capacity and margin to respond to unanticipated events.

The integration of trade-offs into the resilience assessment and control processes leads to three issues, namely:

- **System description**. This concerns the identification of trade-offs that can influence resilience performance, specific data collection requirements and organisational approaches. What information is necessary to identify and define trade-offs? How is this information acquired? How is the quality of the information defined? How is this information structured?
- **Causality between trade-offs and resilience variability**. For each resilience factor: how to identify the trade-offs that influence variability? How to define and model variability that is due to trade-offs and variability that is due to resilience factors?
- **Trade-off control**. The definition of an improvement action plan and key resilience performance indicators must take into account trade-offs. How to control trade-offs? How to prevent trade-offs negatively influencing resilience factors? What new trade-offs emerge as the result of controlling trade-offs? Do these emergent trades-offs influence resilience?

The following section discusses the identification of trade-offs during system observation and description and causalities between trade-offs and resilience abilities.

3 INTEGRATING TRADE-OFFS INTO RESILIENCE ASSESSMENT

The integration of trade-offs into resilience assessment means that: i) it must be possible to characterise them through observation and description of the system; and ii) the causalities between them and resilience abilities must be understood.

3.1 Identifying and describing trade-offs

The information collected about the system with the objective of modelling trade-offs relates to the individual, collective and organisational level. Here we propose a framework to describe a system that takes trade-offs into account. This framework looks at the system from four perspectives: the system, the network, the unit and the agent.

System perspective

The optimality–fragility trade-off is linked to the description of threats and safety management. The set of threats that can affect the system are identified and structured in terms of: known threats where specific barriers exist; known threats where there are no specific barriers; and unanticipated situations (if any). The information to be collected relates to the safety management system, safety barriers, accident investigation reports, agent's experience of unanticipated situations and the adaptive capacity required to respond to them.

The evolution of the system and the removal or modifications to safety barriers has an impact on the optimality–fragility trade-off and consequently how agents see such situations (such as confidence in ineffective barriers or an improvised response to a situation where a procedure exists).

Network perspective

The system can be seen as networked units that interact. A first network consists of the organisation's social structure, which is composed of strategic decision-making units, hierarchical units and operational units. A second network is the activity network that consists of all the units (from different social structures) participating in the execution of an activity (production, control, etc.).

The specialist–generalist and distributed–concentrated trade-offs are linked to the description of the system's organisational networks. The system's formal and informal units are identified in terms of their interrelations and perspectives. In order to map the organisational network of a system, data must be collected about the organisation's formal social structure, its activity networks and agent's perceptions of informal units.

Changes in the organisational structure of the system and its economic environment will affect the model of its network structure.

Unit perspective

Units are the nodes of the system's organisational network. The specialist–generalist and distributed–concentrated trade-offs are linked to the unit perspective and the efficiency–thoroughness trade-off influences a unit's performance. Data concerning aims, responsibilities, procedures, performance indicators and the profile of agents belonging to units defines this perspective. Data related to minimal condition profiles (time, information, knowledge, resources, etc.) required to perform activities under normal and abnormal conditions defines unit performance variability.

Variability in both a unit's internal structure and any units connected to it affect the unit's performance.

Agent perspective

Units are composed of agents who work to meet the goals of the unit. The acute–chronic trade-off is linked to the agent perspective and the efficiency–thoroughness trade-off influences their performance. This perspective is defined by data related to the training of agents, their culture and perceptions of activities and risks.

Changes in the unit perspective, unit organisation, agent training or the occurrence of an event can cause variability in the agent perspective. An agent's performance in the unit and the performance of other units can affect the agent's capacity to perform tasks.

3.2 Linking trade-offs and resilience performance models

The following sections describe the potential impact of trade-off variability on each of the four resilience capacities (respond, monitor, anticipate, learn).

Capacity to respond

Organisational and inter-organisational trade-offs influence the capacity of a system to respond in the following ways: the ability to detect that something has gone wrong, to recognise the situation and its criticality, the ability to define a response plan and to actually respond (cf. Table 3)

Table 3. Influence of trade-offs on the capacity to respond

Trade-off	Dimensions affected
Acute–chronic	Agent's perceptions of: - Normal and abnormal functioning of the system; - Criticality of situations; - Response plan; - Adaptation to unanticipated situations.
Efficiency–thoroughness	Availability of time, knowledge, information and resources to: - Detect an abnormal situation; - Recognise the situation; - Consider the criticality of the situation and decide to respond; - Respond.
Specialist–generalist	Communication capacity between units. Variability in unit's perspective of the criticality of situations.

Trade-off	Dimensions affected
Distributed–concentrated	Communication capacity between units.
Optimality–fragility	Safety culture. Safety barriers.

Capacity to monitor

Organisational and inter-organisational trade-offs influence the capacity of the system to monitor in the following ways: the ability to define and revise indicators, the ability to collect information, the ability to analyse indicators, the ability to respond to variability in indicators (cf. Table 4).

Table 4. Influence of trade-offs on the capacity to monitor

Trade-off	Dimensions affected
Acute–chronic	Agent's perceptions of: - Nature of indicators; - Measurement frequency; - Criticality of variability in indicators.
Efficiency–thoroughness	Availability of time, knowledge, information and resources to: - Collect data; - Evaluate indicators; - Analyse indicators.
Specialist–generalist	Communication capacity between units. Variability in unit's perspective of the criticality of situations.
Distributed–concentrated	Communication capacity between units.
Optimality–fragility	Safety culture. Safety barriers.

Capacity to anticipate

Organisational and inter-organisational trade-offs influence the capacity of the system to anticipate in the following ways: the ability to detect changes and innovations and to analyse them in order to identify threats and opportunities (cf. Table 5).

Table 5. Influence of trade-offs on the capacity to anticipate

Trade-off	Dimensions affected
Acute–chronic	Agent's perceptions of: - The potential consequences of change and innovation for risk and the ability to respond; - Ability to identify new threats; - Ability to identify opportunities.
Efficiency–thoroughness	Availability of time, knowledge, information and resources for: - Change and innovation identification; - Change management; - Risks and opportunities analysis.
Specialist–generalist	Communication capacity between units. Variability in unit's perspective of the criticality of change and the potential consequences of innovation.
Distributed–concentrated	Communication capacity between units.

Trade-off	Dimensions affected
Optimality–fragility	Safety culture. Safety barriers.

Capacity to learn

Organisational and inter-organisational trade-offs influence the capacity of the system to learn in the following ways: the ability to select relevant situations for learning, the ability to identify relevant lessons from situations, the ability to learn from lessons (cf. Table 6).

Table 6. Influence of trade-offs on the capacity to learn

Trade-off	Dimensions affected
Acute–chronic	Agent's perceptions of: - The choice of relevant situations for learning; - The ability to identify a diversity of lessons from situations; - Ability to learn lessons.
Efficiency–thoroughness	Availability of time, knowledge, information and resources to: - Study situations; - Learn from the results of investigations.
Specialist–generalist	Communication capacity between units. Variability in unit's perspective of lessons to be learned from past events.
Distributed–concentrated	Communication capacity between units.
Optimality–fragility	Safety culture. Safety barriers.

4 CONCLUSION

The initial test of a resilience assessment framework dedicated to railway management processes highlighted three areas for improvements: the need to refine the description of resilience abilities, the integration of trade-offs and improved data collection processes. This article presented the preliminary results of the refinement process with the aim of producing a new prototype framework. In particular we discussed the issues related to the integration of trade-offs into system observation and description and understanding the causalities between trade-offs and resilience abilities.

These results will be used to define a new structural model of resilience abilities, to improve the data collection processes related to the model and develop an improvement plan.

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Performance variability: Black and white or shades of grey?

Cornelissen, Miranda[1], Salmon, Paul M. [2], McClure, Roderick[1] and Stanton, Neville A.[3]
[1] Monash Injury Research Institute, Monash University, Melbourne, Australia
Miranda.Cornelissen@monash.edu; Rod.McClure@monash.edu
[2] University of the Sunshine Coast Accident Research, Faculty of Arts and Business, University of the Sunshine Coast, Maroochydore, Australia
PSalmon@usc.edu.au
[3] Civil, Maritime, Environmental Engineering and Science Unit, Faculty of Engineering and the Environment, University of Southampton, United Kingdom
N.Stanton@soton.ac.uk

Abstract

Road transport is a complex sociotechnical system prone to performance variability. Unfortunately, performance variability of road users is not well understood and methods do not provide sufficient means to provide understanding and manage performance variability in complex systems appropriately. This article demonstrates how this gap can be addressed using Cognitive Work Analysis and the recently purposefully developed Strategies Analysis Diagram. It is demonstrated how application in road transport provides understanding of performance variability. It outlines that even if system constraints are similar for all road users, road users can and will engage in different behavior and this is induced by their own characteristics and interaction with infrastructure, environment and other road users. It is further demonstrated how Cognitive Work Analysis and the Strategies Analysis Diagram can be used to evaluate behavior induced by new intersection designs before these are build in the real world. Such understanding can then be used to adequately manage performance variability.

1 INTRODUCTION

Road transport is a complex sociotechnical system (Larsson, Dekker & Tingvall, 2010; Salmon, McClure & Stanton 2012). Many components such as road users, vehicles, infrastructure and environment interact and circumstances and demands vary which makes it prone to performance variability. Performance variability of road users has, however, received limited attention and is not well understood (Larsson et al., 2010).

Unfortunately, few conceptual frameworks or modeling methods exist and complex sociotechnical systems lack the means to understand and manage performance variability. For example, the Functional Resonance Accident Model (FRAM; Hollnagel, 2004) and system dynamics (Kontogiannis, 2010) model the interaction of performance variability in the system. However, a *structured* approach to *identify* a wide range of performance variability *possible* remains absent (Cornelissen, Salmon, Jenkins & Lenné 2012). The Strategies Analysis Diagram (SAD; Cornelissen et al., 2012) has been developed to augment the Cognitive Work Analysis framework (CWA; Rasmussen, Pejtersen & Goodstein, 1994; Vicente, 1999) to model performance variability. This article will describe how CWA and SAD when used to model performance variability, provide an understanding of and support management of performance variability in complex sociotechnical systems such as road transport.

1.1 Cognitive Work Analysis

CWA is used to design and evaluate complex sociotechnical systems and comprises five phases, each modeling a different constraint set (Vicente, 1999). The first three phases will be applied here. First, Work Domain Analysis (WDA) models system constraints from physical objects to the functional purpose of the system. Second, Control Task Analysis (ConTA) models situational constraints and decision making processes. Third, Strategies Analysis (StrA) models potential ways in which activities can be carried out within these constraints.

2 UNDERSTANDING PERFORMANCE VARIABILITY

CWA and SAD can be used to provide understanding of performance variability in road transport. Using these methods the interaction of constraints and behavior will be described outlining how road users, vehicles, infrastructure and environment interact and subsequently road user’s behavior may vary.

2.1 System constraints

System constraints on performance variability can be described conducting a WDA. The functional purpose of a road transport system can for example be defined as supporting negotiation of intersections by road users. Values and priority measures include safety, positive subjective experience, reach desired end point, efficiency, compliance and keeping upright in case of two wheelers and pedestrians. Purpose related functions that have to be executed to achieve the functional purpose include, for example, monitor infrastructure, determine path, establish position at the lights, negotiate stop or go and avoid conflict with other road users. Physical objects in the system include road users, vehicles, road, traffic lights and weather conditions, for example. These afford object related processes such as show behavior, control vehicle, allow movement of traffic and affect vehicle performance. These aspects of the road transport system constrain performance variability possible. For example, road users can only engage with the objects provided and have to execute purpose related functions to achieve the purpose.

2.2 Situational constraints

Situational constraints on performance variability can be described using the ConTA phase of CWA and the Contextual Activity Template (CAT; Naikar, Moylan & Pearce, 2006) in particular. The CAT describes for each situation defined whether purpose related functions can and are likely to be employed. In road transport, situations can be defined as approach, at the intersection and exiting the intersection, for example, (Fastenmeier & Gstalter, 2007).

In road transport systems, and Melbourne intersections in particular, the spatial distribution of function execution is similar across road users. Pedestrians and cyclists using the footpath, however, do not execute functions such as determine and take lane, and the emphasis of function execution is on the approach and at the intersection, rather than upon exiting the intersection.

2.3 Decision making processes

Decision making processes can be analyzed using decision ladders which display information requirements, options for purpose related functions and task execution (Rasmussen, 1974). Here, information requirements and options are of interest.

Road users' information requirements are similar but differences exist. For example, all road users are concerned with the location of other road users and status of the traffic light. Drivers, motorcycle riders and cyclists are concerned with speed control and following lane markings. In addition, vulnerable two wheelers, motorcycle riders and cyclists, for example, enquire about car doors opening and road conditions ahead. Road users using the pedestrian facilities on the other hand are focused on locating pedestrian crossings and assessing the status of the activation light.

Performance variability is also shaped by different options road users have for execution of purpose related functions. These are influenced by the facilities road users use and their vehicle characteristics. For example, to establish a position at the traffic light, road users can position their vehicle at the stop line, traffic light sensor, behind or adjacent to other vehicles. In addition, two wheelers can filter to the front and position themselves in front of other vehicles. Cyclists and pedestrians can position themselves at the pedestrian lights.

2.4 Courses of actions

SAD can be used to define how the above constraints influence variability in road user behavior, see figure 1. SAD provides detailed descriptions of how system constraints can be used to achieve functional purpose, defined in WDA, and describes both information requirements and task execution, defined in the decision ladders. Such descriptions follow a syntax including the different levels of the SAD. For example, road users can 'assess vehicles directional heading' to ensure they are 'travelling in the same direction' or 'assess vehicles speed control' to 'avoid conflict with other road users' when establishing a position at the lights. Each pathway in SAD represents a possible course of action. Road users can employ multiple courses of actions in varying orders across situations and these can be discovered following the links in the diagram.

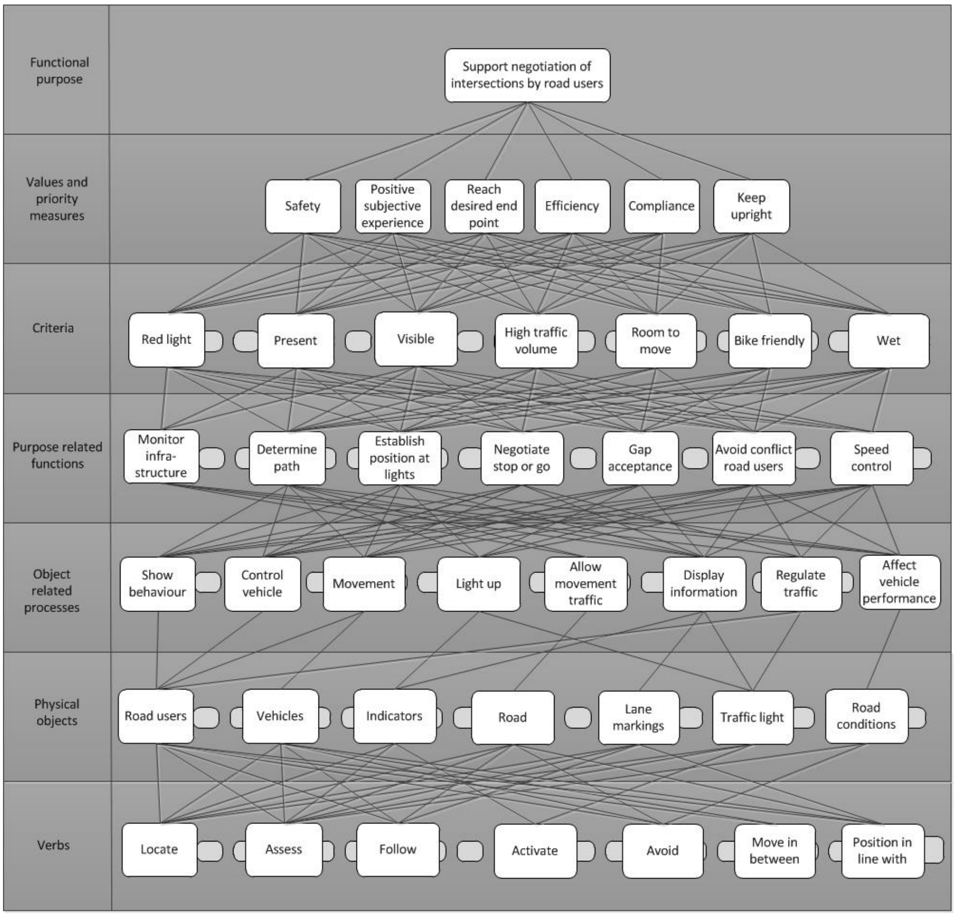

Figure 1. *Strategies Analysis Diagram highlights*

Different road users can, for example, engage in different courses of action for the same function. For example, to decide whether to position behind other road users, drivers, motorcycle riders and cyclists may 'assess road user movement and directional heading'. Motorcycle riders and cyclists, however may consider to position in front of other vehicles and can therefore engage in strategies such as 'assess whether road users controlling vehicles in front appear friendly' or are likely to 'block access'.

The availability of physical objects also influences employment of courses of action. For example, if arrow lane markings are blocked by other traffic, 'road users may assess indicators, recall information on the directional sign or anticipate information on the traffic light ahead' to make up for the missing information.

Different courses of action may be employed in different circumstances as represented by criteria in SAD. For example, when motorcycle riders and cyclists assess road users in front to be unfriendly motorcycle riders and cyclists are likely to position their vehicle behind those road users. On the other hand, if road users appear friendly they may move in between and position their vehicle in front.

Different courses of action may also be employed when behavior is driven by different values and priority measures. For example, safety is likely to motivate road users to wait for the green light at pedestrian crossings whereas efficiency values may motivate a pedestrian to jay walk or cross mid block.

Different courses of action may also be the result of complementary or redundant courses of actions. For example, motorcycle riders positioning themselves behind other road users can position themselves in line with wheels or mirrors of the vehicle in front. Positioning in line with wheels prevents tripping over obstacles appearing from underneath but puts them in a blind spot while positioning in line with mirrors increases their visibility.

Therefore, different road users operating within the same system constraints can and will display different behavior based on their characteristics and interaction with other road users, vehicles, infrastructure and the environment. CWA and SAD provide comprehensive insight into constraints shaping variability in behavior of road users.

3 MANAGING PERFORMANCE VARIABILITY

To demonstrate how understanding of performance variability can help manage it, an evaluation of a future intersection design will be discussed next. The cut-through intersection, see figure 2, was designed (Corben et al., 2010) to make intersections safer. Traffic islands are placed in the middle of the intersection to separate turning and straight through traffic meeting at 90^0 angles and allow them to meet under more favorable angles in different parts of the intersection. Changes in road user behavior, induced by this new design, will be discussed next using CWA and SAD.

3.1 System constraints

From a system constraints perspective the cut-through intersection is not that dissimilar from a traditional Melbourne intersection. It aims to achieve the same functional purpose (support negotiation of intersection), is driven by the same values and priority measures (e. g. safety, efficiency, compliance) and the functions that have to be executed are the same (e.g. although gap acceptance has been removed in the middle of the intersection by creation of the cut-through lane the task still has to be executed elsewhere in the intersection). The main difference from a system constraint perspective is that the slip lane as an option to turn left has been removed and lane markings across have been replaced by traffic islands.

3.2 Situational constraints

The physical distribution of constraints through the intersection, situational constraints, do affect road user behavior differently. For example, traffic islands in the middle of the intersection remove the gap acceptance task there but create instances of gap acceptance when entering and exiting the intersection and cut through lane. The traffic island separating traffic entering the cut through lane from other traffic, ensures determining a path and lane occurs earlier on approach as changes cannot be made after the traffic island has been reached.

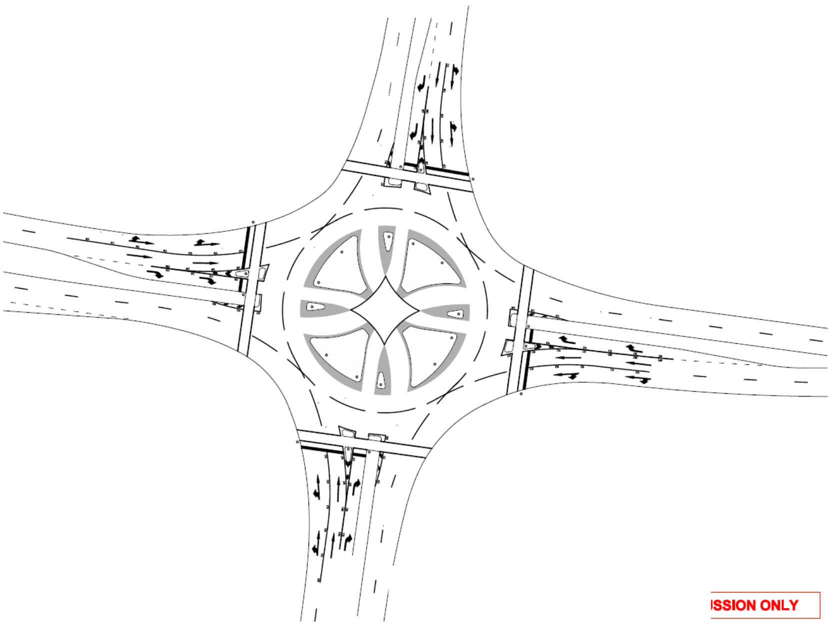

Figure 2. *Cut-through intersection*

3.3 Decision making processes

The decision to determine a path and lane to negotiate the intersection are positioned earlier on approach. Unfortunately, the information elements required, e.g. arrow lane markings, as determined in the decision ladders are not. Therefore information requirements are not satisfied by the new layout.

The layout creates new options to negotiate the intersection. More specifically, road users can use the intersection in a fashion similar to a roundabout and travel the long way around. Pedestrians and cyclists furthermore can use the traffic islands in the middle to cross the intersection diagonally.

3.4 Courses of actions

Changes in behavior will be induced by the design and were analyzed using SAD. For example, due to the removal of the slip lane, courses of action no longer include 'locate and enter slip lane' while courses of actions such as 'locate and follow lane markings' are replaced by 'locate and follow traffic islands'. Furthermore, traffic islands in the middle of the intersection 'divide and protect road users'. Therefore conflict avoidance and gap acceptance tasks will be easier. These changes will satisfy the values and priority measures of safety and efficiency. Those traffic islands also afford movement. Therefore when 'traffic volumes are low and speeds are low or traffic is stopped' and safety values are satisfied, pedestrians and cyclists may enter and exit the traffic islands in the middle to cross diagonally, motivated by efficiency values.

Road users can negotiate the intersection in a similar fashion to a roundabout and travel the long way around. Drivers' efficiency values will motivate them to use the cut-through lane. However, cyclists may find that this is a valid option depending on the situation. On approach, in addition to weighing of the many other options they have, they will have to decide whether they are going to use the cut through lane or use the intersection in a similar fashion to a roundabout. Therefore they may assess traffic, road and weather conditions to make such decision. This increases cyclists' workload and their unpredictability to other road users.

Altered traffic light positioning will also induce variability in road user behavior. In the cut-through lane, for example, road users will find an arrow light positioned upon exiting. A yellow or red light may cause road users to stop in the lane. However, as all directions of traffic will have to use the space in the middle this will block all traffic. Also, the designers do not intend road users to travel the long way around and therefore road users will not face a traffic light when facing traffic entering the intersection from the opposite direction. Therefore both streams of traffic have a green light and expect to have right of way, which may prove challenging.

Taking such changes in behavior into account is essential to understand how behavior is induced by design and can be managed adequately. For example, based on such evaluation cyclists can be provided with a dedicated facility which removes the many path options and therefore the decision making workload and unpredictability of these road users. Also information elements, such as arrows, used to determine a path and lane can be positioned earlier on approach to accompany the new decision point.

4 DISCUSSION AND CONCLUSIONS

This article aimed to demonstrate the value of CWA and SAD to model performance variability to improve understanding and to better manage performance variability. The application in road transport demonstrated that using such a low cost desktop approach, it can be easily assessed how designs induce different behavior for different road users, whether current systems support all road users and the interaction between them, whether additional support should be provided, reveal whether timely, redundant and complementary information elements are provided, consider road users as part of the design and assess whether performance variability with positive outcomes is encouraged and negative outcomes are discouraged. It provides insight into the interaction of a wide range of variables and provides insight into what, why, when, where, and who will be in conflict in road transport systems. Designing based on such understanding to manage performance variability will deliver holistic solutions. It is therefore argued here that the use of CWA and SAD to model performance variability to understand and manage performance variability should be explored further.

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How the Simplification of Work Can Degrade Safety: A Gas Company Case Study

Hortense Blazsin, Franck Guarnieri, Christophe Martin
Centre for Research on Risk and Crises (CRC),
MINES ParisTech, Rue Claude Daunesse, CS 10207, 06904 Sophia Antipolis, France
hortense.blazsin @ mines-paristech.fr
franck.guarnieri @ mines-paristech.fr
christophe.martin @ mines-paristech.fr

Abstract.

Work is focused on a gas company that wishes to develop a better understanding of its safety culture and identify potential enhancement opportunities. The hypothesis that emerged from an exploratory phase of work suggests that the corporate restructuring initiated four years ago, which has divided the company into distinct business units, has reduced organizational reliability. This issue raises a question faced by most industrial organizations, namely the trade-off between productivity and safety. On the one hand, streamlining activities offers an opportunity to save money, particularly through economies of scale and employee specialization. On the other hand maintaining flexibility generates costs, but provides a defence against silo effects, which are detrimental to safety. This paper describes how the company was restructured and the effects on risk management. The aim is to better understand the effects of the rationalisation on organizational reliability and performance, in order to identify potential solutions that may limit any counter-productive impacts.

1 INTRODUCTION

This article examines the safety culture of a major gas company, and potential ways to enhance its safety culture and safety results. The research project is carried out in partnership with a major company in the gas sector, whose mission is to transport and distribute natural gas at medium and low pressure from the network to the end user.

Research is focused on events that degrade safety performance and the conditions under which they occur. The initial phase consisted of participant observation (at the company's headquarters) and (on-site) non-participant observation, combined with semi-structured interviews. This phase revealed that the corporate restructuring exercise, which had begun four years earlier, had profoundly transformed the company's work. Restructuring consisted of dividing gas distribution activities into distinct entities, with the consequence that each entity covered a wider geographical area and the work of employees became more specialized.

The initial phase of research led to the hypothesis that the corporate restructuring had deteriorated organizational reliability. This article therefore examines the following question: what was the impact of corporate restructuring on organizational reliability and performance? The answer should help shed more light on a situation faced by most industrial organizations, namely the trade-off between productivity and safety.

We begin with a description of the organization in its current state and the impact of this structure on work. We then examine the issues in detail and outline the methodology, before finally presenting some initial findings.

2 RESEARCH QUESTION

The question which arises from the initial phase of research is: why has this corporate restructuring had an impact on its ability to manage risks?

After quickly presenting the organizational context, we outline some of the answers provided by the safety science literature. Next, we put forward a hypothesis related to changes in the nature of risk and the work of those who have to deal with it on the ground, namely field operators. Finally, we present our methodology.

2.1 Organizational context

The corporate restructuring has resulted in the division of gas distribution activities into four departments: network operations (BEX); planning (CAPA); actual field operations divided into routine maintenance (ARG) and specialized operations (MSG). In the new structure each employee is linked to a single functional group, and is expected to routinely carry out a clearly-defined set of tasks related to a particular aspect of the project.

Specifically, in terms of day-to-day activities this led to both a simplification of “real” work (employees carried out a limited range of simplified tasks more often) and increased the time spent on administration, which became necessary in order to coordinate the work of the various departments (Dujarier, 2006). If we take a definition of the organization of work as, “a dynamic set of responses to contradictions” (Pagès et al., 1979) administration describes the need to integrate individual actions, which has become necessary at all levels, including that of field workers, on whom research focuses (along with the relationship with their direct supervisors). As far as they are concerned this is due mostly to an increase in the meta-work they must take care of, i.e. familiarising themselves with procedures and tracking activities (reporting, providing feedback, etc.).

2.2 Division of Activity, Risk Homeostasis and the Silo Effect

The safety science literature provides some useful approaches to understanding the effect of the corporate restructuring on the company’s safety performance.

In normal (functional) mode, where there are no hazards to manage, the new division of responsibilities seems to undermine the resilience of the socio-technical system. There is a decrease in individual vigilance, as each worker tends to rely on his colleagues, in a way that is consistent with the principle of risk homeostasis (Wilde, 1988, see section 4.2). Moreover, it has created a silo effect within the organization. This makes it impossible to maintain an overview of ongoing projects and operations and degrades individual and collective effectiveness, making it more difficult for everyone to take the constraints of their colleagues into account in their daily work. This is an example of the negative impact the silo effect has on safety – and the limited awareness effect that it creates (Hopkins, 2006).

In dysfunctional, hazard management mode, these negative effects are compounded by the need for a rapid response to contain risk (Knegtering and Pasman, 2009). Various factors slow down the company’s ability to respond. These include: decentralization of decision-making and ability to take action; identification of the most appropriate interlocutor; different working practices / vocabulary in different departments (which slows down mutual understanding); need to arbitrate between the priorities and constraints of departments; etc. In other words, the proliferation of sub-systems within the organization acts as a brake on action (Crozier and Friedberg, 1977).

2.3 The Managerialisation of Field Workers for Risk Management

What’s more, as risks have become both pervasive and chronically unpredictable (see e.g. Beck, 2001; Mignard and Terssac, 2011), they cannot be fully anticipated during preparatory work. Therefore, when unforeseen risks arise once work has begun, it is the field operators who are actually there who have to deal with the situation. In this perspective, risk management means identifying emerging risks, analysing the underlying causes and making the appropriate decision. Effective risk management is therefore based on the worker’s capacity to go beyond their formal role of operator and on their ability to pay proactive attention to their environment, carry out a context analysis and make sensible decisions. However, such roles and skills are traditionally expected of managers (Mintzberg, 1973), not field operators. It also means that the operators must base their actions on a clear understanding of the cause of the problem and that they are able to articulate why they chose to take such action. On a practical level, it emerged from semi-structured interviews that this was the main characteristic of a “good gasman”, while at a theoretical level it refers to the exercise of practical reason as described by Paul Ricœur (Ricœur, 1986).

Our first hypothesis was that corporate restructuring had had an impact on organizational resilience, which led to an examination of risk management at the organizational level. Subsequent research led to a second hypothesis, which is that effective risk management must rely on the managerialisation of field operators. However, the current practice of confining field operators to a strictly operational role, which has been reinforced by the corporate restricting, prevents this managerialisation and therefore degrades organizational reliability.

2.4 Methodology

Research was mainly based on observational techniques that combined non-participant observation in the maintenance department (within operational teams) and participant observation at the company’s headquarters.

Observational techniques were chosen as they avoid the filter of discursive constructions and make it possible to capture simultaneously the technical and cognitive practices of agents (Arborio, 1999; Thiétard, 2007). The method involved making direct observations of the way in which projects were “framed” at briefings (i.e. the information volunteered by the supervisor); how workers prepared for work; what happened when they arrived on-site; their behaviour throughout the duration of the operation; what provoked discussions with colleagues (operators usually work in pairs) and potentially supervisors, and the nature of these discussions; etc.

The aim is ultimately to apply a ricœurien approach based on the concept of practical reason (ibid.), which is founded on ideas of “motivation”, “rationale”, “attitudes” and “practical reasoning”. The value of taking this approach lies in the ability it provides to analyse the actions of field operators in their own terms, i.e. in the context of their own configuration and dynamic (and not only in their relation to procedures and external constraints, as is frequently the case), while retaining the ability to link these actions to the (notably organizational) context, in which they originate.

Participant observation is ongoing. A particularly useful exercise was participation in post-incident analyses, a procedure that had been established by the company four years earlier (Desmorat et al., 2013).

3 INITIAL RESULTS

The analysis of the following incident focuses on the impact of corporate restructuring on risk management. It describes the impact of the new organization on on-site project management.

3.1 The Overlooked Bypass

During operations to replace a length of pipe, failure to install a bypass led to the gas supply to hundreds of customers being cut off.

This oversight was the result of a failure to prepare. While preparing the project, an employee in the engineering department had handwritten “bypass?” on the plans. A bypass is necessary when the network has an “antenna” topology, i.e. the rest of the network is only supplied from one side, unlike a “mesh” topology where the rest of the network is supplied from both sides. In this case, the bypass maintains the mains gas supply to both sides of the section where the work is done.

The employee in the operations department who was responsible for the case did not see the hand-written note, assumed that the network was a mesh configuration (the most common situation), consequently did not run a check with mapping tools and did not therefore recommend the use of a bypass. The employee in the maintenance department who was in charge of site preparation did not therefore provide the equipment necessary for the work to be carried out.

On-site work was carried out by a service company. Once the supply to the segment had been cut, they did not check the gas pressure on each side (a required procedure involving the installation of balloons that check gas pressure). They did not even have the necessary equipment, having assumed in the absence of any indication to the contrary that the network must be a mesh. Complaints about a cut in gas supplies began to arrive shortly after the gas had been turned off (any gas remaining in the pipeline is rapidly used when the part of the network no longer being supplied is cut off), which led to the realization that an error had occurred.

3.2 Lessons Learned

As this case demonstrates, it was not one single event (a lack of gas-pressure balloons, a stuck valve, etc.) but a series of events that led to the incident. It seems clear that in these situations, not only did barriers not play a defensive role (Reason, 1990) but they also made it more difficult to manage the incident.

The separation of the engineering department and the operations department and the fact that employees did not know each other led to a reliance on a written note rather than checking in person. The operations department relied on the fact that the file had been prepared by the engineering department, and decided that it was therefore not necessary to check the network configuration. Similarly, the operator carrying out the work decided that pressure testing was not necessary; the fact that there was no bypass and the lack of any specific indicators about the network configuration was considered sufficient information.

What’s more, classical communication theory argues that successful communication depends on the correspondence between the message sent by the transmitter and that received by the receiver. The quality of the match depends on the quality of the channel through which the message flows and the ability of stakeholders to use the same codes to encode/decode the message and ultimately, to understand the same thing. As signs (in this case, mostly words) are essentially polysemic, they must be interpreted (Ricœur, 1986). If the interpretation is to be correct, (i.e. the selected meaning is the one which the transmitter wanted to convey) there must be a common reference point, which can only be established on the basis of shared experience. Moreover, the finding that interpersonal relationships are necessary for successful workplace communication is confirmed by ergonomics research (Karsenty and Le Quellec, 2009).

It can therefore be argued that the lack of interpersonal relationships, as brought about by the corporate restructuring, makes it impossible to establish the common references necessary for successful communication. As such, it constitutes degraded conditions for risk management.

4 CONCLUSION AND OUTLOOK

Based on initial results of the on-site observation and the overlooked by-pass incident, it is possible to identify two principal adverse effects of corporate restructuring. The first concerns the impossibility of establishing a common reference point, as there are few or no shared experiences at the functional level (the silo effect) and the human level (geographic separation). This then triggers the organizational risk homeostasis phenomenon, which encourages employees to rely on checks carried out by their colleagues (i.e. other barriers found in the defence system).

The identification of these effects can help to suggest actions to counteract the negative effects of corporate restructuring and restore – or even enhance – organizational resilience. The ultimate goal is to create conditions that lead to the emergence of a shared framework and “organizational intelligence”, which at the same time maintains the risk management benefits offered by the technical specialization of employees and the implementation of defence systems, hence helping optimize the trade-off between the separation of activities/employee specialization and the maintenance of flexibility.

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Analysis of the human role in the resilience of air traffic management

Sybert H. Stroeve, Bas A. van Doorn, and Mariken H.C. Everdij
National Aerospace Laboratory NLR, Amsterdam, The Netherlands
Sybert.Stroeve@nlr.nl,
Bas.van.Doorn@nlr.nl,
Mariken.Everdij@nlr.nl

Abstract

The objective of this study is to identify and analyse strategies that are applied by pilots and air traffic controllers in dealing with a wide set of disturbances that may affect current air traffic operations. An extensive set of 459 disturbances is identified, which are clustered at three abstraction levels and characterised with respect to frequency of occurrence. Strategies of pilots and controllers for dealing with these disturbances are identified, and these strategies are also clustered at three hierarchical levels. The strategies are analysed with respect to key characteristics, such as detection and interpretation of the disturbances, coordination about the strategy, level of human flexibility, and strategy acquirement. The effects of the strategies on the key performance areas (KPAs) safety, capacity, environment and cost-efficiency are characterised and ranked. The results show that the strategies have positive safety implications for the majority of disturbances and negligible safety effects for the remaining cases. The effects on the other KPAs are negligible in the majority of cases, but they are negative for a variety of disturbances.

1 INTRODUCTION

Air Traffic Management (ATM) is a complex sociotechnical system involving large numbers of interacting human operators and technical systems, which function in different organisations at a variety of locations, and do their job in the context of uncertainty and disturbances (e.g., delays, weather, system malfunctioning, airspace closure). The ability of the ATM system to sustain operations by adjusting its functioning in the face of a wide range of disturbances is recognized as an important asset. The introduction of this resilience perspective in ATM has been supported considerably by the Resilience Engineering research field (Eurocontrol, 2009; Hollnagel et al., 2006; Woltjer, 2009).

Although procedures and regulations tend to specify working processes in ATM to a considerable extent, the flexibility and system oversight of pilots and air traffic controllers are essential for efficient and safe operations in normal and uncommon conditions (Eurocontrol / FAA AP15 Safety, 2010). In choosing suitable strategies for dealing with disturbances, the human operators have to balance the interacting and potentially counteracting effects on ATM key performance areas (KPAs), prominently including safety, capacity, and cost-efficiency. Some types of disturbances can be handled well at an early stage environment by human operators, other types of disturbances are more difficult to handle efficiently, and the strategy may come at the cost of particular KPAs.

The objective of this study is to obtain an overview of strategies that are applied by pilots and air traffic controllers in dealing with a wide set of disturbances that may affect current ATM operations, and to characterise the effectiveness of these strategies for attenuating the effects of disturbances with regard to KPAs in ATM.

This paper is structured as follows. Section 2 presents the identification of disturbances in ATM, clustering of these disturbances and an assessment of their frequency. Section 3 presents the identification, clustering and characterization of strategies for dealing with the disturbances. Section 4 presents an assessment of the effects of the strategies on KPAs in ATM. Section 5 presents a discussion of this research.

2 DISTURBANCES IN ATM OPERATIONS

2.1 Identification of disturbances

Resilience is the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions (Eurocontrol, 2009). As a basis for the analysis of the human role for resilience in ATM, there is a need for a wide list of disturbances that may perturb its operations and thereby require actions from human operators.

For the analysis in this study we adopt a wide list of events, conditions and circumstances that may occur in current and future ATM operations (Stroeve et al., 2011). These events, conditions and circumstances have been identified during brainstorm sessions with pilots, controllers and other experts, as part of a large number of ATM safety assessment studies. These sessions used ‘pure brainstorming’ guidelines (De Jong, 2004), wherein the participants were asked to identify as many as possible events, conditions and circumstances that may perturb ATM operations, and to refrain from criticism and/or analysis of their potential effects. They have resulted in a wide variety of disturbances, which may influence ATM KPAs, including safety, capacity, environment and cost-efficiency.

The list of disturbances of (Stroeve et al., 2011) contains 525 items, which cover a wide range of subjects including technical systems in aircraft and in the ATC system, performance of pilots and controllers, communication and coordination in ATM operations, weather, traffic relations, etc. Examples of disturbances related to technical systems are ‘Degradation of the brake system of an aircraft’, ‘Trajectory disappears from FMS’, ‘Radar is not working’, and ‘Flight plans of ATC system and FMS differ’. Examples of disturbances related to human operators are ‘Pilots report wrong position’, ‘Pilot mixes up different types of ATC clearances’, ‘Controller corrects wrong aircraft’, ‘Controller switches wrong stopbar off’, and ‘Pilot is fatigued’. Examples of disturbances related to traffic relations are ‘Speed differences between aircraft in a sequence’, ‘Emergency flight’, and ‘Unknown flying objects, e.g. weather balloons, leisure balloons, paragliders’. Examples of disturbances related to weather are ‘Reduced visibility’, ‘Runway is more slippery due to rain, snow, icing’, and ‘Wind influences expected time of arrival’.

2.2 Clustering of disturbances

The collection of disturbances describes a wide variety of events and conditions that may occur in air transport operations. As a starting point for the analysis of the human role to resilience in ATM, these disturbances are clustered. In this way the set of disturbances is structured and the number of types of disturbances that needs to be evaluated is reduced.

The clustering process describes the disturbances at three hierarchical levels of abstraction and forms subsets of disturbances on these hierarchical levels:

- Low-level: detailed description of a disturbance;
- Mid-level: an aggregation of a number of related low-level disturbances;
- High-level: a generic principle of a group of mid-level types of disturbances.

Disturbances are clustered with regard to similarity of the source of the disturbance, such as disturbances due to particular technical systems, disturbances resulting from particular human operators, or disturbances arising in particular processes. For example, high-level disturbance clusters include ‘Aircraft/navigation technical systems’, ‘Controller pilot communication’, ‘Controller working context’, ‘Pilot performance’, and ‘Weather’. The high-level cluster ‘Aircraft/navigation technical systems’ contains mid-level disturbance clusters such as ‘Accuracy of FMS routing’ and ‘Instrument landing system’, and the latter cluster includes specific low-level disturbances, such as ‘Wrong localizer frequency of the instrument landing system’, ‘Technical ILS failure’ and ‘Failure to capture or track the precision approach lateral or vertical guidance’. The details of the three-level clustering of disturbances are reported in (Stroeve et al., 2013).

The total set of disturbances contains 525 items. A number of 66 disturbances are out of the scope of this study, since they refer to future operations or to security issues. The remaining 459 disturbances have been clustered in 18 high-level disturbance categories and 149 mid-level disturbance categories. The mid-level disturbance categories contain in the range of 1 to 16 low-level disturbances. In half of the disturbances (229 out of 459), pilots or air traffic controllers may contribute to the existence of the disturbance, e.g. misconceptions of human operators, or errors in task performance. The other half of the disturbances are not somehow the resultant of the performance of pilots and controllers.

2.3 Frequencies of disturbances

The frequency of the occurrence of the mid-level disturbances has been assessed using four flight-based frequency categories, ranging from more than once every 100 flights to less than once every million flights. This frequency assessment is based upon expert opinions expressed during a dedicated workshop with pilots and air traffic controllers, results in the literature, and judgements by NLR safety experts. The frequency assessment is quite rough, since specific contextual factors, which may have a considerable influence on the frequency of the disturbance, have not been taken into account in this assessment.

The results show that the whole pallet of frequency categories is applied to characterise the disturbances, ranging from very rare disturbances, such as general system outages or evacuation of ATC centres, to regular disturbances, such as workload problems, aircraft speed differences and poor weather conditions (Stroeve et al., 2013). The majority of the identified mid-level disturbances occur more often than once every 10,000 flights. Thus the set includes many disturbances that are quite common, as well as a range of rarer disturbances.

3 STRATEGIES FOR DEALING WITH DISTURBANCES

3.1 Identification of strategies

Identification of strategies for dealing with the disturbances has been achieved by a dedicated workshop with pilots and controllers, by results in the literature, and by judgements of NLR experts. For each of the 149 mid-level disturbances, the strategies of pilots and controllers for dealing with them are described in detail in (Stroeve et al., 2013). In addition to these detailed strategy descriptions, for each mid-level disturbance one or a few key strategy elements have been identified, which summarize the main aspects of the strategies applied by pilots and controllers.

3.2 Clustering of strategies

As a basis for structured analysis of the strategies, a clustering of the strategies has been done, both for the strategies of controllers and pilots. Similar to the clustering of disturbances in Section 2.2 and similar to the resilience markers framework of (Furniss et al., 2011), the clustering uses three hierarchical levels of abstraction:

- Low-level: detailed description of a strategy, which is an identified key strategy element;
- Mid-level: an aggregation of a number of related low-level strategies;
- High-level: a generic principle of a group of mid-level strategies.

The strategies of controllers are clustered at 7 high-level strategies, 27 mid-level strategies and 98 low-level strategies (Stroeve et al., 2013). The high-level strategy clusters of air traffic controllers are:

- Adapt to context – describing strategies to deal with differences between airlines, large workload, and situations lacking procedures;
- ANSP organisational task – describing tasks within the ANPS organisation such as reporting of problems, safety management and training;
- ATC-pilot interaction – describing all kinds of communication actions between controllers and pilots, such as providing instructions and information, or requesting information;
- Configuration management – describing management of airspace or airport configurations, for instance in reaction to weather conditions;
- Coordination & information provision – describing coordination actions between controllers as well as with other entities (e.g., airline, vehicle driver);
- React to non-nominal situations – describing the application of contingency and emergency procedures; and
- Tactical control cycle – describing planning, monitoring, and interventions during tactical control as strategies to deal with disturbances.

The strategies of airline pilots are clustered at 7 high-level strategies, 25 mid-level strategies, and 71 low-level strategies. The high-level strategy clusters of pilots are:

- Adapt to context – describing strategies to deal with large workload, and situations lacking procedures;
- Airline organisational task – describing tasks within the airline organisation such as reporting of problems, safety management and training;
- ATC-pilot interaction – describing all kinds of communication actions between controllers and pilots, such as providing instructions and information, or requesting information;
- Coordination & information provision – describing coordination and information provision actions within the crew as well as with some other entities (e.g., other aircraft, passengers);
- Flight control – describing flight planning, monitoring and control by the pilots;
- React to environment – describing strategies to deal with weather conditions; and
- React to non-nominal situations – describing the application of contingency and emergency procedures.

3.3 Characteristics of strategies

Each strategy for dealing with a mid-level disturbance is characterized with respect to:

- First detection of disturbance - Which human operator or which technical system may detect the disturbance first?
- Establish common ground – Which kinds of communication/coordination actions are done to achieve a common understanding of the disturbance and of its effect on the operation?
- Strategy coordination – What kinds of communication/coordination actions are done in the strategy to deal with the disturbance?
- Level of human flexibility in strategy – What is the level of human flexibility in the strategy?
- Strategy acquirement – In what way has the strategy been acquired?

The results show that most mid-level disturbances can be detected at first instance by pilots (71%) and/or controllers (82%), but that only a minority of the disturbances can be detected via a notification or alert of a technical system (19%) (Stroeve et al., 2013). The analysis also shows that there are always some kinds of interactions between human operators to interpret the disturbance and to achieve a strategy, where most coordination is at the level of the controllers at local facilities, cockpit crew and air-ground interaction. For the majority of strategies medium to high levels of human flexibility are required, and these are mainly based upon a combination of training and experience. It appears that the precise application of the strategy mostly depends on the specific circumstances and cannot be based on standardized actions only.

4 EFFECTS OF STRATEGIES ON KEY PERFORMANCE AREAS

A qualitative assessment has been made of the effects of the strategy for dealing with disturbances on the main ATM key performance areas, regarding safety, capacity, environment and cost-efficiency. For each mid-level disturbance an assessment of the effect of the strategy on each KPA has been made on a 5-class scale (large negative, small negative, negligible, small positive, large positive). Next, by combining the frequency of the disturbance and the effect of the strategy on the KPA, a ranking for each KPA has been determined, where the strategies with the largest effects that deal with the most frequent disturbances rank highest (Stroeve et al., 2013).

Table 1. Effects of strategies for dealing with disturbances on ATM key performance areas. The percentages relate to the number of associated mid-level disturbances.

Effect	Safety	Capacity	Environment	Costs
Large negative	0.0%	9.4%	6.7%	8.1%
Small negative	0.0%	17.4%	20.8%	22.1%
Negligible	20.8%	65.1%	68.5%	64.4%
Small positive	49.7%	8.1%	4.0%	5.4%
Large positive	29.5%	0.0%	0.0%	0.0%

Table 1 shows a summary of the effects of the strategies by pilots and controllers on the ATM key performance areas. The results show that the strategies have positive safety implications in about 79% of the mid-level disturbances and negligible effects on safety for the remainder of the disturbances. This result indicates the safety priority of these operators working at the sharp end in ATM, when dealing with disturbances. Rankings of the effect of mid-level strategies on the KPAs are listed in (Stroeve et al., 2013). Examples of strategies with considerable positive safety implications include communication and coordination actions for explanation, verification and correction, monitoring and intervention actions in the tactical control cycle, and using different traffic configurations depending on weather conditions. These strategies can all be recognized as being very normal in ATM and such normal actions are important for maintaining safety in day-to-day operations.

For the other key performance areas (capacity, environment and cost-efficiency) the effects of the strategies are negligible in the majority (64% - 69%) of the disturbances, but the strategies also have negative implications in a considerable number of cases (27% - 30%). Prominent negative implications arise from weather-related disturbances (e.g., low visibility, strong winds, winter conditions, thunder storms) and from disturbances related to the ANSP organisation and workforce (e.g. strikes, controller shortage). The strategies to deal with such disturbances are aimed at maintaining safety and typically lead to considerable reductions in capacity, increase in delays, additional miles flown per flight, and decrease in cost-efficiency.

5 DISCUSSION

As a way to understand the human role in the resilience of ATM, we performed a qualitative analysis of the strategies of pilots and air traffic controllers in dealing with a large set of 459 disturbances that may occur during current air traffic operations. These disturbances stem from a considerable number of 'pure brainstorming' sessions for the assessment of the safety of air traffic operations. Since the 'pure brainstorming' guidelines prohibit analysis during the sessions, a wide diversity of disturbances has been identified, which may have effect on various KPAs. Notwithstanding the size and variety of the set of identified disturbances, it is recognized that the disturbances are mostly focused on the air traffic operations themselves, i.e. they are mostly disturbances on the sharp end in the ATM organisation. For processes, humans and technical systems that reside more towards the blunt end of the ATM organisation, other disturbances may also be relevant for the resilience of the overall ATM system.

Given the broad scale of the study, the large number of mid-level disturbances and the generality of the assessment, the assessment results provide a rather rough overview of the implications of the strategies on the various KPAs. A more precise characterisation of the effects can be achieved in more detailed assessments that take into account the specific context of the disturbance occurrences, and the potential interactions between a variety of disturbances.

The results show that pilots and controllers have a safety priority when being faced with disturbances. In the majority of disturbances, their performance is focused on improving the level of safety given the disturbance occurred, and in the remaining cases the effect on safety is negligible rather than negative. In contrast, negative implications of the strategies exist in a considerable number of cases (27%-30%) for the KPAs capacity, environment and cost-efficiency. The observed safety priority in the strategies does not mean that the performance of pilots and controllers cannot have negative safety effects. In half of the disturbances, pilots or air traffic controllers may contribute to the existence of the disturbance (e.g. misconceptions, errors) and the net effect of human-induced disturbances and the mitigating strategies may still be negative for safety. To well assess the overall effect on safety, more detailed studies, which take into account the context of a specific operation, are needed.

In conclusion, we identified, hierarchically clustered and characterized a large set of disturbances that may occur in ATM operations. The majority of these disturbances are quite common. We identified, hierarchically clustered, and characterized strategies of pilots and controllers for dealing with these disturbances. Interactions between human operators and medium to high levels of human flexibility are typical ingredients of these strategies. We assessed the implications of the strategies on ATM KPAs. Most strategies have positive safety effects, which come at the expense of negative effects on other KPAs in a considerable number of disturbances.

Acknowledgements

The research presented in this paper is done as part of the Resilience2050.eu project and is funded by the Seventh Framework Programme of the European Commission. We thank all participants of the Resilience2050 Task 1.2 workshop for their contributions, and we are grateful to the Turkish ANSP DHMI and the Technical University of Istanbul ITU for their support in its organisation.

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The relevance of resources for resilience at different organizational levels within the military deployment cycle[4]

Wim Kamphuis and Roos Delahaij
TNO, Kampweg 5, 3769 DE Soesterberg, The Netherlands
wim.kamphuis@tno.nl
roos.Delahaij@tno.nl

Abstract

In the current study, the relative importance of different resources for psychological resilience of service members is investigated. The study employs a model of psychological resilience developed for the Netherlands Armed Forces, which identifies 25 resources for resilience at 5 different levels (individual, home front, team, leader, organization). To assess the relative importance of 5 of these resources (one for each of the levels), measured pre and during military deployment, in predicting psychological resilience post deployment, regression analyses were conducted on data collected from three Dutch Task Forces part of the NATO mission ISAF. Results indicated that the relative importance of the resources differed pre and during deployment. The most important pre deployment resources for post-deployment resilience (operationalized as the absence of fatigue complaints) were self-efficacy, home front support, leadership, and information provision by the organization. During deployment group cohesion became the most important resource whereas information provision did no longer predict post-deployment resilience. These analyses illustrate that the relative importance of resources at different organizational levels varies with the phases of the operational cycle. This knowledge can be used to decide which resources should be targeted at what moment to get the maximum return on investment.

1 INTRODUCTION

Psychological resilience of service members is an important prerequisite for the success of military operations. Current deployments are characterized by a wide diversity of tasks and a broad range of stressors (Bartone, 2006; Boermans et al., in press). Military personnel must be able to cope with these demands in order to maintain optimal performance during operations, and also stay healthy and motivated post deployments. Therefore, it is important for military organisations to have an understanding of the factors that contribute to and affect psychological resilience. Organisations can use this knowledge to monitor the psychological resilience of their personnel and, where necessary, implement interventions specifically designed to enhance it.

Research has shown that different types of factors (on individual, team, and organizational level) may help a person deal with stressful circumstances. Traditionally, most research focuses on individual resources (Boermans, Delahaij, Korteling, & Euwema, 2012). Recently, the importance of environmental resources and thus the multidimensional nature of resilience has been acknowledged (Meredith et al., 2011; Zautra, Hall, & Murray, 2010). The multidimensional nature of resilience has also been acknowledged by the military (cf. the United States' Comprehensive Soldier Fitness and Total Force Fitness programs). In the Netherlands, a model of psychological resilience has been developed for the Armed Forces (NLD-AF), that defines 5 levels at which resources for resilience can be found (individual, team, leader, home-front, organisation; see Figure 1; Kamphuis et al., 2012). Although, the multidimensional nature of resilience is acknowledged in the military by developing programs that address resources from multiple domains, studies that combine resources from multiple domains are still scarce.

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[4] The results discussed in this paper were also part of a presentation at the 2012 IMTA Conference: Kamphuis, W., Venrooij, W., & Berg, C. E. van den (2012). *A Model of Psychological Resilience for the Netherlands Armed Forces.* Proceedings of the 54th International Military Testing Association Conference, November 5-9, Dubrovnik, Croatia.

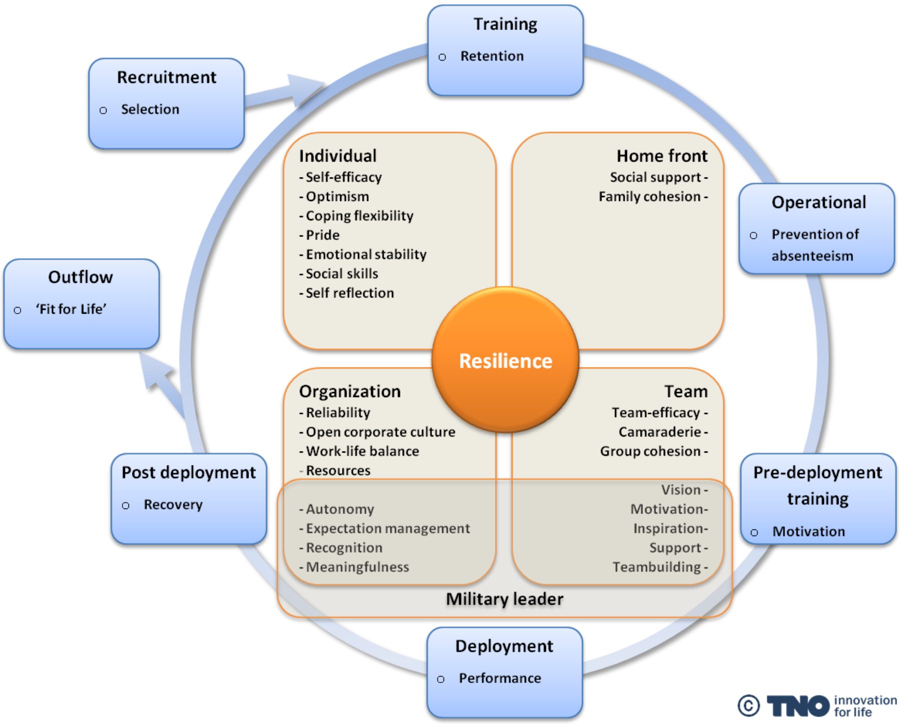

***Figure 1**. Psychological Resilience Model of the Netherlands Armed Forces*

Many studies investigating military resilience focus on one (or sometimes two) level(s) of resources only. In this way, no knowledge base can be developed to assess which resources, at which levels, have the largest relative importance for military resilience. Moreover, the relative importance of resources on these different levels will change as the characteristics of military operations change due to differences in missions (i.e. peace keeping or peace enforcing) but also due to the specific readiness phase a unit is in. Military deployments for example distinguish a preparatory phase pre deployment, and a mission phase during deployment phase. These two phases are both characterized by high demands, but also differ in the nature of these demands. The pre-deployment phase is often characterized by high workload and uncertainty about mission goals and timing. During deployment, main demands are threat and separation from home. In the model, the importance of distinguishing the different phases in the operational cycle is stressed by placing each of these phases around the 5 levels with resources. Not many studies have addressed the changing contribution of resources on military resilience over time. This study aims to address these gaps by a) investigating the relative importance of resources for military resilience at different levels and b) investigating changes in relative importance of these resources in different phases of the deployment cycle.

Resources included in this study were self-efficacy, group cohesion, social support from the family, leadership efficacy and provision of information by the organisation (one for each of the levels defined in the model). These resources have all been shown to contribute to service members' resilience.

Self-efficacy has been shown to buffer against the negative effects of stressful circumstances during military training (Delahaij, Gaillard, & van Dam, 2010) and military deployment (Benotsch et al., 2000). People who are highly self-efficacious have a strong belief in their ability to manage life's challenges, and consequently experience less distress and act more pro-actively (e.g., Skodol, 2010; Bandura, 1997; Pietrzak et al., 2010).

Group cohesion is a resource for resilience for service members because it provides them with a shared reality, enabling them to make sense of their experiences and sustain meaningful engagements (Mouthaan, Euwema, & Weerts, 2005). Cohesive teams are characterized by trust and teamwork, which provides soldiers with confidence in their personal capabilities and joint team efforts to successfully deal with situational demands, in turn enhancing team performance (Stetz, Stetz, & Bliese, 2006) and well-being (Griffith, 2002).

Social support from the family promotes service members' resilience before, during and after deployment because it provides them with emotional (i.e., understanding and comforting) and instrumental (i.e., helping out) support that enables them to perceive the experience as less threatening and pro-actively cope with the situation. Social support from the family has been shown to sustain combat motivation during, and facilitate recovery in the aftermath of deployment (e.g., Andres, Moelker, & Soeters, 2012).

The importance of leadership for psychological resilience of service members is multifaceted. Leaders provide in physical needs such as good equipment and living conditions (Boermans et al., 2012). In addition, leaders facilitate team processes (e.g., Griffith, 2002) and have a strong influence on the way stressful experiences are appraised (Bartone, 2006; Britt, Davison, Bliese, & Castro, 2004). As such the efficacy of the leader contributes to resilience of service members before and during deployment.

In the pre-deployment phase and during deployment service members' lives are largely determined by the goals of the mission and the ways the mission is organized. As such, knowing what to expect from the mission (i.e., job description, duration, threat levels, R&R possibilities) is important to reduce levels of uncertainty and associated distress (Bliese & Castro, 2000; Lazarus & Folkman, 1984). The amount and quality of information that is provided by the organization to reduce uncertainty and prepare for stressful circumstances can therefore be seen as a resource for resilience (e.g., Paton & Burke, 2007).

All in all, previous research shows that each of these resources affect resilience of service members in their own way. However, not much is known about how these resources affect resilience of service members together. The goal of this study was to investigate the combined effect and relative importance of these resources for military resilience and to determine when (at what point in time in the operational cycle) which resources are most important.

In the present study, the effect of these resources was examined on the recovery after deployment. The rate of recovery or adaptation after deployment is considered an important indicator for military resilience. Most service members who return from deployment will experience some adaptation difficulties, including somatic complaints or problems adapting to family life. However, only a small percentage develops more enduring complaints or problems (Dickstein, Suvak, Litz, & Adler, 2010). Therefore, the absence of somatic complaints after deployment is used as indicator of psychological resilience in this study.

2 METHOD

To assess the relative importance of the resources in the different phases of the deployment cycle, secondary analyses were conducted on data collected from three Dutch Task Forces that were part of the NATO mission ISAF in 2009-2010 (1576 participants nested in 87 units), assessing resources for resilience pre and during deployment, and somatic complaints post deployment. The data had been collected by DienstenCentrum Gedragswetenschappen (GW) (the Behavioural Sciences Services Centre of the Support Command of the Dutch Ministry of Defence) using the Morale Questionnaire (Boxmeer, Verwijs, De Bruin, & Duel, 2007) during pre-deployment training (T1) and during deployment (T2), and the Post-Deployment Questionnaire six months after deployment (T3).

The Morale Questionnaire (T1 and T2) includes measures of self-efficacy, group cohesion, home front support, leadership efficacy, and information provision by the organization. For all these measures, scales have been specifically developed for the NLD-AF (Boxmeer et al., 2007). The reliabilities (Cronbach's alpha) of these scales varied between .70 and .98. The Post-Deployment Questionnaire (T3) assesses measures of stress-related symptoms, including fatigue, a common symptom experienced by service members after deployment. Recovery after deployment was operationalized as the absence of fatigue. Fatigue was measured using a short-form of the Checklist Individual Strength (CIS9; Dittner, Wessely, & Brown, 2004) validated for the NLD Armed Forces (Gedragswetenschappen, 2008). The reliability (Cronbach's alpha) of this scale was .88.

3 RESULTS

Two regression analyses were performed to examine the extent to which the recovery after deployment can be predicted by the resources present during the pre-deployment training phase and the deployment phase. The results of these analyses are shown in Figure 1 and 2. The pie-chart pieces are based on the standardised regression coefficients produced by the regression analyses.

As can be seen in Figure 2, the most important pre-deployment resources for post-deployment recovery were self-efficacy, social support, leadership efficacy, and provision of information by the organisation. Together these resources accounted for 14,7% (adjusted R^2) in the variance of recovery after deployment. During deployment group cohesion became the most important resource for post-deployment recovery whereas provision of information by the organisation was no longer significantly related to post-deployment recovery (see Figure 3). Together, the resources with a significant contribution, measured during deployment, accounted for 15,6% (adjusted R^2) in the variance of recovery after deployment.

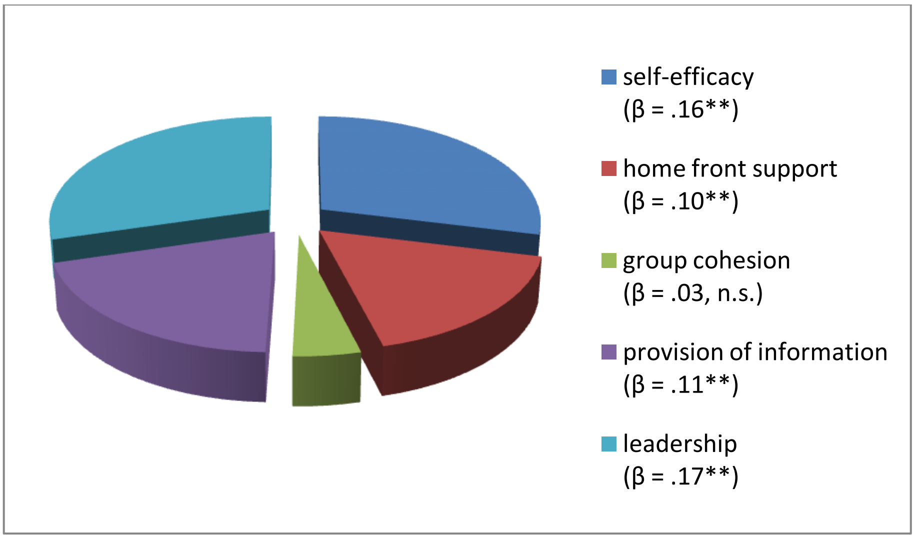

Figure 2*. Relative contribution of determinants measured before deployment in accounting for post-deployment recovery (**p < .001)*

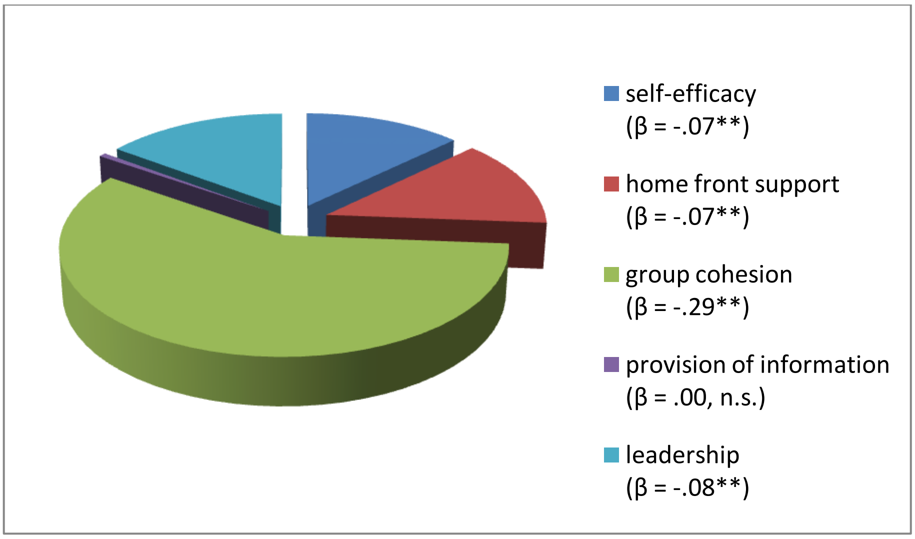

Figure 3*. Relative contribution of determinants measured during deployment in accounting for post-deployment recovery (**p < .001)*

4 DISCUSSION

The findings of this study underline the multidimensional and dynamic nature of resilience. Resilience is the result of the dynamic interplay between individual and environmental resources. This study shows that the relative importance of resources from different domains changes over time. This change is dependent on the characteristics of the situation.

One conspicuous result is the difference between the importance of provision of information by the organization before and during deployment. In the pre-deployment phase this forms a substantial resource whereas the effect of this resource is absent during deployment. This can be explained by the uncertainty and unpredictability of the pre-deployment phase. Team composition and tasks of military units can change during the pre-deployment phase and therefore it seems that in this phase service members have a stronger need for information provision by the organisation. When deployment starts this uncertainty decreases and this need becomes less important.

Like provision of information by the organisation, self-efficacy, home front support and leadership efficacy are all more important before deployment than during deployment, especially in comparison to group cohesion. The importance of these resources does not diminish during deployment, but the results show these resources have a smaller contribution to recovery after deployment. The relative importance of group cohesion increases from the pre deployment phase to the deployment phase. This is probably related to the increased dependence on the group for safety, social support and well-being during deployment. Before deployment, service members will not encounter threatening situations and will be able to fall back on their family for social support. During deployment, the group plays a central role in dealing with potentially life-threatening situations and serves as the sole social support system for a service member. The group becomes so important that it seems to partially overshadow the function of self-efficacy, social support and leadership efficacy in dealing with stressful situations.

These result provide practical implications for the military, but also illustrate the importance of using a multidimensional and longitudinal approach when studying resilience. Organizations, such as the military, that are highly dependent on individual resilience of their employees to sustain operational effectiveness are constantly looking for ways to enhance the resilience of their employees. At the same time, these organisations need to be cost-efficient and ensure that investments in resilience pay off in the longer term. Knowledge about the relative importance of resilience resources at different organizational levels and in different phases of the operational cycle can be used to decide which resources should be targeted at what moment to get the maximum return on investment.

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Sociotechnical Systems Issues in Worker Safety: Implications for Managing System Tradeoffs

Lawrence J. Hettinger, Marvin J. Dainoff, Michelle M. Robertson and Yueng-Hsiang Huang
Center for Behavioral Sciences, Liberty Mutual Research Institute for Safety, 71 Frankland Road, Hopkinton, MA 01748, USA
{Lawrence.hettinger, marvin.dainoff, michelle.robertson, yueng-hsiang.huang}@libertymutual.com

Abstract

Resilience engineering (RE) has strong roots in the traditions of sociotechnical systems thinking. Many RE concepts specific to system productivity, safety, anticipation of and recovery from system perturbations build on and extend core concepts from the sociotechnical systems literature. In this paper we discuss several key themes that emerged from a recent international symposium on sociotechnical systems and safety, with emphasis on their relevance to managing sociotechnical system tradeoffs. Joint optimization, asynchronous evolution, safety climate, and system observability and controllability are discussed from the perspective of how each impacts the ability to understand factors that promote functional or dysfunctional system tradeoff decisions. Additionally, the concept of the sociotechnical systems model is introduced.

1 INTRODUCTION

On October 18-19, 2012, a symposium entitled "The Hopkinton Conference on Sociotechnical Systems and Safety" was held at the Liberty Mutual Research Institute for Safety's campus in Hopkinton, MA, USA. Co-organized with the Massachusetts Institute of Technology and the University of Wisconsin-Madison, the symposium's objectives were to examine the state-of-the-art in sociotechnical systems thinking related to workplace safety and to identify research priorities. Resilience engineering (RE) was one of several sociotechnical perspectives discussed, and its influence can be seen in many of the key symposium themes and findings.

Participants included researchers and practitioners in domains associated with sociotechnical systems safety and performance. Five working groups were established, each addressing an area considered to be of importance to the overall topic of sociotechnical systems and safety. Participants selected the topic they wished to address and were assigned to the appropriate group. The working group topics were:

- Concepts, definitions and frameworks
- Defining research methodologies
- Modeling and simulation of sociotechnical systems
- Communications and decision-making
- Sociotechnical attributes of safe and unsafe systems

For approximately 3-4 months prior to the symposium, working group members collaborated on the preparation of draft manuscripts (scheduled for publication as a special issue of *Ergonomics*). The manuscripts critically assessed recent thinking in the areas under consideration and provided recommendations for future directions in research and practice. Each manuscript was peer-reviewed by a separate working group and was presented and discussed, along with its critique, at the symposium.

While RE was not an initial focus area of the symposium, it emerged as one of the more promising approaches to the design and operation of complex sociotechnical work systems. Additionally, research into influences on and outcomes of implicit and explicit tradeoff decisions was seen as critical to understanding the dynamics of sociotechnical systems. Whether at the managerial or "shop floor" level, tradeoff decisions, particularly those related to safety-production conflicts, were considered to be a key influence on overall system safety.

On an organizational/managerial level, tradeoff decisions that impact productivity, safety and resilience (i.e., a sociotechnical system's ability to accurately anticipate and/or adaptively respond to perturbations and upset conditions) generally focus on strategic issues related to the allocation of financial, technical, schedule or personnel resources (e.g., Goodwin & Wright, 2004). Developing the capability to meaningfully forecast the potential impact of such decisions on system performance, safety and resilience was seen as central to effective system design and operation. On the shop floor level, tradeoffs associated with tactical decision-making by individual workers or work groups, such as efficiency-thoroughness tradeoff decisions (Hollnagel, 2009), are also clearly vital to sociotechnical system performance, safety and resilience.

Simply put, tradeoff decisions occur at all levels of sociotechnical work systems. They occur within distinct but overlapping time scales that impact short- and long-term aspects of system design and operation. An understanding of the factors that drive these decisions, as well as an understanding of their potential impacts on system safety, performance and resilience is essential to understanding how complex sociotechnical work systems operate, and how they can be designed to operate more effectively.

2 RESILIENCE THEMES

The concepts of RE and organizational resilience featured prominently both in the manuscripts and in the symposium presentations and discussions. Among the common themes that emerged across the working groups, we have selected five that are relevant to discussions of resilience engineering and managing system tradeoffs. These include:

- Joint optimization and asynchronous evolution
- Safety climate and leading indicators
- The sociotechnical systems model
- System observability and controllability

While each topic covers unique aspects of sociotechnical systems design, operation and analysis, they are each derived from a common set of assumptions that are ultimately traceable to general systems theory (von Bertalanffy, 1968). To a large extent, sociotechnical systems theory is simply one of many derivatives of general systems theory. Its emphasis on safety and, by extension, resilience as emergent properties of the multiple interactions between social and technical system components is directly related to one of the foundational elements of general systems theory.

Similarly, the acknowledgment within sociotechnical systems theory of the non-linear nature of component interactions is vital to an understanding of the impact of tradeoff decisions on system operation. Like any other significant system change or manipulation, tradeoff decisions and the behaviors that stem from them are quite often as likely to have unintended and undesired consequences as they are to achieve their intended purpose. Therefore, attempts to understand the dynamics that such decisions set into operation is vital to safe and resilient system design and operation.

2.1 Joint Optimization and Asynchronous Evolution

Joint optimization has long been a central concept in the sociotechnical literature (e.g., Beekun, 1989; Hendrick, 1995). It refers to the goal, ideally central to the design and operation of any sociotechnical system, of conscious, thoughtful coordination of social/organizational and technical assets. A simple corollary of this principle, albeit one that is frequently violated, is that the introduction of new technology into a work system must be pursued in close coordination with appropriate training and/or changes in the number and type of personnel required to execute work activities.

A consistent effort toward such optimization in the face of current or projected hazards is particularly critical to enhancing system resilience, and represents a key domain within which many critical tradeoff decisions are made. Joint optimization could potentially serve as a critical lens through which to view design- and/or operations-specific tradeoff assessments and decisions.

Asynchronous evolution, or “out-of-phase” enhancement or degradation of social/organizational and technical components of a system has recently been discussed as a key factor in several major accidents (Leveson, 2012). For example, in the 1984 Bhopal methyl isocyanate release that resulted in the deaths of over 8,000 people, the substantial downsizing of experienced plant personnel (including safety and training staff) in the preceding months directly contributed to the remaining crew’s inability to adaptively respond to the accident. Maintaining a proper “sociotechnical balance”, particularly in safety-critical or high risk systems, is not only vital in maintaining day-to-day operational safety, but also the ability to adaptively respond to upset conditions.

2.2 Safety Climate and Leading Indicators

Recent years have witnessed a significant increase in research devoted to safety climate, generally defined as workers’ perceptions of their organization’s commitment to supporting safe work practices and policies (e.g., Huang et al., 2007; Zohar, 2011). Of particular interest is the potential gap between an organization’s espoused policies and commitments versus actual implementation and practice. Workers, as demonstrated by much of the safety climate literature, are often acutely sensitive to such discrepancies and gauge their behaviors accordingly.

Tactical tradeoff decisions made by individual workers and small work groups, such as those related to efficiency-thoroughness tradeoffs (Hollnagel, 2009) are almost certainly impacted by safety climate. For instance, an organization that nominally maintains a "safety first" policy, but reprimands or otherwise punishes employees who sacrifice productivity for safety are in all likelihood contributing to the development of a work system that is more brittle than resilient. Specifically, the ability (or even the inclination) to adaptively respond to a system upset or other perturbation is at least partially a function of workers' perceptions of the likely consequences they may face if non-standard but apparently necessary (under the circumstances) actions turn out to be unsuccessful or in fact ultimately unnecessary.

An important future direction for research in both safety climate and resilience is to assess the degree to which the former impacts behaviors essential to the latter. As has been previously noted, adaptability and flexibility in the structure and execution of work are requisite conditions for system resilience (Hollnagel, 2006). A poor safety climate is likely to stifle the adaptability and flexibility needed to help ensure a system's ability to functionally adapt to unusual, high risk conditions.

There are also intriguing indications that safety climate is a valid and useful leading indicator of an organization's susceptibility to serious accidents and injuries (Christian et al., 2009). The extent to which safety climate overlaps with similar issues related to sociotechnical system resilience is an emergent theme from the conference, and one deserving of future research. Given our argument above, we hypothesize that safety climate might also serve as a useful leading indicator of system resilience.

2.3 The Sociotechnical Systems Model

As the safety climate literature has made clear, individual workers, whether at the sharp or blunt end of a work system, are acutely aware of the separation between espoused and actual management policies regarding how work is to be performed. This suggests that workers may conduct their activities within the context of their understanding of the technical system(s) involved while also heavily influenced by their understanding of the social/organizational context within which work occurs. We refer to this interwoven pattern of cognitive influences on work behavior as a *sociotechnical systems model* (SSM). Simply stated, when faced with decisions about how work is to be performed, particularly under adverse or potentially dangerous situations, it is in our opinion unreasonable to assume that technical considerations are the only factors taken in to consideration. The potential for negative (or positive) social impacts (e.g., promotion, dismissal, etc.) and their related financial and personal affordances for the worker almost certainly play a significant role in his/her decision-making processes. Future research should focus on developing an understanding of how SSMs are formed, modified, etc. and their impact on workers' abilities to successfully conduct adaptive, non-standard activities.

Much attention has been devoted to workers' mental models and their impact on performance and safety (e.g., Hollnagel & Woods, 1983; Moray, 1990). The principal focus has been on operators' internal models of a given technical system or the "system model" (Hollnagel & Woods, 1983). Leveson (2012) has introduced the notion of the "process model", which extends the notion of the system model to encompass the model of the system as it exists within automated, technical systems[5], as well as system design plans and other artifacts.

Our concept of the SSM takes both notions a step further to incorporate concepts derived from the safety climate literature. To summarize, we hypothesize that any critical work-related decision, and in particular those that involve potential tradeoffs, are made within the context of a worker's sociotechnical model of his/her work environment. At the managerial level, for instance, tradeoff decisions are in some cases just as likely to be weighted on the basis of potential career impacts for the decision maker as they are on the technical, work-related nature of the situation at hand.

[5] As an example, Leveson (2012) describes the process model as instantiated within a thermostat: "At one extreme, this process model may contain only one or two variables, such as the model required of a simple thermostat, which contains the current temperature and the setpoint and perhaps a few control laws about how temperature is changed. At the other extreme, effective control may require a very complex model with a large number of state variables and transitions, such as the model needed to control air traffic" (p. 87).

2.4 System Observability and Controllability

Effective decision-making and communications are obviously critical in promoting and sustaining sociotechnical system resilience (e.g., Flin, 2006). When viewed from a control theoretic perspective, such as that developed by Leveson (2012) and applied by Flach et al. (in preparation) to the analysis of risk and accidents in occupational settings, these processes become manifest in terms of multi-level, organizational *observation* and *control* of key system parameters and objectives.

As with other complex adaptive systems, sociotechnical work systems are almost universally hierarchal in nature. To borrow from Leveson's (2012) terminology, the upper levels of the hierarchy are responsible for imposing and enforcing safety constraints on lower levels, while the latter are responsible for providing useful feedback about the effectiveness of such constraints to the former. The effectiveness of these communications (observability) significantly influences the degree of controllability afforded to decision makers. Strategic and tactical tradeoffs that impact each level of the hierarchy form a complex network of influences shaping the constraints on overall system performance and safety.

Similarly, we hypothesize that system resilience is an emergent property of the same complex network of interactions. As noted above, a sociotechnical system's ability to adaptively respond to unusual conditions will be significantly impacted by past tradeoff decisions at all levels of the hierarchy. However, and more to the current point, the ability to ensure that the results of tradeoff decisions approximate their intended effects will be largely dependent on the degree to which they impose effective constraints and make available functional affordances for resilient behavior (controllability), as well as the extent to which the outcomes of such decisions can be accurately and efficiently incorporated into subsequent decision making (observability), both strategic and real-time.

3 IMPLICATIONS FOR MANAGING SYSTEM TRADEOFFS

While managing system tradeoffs was not the principal focus of the Hopkinton Conference on Sociotechnical Systems and Safety, it became clear in the papers and discussions that it is central to most, and perhaps all of the topics that were examined. As illustrated in the examples provided above, system tradeoff decisions are themselves products of complex sociotechnical processes and, in turn, can exert tremendous reciprocal influence on those same processes. This suggests that understanding the dynamics underlying such decisions could be as important as understanding their impact if we hope to positively influence them.

Given the widespread conception of sociotechnical systems as exemplars of the broader class of complex adaptive systems (e.g., Miller & Page, 2007; Rouse & Serban, 2011), there are compelling reasons to hypothesize that the frequently non-linear effects of tradeoff decisions are likely to impact systems in unintended and occasionally damaging ways. Understanding the sociotechnical roots and impacts of system tradeoffs is therefore an important step in reducing the uncertainty associated with such decisions.

An important direction forward may be the systematic examination of sociotechnical work systems using methods derived from general systems theory and, specifically, the study of other complex adaptive systems. While it is possible that the distinction between *engineered* and *biological* or *natural* complex systems is so profound as to negate the benefit of applying methods derived from analysis of the latter to the former, it is nevertheless worth an initial examination (e.g., Raichman et al, 2004).

4 CONCLUSIONS

Analyses of worker and system safety are undergoing a shift away from traditional, reductionist paradigms to approaches that are more cognizant of the multiple social and technical factors whose interactions shape the work environment and associated aspects of the psychological climate. The Hopkinton Conference on Sociotechnical Systems and Safety brought together many of the world's leading researchers and practitioners to analyze the state-of-the-art in the area and to identify research priorities. The majority of issues that were examined are directly relevant to conceptions of organizational resilience and, more to the point, the impact of system tradeoffs on the design, operation and maintenance of safe and effective sociotechnical systems.

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Identifying Imbalances in a Portfolio of Safety Metrics: The Q4-Balance Framework for Economy-Safety Tradeoffs

David D. Woods[1] Ivonne Herrera[2] Matthieu Branlat[3] and Rogier Woltjer[4]
[1] The Ohio State University, USA
woods.2@osu.edu
[2] SINTEF Information and Communications Technology, Norway
Ivonne.A.Herrera@sintef.no
[3] 361 Interactive, USA
matt@361interactive.com
[4] Swedish Defence Research Agency, Linköping, Sweden
rogier.woltjer@foi.se

Abstract

Despite the desire to utilize proactive safety metrics, research results indicate imbalances can arise between economic performance metrics and safety metrics. Imbalances can arise, first, because there are fewer proactive metrics available relative to the data an organization can compile to build reactive metrics. Research also has shown a number of factors that lead organizations to discount proactive metrics when they conflict with shorter term, more definitive reactive metrics. This paper introduces the Q4-Balance framework to analyze economy-safety trade-offs. Plotting the sets of metrics used by an organization in the four quadrant visualization can be used to identify misalignments, overlap, false diversity as well as to identify complementary and reinforcing metrics that produce a balanced portfolio for an organization.

1 PROACTIVE SAFETY METRICS IN AVIATION

Aviation continues to achieve excellent safety levels. Yet the record of success is punctuated by notable accidents such as Überlingen, Air France 447, and Linate. To maintain and extend the safety record of aviation, the industry would like to use proactive metrics that anticipate and warn of areas of possible increased safety risks and be able to act in advance of incidents and accidents (e.g., European Commission, 2011). This becomes more important as traffic loads increase, as extreme weather events occur more frequently, as new technologies are introduced (e.g., unmanned aircraft, satellite navigation), and as potential system improvements are considered. Proactive safety metrics are an important addition to the set of measures available to manage aviation systems because improvements in aviation often come about in response to specific incidents, failures, or rare accidents.

Today's Air Transport System (ATS) has grown in complexity as it meets increased pressures for efficiency and productivity in a changing technological, environmental, and competitive world while maintaining or improving its record of safety (ACARE, 2012). This increase in complexity requires new metrics that allow ATS to identify when brittleness is increasing and evaluate cost effective sources of resilience (Hollnagel et al., 2006). Reactive safety approaches can look at specific risk factors one or a few at a time. Proactive measures, especially given the increasing complexity of the aviation system, help identify emergent phenomena and multi-factor patterns that can contribute to new risks (Herrera, 2012).

One impediment to anticipate changing or new risks before they lead to serious incidents or accidents is a dearth of valid and practical proactive safety metrics (see Hale, 2009). But another impediment is the tendency for organizations to discount available proactive safety indicators when they come into conflict with short term economic and productivity pressures (Woods, 2006). This was seen most vividly in the events leading up to the Columbia Space Shuttle accident where productivity metrics and pressures took priority over indicators of a change in safety risks, i.e., the energy and location of debris (foam) strikes as well as surprises in the source of debris and phase of flight when these strikes occurred (CAIB, 2003).

2 BALANCING ECONOMY-SAFETY TRADEOFFS: THE Q4 FRAMEWORK

This paper describes a new way forward based on the need to balance reactive indicators with proactive indicators on both safety and economy. The authors have drawn on work on proactive safety metrics and advances toward measures of system resilience to develop the Balancing Economy-Safety Tradeoffs framework. The four quadrants of the Balancing Economy-Safety Tradeoffs framework (or Q4-Balance framework) are shown in Figure 1. The framework allows an organization to map the metrics it uses into the four quadrants. The resulting visualization provides the means to develop and utilize a balanced portfolio of metrics that assesses the state of and interactions across all of the performance dimensions critical to modern aviation systems and organizations.

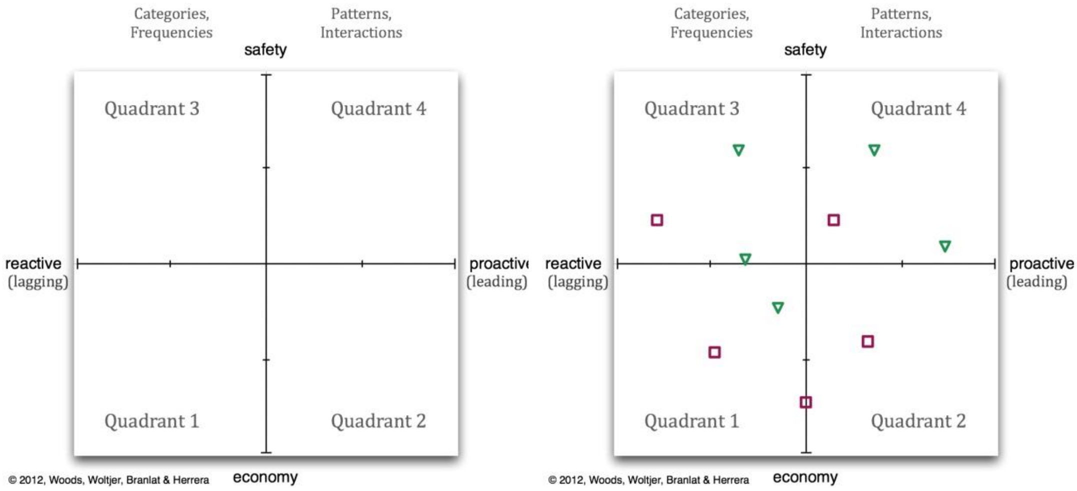

Figure 1. The Q4-Balance framework.

Q4-Balance framework in Figure 1 depicts relationships between classes of performance metrics. Performance metrics fall into a space defined by 2 dimensions: reactive-proactive (the endpoints on the x axis in Figure 1A); economy-safety (the endpoints on the y axis in Figure 1A). The specific performance metrics or indicators used by a specific organization can be plotted relative to the 2 axes: safety/economy and reactive/ proactive. A set of indicators used by an organization, or a function within an organization or across organizations, to guide decisions can be seen in a pattern formed by the distribution of the indicators over the 2x2 space of performance measurements as shown in Figure 1B (note that the figure at the left side shows indicators for two organizations). The structure of Figure 1 reveals an emergent pattern where metrics can be grouped into 4 classes -- economy-reactive, economy- proactive, safety-reactive, safety-proactive -- shown as the quadrants 1 through 4 respectively.

Figure 1. The Q4-Balance framework. Performance metrics fall into a space defined by 2 dimensions: reactive-proactive (x axis); economy-safety (y axis). As a result, metrics are grouped into 4 quadrants (Quadrant 1 = reactive-economic; Quadrant 2 = proactive-economic; Quadrant 3 = reactive-safety; Quadrant 4 = proactive-safety). Figure 1B shows how specific performance metrics used by specific organizations can be plotted as a position in this space to assess the distribution across the quadrants and to look for patterns of imbalance that hinder organizations as they confront trade-offs in risks and uncertainties

The Q4-Balance framework provides the analytic and visual basis to assess balance and imbalance across the four interdependent classes of metrics highlighted in the four quadrant visualization. Imbalances arise when there are fewer proactive metrics relative to reactive ones as shown in Figure 2A. The prevalence of reactive over proactive metrics in a portfolio is shown as shift in the balance point (the 0,0 point in x-y space) so that the left 2 quadrants are larger and the right 2 quadrants have shrunk in size indicating the misbalance in the metrics portfolio. A misbalance can show an organization focusing on reactive metrics while weak on proactive metrics. This will have an impact on the ability to anticipate and cope with future situations. Importantly, research on measures of resilience and brittleness, such as methods to forecast the risk of loss of resilience, provide a new paradigm for developing valid and useful proactive metrics that apply to both safety and longer term economic viability (business continuity).

Figure 2. Sample Patterns of Imbalance. Some classes of metrics tend to dominate others when there is uncertainty or conflict. Panel A depicts the tendency for reactive metrics (odd quadrants) to get priority over proactive ones (even quadrants). Panel B depicts the tendency for reactive-economy indicators (Quadrant 1) to take precedence over proactive metrics, especially proactive safety indicators, when there is uncertainty,

conflict, and differential costs at stake. Note that in both of the cases illustrated in this figure, the indicators that show threats to longer term economic viability also tend to be discounted relative to reactive-economic metrics

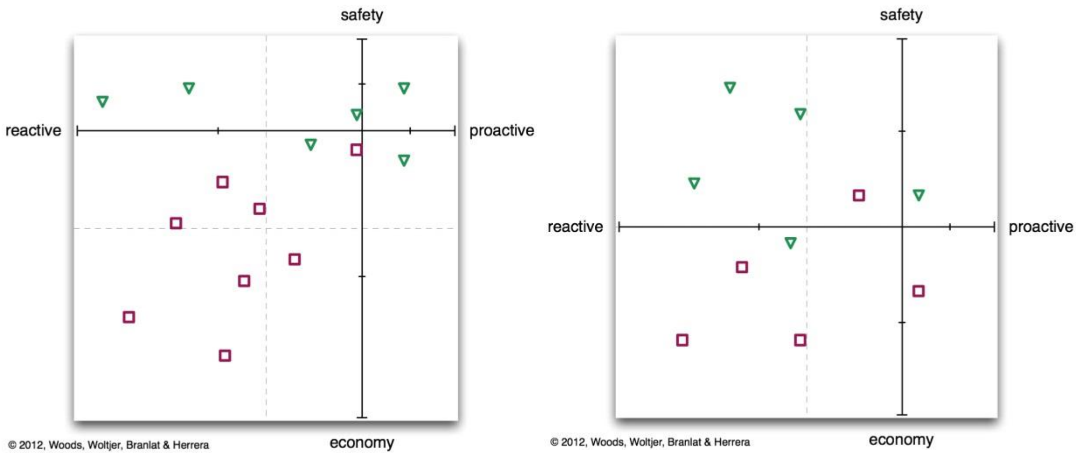

Figure 2 *Sample Patterns of Imbalance.*

Research also has revealed factors that lead organizations to discount proactive metrics when they conflict with shorter term, more definitive reactive metrics (the Columbia accident provides the classic example; see Woods, 2005). Reactive measures tend to be much more tractable and appear more definitive than proactive ones. For example, frequencies can be established from standard databases and reporting systems, and these can be compiled according to different categorization schemes when one is dealing with events that have already occurred (as noted in the column headings in Figure 1). Proactive metrics tend to look for patterns and relationships that can help recognize anomalies early (Klein et al., 2005); these are much harder to compile semi-automatically and they are valuable especially because these indicators have the potential to trigger re-evaluation and re-conceptualization about changing risks before serious incidents or accident occur. Figure 2B depicts this class of imbalance where reactive economic indicators dominate organizational decision making leading to discounting of safety indicators and to discounting of proactive indicators in general. Metrics that capture different aspects of resilience are a particularly valuable means to redress this imbalance, since these were developed specifically in order to assess the risk of this basic pattern (Cook and Woods, 2006).

3 EXAMPLE OF PATTERNS OF IMBALANCE

To illustrate a Q4 application, we use information from the Alaska Airlines Flight 261 accident (NTSB, 2003; Woltjer and Hollnagel, 2007). This case was selected because a large number of human, technological and organizational factors played a role. It also combines inter- and intra-organizational aspects of everyday ATS operations. The accident report determines that excessive wear and lack of lubrication of horizontal trim system jackscrew assembly contributes to the event. The airline extended the lubrication interval and the regulator´s approval of that extension, contributed to increase the likelihood of excessive wear. The design of this component did not include a fail-safe mechanism.

The Q4-balance visualization in Figure 3 is one of a series that was populated through analysis of the accident report, review of potential indicators, changes made based on the accident, and literature review on indicators. Using the accident report, a large list with all possible indicators was prepared. This list was then analyzed, and a subset was selected as important and relevant of indicators to plot into the quadrants. This was done through interdisciplinary and iterative discussions between the analysts.

The following was used as guidance to populate the quadrants:

- Q1 economy-reactive, lagging indicators that usually change after the economic pressures change. The lag is typically few quarters or a year. Examples: turn over, operational costs, fuel prices.

- Q2 proactive-economy, leading indicators that usually change before the economy as a whole has changed. These indicators are useful as short-term predictors. Examples: market growth, expected traffic volumes, new aircraft orders.
- Q3 safety-reactive, lagging indicators referring to what has occurred in the past or system states of the past. Examples are technical failures, incidents.

Q4 proactive-safety, leading indicators referring to aspects that might be critical, what may occur or to possible states of the future. Examples are set of indicators across actors and domains, related to preparedness, interactions, and anticipation of bottlenecks ahead and buffers from resources available to respond to new incidents.

The Q4 framework in Figure 3 shows that the assessment of resilience is not related to single indicator, but is an emergent property given the portfolio and discounting processes that go on when new signals and conflicts arise. Indicators 1 and 2 are required staffing levels for management (decided by the airline) and inspectors (decided by the regulator). The lack of staff effects both production as well as safety. and indicates reactive tendencies. Indicator 3, fleet utilization rate, focuses on economy. Indicator 5 trades economy and safety with different emphasis for the airline and the regulator. Some indicators may be tracked but have little impact on actual investment decisions in safety programs prior to major incidents or accidents. An example is indicator 6 on optimizing maintenance intervals against history and design.

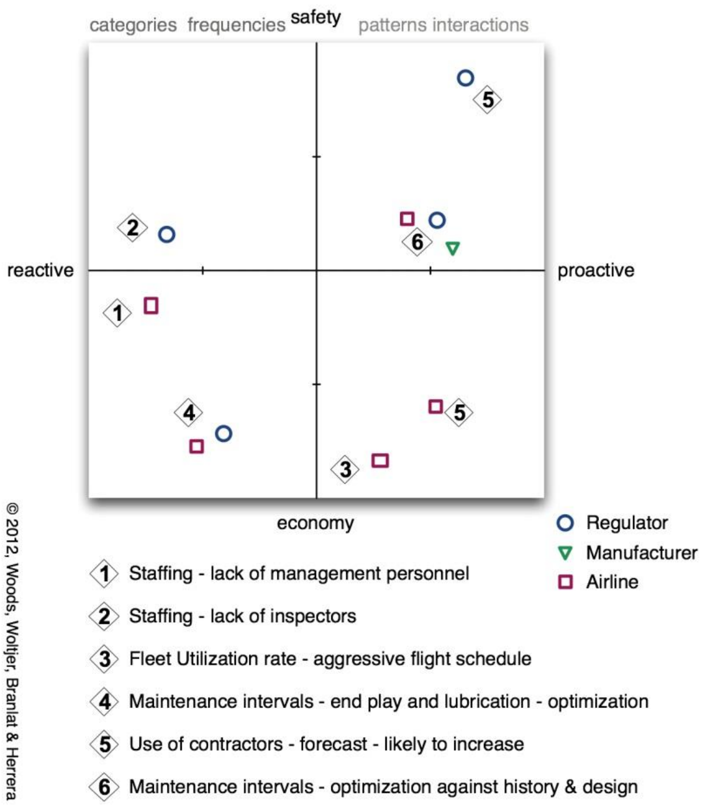

Figure 3. *Portfolio of some of the metrics extracted from the case of Alaska Airlines Flight 261 accident (NTSB, 2003).*

The example was used to stimulate discussions with representatives from regulators, maintenance personnel, and accident investigation board and safety managers on proactive safety management. The Q4-framework provided a representation that can highlight misalignments in the metrics portfolio and imbalances in discounting when conflicts arise in interactions between safety and economic goals. The visualization helped both operational and management personnel reflect on proactive safety and on how organizations respond when conflicts between metrics are made salient. The participants in the discussions based on the Q4 sample were positive about the potential of Q4-framework to contribute to the development of truly proactive safety processes.

4 IMPLICATIONS AND FUTURE DIRECTIONS

Theoretically for safety science, the Q4-Balance framework provides a new path to model the safety-economy goal conflict. We believe this model can explain paradoxes about safety such as why is it so difficult to make and sustain a business case for safety. Practically for safety management, the Q4-Balance framework provides a visualization to reveal balance or imbalance on a portfolio of performance metrics. The Q4-Balance can be into practice first as a way to describe metrics that are currently used by an organization. It can be used as a part of an assessment of resilience in terms of balance, conflict resolution, and discounting dynamics (as well as metrics in Quadrant 4). Third, it can serve as a critical tool to helping the organization manage its safety investments relative to financial pressures. The visualization of the portfolio helps determine when interventions are needed and which type of interventions (deciding what to do and following through so that these investments produce impacts). When subsets of metrics in the different quadrants align, the overall picture is consistent, despite the uncertainties associated with each specific metric, so that the organization can make investment decisions with confidence. When there is a divergence between reactive and proactive indicators and between safety and economic indicators, organizations can conclude that their ability to balance trade-offs and to assess changing risks has weakened or new risks could arise to threaten organizational performance in the future (Hollnagel, 2011). New analyses are underway in aviation and health care to develop guidance to analysts on how to plot/ position indicators in the quadrants, how to capture discounting, and new ways to populate quadrant 4.

In summary, despite the desire to utilize proactive safety metrics, research results indicate imbalances can arise between economic performance metrics and safety metrics. Research also has shown a number of factors that lead organizations to discount proactive metrics when they conflict with shorter term, more definitive reactive metrics. This paper introduces the Q4-Balance framework to analyze economy-safety trade-offs. Plotting the sets of metrics used by an organization in the four quadrant visualization can be used to identify misalignments, overlap, false diversity as well as to identify complementary and reinforcing metrics that produce a balanced portfolio for an organization. The Q4-Balance framework depicts relationships between classes of performance metrics. Performance metrics fall into a space defined by 2 dimensions: reactive-proactive and economy-safety. The Q4-Balance framework provides the analytic and visual basis to assess balance and imbalance across the four interdependent classes of metrics highlighted in the four quadrant visualization.

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Planning Measuring Resilience Potential and Early Warnings (SCALES)

I.A. Herrera[1], A. Vennesland[1], A. Pasquini[2] and S. Silvagni[2]
[1] SINTEF Information and Communications Technology, Strindveien 4, NO-7465, Norway
ivonne.a.herrera@sintef.no
[2] Deep Blue SrL, Via Lucrezio Caro 7/A, RM-00193, Italy
alberto.pasquini@dblue.it

Abstract

The central goal of SCALES is to link Resilience Engineering and Enterprise Architecture principles into a framework (the "SCALES Framework") that enables a context driven analysis of resilience. Enterprise architecture will offer the opportunity to model system of systems and to consider the system from different viewpoints (functional, communication, information and process view). For each viewpoint SCALES will identify appropriate resilience related indicators. These will be measured and monitored during system in operation, providing information about system ability to adapt to perturbations and maintain its functionality. This paper explains how the SCALES project will be organised to guarantee the achievement of these objectives and to ensure that its results are properly validated. Then, the relation to fundamental trade-offs is included. Finally, it invites to a critical discussion of the approach proposed and possible improvements.

1 INTRODUCTION

Traditionally, most safety indicators and metrics are related to deviations, failures or "after the fact" information. Since the seventies of the last century, the progressive improvement of safety methods relying on these indicators has certainly contributed to the excellent safety score of aviation. However, systems today are exposed to new changes that challenged the established approach to measure performance. These changes are the fast pace of technological change, the change in management structures, the changing nature of accidents, new types of hazards, decreasing tolerance for single accidents, increasing complexity, integration and coupling of systems, additional complex relationships between people and automation, changing regulatory and public views of safety (Amalberti, 2001; Dekker, 2005; Leveson, 2004; Woods, 2003; Rasmussen and Svenung, 2000). Moreover, the introduction of the ambitious improvements foreseen in the new Single European Sky will carry new challenges that the Single European Sky ATM (Air Traffic Management) Research (SESAR) is trying to address. These improvements are significant in terms of traffic management capacity, safety and flexibility. Using advance technologies, the ATM system will have to be able to tolerate and adapt ensuring that performances are maintained in spite of inevitable perturbations. Since the system will be dynamically adapted to ensure user-preferred trajectories and demand-capacity balancing, the solely focus on accidents and incidents is inadequate for ensuring and monitoring these performances. New approaches for more proactive performance monitoring have been proposed in different industries: nuclear (Wreathall, 2006; Reiman and Pietikäinen, 2010); petroleum (Step-Change in Safety, 2001; Øien et al, 2010, Vinnem 2010) and aviation (Eurocontrol, 2009, Herrera, 2012). None of these approaches consider the combined challenges posed by SESAR.

Monitoring the performance of the system from a resilience perspective is required since it leads to interventions aiming to manage and adjust the adaptive capacity of the systems in face of inevitable disturbances. This requires an adequate representation of the system under analysis that in the specific of ATM can be so complex that it can be considered as a system of systems. Enterprise Architecture principles facilitate an effective modelling of such complex systems, roles, functions and procedures within and across organizations. Therefore, the central goal of SCALES is to link Resilience Engineering and Enterprise Architecture principles into a framework (the "SCALES Framework"). This framework shall enable a context driven analysis to measure the potential for resilience with respect to small and large perturbations. Our motivation is to take resilience engineering out of the pure academic setting and translate it into practical solutions in the real world. SCALES addresses the research question: What added value can the combination of Enterprise Architecture and Resilience Engineering contribute to measure the resilience potential of the ATM system?

SCALES will investigate the combination of Enterprise Architecture and Resilience Engineering that has not yet been explored in safety critical domains. The concrete outcomes will be a web tool and guidelines demonstrating how resilience related indicators can be identified and measured using different viewpoints of a system. Each viewpoint enables the analysis of the system from different angles (functional view, information view and process view). The Web tool will help resilience analysis offering an automated support that is still missing in the resilience domain.

2 METHOD

2.1 Combining Enterprise Architecture and Resilience Engineering

Enterprise Architecture (EA) is an architectural technique that is typically applied on complex environments, such as advanced systems or system-of-systems. It prescribes a holistic approach where the technology is not isolated from human and organizations; these aspects are treated equally important. Furthermore, separation of concerns and abstraction are techniques that are applied in EA. Decomposing the total system into separate viewpoints, provides a global overview and detail when necessary that enables an immediate focus on relevant areas while reducing impact from irrelevant aspects.

An ATM system is typically composed of a number of complementary and interacting systems, such as regulators, airlines, aircraft operations, air traffic control systems and air traffic management and has the characteristics of a system-of-systems environment. Moreover, human and organizational involvement with such systems is critical. In a well-functioning ATM system workflow-based procedures and protocols as well as clearly defined responsibilities to be performed within and across systems are essential for safe operation. Hence, principles from EA should lend themself well to support a resilience approach because it supports the description of the system as the system works and its contextualization.

We will use the ARKTRANS (Wes, 2004) methodology to analyse and to identify resilience related indicators of the ATM system in a specific context. ARKTRANS is an EA variant that includes the following architectural aspects: Roles, Functional Viewpoint, Process Viewpoint and Information Viewpoint. Roles specify a delimited set of responsibilities and can be used to identify the relevant responsibilities of both systems and human actors. The Functional Viewpoint defines the functions that the roles must perform as a part of their area of responsibility. The Process Viewpoint defines procedures and protocols as well as information interfaces between roles and their functions. The Information View further details the information that is exchanged in the interfaces.

Resilience Engineering analysis will adapt resilience properties (Woods, 2006) and abilities (Hollnagel, 2009). The properties are buffering capacity, flexibility and cross scale interaction. These properties will extend the method Resilience Analysis Grid addressing the abilities that are analysed to monitor, anticipate, respond and learn (Hollnagel, 2011). The properties and abilities will be associated with a set of questions that need an answer to identify candidates for indicators. Buffering capacity questions relate to the size or kind of disturbances that the system can adapt maintaining operation. Flexibility questions address the possibilities of the system to restructure in response to external or internal changes and pressures. Cross-scale interactions questions relates to the influence of the context to local adaptations, and how local adaptation has an impact on more global, strategic goals. Monitoring questions address system performance and its possibility to identify what might become critical. Anticipation questions address threats and opportunities, not only single events but also how the system works and potential for cascade. Respond questions look into the ability of the system to cope with specific events (limited to the case studies). Learning questions address if the system has learned from experience as reflected in practices and procedures.

This initial version of the framework will identify relevant and critical systems and human actors, required functions, procedures and protocols, as well as information exchange. This will be mapped to appropriate viewpoints of the initial framework. Associated with these viewpoints is a set of resilience properties, abilities and corresponding questions adapted from state of the art literature within RE. Combining EA and RE this way will enable an ATM system to be analysed in terms of its resilience potential as shown in figure 1.

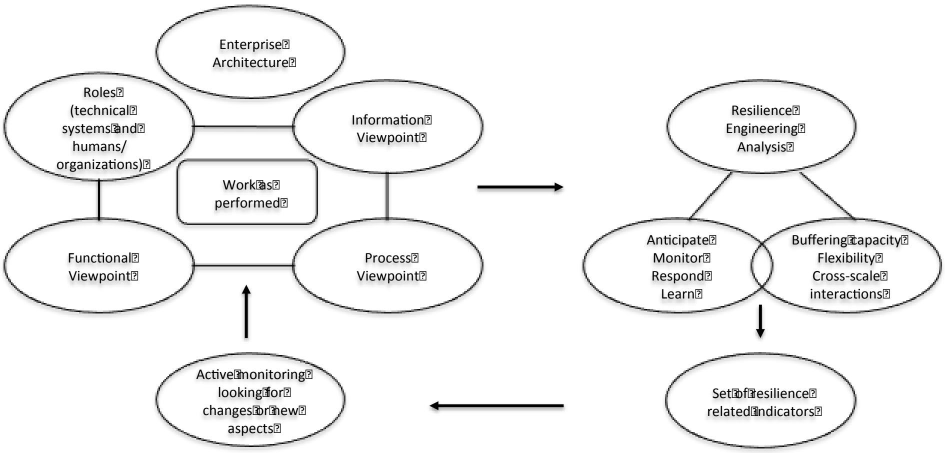

Figure 1. *Combining Enterprise Architecture and Resilience Engineering. It shows EA modelling and viewpoints. Each viewpoint will be subjected to a RE analysis considering resilience abilities, properties and corresponding questions to determine a set of resilience related indicators. These indicators must be actively reviewed looking if new critical aspects for operation need to be considered as situation changes.*

So for example, in the Functional Viewpoint SCALES will define which functions a pilot (role) must perform in order to ensure good ability to respond to a potential event. In the Process Viewpoint the pilot role´s interaction with its environment is defined with respect to the sequence of functions performed by each role (e.g. pilot, air traffic control system, air traffic controllers, technicians) and how these roles and functions interact with other roles and functions. It includes, at which step of the workflow should the pilot communicate with the air traffic control system (role) and which information should be communicated (and when). The information being communicated in the interface between the pilot and the air traffic control system is then further defined in the Information View. Each of these viewpoints of the framework will be accompanied by a set of set of questions related to resilience abilities, properties with corresponding questions that contribute to identify indicators related to (un) successful operation. Two type of operations are mapped in SCALES everyday successful operation and case studies (incidents).

2.2 Case studies and SCALES

In order to get trustworthy results the SCALES approach will have to be adjusted and refined in realistic cases. We plan to use two different events, adopting a retrospective approach. Evaluation through retrospective studies ensures a high degree of realism and objectivity once appropriate actions for an objective and complete collection of information about the past events have been taken (Leveson, 2001).

The first event will be the runaway incursion of Milano Linate, one of the most severe ATM related accidents that occurred in Europe in the last decade. The Milano Linate accident happened in 2001 when a departing MD-87 collided with a Cessna 525-A, which taxied onto the runway. All 114 occupants of the two aircrafts were killed along with four ground staff. The Cessna's crew crossed by mistake the active runway under low visibility conditions, the ATM system was unable to support the crew adequately and to tolerate their mistake (Agenzia Nazionale per la Sicurezza del Volo, 2004).

The second case was an incident that occurred in 2005, when severe weather conditions obliged a B737 aircraft to divert from its original destination airport of Ciampino to Fiumicino and then to Pescara. The aircraft violated altitude restrictions in Fiumicino. Crew operations were in an area of intense traffic. Technical constraints in the ATM system contributed to deficiencies in the insurance of adequate traffic management services. The incident had no consequences for humans or goods (Agenzia Nazionale per la Sicurezza del Volo, 2009).

The two events have several aspects in common that make them suitable for a comparative analysis. Both happened in severe weather conditions combined with operational, technical and organizational factors. Contributing factors were workload, safety nets missing or out of service and communication issues. In both of them the ATM system (managed by the same service provider) had a major role. However, there were also substantial differences that in one case led the ATM system to the inability to adapt and tolerate the negative situation, while in the other to still ensure adequate traffic management services. We intend to apply the SCALES framework in the two case studies, identifying the key indicators that should quantify the resilience of the ATM system, and their values and evolution till the events. We also plan to identify and measure the early warning signs that should have indicated the likely system degradation.

The idea is to apply SCALES to the story of everyday successful operation and the stories that led to these two events. The mapping in EA will allow system of systems consideration of operational, contextual and organizational conditions. The RE analysis will allow to identify relevant indicator candidates and measure these in those events. We will include a predefined period before those events (e.g. 12 and 6 months prior to the event and right before the event). These data will allow identification and evaluation of relevance of these indicators and to measure the potential for resilience; quantitatively and qualitatively. We would like to see how the indicators evolve over time and are used by the organizations. Furthermore, we will analyse if some indicators can be seen as early warnings for system degradation. SCALES and indicator candidates will be discussed in workshops with operational and organizational aviation personal to have a consensus on the most appropriate indicators for these cases.

3 EVALUATION

Using the retrospective studies we will be in condition to apply and validate the SCALES approach in realistic conditions evaluating the following functional characteristics:

1) Ability to identify quantitative and qualitative set of indicators that are representative of the system resilience before and up to the events of the case studies;

2) Ability to identify early warning signs for likely system degradation and

3) Ability to show significant trends of indicators and early warning signs before and up to the events of the case studies.

In addition, the case studies will allow evaluating quality characteristics of the SCALES framework. These are reported in Table 1 including how the evaluation is performed.

Table 1 *Validation criteria to evaluate SCALES framework*

Characteristic	Explanation of the quality characteristic	How to evaluate
Applicability	Check if the SCALES framework is reasonably easy to use and understand	Practical use in the case studies
Reliability	Check if results are credible and correct, and if there are reasonable confidence margins	Comparison of SCALES vs. real outcome of the events
Cost effectiveness	Check if the application effort required and associated costs are acceptable	Expert judgement
Scalability	Check if the SCALES approach can be used with systems of higher complexity with a reasonable increase in cost and workload while maintaining its quality characteristic	Practical use in the case studies and theoretical evaluation of its applicability to larger systems

4 DISCUSSION AND CONCLUSIONS

In complex socio-technical system like ATM, we plan to address how the system adapts to continue operation focusing on the identification of resilience related indicators. The trade-offs can provide the theoretical basis to produce metrics in this context (Hoffman and Woods, 2011). SCALES will address the five fundamental trade-offs as follows:

- Optimality-Resilience of Adaptive Capacity Trade-Off: Indicators related to the capacity to adapt (respond), to identify degradation (early warnings) and anticipation of resources needed to cope with situations.
- Effciency-Thoroughness Trade-Off: EA enables the representation of the work as performed, including procedures and practices. Indicators related to the flexibility of these procedures and ability to put and update plans in practice are explored (anticipate and learn).
- Revelation-Reflection on Perspectives Trade-off: EA enables different view points on the system stimulating to identify indicators related to cross-scale interactions within and across systems-organizations.
- Acute-Chronic Goal Responsibility Trade-Off: Indicators related to management and prioritizing of roles and responsibilities within and across organizations when addressing conflicting goals.
- Concentrated-Distributed Action Trade-Off: Indicators related to quality of coordination of activities within and across organizations.

The ATM system is characterized by dynamic interactions among different aviation stakeholders. Each actor focus its adaptation to their priorities, to analyze the system it would be necessary to see the combined interactions to determine the effect of the interaction and the manage of trade-offs (time pressure, resources, collaboration within and across organizations). Existing approaches for safety analyses apply decomposition. We build upon a system of systems approach modeling of interaction and adaptations via Enterprise Architecture. The main result from the project will be the SCALES framework. In addition, we aim to produce the following results:

- Advances in theory: by combining the fields of Enterprise Architecture and Resilience Engineering to provide more efficient and more confidence of the representativeness of the indicators.
- Advances on practical representations of resilience analysis including a questionnaire. Currently resilience analysis lack of the use of advanced tools that support Resilience Engineering.
- Promote and facilitate use of enterprise architecture and resilience engineering: Verification and validation in realistic cases representing highly relevant technical and operational functions and typical for future ATM.

The expected benefit of combining an EA with RE is two-fold. Firstly, SCALES will apply principles from EA in order to get a good system of systems overview ATM system and from RE to support the identification of the related logical, organizational and technological resilience related indicators. Secondly, after having validated and refined the initial SCALES framework in a case study consisting of two real incidents (reference) the resulting SCALES framework will, accompanied by a set of guidelines, demonstrate how resilience related indicators can be identified and measured using different viewpoints of a system and be made available for others to use via an accessible and user-friendly web interface.

This paper presents the preliminary ideas to combine EA and RE, further work is needed in the detail specification of questions and application of the SCALES framework in the case studies. We invite the Resilience Engineering community to provide a feedback on the method and ideas presented in this paper.

Acknowledgements

The work planned in SCALES will be partly funded of the SESAR WP-E Programme on long-term and innovative research in ATM. Disclaimer: this paper presents autors view.

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Understanding Resilience in Flight Operations
"Find the story behind flight safety reports and learn from successes."

Arthur Dijkstra MSc.
ADMC
Dijkstra@admc.pro

Abstract

Every day the hypothesis about safe operation materialised in procedures and standards is tested by actual flight operations. FOREC helps to understand both the adequacy of standards and procedures and situations where shortfalls may appear. This is done via collecting the stories pilots tell about their safety events and how they signify their experience against resilience concepts. Analysis can then show patterns that might be weak signals for impending problems. FOREC goes beyond simple counts of failures and errors, it reduces the interpretative layers between the operation and company management by allowing managers to read the pilots' stories in their context, and thereby understand the successes of flight operational resilience.

1 INTRODUCTION

This paper is about using a sensemaking method to collect the story behind a safety report and gain a better understanding of safety threats, operational disturbances and how flight crew members deal with them.

Resilience, as the capability to absorb disturbances that threaten a safe flight, is not yet part of current Safety Management System (SMS) methods. Most of today's SMSs focus is put on hazard identification, mitigation and the failures that occurred. Current practices for data collection from flight operations consist of Flight Data Monitoring (FDM), the monitoring of about 160 flight parameters, Air Safety Reports (ASR), reports written by pilots giving factual data about a safety related event, and legally required flight inspections executed by flight inspectors. These practices have not changed a lot since the last 20 years except for the introduction of voluntary Line Oriented Safety Audit (LOSA) (ICAO 2002). During LOSA a trained observer fills out a LOSA form about how threat and errors were managed and what kind of errors or violations were made. Flight Operations Resilience Experience Collector (FOREC) is an attempt to give voice to the pilots themselves and allow them to give their view of a safety related event and allow them to express how they (almost always) successfully dealt with the situation. When a resilience perspective is included in SMS practices a richer understanding arises of how safety threats are handled in flight operations. It should be recognised that, due to the complexity of flight operations, hazard identification and risk mitigation will always fall short of the almost infinite ways in which factors can combine in the actual execution of a flight. Operational risk mitigation and the handling of disturbances is therefore an essential quality of the flight crew. The FOREC allows the pilots to enhance the flight operational human sensor system so the organisation can create more information about itself so it can manage itself more effectively (Beer 1972).

2 METHOD

FOREC is inspired by sensemaking. This field of research can be traced back to the 1970's (Dervin 1983). Weick and Sutcliff (1999, 2005) applied sensemaking concepts to understand how organisations develop and maintain high reliability in complex environments. Kurtz and Snowden (2003) included explicitly complexity theory concepts to their sensemaking approach. Complexity theory claims that it is not a priori possible to know all the issues in a complex system. Therefore open questions are needed to collect relevant data as opposed to closed questions which assume the issues are known. FOREC provides pilots a way to share their operational experiences and their view on the event. Standard ASRs that are currently filled out by the pilots when a safety event has occurred, have only boxes to tick and a field for a narrative. The pilots view on the event is not systematically collected. The ASRs are categorised by which context is lost and used for trends in SMS reports. Combined FOREC and ASR, data remains contextual and is treated differently. The FOREC forms add to the diversity of perspectives which is required for an increased understanding of the complexity of flight operations. (Page 2010).

The pilot is challenged by an opening question to share his experience in a short narrative with some tag words. The answer to the opening questions serves as the event description for the ASR. The triangles or triads have a topic at each corner. The interpretation of this corner text provides a reference for the opinion of the pilot about the event. The corner points or signifiers provide some closure on the opinion the pilot can express about his experience. The signifiers in FOREC will be operationalization of resilience engineering concepts such as the work of Hollnagel and Woods and the Viable System Model VSM (Beer 1972) control functions. The signifiers will be expressed in a language that the pilots are familiar with. This is how the pilots can give their view on the event in Resilience Engineering (RE) concepts.

2.1 Data collection method

The ASR collects mainly facts such as date, aircraft type, visibility, etc. These facts provide insufficient data to provide a rich understanding of the reported event. For this experiment the FOREC will be an extension of the ASR. The narrative of the ASR is also used for FOREC. The narrative describing the operational experience provides qualitative data and the pilots view expressed via the triangles and scales provides quantitative data. The quantitative data is used to find patterns in the data. The qualitative data is used to support understanding of the patterns found. The FOREC form consists of three parts.

The first part starts by asking the pilot an open prompting question (such as: Please describe your experience in a way other pilots can learn from your event.") Here the pilot provides his narrative of the event. The first part also gathers some personal data such as function, experience and emotional impact (this is an indicator for the impact of the event). The pilot is also asked about the risk level he assigns to this event. This allows to compare SMS assigned risk levels done by the safety office and the view of the pilots.

The second part of the FOREC form has ten triads to covering all important RE concepts. The concepts are placed in a triangle, a so called triad (Snowden 2011) or trikon (for interpretation and knowledge sharing). The area between the concepts in the triad allows the reporter to weight his judgement. The distance from the selection point in the triad to each concept corner is a value indicative for the significance of the concept for the specific question. Research (Snowden 2011) has shown that respondents using the triads used more time and consideration where to place the mark than when two point scales are used. A triad signifying space is richer than a two point scale and also more two point scales than triads would be required to get the same amount of data. A triad provides a way to indicate which or how trade-offs were made.

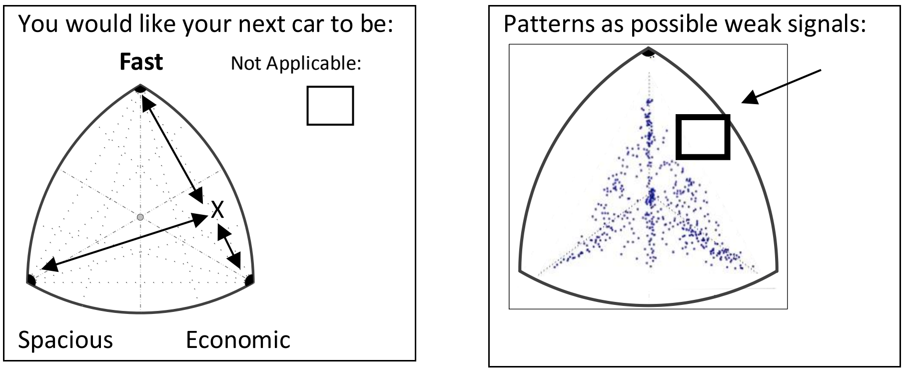

***Figure 1.** FOREC form: triads*

In this case the triad helps to establish what mixture of car properties are desired. In this case 'Fast' is considered more important that 'Economical. The least important is 'Spacious'. A mark in the middle would indicate all three features are equally important. If none of the labels are applicable one can choose to check the 'Not Applicable' box.

The answers given on the triads and two point scales provide quantitative data which can be used for pattern discovery.

For the analysis, every dots represents an event. Dots that appear outside the existing pattern over time may indicate a weak signal. These reports can be read to understand the events and related issues.

A time slider can be used to see changes over time which may be an indication of the effects of e.g. a management intervention, a change procedure effectiveness but also of external factors increasing their disturbance effect.

The third part of the FOREC form contains the Common Performance Conditions (CPC) as developed by Hollnagel (1998). The CPC can be rated on a scale for their supportiveness to handling the situation. CPCs can be viewed as the factors that are managed by the airline organisation, through the SMS, that shape the performance of their flight operations. The combination of CPC rating and resilience safety performance can provide and increased understanding of how to engineer more operational resilience.

2.2 Triad design method

Snowden (2011) suggests two options to design relevant labels for the triads. One is to search for cultural established organisational constructs, the other is a researcher designed set related to the aim of the research. The labels provides references for the respondents to signify their opinion of judgement about the event they are reporting about. I followed these steps.

1. Identify the concepts in the field of safety, safety management and resilience by clustering subjects, behaviours, decision points, etc. from a priming set of narratives and literature. Choose the key concepts that relate strongest to the project, here resilience.
2. For each key concept create a triad with balanced negative or positive labels, the idea is to force trade-offs
3. Identify hypotheses and for each serious one create a dyad.

The concepts are based on a review of Resilience Engineering (RE) (Hollnagel et.al.2011) and Management Cybernetics literature (Ashby 1956, Beer 1972). Both fields of theory align well as argued in Dijkstra (2007). The following key concepts were selected and used in the questions.

1. System identification, what are the essential variables which could be affected.
2. What was the source of the disturbance
3. How complex was the event
4. Response characteristics
5. VSM related concepts, the four essential abilities
6. System dynamics, time, margin, fall back options.
7. Learning system

2.3 System identification, whic are the essential variables that could be affected

The core values are the performance criteria for flight commanders. The core values represent the essential variables (Ashby 1956) of the system: flight. When an essential variable shifts outside its limits the survival (the identity) of the system is endangered (Ashby 1952). This is obvious for safety e.g. when an aircraft crashes but also when passenger service is below limits the identity of a reliable friendly service may be lost. I selected three important variables for the following question.

Question:	The core value that was most threatened by the reported event is:
Triad labels	Rationale
Safety	Safe operations is an essential precondition. An often used safety definition is: "Safety = The state in which the possibility of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level."
Cost	The airline operating cost most relevant for a flight are fuel and passenger connections. The cost of fuel is a large part of the total operation cost. Fuel on board the aircraft gives the pilots more time to handle disturbances, allow for delay recovery etc. The carriage of fuel also costs fuel and increases the operating costs. Recovery costs for lost connections are considerable and can to some extent be reduced by flying faster, which costs more fuel.
Passengers	Passenger comfort, service, on time arrival and departure and trust are examples of essential performance values. Execution of the published time schedule is important for passenger satisfaction

2.5 The source of the disturbance

A disturbance is some amount of variety that is potentially able to affect the essential variables of a system (Ashby 1956). For a commercial airline the essential variables are among others, safety, cost and passenger satisfaction. Disturbances may thus threaten safety, cost or passengers individually or in any combination. Therefore disturbances are also called threats.

It is not always obvious what the essential variables threshold values are for flight crew intervention. A master caution signalling engine fire is obvious but an increase in headwind which results in a later arrival time and less fuel upon arrival is not so obvious.

An operation is managed in an environment. Disturbances can come from several sources. The source of the disturbance, relative to the flight, limits the extent to which the disturbance can be controlled by the flight- and cabin crew or company management.

Question:	The source of the disturbances that caused the event came from:
Triad labels	Rationale
Outside the company, e.g. ATC, Weather etc.	Beyond direct control of the airline. Indirect control or coping is possible via e.g. flying a different route to avoid bad weather.
Inside ABC organisation or technical failure. Outside Flight crew	Mainly in control of airline management but beyond direct control of the flight crew. E.g. a faulty loading process or technical failure of an aircraft component
Inside the Flight crew	Mainly in control of the crew but may be due to (a) crew member(s) because of performance variability e.g. an incorrect read-back of an ATC clearance. By effective Crew Resource Management (CRM), Standard Operating Procedures (SOP) this disturbances should not affect the safety of the flight.

2.4 Complexity of the event

It is important to understand the complexity of events in which human actors find themselves to understand their performance. Woods (2010). Complexity varies with the degree of agents, connections, connectedness and interdependence. Miller (2007). The CYNEFIN model (Snowden 2007) provides a language for simple, complicated and complex events which are the three labels I use. The perceived nature of the event is relevant for the way the event was dealt with. This flight crew judgement can be compared to the other complexity related triad summits. These comparisons can reveal insight into the relation between resilience, complexity, complicated and simple event aspects. The answer is based on hindsight and thus a disturbance that was initially seen as simple might be seen as complex after the event.

Question:	To handle this event we had to deal with:
Triad labels	Rationale
A single factor	This refers to the simple domain where things are known and easy to understand. One can come up with a best answer and often a simple procedure (by memory) is used to handle a simple situation.
Multiple but un-related factors	This refers to the complicated domain where experts can understand the situation by analysis. Cause and effect may be separated by time and space. Checklist procedures will assist to handle the situation.
Multiple, Interacting and interdependent factors	This refers to the complex domain where cause and effect cannot be established and predictions about the future are of very limited value. Improvisation and combination of procedures will be needed to handle the situation.

For brevity and limitations of the number of pages in this paper I will only list the rest of the questions without all the arguments why they are as they are:

- The event could be handled because ?
    - Verifying presence of norms, anticipation and ability

- The event did not become worse because ?
    - Interrogating about margins and response options.
- We could handle the event by using ?
    - Asking for methods used to handle the situation.
- How familiar was this event ?
    - Was event new (possible surprise) or known.
- Who should learn most from this event ?
    - Which part of the system should learn.

3 RESULTS

I was not able to get actual results before the symposium. The fact that higher management supports the test project may be indicative for the expectations that the project will provide a richer view of the actual flight operations.

The plan for the first evaluation is to collect sufficient forms so patterns start to appear. This is expected to be at least 150 forms which will take several months since for the project initially only a limited group of pilots will participate. This group will consist of flight- inspectors and instructors. The lessons about the method we learn from the initial group will be used to spread the project over all pilots. The project must not reduce the normal reporting willingness.

During the development of the FOREC form I asked pilots to test the form and give their view on the method. Most pilots thought that answering all the FOREC questions would take quite some time. This complaint was taken seriously and the text was simplified. Also the form will be an electronic form that can be filled out anytime.

Pilots reacted positive to the opportunity to provide their view on the event they had experienced. They also were positive to share experiences with other pilots about flight, aircraft and route specific issues.

Much interest was also received from the training and human factor department. They anticipate to get a richer view on training effectiveness and training needs.

4 DISCUSSION

Flight operations data collection has not changed much during the recent years. The changes that have occurred, e.g. more data-mining and LOSA have increased the number of interpretation layers between the event during the flight and relevant managers. These layers act as variety transduction and attenuation which reduces the richness of understanding of the event for managers who can effectively change operations. The complexity of flight operations needs multiple perspectives from the people managing the flight operation. A minimum number of interpretation layers maintains the high variety of data required when striving for requisite management.

FOREC allows managers to read the raw story from the pilot not the story about the pilot. An interview with managers after they have experienced reading the FOREC reports should indicate the validity of this hypothesis.

5 CONCLUSION

Expectations about FOREC are high. The methodology has been effective in other domains(Deloitte 2010). Some threats that might reduce effectiveness of the method are recognised and will be mitigated as much as possible before all pilots become part of this humans sensor network for a better understanding of resilience in flight operations.

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Sending up a FLARE: Enhancing resilience in industrial maintenance through the timely mobilization of remote experts

Elizabeth Lay[1] and Matthieu Branlat[2]
[1] Calpine Corporation, 717 Texas Ave., Suite 1000, Houston, TX 77002, USA
Elizabeth.A.Lay@Outlook.com
[2] 361 Interactive LLC, 400 S Main St, Springboro, OH 45066, USA
matt@361interactive.com

Abstract

Turbine maintenance is a highly planned operation, but field teams regularly encounter situations that challenge the implementation of the plan. Maintaining control of the schedule of operations in the face of anomalies is a complex task for project managers. This paper describes the Front Line Anomaly Response (FLARE) process, wherein remote expertise is connected to operators directly in touch with the situations within an hour of the issue being raised. Anomalous situations typically represent complex problems for which no clear-cut path exists. Often, the process, rather than solving the problem at hand, serves as a means to expose and discuss the relevant aspects of problem and solutions. This paper describes how the FLARE process leverages external expertise and diversity of perspectives in anomaly response during complex maintenance operations. This paper also describes the organizational challenges faced by the organization in implementing such process, and the approach it adopted to address the associated trade-offs.

1 INTRODUCTION

The Front Line Anomaly Response (FLARE) process was designed for responding rapidly to emerging issues in power plant maintenance. Turbine maintenance involves the disassembling, inspecting, repairing, reassembling and re-starting of the turbine-generator system. It relies on expert workers with specialty tools mobilizing to remote locations to work in a plant they may not be familiar with. Turbine maintenance is a highly planned operation, but field teams regularly encounter situations that challenge the implementation of the plan; challenging situations can arise from adverse events such as an incident with a power tool or from unanticipated conditions such as related to weather or to particular site characteristics. During a power plant maintenance outage, teams work around the clock to meet tight schedules necessary to bring the power plant back to service as soon as possible, since the cost from lost generation of a shut down power plant ranges from several hundred thousand to millions of dollars a day. Maintaining control of the schedule of operations in the face of anomalies is a complex task for project managers: operations involve numerous tasks that are highly synchronized and interdependent; anomalies also represent multi-faceted problems that might require specific technical expertise. Successfully and efficiently managing unexpected situations that arise is critical to the success of turbine operations and to the power plant owner's business objectives.

The situations of interest in this paper are of a challenging and variable nature and arise unexpectedly. Typically, a person working at the front lines initiates the process by a call to a central group of experts in risk management. These experts send up a "flare" and, within one hour, a geographically separated group convenes via telephone conference to address the problem. Participants are diverse in terms of knowledge, skills, function level, and roles. During the one-hour call, they describe and diagnose the problem (explore risks and multiple solutions), they agree on and produce a plan that includes actions, decisions, decision authority and accountability, check-in points, iterative solutions, and contingencies.

The paper describes how the successful implementation of this process relies on the capacity of the system to identify and mobilize the relevant participants for the particular problem faced. Through the practices described in this paper, an ever changing, ever expanding pool of knowledge is tapped into and brought to bear at point of need (often the frontline) to address emerging situations. In his analysis of conversations that occurred prior to the Columbia shuttle accident, Garner (2006) concluded "Connecting people is not always enough…" A central question addressed here is: If connecting people is not enough, what else is important?

2 CONNECTING REMOTE EXPERTS TO FRONTLINE OPERATORS

The identification of participants is one of the most important parts of the process and sometimes continues up until minutes before the call (and occasionally into the call). Critical roles for the process include: risk decision owner (usually the person responsible for profit and loss), a contrarian, design experts (what to do), repair experts (how to do), person(s) with related experience, practitioners needing help, and risk knowledge broker. Other keys roles emerged from conducting the process over the years: “one person who makes a difference”, “matchmakers”, and “critical participants”. Several key roles are described below.

2.1 Diverse expert knowledge

Weick and Sutcliffe (2001) note the importance of bringing expertise to bear on complex problems. “HROs cultivate diversity” as it “helps them notice more in complex environments, but also helps them do more with the complexities they do spot.” “HROs push decision making down and around. Decisions made on front lines […] migrate to people with the most expertise, regardless of rank.”

It is commonly accepted that a group of diverse problem solvers will outperform a homogenous group. Hong and Page (2004) take this a step further with their model of functionally diverse problem-solving agents; they conclude that “a random group of intelligent problem solvers will outperform a group of the best problem solvers.” Their results are based on a random group bringing more diversity in problem solving approaches through differing perspectives and heuristics. Project and work teams tend to stay within the team in solving problems. Key to the FLARE process is bringing in people who have not been involved with the situation or the project in order to challenge and bring fresh perspective.

2.2 Risk Knowledge Brokers

Knowledge brokers are “persons or organizations that facilitate the creation, sharing, and use of knowledge.” (Sverrission, 2001). In responding to dilemmas and disturbances, the knowledge broker brings together specialists and practitioners for problem centered collaboration and co-creation of knowledge. They link “know-how, know-why and know-who” (Blondel, 2006). According to Garner (2006), “some organizations recognize the importance of getting information to the right people and designate a central person or group to manage expertise recognition. Network centrality would be an appropriate indicator of that person or group.” Garner uses the term “bridge” people or teams; they span organizational and knowledge boundaries. He shares the example of NASA’s Mission Management Team, which is comprised of representatives “from every part of the organization”. Meyer (2010), emphasizes that knowledge brokers do more than link knowledge: they facilitate co-creation of knowledge and participate in constructing a common language. In this case, the common language is the language of managing risk. The Risk Knowledge Broker holds distinctions for risk management terms, actively translates the conversation into these terms, and helps the group formulate the situation around the risks.

The Risk Knowledge Broker is the first responder to the front line call for help. During the initial call, they probe the situation, possible solutions, and who the practitioner thinks could be of help. Probing potential solutions in the initial call enables identification of repair specialists who can support exploring solutions, which in turn, enables defining a plan of action during one call. The Risk Knowledge Broker then transmits the alarm (“Heads-up. We have this problem. Who can help? A call will occur within 1 hour.”) and identifies participants by talking to people with project or technical knowledge. Strategies for this step include contacting “matchmakers” (especially for novel events – see below), reviewing a list of experts, and conducting a quick check for similar issues in risk database. They may brainstorm with other knowledge brokers to get ideas of who, outside commonly tapped knowledge clusters, could bring value and who may have experience with similar but different situations.

During the call, the Risk Knowledge Broker orchestrates the conversation (who to speak-up or who to quiet down; when to bring focus or let drift). However, this role involves much more responsibility and knowledge than typical facilitation roles. They probe concerns and listen for phrases that indicate risk; they tune into risk and uncertainty. Risk management is about asking the right questions; thus the knowledge broker challenges and questions, using specific questions designed to raise risks. They close with asking each participant if they have concerns or comments. This final probing almost always surfaces information or a concern important to the issue. After the solution has been implemented, the knowledge broker follows back around with the practitioner to see how the situation turned out. They then share this information with those who supported resolving the issue and with those who might benefit from the knowledge.

In order for the knowledge broker to be able to guide such a brief conversation to solution, they need fundamental knowledge of product and process so they can speak the technical language. In order to support decisions being made at the appropriate level, by the person accountable for that part of the business, they also need knowledge of limits of authority and domain responsibilities, as well as an understanding of the business considering the potential consequences of the decided actions. In order for the knowledge broker to invite people who can come to effective solution, they need access to networks of people who know where certain knowledge resides within the organization, "matchmakers" so to speak.

Table 7. *Summary of key competences of the Risk Knowledge Broker*

Skills & attributes	Ability to understand & probe concerns Ability to hear or tune into risk statements Ability to orchestrate fast moving, focused conversation Are part of the team, typically in operations
Knowledge	Product / Process Limits of authority & accountabilities Who has knowledge, who's had certain experiences Roles within the organization

2.3 Other essential roles

There are people in an organization who "know what others know"; such people can act as *Matchmakers*. They have wide networks and deep or broad experience. They may have held many roles or held one role for a long time. When approaching an especially novel problem, the knowledge broker's first step is to reach out to Matchmakers and brainstorm with them on who might know something related to the issue at hand. This brainstorming sometimes identifies a person whom those involved in planning the project may not have thought of and whose relevant knowledge could make a difference in the outcome

The *one person who makes a difference* shares unique and particularly relevant knowledge during the risk assessment that significantly impacts the plan or project and they were not previously known by the project team. All knowledge brokers have identified such people on multiple occasions as part of the FLARE process and they speak of feeling like they got lucky, as if they found this person by pure chance. This has happened frequently enough that the authors speculate finding this person actually emerges from the process: through a mechanism not entirely understood, it may be a function of contacting Matchmakers (who have deep history) and then following the threads they provide.

A *critical participant* is a person who has critical knowledge needed to solve the problem at hand. Their identity as having critical knowledge emerges from the network as multiple people suggest to include this person in the risk assessment.

2.4 Constituting the group of participants

Participants are raised through sending out a call for help (sending up a flare) that flows through the organizations in an organic, interconnected way; one person contacts another who contacts others until "hits" are identified. The flow of communication transcends organizational hierarchies and quickly spreads throughout the organization.

In their book "The Management of Innovation" (1961), Burns and Stalker compared linear, hierarchical, mechanistic organization models to non-linear, flexible models, which they termed "organic". According to the authors, mechanistic organizations work well for stable conditions while organic models are "appropriate to changing conditions which give rise constantly to fresh problems and unforeseen requirements for action which cannot be broken down or distributed automatically arising from the functional roles defined within a hierarchic structure."

Between 10 and 15 participants are typically on the calls with a 3 to 1 ratio of workers / professionals to managers. This is a size that is manageable in terms of assembling the group within an hour then orchestrating a conversation via conference call and coming to solution within a short duration. The worker to manager ratio demonstrates that the risk assessments almost always have more workers, including experts, than managers, in alignment with HRO and resilience engineering philosophies to listen to the experts and the frontline workers.

3 SUCCESSES AND CHALLENGES IN SUPPORTING RESILIENCE

Woods and Branlat (2011) discuss how failures to adapt successfully to adverse events can occur in a system and identified three basic patterns of adaptive failure: (1) failure of adaptive responses to match the *tempo* of the disruptions faced (before events cascade and situations get out of control); (2) failure to maintain sufficient *coordination* while implementing adaptive responses; and (3) failure to recognize the novel character of the situation faced and devise *new forms* of adaptive behavior. The FLARE process represents a way to enhance resilience through avoiding these patterns. Furthermore, the success of the process depends on the organization's capacity to manage difficult trade-offs: associated with the implementation of solutions to complex problems, and associated with the use of the organization resources to explore such solutions.

3.1 Supporting distributed anomaly response

Anomalous situations in this domain typically represent complex problems for which no clear-cut path exists: affected sites often present specific characteristics, anomalies can be of novel nature, and different dimensions of the situations need to be considered. Often, the assessment process, rather than solving the problem at hand, serves as a means to expose and discuss the relevant aspects of problem and solutions. The process represents a form of distributed anomaly response that leverages external expertise and diversity of perspectives to handle the complexity of the problem and responses. The process represents a mechanism to avoid patterns (3) and (2) described above, respectively: identifying and implementing appropriate adaptations to unanticipated situations, and managing interactions across the system due to interdependencies between tasks. The rapid conduction of the conference call supports the avoidance of pattern (1), i.e., of a fast degradation of conditions into an even bigger problem. In addition to identifying potential courses of action, the FLARE process allows the project manager on site to better anticipate constraints and risks associated with re-planning portions of the mission, in order to balance these constraints against each other. It therefore supports the project manager in anticipating and managing difficult trade-offs associated with anomaly response in the context of large maintenance operations.

Key operational aspects of successful calls reside in the preparation of the material to be discussed and exchange of information among participants, and in the rigorous exploration of courses of actions and associated constraints. The conversations were semi-structured, free flowing, open with no tolerance for blaming, and a focus on better understanding the situation and risks. The oral exchange enabled emotions and level of concerns to be heard and improved sharing context. In addition to the role played by participants in leveraging diversity of expertise (as discussed in the previous section), the process requires a capacity to correctly assess the situations at a distance. Use of technology, such as streaming video or other forms of real-time exchanges of information, could improve the process by improving the completeness and timeliness of information between the site and the remote experts. Exchanges of material (pictures, diagrams, etc.) are currently made mostly up-front, based on the anticipated informational needs. At times, particularly for situations with a lot of uncertainty, the process was adapted in order to address these issues of availability of information to correctly assessment the situation: a first call (initial probing) would be conducted in order to frame situation and identify gaps in information and knowledge; the group would then come back together in a second call with additional information, and decisions would be made at that point.

Goal conflicts faced by both Risk Knowledge Broker and requestor included:

- Risk Knowledge Broker balances subtle escalation of "sticky" issues while attempting to maintain trust of requestor / front line.
- Risk Knowledge Broker does not address why the situation arose to begin with (which could bring blaming tone) to maintain trust of requestor.
- Requestors balance the value of help versus the loss of autonomy that comes with making the issue public. When an issue was raised to this forum, it went from private (site / local had more autonomy) to public (inputs of crowd must be considered). The calls changed course of action to one that was not favored by front lines on several occasions ("When you call, we gonna come and you might not like what you hear.").

3.2 The difficult management of resources

For organizations that spread operations across space, responding to risky anomalies relates to resource allocation trade-offs: the most relevant people for a particular situation might not be at the location of the event, and the organization needs to temporarily make these resources available for the process. For the conduction of the FLARE process, the organization's pool of experts represents the critical resource. However, participants are conflicted between being temporarily deployed for anomaly response or tending to their own urgent work (they are highly solicited as experts). The process requires their ability to sacrifice other professional (or personal) activities, and the organization's support of shifts in priorities. Organizational measures include creating the conditions for the involvement of the highly experienced members of the organization, as well as of the divisions they belong to through negotiated agreements that are based on the recognition that the calls are valuable to all organizations involved.

A variety of issues associated with resource trade-offs were experienced during the conduction of the process. First, there were no different levels of urgency (at least in a formal sense). Most calls were high priority, requiring all resources to be available immediately. Initially there was pushback from people who were requested to support with short notice but over time they began to act with a level of urgency that matched the need of the front lines. Occasionally the requestor indicated less urgency and the call was scheduled for a later point in time. Also, 24/7 support was offered but in reality everyone knew that a 3 am call would get less help so most calls occurred during the work day until 10 pm. A more flexible design for the process should consider real criticality of events in order to avoid creating unnecessary resource constraints. On the other hand, the unavailability of key resources could constitute serious challenges: there was a minimal "must participate" list but it was occasionally violated with a requirement to follow-up and actions held up until the risk decision owner approved.

FLARE was assessed as valuable by the field managers and organization. Resource management issues become crucial and the trade-offs grow in complexity as the organization is experiencing and adapting around the tool's successes. As resources are stretched further conflicts increase relative to how trade-offs are managed. One issue relates to how field teams decide whether or not a call is valuable for them, and how the organization reacts immediately and after the fact Trade-offs associated with the deployment of valuable resources for the process appear analogous to those related to the use of resources in the investigation of adverse events: selecting which events constitute worth investments of resources requires recognizing the signification of events and balancing against pressures that steer efforts toward the obvious cases only. While numerous events would benefit from those calls, after-the-fact analyses could view them as superfluous given the use of valuable resources. When asked whether the situation was worthy of a call, the risk team took the approach of always recommending it based on the philosophy that up-front cost was low compared to potential losses. Ironically, the expansion of the FLARE process (international operations, more general scope) risks being the source of future challenges by stressing the demands for resources and associated trade-offs further (the organization's pool of available experts is not expandable beyond certain limits or without important modifications to their roles).

4 CONCLUSION

Quickly assembling distributed knowledge at point and time of need is a common problem in critical outcome industries and a problem, albeit with less urgency, faced by industry in general. This paper documents the FLARE process which has proven successful at solving this problem and could be used across industries.

The FLARE process is contingent on diverse, knowledgeable people being available to help and willing to respond with an urgency that matches the needs of the front lines. Diversity was brought in through both designed and evolved roles. The question initially posed was "If connecting people is not always enough, what else is important?" This paper attempted to answer one aspect of this question, focusing on characteristics and roles of people, who, when brought together to solve a problem, will be able to use their skills, knowledge, and diversity to thoroughly explore risks and design solutions. The Risk Knowledge Broker appeared as a central role in this process due to its responsibility in managing the diversity.

Edward Deming (1980) said "Uncontrolled variability is the enemy of quality." Yet variability is inevitable in complex work. Planning for variability (*in* control rather than *under* control) is necessary for system resilience. This paper describes a practice wherein variability is embraced and managed in a way that brings risk to an acceptable level.

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Training of Resilience Skills for Safer Railways: Developing a New Training Program on the Basis of Lessons from Tsunami Disaster

Shigeru HAGA[1], Osamu ONODERA[2], Tomoko YAMAKAWA[2], Akio OISHI[2], Yuichi TAKEDA[2], Ken KUSUKAMI[2], and Toshiko KIKKAWA[3]
[1] Department of Psychology, Rikkyo University, Niiza-shi, Saitama 352-8558 Japan
haga@rikkyo.ac.jp
[2] Research and Development Center of JR East Group, East Japan Railway Company, Saitama-shi, Saitama 331-8513 Japan
[3] Department of Business and Commerce, Keio University, Minato-ku, Tokyo 108-8345 Japan

Abstract

Railway operators such as drivers, conductors, and station staff faced difficult situations related to the earthquake and tsunami disaster in 2011. They had to decide by themselves what to do with limited information and to act quickly. They nevertheless performed remarkably and saved many lives of passengers as well as their own lives. We interviewed 104 such operators and found that (1) imagination, (2) sensitivity to risk, and (3) decision-making abilities are the most important for front-end operators to overcome a crisis. In order to enhance these abilities, we started to develop a new training program based on a serious game, "Crossroad", that had been developed as a training tool to increase awareness of conflicts in the face of natural disasters. About 1500 railway practitioners from the East Japan Railway Company participated in experimental trials of the new training method. As expected, the program was found to be effective to enhance the ability of resilience, which would help front-end practitioners respond flexibly and adaptively to critical situations.

1 INTRODUCTION

The 2011 Off the Pacific Coast of Tohoku Earthquake (The Great East Japan Earthquake) was disastrous beyond imagination and more than 18,000 lives were lost in the Tohoku District in Japan. Most of the victims drowned in the tsunami that engulfed the Pacific Coast of Tohoku 30-60 minutes after the earthquake. As a consequence of the Earthquake, many people and organizations faced unanticipated problems that required responses for which they were not trained, had not practiced, or that were not prescribed by manuals, rules, or laws. Some responses were successful and some ended in failure. Organizations and individuals who responded to the event flexibly and adaptively could provide great help to the people who were suffering or in danger. They displayed the competence that is considered in resilience engineering to be important for safety.

The East Japan Railway Company (JR-East) was one of the most successful organizations in this disaster. Their operators and local managers responded resiliently, saving many lives. The disaster has provided precious opportunities for us to learn from successful experiences and develop ideas on new training methods for resilience skills.

2 RESPONSES TO THE EARTHQUAKE AND TSUNAMI

At 14:46 hours on March 11, 2013, a massive earthquake with a moment magnitude of 9.0 occurred in the offing of the Pacific coast of the Tohoku District, Japan. The seismic centre was at about 130 km off the coast of Ojika Peninsula, Miyagi Prefecture, and at a depth of 24 km. The big tremor reached the coast within 1 minute. All the trains stopped quickly, automatically for Shinkansen trains and manually for trains on conventional lines, after receiving an automatic radio alert.

The Japan Meteorological Agency issued a tsunami alert 3 minutes later. Tidal waves attacked the coast several times, and the largest one came between 15:15 to 15:50.

Train drivers and conductors of 27 trains in service along the Pacific coast evacuated their passengers. Then the crews of 26 trains among them guided the passengers on foot to the nearest tsunami shelters before 5 of these trains were swept off the tracks. The crew of one train, which happened to stop on a hill, told their passengers to go back and stay on board according to the advice of a passenger who lived nearby. If they had left the train and moved downhill toward the shelter, the tsunami would have engulfed them. The decision to stay on board was against the dispatcher's instructions to evacuate the train, but owing to their noncompliance, all passengers and crew members survived to be rescued the next day.

Not only train crews on board, but also other front-end railway practitioners such as station staff, dispatchers, facility maintenance engineers, etc., showed remarkable reaction to the disaster. All of those on duty survived and many of them helped people in and near their workplaces.

Figure 1 shows the railway network of the JR-East. Squares represent the stations whose staff guided people to tsunami shelters and circles represent the trains from which train crews evacuated passengers on March 11, 2011.

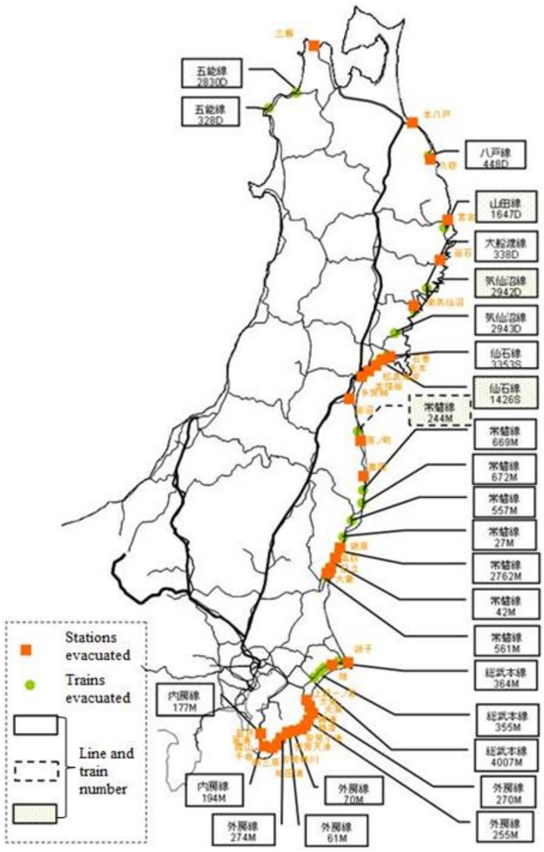

Figure 1. *Railway network of the JR-East and its stations (squares) and trains (circles) from which station staff and train crews helped passengers move to or stay at safe places on March 11, 2011*

3 INTERVIEWS

3.1 Purpose

The purpose of the interviews was to find factors that contributed to successful responses by front-end railway practitioners.

3.2 Method

In May and June in 2011, a total of 14 interviewers visited 48 workplaces of the JR-East in the areas affected by the tsunami. Most of the interviewers were human factors specialists working for the Research and Development Center of the JR East Group and the remaining were risk managers in the headquarters of the JR-East. They interviewed 104 railway personnel consisting of 26 train crews (drivers and conductors), 24 station staff members, 19 dispatchers, 10 facility maintenance engineers, and 25 local managers. Each interview session was performed by two interviewers for each interviewee.

In an approximate 30-minute semi-structured interview, we asked the interviewee about his/her behaviour, decision-making, and content and sources of information that was utilized. Local managers were also asked about preparation and anticipation for natural disasters before the event.

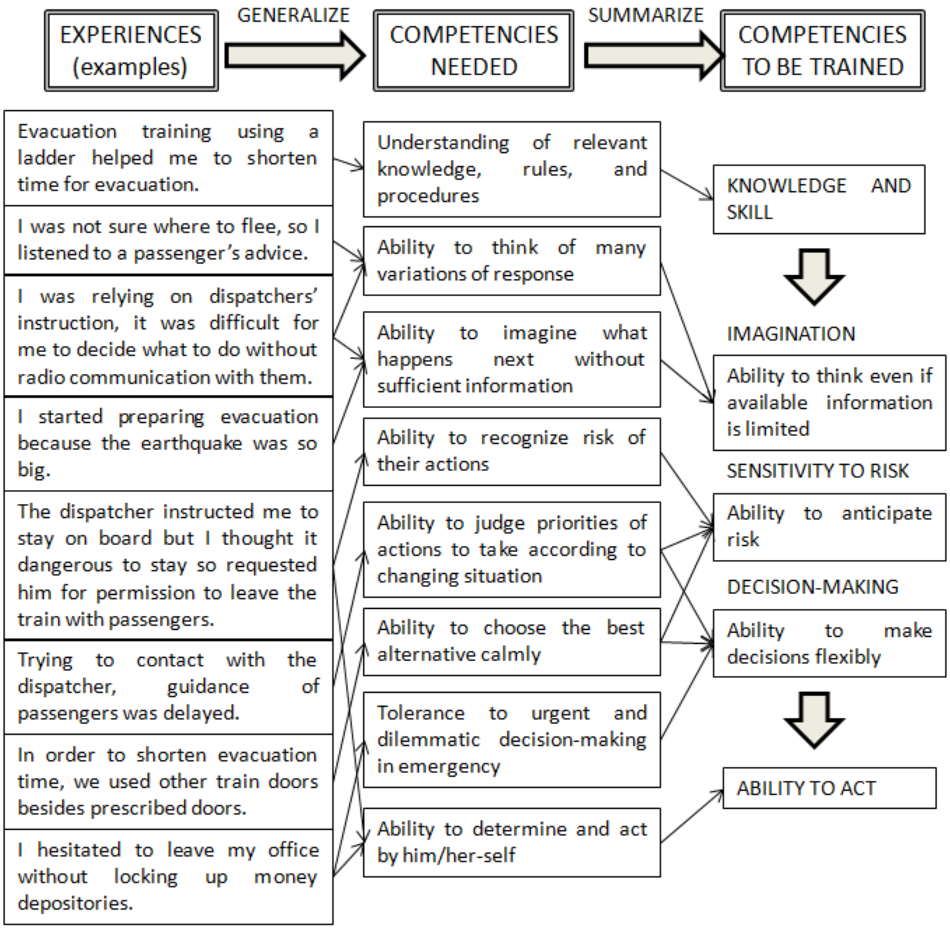

Figure 2. *Summary of results of the interview*

3.3 Results

As shown in Figure 2, both from successful and defective experiences by front-end practitioners, we extracted general competencies that would contribute to overcoming not only a crisis as a consequence of natural disasters but also overcoming various other emergency situations. These competencies are summarized as (1) professional knowledge and skill, (2) imagination, (3) sensitivity to risk, (4) decision-making ability, and (5) ability to act.

Additionally, from these interviews we identified three requirements for an adequate response to an imminent crisis: (1) immediate and reliable information should be available to frontline operators, (2) onsite decision-making should be done promptly, and (3) both passengers and operators can if deemed reasonable immediately leave the train or station in danger and move to a safer place. For requirement 1, operators should not only passively wait for reliable information but actively seek it from various sources. For requirement 2, operators should be able to make decisions by themselves. Lastly, for requirement 3, operators should be encouraged to leave their workstations, if necessary, for safety rather than to stay at their posts and perform duties there.

4 THE TRAINING PROGRAM

4.1 Need for a New Training Approach

From the interviews, we identified five competencies required in emergency situations. However, the company had not trained its employees to acquire those competencies. Traditionally, education and training in railway companies in Japan in general put stress on compliance to written rules and standard procedures. However, to act after making independent decisions was found by the present study to be very important in overcoming the crisis.

Japanese railways have a reputation for safety, as well as punctuality, but in order to enhance safety to a higher level, we concluded that a new training program should be developed and introduced as part of the regular training course.

Since the JR-East already has training programs for professional knowledge and skill, among the five competencies summarized above our focus of concern in developing a new training program was put on (2) imagination, (3) sensitivity to risk, and (4) decision-making abilities.

4.2 Method of Training

The training program utilizes a modified version of a serious game named “Crossroad”, which had been developed as a training tool to increase awareness of interpersonal and intrapersonal conflicts in the face of natural disasters (Kikkawa, Yamori, Ajiro, and Hayashi, 2004; Yamori, Kikkawa, and Ajiro, 2005; Kikkawa, Yamori, and Sugiura, 2009). In our training program, the chairperson of a group of four to six trainees reads aloud a short description of an irregular event (scenarios) on the railway. For example, “The train stopped at a red signal in a tunnel, and, at the same time, smoke arose in a carriage. A few passengers were trying to open the door and escape.” Then each group member is told to think about the situation and decide what he or she should do. After intensive discussion with experts in railway operations and front-end practices, we tentatively created 64 scenarios for the training.

In one version of the training procedure, members are given a question such as “Do you tell passengers to stay on board until instructed to evacuate?” Each member chooses one of two cards, “YES (tell them to stay)” or “NO (let them leave)” and puts the card on the table face down. In the other version, each group member writes down the answer on a blank card. In both versions, after all the participants make their decisions, they simultaneously flip the card face up.

Next, the chairperson asks members the reason for their decision and starts a debate between the supporters of decision alternatives. This inevitably leads to a discussion of trade-offs that must be made in decision-making in an unstable situation.

4.3 Trial of the Training Program

The new training program was put into practice experimentally in various local workplaces of the JR-East. About 1500 railway personnel in total participated in the experimental trial of the new training method. They were comprised of station staff, train crews, maintenance engineers, and construction supervisors. Through discussions in the training, participants discovered that there were different ways of thinking and many factors to consider, and that there was no “correct answer”. They found that alternative responses were numerous, but that each alternative involved trade-offs. They learned that to make better decisions they should anticipate what could happen as a result of their decisions. Using YES/NO cards was found to be more suitable for novice trainees because some of them could not think of possible alternatives and were unable to think out trade-offs.

4.4 Evaluation of the Program

We asked the participants for comments on the new method right after each trial. The evaluation was quite positive. Qualitative analysis of the comments showed that there are two major advantages in the new program compared to traditional approaches.

Firstly, participants found it effective for trainees to think by themselves about various emergency situations before they actually faced such a situation. Without an opportunity to receive this kind of training, they would not think of or imagine such critical situations. Many participants in the trial program expressed thanks for the opportunity given to them. They found difficulty in dilemmatic decision-making but they understood its necessity.

Secondly, participants evaluated group work as a good practice. They said that listening to other trainees’ opinions helped them to expand their own imagination and behavioural variations. They learned there were various alternative ways to respond to a single event and that there was no “correct answer”. In spite of this uncertainty, they must make a decision and choose the best alternative, taking trade-offs into account.

Before finishing the development of our training program, we must increase both the number and quality of scenarios available. In addition, we will need to collect quantitative evaluations by trainers and trainees, not only right after the training but also some time later (say a year) to ensure the effectiveness of the training.

5 DISCUSSION

Several previous training techniques have aimed at enhancing front-end practitioners' ability of resilience. For example, the National Patient Safety Agency in the United Kingdom developed a training program named "Foresight Training", and put it into practical use. The program aims to develop mental skills of nurses and midwives to identify, respond to and recover from the initial indications that a patient safety incident could take place (National Patient Safety Agency, 2008). Dekker, Dahlström, van Winsen, and Nyce (2008) suggested that an efficient use of low fidelity simulation could serve as an important complement in the creation of resilient crews in aviation and shipping. Bergström, Dahlström, Dekker, and Petersen (2011) developed a program for Swedish fire safety engineers engaged in rescue services. Using scenarios involving escalating situations, they tried to force trainees beyond their learned roles and routines and to force them into proactive thinking and articulation of their expectations of what might happen.

The approach of our new training program is in line with these preceding attempts at resilience engineering. Hale and Heijer (2005) admitted that railways have achieved remarkably high level of passenger safety without resilience, but claimed that safety management in railway track maintenance was not sufficient and needed to be improved by incorporating the strategy of resilience. However, It is obvious from our experience of the 2011 earthquake and tsunami that railways surely need resilience to achieve a higher level of passenger safety.

In an emergency situation, professionals working at the frontline face the dilemma of deciding how to respond to a critical event. Each reaction alternative has its own trade-offs between risks and advantages. Railway practitioners of the JR-East faced difficult situations related to the earthquake and tsunami disaster in 2011. They had to decide by themselves what to do with limited information and to act quickly. Tsunami alerts had been issued many times in Japan but railways had never been flooded before. Evacuation of trains and stations could be useless and could be more dangerous or risky than staying in carriages or buildings. Practitioners experienced the dilemma of making trade-offs among their choices. Ultimately, they made the best decisions and saved many lives of staff and passengers.

The training program that we are developing is expected to improve operator's ability to manage trade-offs in a crisis and enhance resilience of individual workers as well as groups of workers. It is the first attempt to apply resilience engineering to the field of practical operations in Japan. It will contribute to the development of resilience engineering and add new findings in the application of the theory.

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Reducing the Potential for Cascade: Recognizing and Mitigating Situations that Threaten Business Viability

Katherine E. Walker, David S. Deary, and David D. Woods
The Ohio State University, 1971 Neil Avenue, Columbus OH 43210, USA
walker.891@osu.edu, deary.1@osu.edu, woods.2@osu.edu

Abstract

In today's rapidly changing, highly interconnected global business environment, small disturbances can quickly produce a cascade of further disruptions that challenge an organization's plans and ability to respond. The disturbance cascade can lead to an adaptive system failure as the system's capacity to keep up with the pace of events becomes exhausted. As the capacity to handle the demands of the cascading difficulties is consumed, mobilizing or generating additional capacity requires time and effort and must be begun early in order to match the pace and tempo of cascading disturbances. As a result, a key property of adaptive systems is the ability to forestall, cope with, and break disturbance cascades. This paper reports results on the strategies used by one organization to recognize where cascades may develop, to build a readiness to respond effectively in the face of cascading disturbances prior to actual events, and to respond effectively when cascades begin to develop. The results come from an on-going study with the operations center of a transportation firm that conducts continuous operations with hundreds of movements per day.

1 INTRODUCTION

In today's highly interconnected, rapidly paced global business environment, firms are facing challenging events with effects that propagate and cascade in surprising ways to disrupt business operations. Both large-scale events, such as "Superstorm" Sandy or Japan's 2011 tsunami, and small-scale events, such as the recent fake Associated Press tweet about explosions at the White House, have impacted businesses by affecting vital infrastructure, supply chains, and the decisions of other firms. To maintain continuity, resilient businesses must manage disturbances not only reactively but also proactively; they must look ahead to anticipate bottlenecks and challenges ahead.

This paper is the result of an on-going study with the operations center of a transportation firm. The company conducts continuous operations, performing hundreds of movements per day. The firm provides an excellent natural laboratory for resilience research due to its scale and complexity; up to sixty percent of the schedule may change on a typical day and many of its operations are performed on short notice or with last-minute changes. The organization to be successful has to maintain a continuous ability to adjust to new events and disruptions for long term economic success and to conduct operations extremely safely at the same time. As a result, all parts of the operation are working to balance short term costs and productivity with the two chronic goals of long term economic viability and ultra-high safety.

The research team began by conducting a study of routine operations, then returned to observe operations when challenges occurred, some of which were known well in advance (e.g., associated with holidays or special events) and some with short notice (e.g., extreme weather; Deary et al., 2013). The team also conducted interviews with both management and operations personnel to understand how they prepared for and responded to these disturbances. An important aspect of this analysis was to understand how goals, trade-off management, and communication strategies changed in the face of disruptions.

Observing how management and operations personnel adapted their work in the face of challenge events revealed what the organization had learned about how to be prepared to handle surprises (readiness to respond) and how these mechanisms had become part of the organization's repertoire. Some of the specific activities we observed before and during challenge events included the establishment of senior management planning groups, weather impact analysis teams, and temporary local command centers.

The field research revealed that many of the mechanisms the organization had developed to handle surprise were tailored to deal with the potential for disturbances and challenges to cascade following a triggering event. The potential for cascade is a critical demand factor in both joint cognitive systems and complex adaptive systems (e.g., Woods, 1994). The *potential for cascade* refers to how a triggering event produces a set of disturbances which can propagate and interact over lines of interdependency. As a cascade of disturbances grows, the difficulties associated with responding also grow (Woods and Patterson, 2000), resulting in a positive feedback loop that reinforces and adds to the cascade of demands (Woods and Hollnagel, 2006). For complex systems under pressure to improve performance relative to acute goals, as changes produce more extensive interdependencies in a system and its interconnections, (higher coupling), the potential for cascade increases. As a result, the risk of falling into one of the basic patterns of adaptive system breakdown increase a great deal, particularly the risk of decompensation and working at cross purposes (Woods and Branlat, 2011). To be able to respond effectively in highly coupled networks, organizations need to be able to act to mitigate the spread of disturbances and break disturbance propagation. Again there is a tight interplay between demands and responses -- it is particularly difficult to try to cope with the challenges of cascades while in the middle of a cascade. This risk -- poor or delayed responses which then exacerbate the cascade, producing more demands on operational units and for coordination across units -- means that preparation is essential. Organizations that confront the potential for cascade develop mechanisms in advance that can be brought to bear to cope with the general demand properties of cascades.

Among many examples of cascades that challenged organizations or industry sectors, consider the 2010 European Ash Cloud crisis. While that cascade triggered by the volcanic eruption in Iceland was handled quite poorly, this paper reports the results on an organization that has developed a variety of mechanisms to be prepared to respond to cascades. The observations of the transportation firm before and during challenge events showed utilization of explicit and implicit means to build common understanding about interactions among roles, mechanisms for planning that address goal trade-offs and resource allocation, initiative regarding the exercise of authority at all levels, and the reconfiguration of information flows to accommodate new channels, uncertainties, noise, and increased volume.

2 UNDERSTANDING SYSTEM TRADE-OFFS

All work systems must balance trade-offs; multi-role systems as a rule have goal conflicts and finite resources with which to manage goals (Woods & Hollnagel, 2006). Situations with a high potential for cascade force businesses to confront and change the way they manage trade-offs in order to maintain operations. The trade-offs of particular concern for this paper are acute-chronic trade-offs. Examples of these include balancing the acute need for production versus the chronic need to maximize safety, and the acute need for production versus the chronic need to protect and maintain equipment. These trade-off decisions can be remarkably difficult. They must be made quickly in disruptive situations and mismanaging them can result in losses relative to business viability over the long term. This challenge is compounded by a tendency to sacrifice long-term objectives when there is an increased pressure to meet short-term targets. Work systems must devote resources to ensure that chronic goals are protected and that various roles are not working at cross purposes, which can be quite difficult during a challenge event in which resources are necessary elsewhere (Hoffman & Woods, 2011).

3 MANAGING CASCADES

Woods and Branlat (2011) describe decompensation, or the exhaustion of adaptive capacity in the face of growing disruption, as one of the basic patterns in adaptive system failure. Breakdown occurs when disturbances grow and cascade faster than responses can be formed and deployed. Initially, the system is able to act and compensate for the disruption, but as new challenges arrive, there is no longer capacity to keep up with the escalating situation (Woods, 1994; Woods and Patterson, 2000). Woods and Wreathall (2008) developed the stress-strain model to represent how an organization is able to adapt and match response capabilities to meet changing demands factors that arise to challenge the organization’s ability to stay in control and meet a range of goals. Figure 1 shows the stress-strain adaptive landscape annotated for the challenges presented by the potential for cascade.

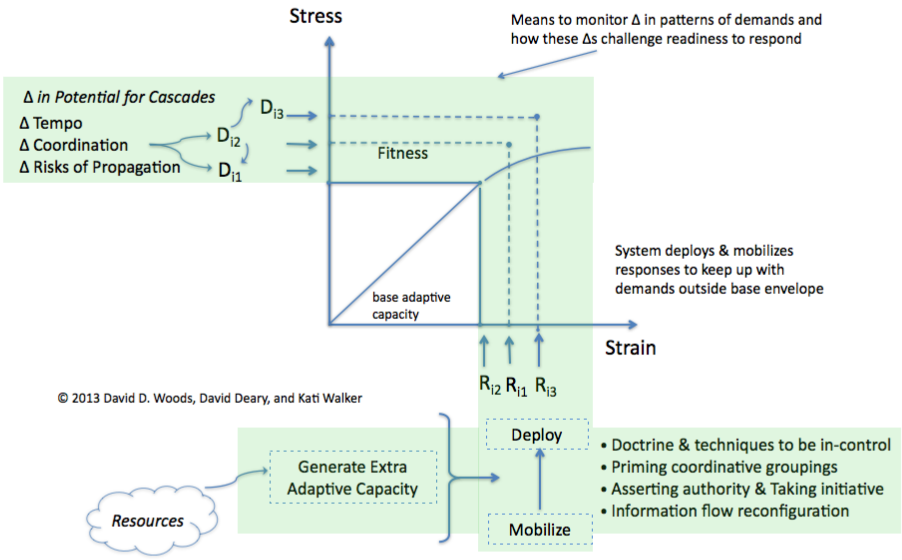

Figure 1. *The stress-strain adaptive landscape annotated for the potential for cascade. Fitness is represented by the match of responses (x-axis) to demands (y-axis). Cascades challenge the boundary of the system's base adaptive capacity, and require the system to mobilize and deploy extra adaptive capacity to handle the demands. This study examined how an organization prepared to deal with high potential for cascade situations, that is, what the organization learned about how to be able to mobilize and deploy responses in the face of the special properties of cascading situations.*

In a cascade sequence, demands increase rapidly and unpredictably as new difficulties arise and interact. Cascade sequences are particularly interesting because of the increase and changes in tempo, the coordination links across units change, and new risks arise about how planned responses can break down (i.e., the risk of failing to mitigate or break the disturbance cascade). During cascade events, the system must monitor for changes in the pattern of demands and understand how the cascade could propagate. This gives rise to a need for adapting coordinative activity, which can introduce more demands into the system as management and personnel are consumed by new tasks, new data flows, and new forms of uncertainty. As difficulties propagate, the tempo of the situation will increase and squeezing the time available to analyze, replan, and execute new courses of action.

In response to these difficulties, an organization must be prepared to generate, mobilize, and deploy additional adaptive capacity to keep pace with or block cascading demands. In our observation, we identified four types of responses tailored to cope with the potential for cascade.

3.1 Doctrine and techniques to be in-control

Businesses may use past experience, their knowledge of resources available, and projections of future resource use to predict which events will pose challenges to adaptive capacity. Once the business recognizes a known or emergent disruption, it will begin to behave in accordance with its doctrine for dealing with the class of event at hand. While it will begin to execute explicit standing policies, in behaving along doctrinal lines individuals and functions will interact based on a shared frame of reference shaped by implicit expectations as well as explicit directives. In organizations with low turnover in key positions, such as our example firm, these implicit expectations are formed through years of shared practice in coping with disruptions. A challenge outside the bounds of the firm's doctrinal experience may constitute a surprise that impairs the group's ability to assess and respond to the risk of propagation associated with a cascade.

During the challenge event, operators must work to make detailed decisions and deploy resources to match the tempo of the disturbance. As time pressure grows, there is less time to evaluate different options; waiting to make a decision may cause the disturbance to worsen. Operators often use previously developed techniques to make the best possible decision as quickly as possible to prevent further disruption. As one senior operator noted while preparing for Hurricane Sandy, “The key is giving a quick response to a new request, otherwise it snowballs.”

Management may help determine these heuristics when they directly affect the business goals, but working-level personnel will often develop their own techniques for working at a faster pace. In the example, while an operator may typically have the time to determine the best and least-expensive option to move an asset from place to place, in an event with high potential for cascade, they might simply use the fastest available alternative without regards to cost in order to maintain maximum adaptive capacity.

3.2 Priming coordinative groupings

When a major disruption can be seen years in advance (e.g., holidays) or just days ahead of time (e.g., a hurricane), management forms priming coordinative groupings to prepare for the event. While established doctrine is an invaluable starting point for responding to an emergent situation, a group convened to deal with a particular event is essential in addressing the unique circumstances of the new challenge. The group’s success hinges in many ways on its ability to apply lessons from similar past events while recognizing potential differences.

In our observation, one of the most important specific activities performed by such groups is to alter resource allocation plans prior to the event to ensure maximum adaptive capacity is available to respond to disturbances. This is not always easy to do; difficulties may cascade in surprising ways, and the highly interconnected economy of the modern world means events that seem distant can still have strong effects. Nonetheless, it is vital to secure resources prior to the event because there are time and work costs to obtaining additional adaptive capacity that challenging situations typically do not allow, and waiting to obtain these resources often means they will arrive too late in the situation to be useful. This requires the firm to focus on chronic goals such as safety and business viability. It is common for these additional resources to be cut if they have not been used in previous events for the acute goal of saving money. In the example, the firm may employ additional operators or assets to deal with increasing demand on the system, or contract with additional businesses outside of the affected area if partner businesses in the area will be non-operational due to the weather system. When dealing with events known well in advance, in particular one that affects operations in only one or a few locations, it is helpful to deploy personnel with the authority and expertise needed to anticipate and ease production bottlenecks to the location. This arrangement has the advantage of enabling the central operations center to gain insight from the on-site team, and by transferring decisions to the local team it frees headquarters personnel to address system-wide issues.

3.3 Asserting authority and taking initiative

In preparing for a disruption, priming coordinative groups of senior managers assert authority that they do not often need to exercise during routine operations. In our observation, many of their most important decisions address acute-chronic trade-offs in the system and ensure that chronic goals such as safety are maintained during challenge events. The example firm might make decisions about when or if they should cease operations in the severe weather area to protect the safety of operators and assets. The firm might also direct working level personnel to secure added resources such as a new supplier just in case it is needed. While the exercise of authority from senior management provides appropriate and necessary guidance to working level personnel, it also creates increased demands, in particular for additional reporting on operational details not normally of interest during routine operations. This behavior is typical of an organization grappling with a difficult technical situation, a circumstance known in the nuclear power industry as “going solid’ (Cook & Rasmussen, 2005).

In typical business operations, individual roles take the initiative to balance local goals, including their own, to create the best possible solution for all roles. However, in an event with high potential for cascade, they may ignore localized goals in favor of chronic, system-oriented goals to best maintain system control. To accomplish this, it is important for working-level operations personnel to understand how their actions impact the system as a whole and their responsibility in maintaining the system’s chronic goals. Armed with this knowledge, they may take initiative to fulfill the intent of top-level direction in advance of specific guidance from senior management, such as pursuing additional asset protection measures in areas on the edge of a nominal weather impact zone.

3.4 Information flow reconfiguration

It is not enough for management to develop strategies to deal with a potential disruption; operations personnel must be informed of changing priorities so those new strategies can be successfully carried out. Ideally, this communication process occurs continuously prior to and throughout the event. In our weather example, this information would be updated and revised as the storm path changes—an area previously assumed to be in the path might be completely safe, while another area might need to be evacuated much earlier than assumed. While this is happening, the changing strategies of partner businesses must also be observed so the firm can update its movements relative to theirs. This process is resource-intensive, but extremely useful in assisting resilient businesses with making decisions that compensate for system disturbances and are in pace with the tempo of disturbances.

During periods of extremely high tempo operations, personnel facing clogged communication channels must change their communication strategies to direct attention to important disturbances. Most roles will have little capacity to monitor all sources of communication during a disruption, especially if there are multiple, simultaneous electronic channels to be monitored. Operations personnel must work to find the most effective communication methods to ensure vital information is seen and understood. This may frequently take the form of communicating face-to-face. Operators seated near each other may elect to speak (or shout) to their colleagues, or personally visit more distant partners. This physical presence is a clearly recognizable sign of the importance and time-critical nature of the information being delivered.

4 CONCLUSION

Resilient businesses manage disruptive events by effectively shifting priorities to support chronic goals and maintain business viability. Within a business, goal conflicts between roles are inevitable; a resilient business must devote resources to understanding these conflicts and how they should be managed to avoid damage to long-term objectives, especially in the face of a major disruption. The transportation firm studied for this paper maintains a strong awareness of each role's responsibility to maintain chronic goals, as a loss of adaptive capacity in a disruptive situation will both place lives and property at risk and threaten business viability. The chronic goal of safety must be strongly emphasized in any such challenge event.

By describing the actions of a highly adaptive firm in the face of disruptions, this paper identifies key behaviors that assist in the successful management of situations that may disturb business operations. Learning to anticipate and mitigate circumstances with high potential for cascade provides several benefits:

- Doctrine and techniques can be updated to support trade-off management,
- Priming coordinative groupings can consider new forms of resource allocation,
- Authority delegation and retention can be adjusted to better balance senior-level involvement and working-level empowerment,
- Information tools can be designed to facilitate new information flows about interdependencies, side effects, disturbance interactions and propagation paths.

Addressing resources such as these assists businesses in further building adaptive capacity and thus becoming more resilient in the face of disruptive change, particularly those events with a high potential for cascade.

Acknowledgements

We thank our transportation research partner, in particular the operations center staff. We also gratefully acknowledge the support of the Eddowes Fund and our transportation research colleagues at The Ohio State University.

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Balancing efficiency and safety in maritime traffic management when approaching a port

Fulko van Westrenen
Umantec, Haarlem, Netherlands
westrenen @ umantec.nl

Abstract

This paper discusses maritime traffic management in the boarding process of pilots when approaching a port. For efficiency reason ships are brought as close together and as close to shore as possible. For safety reason ships should remain well separated from each other and at a safe distance from shore. By realising a clear traffic structure the shore-based pilot maintains situation awareness and manages workload while realising safety and efficiency.

1 INTRODUCTION

Efficiency and safety are the two key factors in maritime transport. For economic reasons, principles like chain planning and just-in-time delivery become more important. To realise this, system availability, reliability and safety is paramount. In this study it is analysed how efficiency and safety are realised in the approach of a port.

Each phase of the voyage poses different requirements to the ship's navigation. At open sea the ship navigates autonomous, optimising its state locally. Near the shore radar guidance is provided to realise fluent traffic. Finally a local pilot navigates the ship into port and moors it at its berth. This change in ship navigation over the voyage is governed by the changing dominating constraints.

In piloted waters the dominating constraints are the navigable area, with the risk of stranding, and the traffic, with the risk of collision. A pilot is a local navigation expert with extensive training and experience in ship handling in constrained situations, unlike the average crew. Pilots also have the ability to make optimal use of local service providers.

Modern technology allows the pilot to provide navigation assistance from ashore in the form of shore-based pilotage, in which a pilot-operator provides heading and speed advise for safe navigation. However, the sensors available are limited in their information, not providing the entire state of the ship. Additionally, when giving shore-based pilotage the workload of the operator will increase with the number of ships.

Shore-based pilotage is discussed by various authors, e.g. National Research Council (1994), Hadley (1999) and Bruno & Lützhöft (2009). These publications largely focus on the limitation of remote pilotage in relation to human control limitations. This paper will focus on a specific part of remote pilotage and look at the process from a control system perspective.

Shore-based pilotage operates within a larger structure of Vessel Traffic Services, that support traffic safety in and around all major ports. While the primary task of a pilot is to provide safety and expedience, the safety perspective of the VTS is not that clear (Praetorius et al., 2010). Within this article the interaction between shore-based pilotage and VTS is not discussed, and differences in safety perception are not addressed.

Ship arrive at a port from different directions at open sea, while in port ships must manoeuvre well separated in a narrow fairway lane. The topic of the study is how the ships, coming from different directions, are merged in a single stream and a pilot is brought on board. Safety needs to be assured under all conditions: Shipping is a continuous process, 24/7. The operating conditions vary considerably, regularly beyond design specifications, requiring the system to adapt and reorganise to maintain safety. It is for this reason that an analysis was done from a resilience perspective, focussing on monitoring and adaptation.

2 PILOT BOARDING PROCESS

The analysis is based on three older studies. The first study was an observation of the boarding process from the ship's perspective. For this over 20 boardings were observed on various ships (Van Westrenen, 1994). The second study was about the pilots work. For this ten pilots were observed during more than 40 voyages (Van Westrenen, 1999). Finally six shore-based pilots were observed during their work and actions, objectives and strategies were discussed. In addition, documents were studied and observations were discussed with trainers and supervisors. Information were collected in notes, illustrated with a few photos and video, for later analysis.

For safe navigation a pilot will board before the ship enters port. At deep sea the ships are free to manoeuvre while in port the navigable area is very constrained. The pilot will assist the ship in this constrained situation. Figure 1 represents the basic structure of the situation. Ships arrive from three directions (traffic lanes) and need to merge at the small arrow in the centre. This is where the pilot boards. The pilot comes from the port towards the boarding area in a fast pilot tender. The ships slows down at the boarding location, the tender comes alongside, and the pilot changes ship. The three sets of lines spreading out from the port represent the navigable area for different draughts, where deep-draught ships need to stay in the narrow channel, and small ships need to stay between the most northern and southern line.

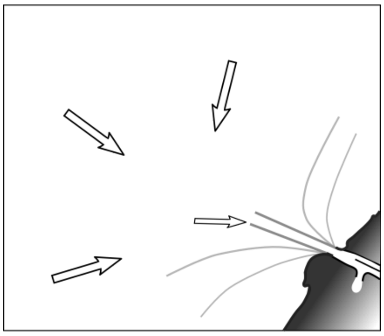

Figure 1. *Representation of the boarding area with three traffic streams and the fairway leading into port.*

To allow a safe and efficient merging of the ships and co-ordinating with the tender, a shore-based pilot monitors all traffic with sensors (e.g. radar) and instructs the ships to safely merge, slow down the ships, and meet the tender. In addition to the ships that need a pilot there will be other ships in the area that are informed about the navigation and traffic situation. The basic structure of this process is shown in figure 2.

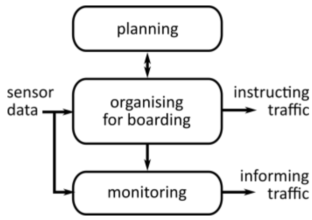

Figure 2. *Primary functions in the shore-based pilot process.*

The functional structure showing the primary functions enabling merging and boarding is shown in figure 3. It has the same three-level basic structure, but now the supporting functions are laid out. These functions are based on the activities displayed by the pilots and discussions about their work. Each function has an input (left), output (right), controls (top), and resources (bottom). The planning process is realised by a specialised planner. The shore-based pilot manages the boarding process and the information provision for other traffic. Important functions for this are monitoring, queuing, deconflicting, instructing/informing, and process management. Various aspects of the functions are discussed in detail later.

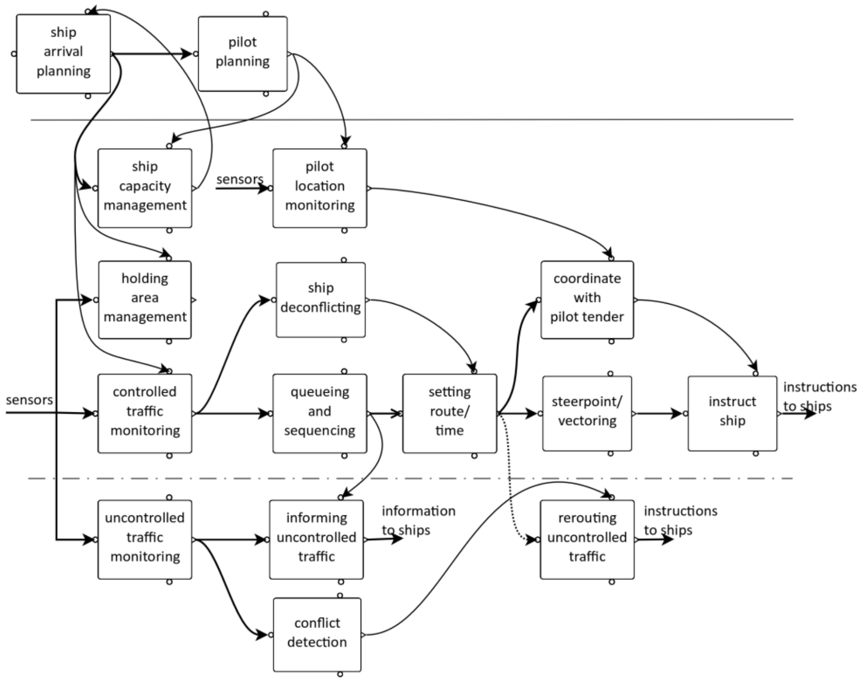

Figure 3. *Diagram with the basic functions of the boarding process (simplified). The top functions are provided by planners. The lower functions are for traffic not in the boarding process.*

Ships arrive in the area from sea where they manoeuvre completely autonomous. When approaching the boarding area they will accept instructions from ashore to realise co-operative and co-ordination manoeuvring. If the co-ordination fails, the ships are expected to stay clear from each other in the navigable area but the merging and boarding process will stop. The relevant ship functions are presented in figure 4. This model is derived from the model by Van Westrenen & Praetorius (2012).

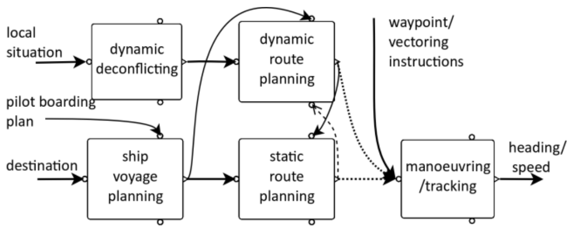

Figure4. *Diagram with the basic functions of the ships.*

2.1 Operating Principles

For efficiency, ships must come as close together as possible. Decreasing their separation also decreases their freedom to manoeuvre, requiring more strict control to realise the same level of safety. Stricter control is realised by changing the type of control, providing control at a lower level.

Ships can be controlled remotely in two ways: by giving it waypoints to be navigated, or by giving it heading instruction to be steered. Some characteristics are in table 1. It shows that control accuracy can be achieved at the expense of workload.

Table1: *Characteristics of two types of ship control.*

	control level	movements	operator workload
waypoint/speed	high	approximate	low
heading/speed	low	precise	high

While adapting the level of control to maintain safety and at the same time increase efficiency, the operator has three basic strategies to mitigate the effects of temporarily increased traffic density. Given that ships arrive at random times with a Weibull-like distribution, they will arrive in “lumps”. By adjusting their arrival speed, spreading them longitudinally, peak-densities are minimised, thereby increasing capacity, but requiring planning and adjusting. The second strategy applied is using the width of the navigable area to spread traffic laterally. This allows the ships more manoeuvring space, allowing for higher levels of control by the operator, but increasing traffic complexity. Thirdly, buffer areas are created to make the ships wait until traffic density decreases, allowing for safe separation but requiring more complex planning.

Pilots arrive in the area from the other side then the arriving ships. They require travel time and time to get on board. Since pilots need to be on the bridge before the first critical event, and smaller ships have a larger navigable area and sail slower, smaller ships can be served closer to the port, increasing efficiency by depending on shorter travel times. However, this can only be done when the ships are spread lateral, separating ships controlled from ashore and by the pilot on the bridge, and spreading increases traffic complexity which might have a negative effect on situation awareness.

2.2 Predictability and Control

There is a large variability in the system. Ship sizes, meteorological conditions, hydrodynamical conditions, traffic density, ship condition and crew quality are just a few examples of this variability. For efficient and safe control, the shore-based pilot depends on the prediction of ship movements. This prediction depends on his knowledge of the ships' characteristics, state and the environmental conditions the ship is in. Current state-information of ships and environment is provided by the sensors and information systems. Knowledge is obtained through training and experience, on board and as a shore-based pilot.

The less predictable the ships' movements are, the larger the minimum separation needed. Because there is such a large variability in the traffic, the shore-based pilot has a large freedom in how he realises efficiency and safety. The merging and boarding process is not fully constrained in procedures, rules and strict criteria. Only a few guiding principles are applied that focus on maintaining separation and flow. For this the shore-based pilot applies the basic strategies, discussed above. In doing their work they focus on maintaining good situation awareness by realising a clear traffic structure and maintaining a sufficiently low workload by realising a minimal conflict rate and choosing the appropriate control level.

3 RESILIENCE CHARACTERISTICS

The domain focuses on separation, buffering capacity and flexibility as the main characteristics of safety. This is very comparable to the resilience system-characteristics defined by Woods (2006): buffering capacity, flexibility versus stiffness, margin, and tolerance.

System resilience is realised by a layered design of control that allows to adapt over a large range of variability. At the lowest layer are the (potentially autonomous) ships. In the middle layer is the shore-based pilot, realising choreography between the ships, utilising the ship's autonomy. At the top layer is planning, spreading the load over time to avoid peak loads. These three levels co-operate to achieve the overall system goal. The system resilience is analysed using system diagrams, focussing on information streams, and on the strategies applied.

Functional resilience is realised by maintaining three charateristics: separation, buffers, and flexibility. Maintaining separation is the primary task while realising traffic fluency. Minimum following-, crossing- and lateral-distance are maintained appropriate for the ship and the meteo-hydrodynamical situation. The resilience is realised by monitoring and applying the strategies and associated traffic-organisation plans.

Traffic complexity can be high in maritime traffic due to the large variation in ships, crews, and sailing conditions. Standard routes and organising principles for the traffic allow for maintaining situation awareness. Workload depends largely on the required accuracy of ship control. When ships come close together more accurate control is required, depending on another type of control, which in turn will increase workload. Workload management requires traffic planning to assure separation minima while realising productivity.

Ship separation is not fixed but depends on ship characteristics, conditions and uncertainty; when uncertainty decreases, separation can be lowered. When separation can no longer be maintained, buffers at predefined waiting locations are brought into use to temporarily lower the traffic load or decouple the chain of ships. Rules of thump are used to decide on the need of buffers. The holding areas are designed together with the standard routes. While separation and buffering allow coping with all standard variations unexpected event may disturb the process. Basic procedures guide the reorganisation required to maintain safety and preferably realise traffic fluency.

Apart from this control structure, there is an organisational structure. All functions needed by the system are not only available via the primary operator but can be provided by others (not presented here), within the team or by other teams ashore or at sea. This functional redundancy is utilised by the organisation to reorganise the system when minimum performance requirements are threatened.

Ships separate themselves which potentially makes the system very tolerant towards a failure of the organising process: When the entire shore-based pilotage system fails, ships will continue to maintain separation. It may even function when the shore-based pilot directs ships against each other and ships themselves avoid collision.

The system design shows various monitoring and management functions. Monitoring is considered a vital function for resilience but depends on the availability well-chosen set of system parameters (Wreathall, 2010). In addition the system needs the ability to anticipate. The system analysed contains these two properties embedded in the three-layer design, although it is unknown how well it functions.

4 CONCLUSION

The shore-based pilot optimises traffic flow while coordinating pilot boarding. For this they focus on maintaining situation awareness and workload development. To maintain the flow pilots use a limited number of basic principles and a basic pattern on which they vary. Their primary control strategy is focussed on accepting no more control from the ship than necessary for the required accuracy. By minimising workload they maximise for opportunity to maintain situation awareness.

There are two trade-offs that are considered important with respect to pilotage. The first one is the trade-off between safety and efficiency. For maximum efficiency the ships are brought as close to the coast as possible, and are grouped as close as possible to minimise the travel-time for the pilots. However, coming close to the coast unaided increases the risk of grounding, and bringing the ships close together increases the risk of collision. By dynamically adjusting the boarding strategy a minimum separation is guaranteed while maximising efficiency. The second trade-off is between required navigation accuracy and workload. The pilot ashore attempts to optimise his control. When safety margins are large, low accuracy is required, demanding low workload. When the navigational area becomes narrower and ships come closer, accuracy demands increase, increasing workload demands. Controllers compensate by changing their control strategy, while workload constraints set an upper limit for traffic capacity.

Acknowledgements

The author would like to thank the crews, pilots and organisations for their generous co-operation in the various studies.

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Developing Resilience Signals for the Dutch Railway System

Willy Siegel[1] and Jan Maarten Schraagen[1,2]
[1]University of Twente/GW, P.O. Box 217, 7500 AE Enschede, The Netherlands
A.W.Siegel@UTwente.nl; J.M.C.Schraagen@UTwente.nl
[2]TNO Behavioral and Societal Sciences, P.O. Box 23, 3769 ZG Soesterberg, The Netherlands
jan_maarten.schraagen@tno.nl

Abstract

A resilience state model for a railway system is proposed consisting of three boundaries putting pressure on the operating state: Safety, Performance (Capacity & Punctuality) and Workload. In order to model the pressure of the boundaries, an additional dimension is added where the slope represents the pressure. By doing so, the model is able to differentiate between internal changes that keep the system in a resilient state or have it move towards brittleness. The resilience state model is also used to develop a quantitative signal model, indicating pressure change of the boundaries. A newly defined resilience signal (RS), a quantitative indication of change in system resilience, can be created with help of the signal model and be used for anticipation during operations. The resulting parametric functions will be evaluated and tuned by empirical testing in further research. Using data from governmental reports on responses to incidents, two empirical cases are worked out using the signal model. The first case shows the correlation between a safety RS and safety risk. The second case analyses a capacity RS and explains the results by the system adaptation process through a multi-layer hierarchy.

1 INTRODUCTION

The Dutch rail is in the process of redesigning its mainly technologically driven system which stems from the previous century. Its focus is on handling disruptions and understand, through the four cornerstones of resilience (Hollnagel, 2009), that its largest gap lies in its ability to anticipate. One aspect of anticipation is to enlarge the operational awareness to the resilience state and stimulate the operators to take a pro-active attitude to explore and anticipate on the unknown and unexpected future. However, a quantitative measure of the resilience state of the whole system is currently lacking in the literature. Woods, Schenk & Allen (2009) compared selected models of system resilience including different concepts to explain resilience phenomena. However, these models do not provide quantitative measures of resilience. As a first step towards resilience quantification, we propose to concentrate on resilience signals (RS), which are measured indications that the resilience of the systems is changing. In a redesign of a system these measurements, and their representations, can be taken into account as well as the tooling to further analyze and possibly anticipate on the RS. Thus, the aim of this paper is to focus on the resilience of a rail system by developing a model from which quantitative RS can be measured. This basis can be used in further research on the quantification of these signals and this model is also valuable to study, analyze and explain specific cases of the past.

2 THEORETICAL RESILIENCE STATE MODEL FOR A RAILWAY SYSTEM

As a start, Rasmussen's (1997) safe operating envelope was used. In Rasmussen's model, three boundaries – performance, economy and workload – are described to explain the different pressures on the Operating State (OS) which may result in crossing one of the borders or readjust them to create a new steady state. In this framework, the performance boundary is directly linked to the 'safety culture' pressure, the economy boundary to the efficiency pressure and the workload boundary to the 'least effort' pressure. In our adaptation of Rasmussen's model, we have introduced some changes to reflect the nature of a railway system. First, we separated 'performance' and 'safety' to reflect their independent nature, while their mutual influence is made explicit in the new model by "upgrading" safety to a boundary entity, which creates safety pressure. Secondly, we moved the economy boundary backwards creating efficiency pressure on the performance boundary, which creates a performance pressure. This change is justified by the fact that in rail systems economic considerations play a more prominent role in the long run strategy and less in daily decisions. However, the performance pressure, created by capacity growth and punctuality to deliver the planned schedule, plays a major role in daily considerations. The workload boundary stays intact reflecting the human importance within a socio-technical rail system. The result of these changes have been depicted in figure 1 - section I.

This model is useful when reasoning about resilience. For example, Cook & Rasmussen (2005) use different areas in the model to explain the stability of a system: unstable, low-risk stable and high-risk stable. The fact that the boundaries put pressure on the Operating Sate (OS) is added textually with the term ‘gradient’ and grey areas show the OS jump domain, due to shallow gradients. These gradients are of interest, since they represent the internal pressure on the OS and may indirectly be measured and can help explain the resilience of the system when the OS is located at a specific position. When a gradient is large it represents system resilience against external perturbations, while shallowness represents brittleness. This gradient can be made explicit by adding a depth dimension to Rasmussens model as if it is viewed from above in a landscape of valleys as described by Woods et al. (2009), who related the work of Walker & Holling (2004) to that of Rasmussen (1997). The slope (α) of the valley (see figure 1 section II) describes the internal force gradient or Resilience Engineering as called by Walker, acting on the Operating State (OS) while the vector $\vec{d}$ describes the external perturbations on the OS. $d_P = d \cdot \cos\alpha_P$ represents the pressure of boundary B_P. This third dimension with the valley slope is important to understand the amount of resilience when moving towards one of the boundaries. A small slope is an analog to a small hurdle, representing brittleness, to approach the boundary, while a large slope represents resilience. As an example, figure 1 section III depicts an OS that is moving towards the marginal boundary. There are two options to reflect the change of the internal state. When only the capacity of the system is enlarged and no safety measures are taken, it will result in a brittle state, option a, where the marginal boundary is at stake. However, when measures are taken to enlarge the safety hurdle as well, as in option b, it may result in a deeper valley maintaining the resilience engineered to cope with a higher capacity.

This theoretical model will be used in the next paragraph to model quantifiable resilience signals (RS) through pressure change of the boundaries.

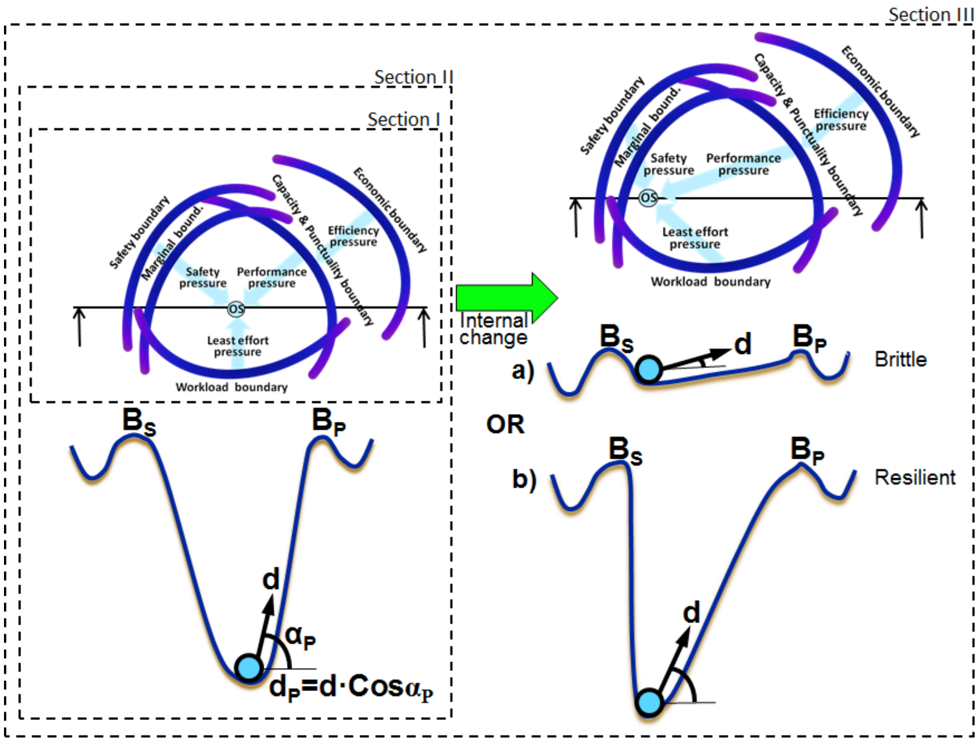

Figure 1. *Resilience state model for a railway system*

section I: Rail-sector boundaries putting pressure on the Operating State (OS)

section II: Rail-sector boundaries with resiliency slope α_P, causing pressure d_P

section III: OS move caused by internal change, a or b, influencing system resilience

3 QUANTIFIABLE RAILWAY RESILIENCE SIGNAL (RS) MODEL

The challenge is to translate the above theoretical resilience state model to concrete measurements. Measuring the resilience boundaries with the relative position of the Operating State is a difficult task. The boundaries of a socio-technical system have a subjective character and are based on acceptance and behavior of the community. Cook & Rasmussen (2005) give an example of the marginal creep determined by socio-technical processes and still "only" describe the phenomena, while quantification is not mentioned. As a first step, we propose to measure the pressure of these boundaries and their change over time, which may be considered as a signal triggering further analysis of the situation and possible anticipation, one of the four cornerstones of resilience mentioned by Hollnagel (2009). The focus is on a rail system which has a specific nature and architecture to be used for measuring pressure change due to 1) safety, 2) capacity and 3) workload.

3.1 Safety

Safety plays a role in many aspects in which a safety pressure could be measured. To quantify the concept, we have chosen to measure the safety pressure in the nominal safety sequence of a rail system. A train collision can either occur on the same track or on the crossing of two tracks. We will analyze the safety process in those situations, where the signaling system plays a role, to understand the sequence from which quantitative measurements can be taken to identify a growing pressure. These two nominal situations are depicted in figure 2. In general, rail systems have a technically separated logistic system, using the infrastructure, and a safety system, guarding it independently. According to a logistic plan and the position of trains, the logistic system requests rail path allocations from the safety system. The independent conventional safety system is based on sections that can be occupied by one train at a time and will allocate one rail path to a switch. As depicted in fig 2a, train A occupies section 1, the signal before the section is red, signaling an approaching train to stop. The signal before section 2 is yellow, signaling an approaching train to reduce its velocity and only the signal before section 3 may be green when a rail-path has been allocated for the following train B. The cross-track situation is depicted in figure 2b, where the path for train A, combined through sections 3b, 2b & 1b, allocates switch S1, connecting sections 1b & 1a. Train B is kept on a distance through red and yellow signals before sections 1a & 2a respectively.

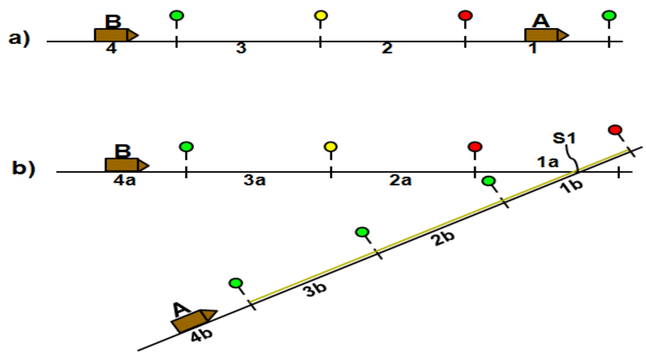

Figure 2. *Safety signalling – one train per rail section and one rail track per switch*

When passing a red signal, commonly known as a Signal Passed at Danger or SPAD (Hollywell, 2005), safety is at stake and the more frequently this occurs, the higher the probability of an accident. The number of SPADs may be used to express the amount of safety pressure. However, this can be extended by measuring the number of yellow signal passages and even by the number of red and yellow signal approaches. The latter is justified by following the safety sequence, and the deviation from the optimal safe “green wave”. In the “green wave” the train has only green signals, until it gets to its station-stop, and does not need to decelerate until then. With the “green wave” as reference, the pressure of the safety boundary can be expressed as a function of red and yellow signal approaches and passages. These variables can be extended by the number of inhibited rail-paths, due to occupation of switches by another rail path.

Thus:

$\alpha_S = f_S$(no. of: SPADs, yellow signal passages, yellow/red signal approaches, switch inhibited rail-paths)

A safety RS can be defined when the slope decrease is larger than a predefined threshold, Threshold-RS$_S$, indicating that the internal system is becoming less resilient as seen in Figure1-IIIa. When assuming a monotonic function, the change of the slope $\Delta\alpha_S$ can be estimated by the cumulative weighted changes of the function variables:

$\Delta\alpha_S = K_{1S}(\Delta$ SPADs$) + K_{2S}(\Delta$ yellow-passages$) + K_{3S}(\Delta$ red-approaches$) + K_{4S}(\Delta$ yellow- approaches$) + K_{5S}(\Delta$ switch-inhibits$)$; Safety RS: $\Delta\alpha_S <$ Threshold-RS$_S < 0$ where the weights K_{1S}, K_{2S}, K_{3S}, K_{4S}, K_{5S} and Threshold-RS$_S$ needs further empirical investigation.

3.2 Capacity

The change in transport capacity can be directly measured by the actual rail-track usage. In rail reports, for example the report of the Dutch Ministry of Infrastructure and Environment - Inspection of Environment and Transport (2011), the number of kilometers driven on the amount of available track is used as a measurement of capacity utilization. This measurement is relevant but a result of planning activities before operation. During operation, the capacity pressure is largely influenced by delays and infrastructure withdrawal due to malfunctioning and maintenance. The capacity is thus a function of all these parameters:

$\alpha_P = f_P$(Driven km's/km track, delays, km infrastructure withdrawal)

Similar to the safety RS, a capacity RS can be defined when the slope decrease is larger than a predefined threshold, Threshold-RS_P. The change of the slope $\Delta\alpha_P$ can be estimated by the cumulative weighted changes of the function variables:

$\Delta\alpha_P = K_{1P}$(Δ driven km's/km track) + K_{2P}(Δ km infrastructure withdrawal) + K_{3P}(Δ delays)

Performance RS: $\Delta\alpha_P$ < Threshold-RS_P < 0

The delay measurement is a complex one still to be tackled in the appropriate context. The weights K_{1P}, K_{2P}, K_{3P} and Threshold-RS_P need further empirical investigation as well.

3.3 Workload

The main driver for managing the rail operation is the prepared logistic plan. When no deviation occurs from this plan, the system can practically be run automatically and causes work under-load. When deviations occur, the plan is updated or direct commands to the infrastructure are executed. The workload can be estimated through these measurable system activities. Neerincx (2003) proposed a model to measure the workload during operations, as a function of three variables: task switches, task time duration and task complexity. Each of the above system activities could be seen as part of a task sequence providing the possibility to count the task switches and task duration. Complexity in this model is defined by Rasmussens SRK-levels (Rasmussen, 1986). Each change of the plan needs reasoning and is at least rule-based but mostly knowledge based. This modeling makes it possible to estimate the workload with indirect measurements and can be expressed as follows:

$\alpha_W = f_W$(plan adaptations, direct actions on the infra);

$\Delta\alpha_W = K_{1W}$(Δ plan adaptations) + K_{2W}(Δ direct actions on the infra);

Workload RS: $\Delta\alpha_W$ < Threshold-RS_W < 0

The workload change can be estimated by the change of plan adaptations and the number of actions on the infrastructure. The workload RS can be defined when the slope decrease is larger than a predefined threshold, Threshold-RS_W. The weighted relations K_{1W}, K_{2W} and Threshold-RS_W need to be worked out empirically.

4 TWO EMPIRICAL CASES USING THE RESILIENCE SIGNAL (RS) MODEL

The RS model described above needs to be verified and tuned according to empirical testing within the railway *operations* itself, which will provide the needed detailed information. However, in the public domain information may be gleaned from reports describing situations on a national level and on a yearly basis. The report from the Dutch Ministry of Infrastructure and Environment - Inspection of Environment and Transport (2011) on red signal passage, chosen for its relevance to the safety boundary, and the report from the Dutch Competition Authority (2010) on the rail capacity, chosen for its relevance to the performance boundary, were analyzed and provided two cases with respect to the RS model.

4.1 Correlation between a safety RS and safety risk

One of the assumptions of the safety signal model, worked out in the previous paragraph, is that a growing number of SPADs indicates a growing safety pressure. This assumption, among others, needs to be proven empirically, since a SPAD does not always create a high risk situation. For example, if no train is in the block behind a red signal the probability of a collision is very low. The aspect of differentiating between a SPAD with a high or low risk has been worked out by the Dutch Ministry of Infrastructure and Environment (2011) that tracks and reports yearly on the status of SPADs. It uses for each SPAD the SPAD Risk ranking methodology, a standard of the RSSB (Rail safety and standards board), which takes into account among others the relative positions, velocities, infra setting, etc. to calculate the risk of a serious accident. These figures, the number of yearly SPADs with a high risk, have been extracted from the report as well as the total number of yearly SPADs, and plotted against each other. The result for the period 2007-2011 shows that the two variables are highly correlated (Pearson r = 0,98), justifying the intuitive safety RS model assumption that a growing number of SPADs indeed signals a growing pressure on the safety boundary. The other assumptions that red signal stopping, Yellow signal passage and crossing rail-paths are safety signals as well, still need to be tested empirically.

4.2 Analysis of a capacity RS and a safety RS

Does a resilience signal (RS) always imply that the resilience of the system is degraded? This is in theory not the case, since a signal implies a growing pressure on the boundaries but the total impact on the whole system still needs to be analyzed. As an empirical example, we have taken the capacity RS reported by the Dutch Competition Authority (Nederlandse Mededingingsauthoriteit - NMa) (2010), stating a yearly capacity grow of the Dutch rail infrastructure utilization, in the period between 2005 and 2009. This situation could be described by the resilience state model in figure 1-III, where the operating state is moving towards the safety boundary, due to a capacity growing pressure. This may lead towards a brittle situation when also a growing pressure on the safety boundary is seen, as in option a, or it may lead to sustain the resilience of the system, as in option b, where appropriate internal measurements are taken. To draw a conclusion, additional data have been used from Dutch Ministry of Infrastructure and Environment report (2011) where SPADs in the period between 2007 and 2011 have been recorded. The two sets of data, in the overlapping period between 2007 and 2009, have been plotted against each other. The result shows clearly that while the capacity utilization is increasing, the SPADs are decreasing, meaning that the internal system has organized itself in a resilient manner as shown in option 3b. This surprising result invites further analysis, which can be extracted from the Infrastructure and Environment report (2011) as well.

Already in the 1990s, the system logged a growing number of SPADs. This triggered the Railned company to write a report on the status of the rail system (Gotz, 2002). This report was presented to the parliament (Peijs, 2004). It was only after the collision in Amsterdam on May 21 2004 that different rail groups were triggered to set up a parliamentary steering committee on the subject of SPADs. This committee defined the following targets:

50% reduction of the 2003 SPADs to be achieved in 2009

75% reduction of 2003 SPAD risks to be achieved in 2009

These targets were adopted by the Minister and presented to parliament. Accordingly, the steering committee set up a program to achieve the targets divided into 4 parts (Rail branch steering committee SPADs, 2009 - the year of the Barendrecht accident on September 24):

1) A program for Train-drivers; 2) Automatic system for influencing trains (ATB) revised version; 3) Emplacement analysis; 4) Setup regulations

The above case shows the adaptive capability of the socio-technical railway system over a period of many years and accidents. This process can be described by a multi-level hierarchy (Rasmussen, 1997) depicted in figure 3.

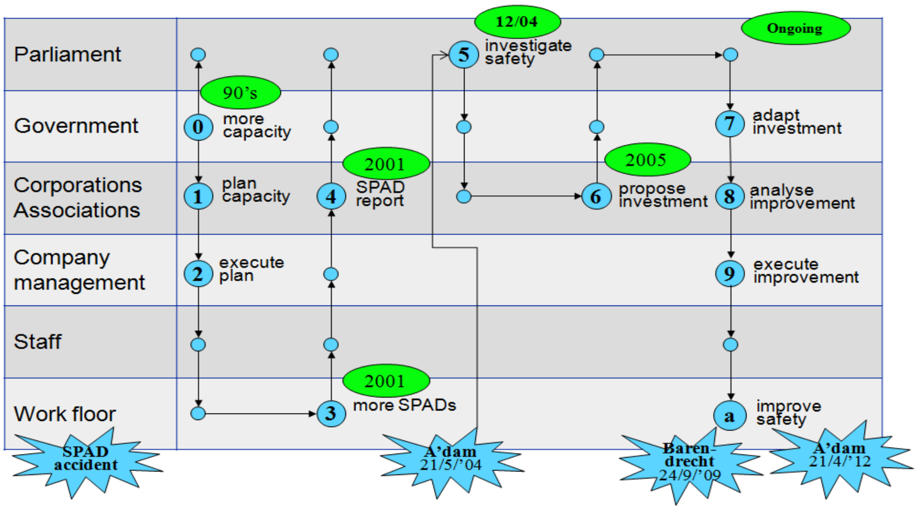

Figure 3. Multi-level hierarchy explaining the adaptation process

Although the main trigger to come into action were the accidents, the initial trigger was the growing number of SPADs - a safety RS.

5 CONCLUSIONS AND NEXT RESEARCH STEPS

Quantification of resilience system-state attributes is important to enhance operational awareness and stimulate rail traffic operators to take an attitude to explore and anticipate the unknown and unexpected future. We have chosen to explore resilience signaling rather than the resilience boundaries themselves since these boundaries are not tangible because, on the one hand, resilience is about regions beyond the standard behavior of the system and, on the other hand, the boundaries are uncertain (Cook & Rasmussen, 2005) and constantly moving, due to the socio-technical nature of the system. Signals are by their nature not solid but give a clue on possible events that may occur.

In this paper, we have developed resilience signals (RS) with a focus on the Dutch railway system. Most probably these results are applicable to other railway systems and to other semi-governmental transport systems. These expectations can only be verified after the modeling has been adjusted according to further empirical investigation within the Dutch rail environment, where more operational parameters will be imposed maturing the results for usage in real-time operations.

The empirical example in this article has a limited significance, due to data of a short three year period with coarse granularity in yearly and national units, but is a good case showing that resilience signals (RS) are by nature not strong signals and need further investigation, to draw correct conclusions. This is exactly the role of the system operators at the anticipation cornerstone.

Acknowledgment

We appreciate the constructive comments of the reviewers and Alfons Schaafma's guidance. This research was conducted within the RAILROAD project and is supported by ProRail and the Netherlands organization for scientific research (NWO) under grant 438-12-306.

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Trade-offs in the planning of rail engineering work

Pedro Ferreira[1], John Wilson[2], Brendan Ryan[2], Sarah Sharples[2] and Theresa Clarke[3]
[1]CIGEST, ISG - Business School, Rua Vitorino Nemésio 5, 1750-306 Lisbon, Portugal
pnpferreira@netcabo.pt
[2]University of Nottingham, University Park, Nottingham NG7 2RD, UK
john.wilson@nottingham.ac.uk
Brendan.Ryan@nottingham.ac.uk
Sarah.Sharples@nottingham.ac.uk
[3]High Speed 2 – 2nd Flr, Eland House, Bressenden Place, London SW1E 5DU, UK
Theresa.Clarke@hs2.org.uk

Abstract

Planning and scheduling activities are progressively recognised as a critical element of any organisation, which often becomes exposed to many sources of business and operational pressures. The underspecified nature of operations in complex sociotechnical systems and the increased degrees of uncertainty and variability that tend to characterise them, may compromise the ability to accurately plan, as the understanding of operational settings and resource availability may also become increasingly uncertain and variable.

This paper initially describes planning activities as complex and distributed decision making processes, throughout which trade-offs emerge, mainly as the consequence of the finite nature of all resources. Based on a case study developed within the Great Britain rail industry, the impacts on planning of high complexity and the exposure to high business and operational pressures are then discussed, as well as the potential contributions of enhanced planning performance towards overall system resilience.

1 INTRODUCTION

The finite nature of all resources is an underlying aspect of every planning and scheduling activity. It is a common realisation that one cannot have everything in life and therefore, as time, money or otherwise resource availability becomes critical, choices must be made. Such choices are the result of decision making processes that give shape to business or operational objectives and priorities. Hence, planning activities are essentially decision making processes that aim to anticipate resource requirements in response to a given set of objectives.

Within many industrial domains, planning functions are faced with decision making processes that assume both business and safety critical roles. In such domains, planning is frequently exposed to significant pressures, stemming from stakeholders that at different stages, try to see their business and safety needs contemplated in the plans being developed. In line with the ETTO principle (Hollnagel 2009), this also means that planning often assumes a critical role in balancing business objectives and commitments, against safety imperatives.

Evidence from recent research (Ferreira 2011) suggests that the underspecified nature of complex sociotechnical systems may bring about an underestimation of the limitations affecting technical, human and organisational resources. The high pace of change in complex operations can impact on the understanding of systems performance. The ability to plan accurately becomes progressively more difficult because it relies on knowing how and when given resources can be allocated.

Within research carried out in the field of GB rail engineering (Ferreira 2011), a case study was developed, based on work delivery failures and serious overruns across the country, with evidence of serious planning and engineering supervision shortfalls. This paper reports on the outcome of this study and discusses how planning decisions can lead to a poor availability of resources, as well as to the underestimation of work complexity and its deliverability risks. The relations between planning and engineering teams (responsible for the work programmes and the oversight of their delivery) are also addressed, in order to demonstrate the extent of the planning failures and their causal factors. Conclusions and events are then discussed in view of resilience engineering concepts, in particular considering the four cornerstones of resilience (Hollnagel 2011).

2 THE GB RAIL INDUSTRY

The GB rail industry is currently experiencing a significant growth. Between 2004 and 2011 it has registered an increase of 23% in the number of passenger-kilometres (PK), one of the highest growth rates in Europe. Within the period going from 2009 to 2014, a public investment of approximately 30 000 million pounds was planned for the modernization and enhancement of the rail network. These indicators reflect the demands for increased capacity and for heightened overall safety and reliability that are imposed on the rail industry. Despite such demands, there is a significant pressure on industry stakeholders to reduce their reliance on public finance and subsidies. Hence, the railways are currently operating under a strong scrutiny, both from government and the public in general.

This high pressure context impacts on all industry stakeholders, but in particular on the infrastructure manager, as it provides a service, relied on by the remaining industry partners. This service mainly consists on providing safe and reliable access to the rail network for the purposes of running trains or delivering engineering work. The main sources of pressure are represented in Figure 1.

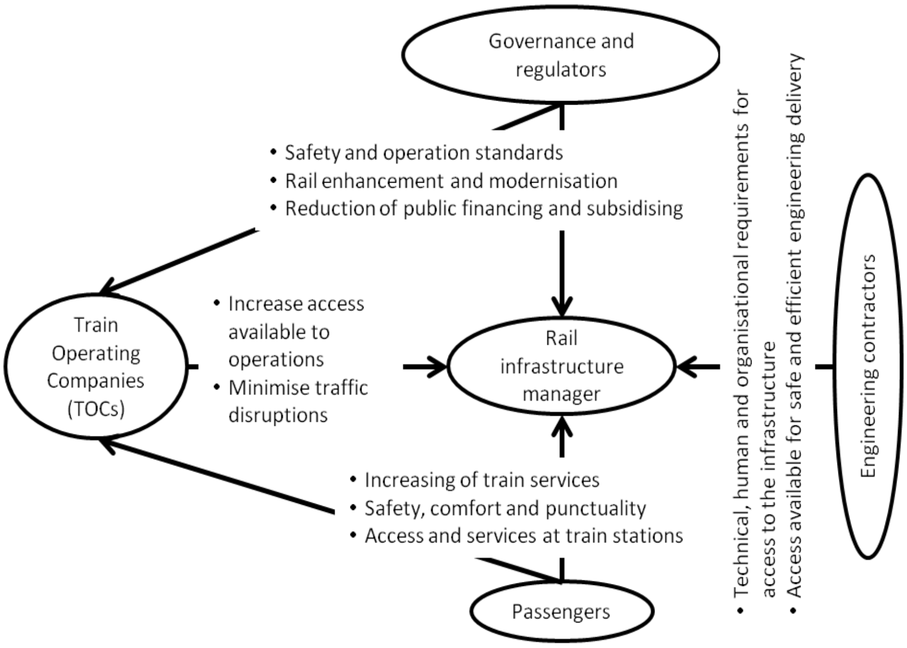

Figure 1. *Main sources of pressure on rail infrastructure manager*

Within this scope, the infrastructure manager must be capable of maintaining a balance between two opposing access needs:

- Providing as much access to rail operators so as to maximise revenues from access charges, as well as respond to increasing demands for rail services.
- Allocate the volume of access necessary to respond to maintenance needs and enhancement projects.

Managing this balance falls considerably under organisational units and teams responsible for both the operational (train services) and the engineering planning activities. While operational planning aims to manage and maximise the response to the first of these needs, engineering planning focuses on the second one. In practice, despite the fact that these two sides of planning are entirely independent, they actually compete for the same critical resource: access to the infrastructure. In line with the concept described by Hollnagel (2009), this emphasises the nature of rail planning as a decision making process that must constantly trade-off between favouring operational efficiency and providing the access necessary for a sufficiently thorough maintenance and engineering work.

2.1 Engineering planning

The engineering planning process focuses on managing and forecasting resource needs, in particular access to the infrastructure, for the purpose of carrying out all maintenance and renewals work. As discussed by Profillidis (2006), the planning and scheduling of rail maintenance is faced with two opposing processes:

- The traffic process which, by means of rolling stock contributes to track wear-out and thus contributing to an increase of track defects and the destabilising of the system as whole.
- The maintenance process which strives to reduce track defects and restore the safety operational conditions, thus maintaining the balance of the system.

The engineering planning process has an average duration of 90 weeks, going from the definition of a basic scope of work, down to all the necessary details of work delivery. It is structured around three main stages, which progressively integrate details regarding the different items of engineering work to be delivered. These three stages can be described as follows:

- Access planning: establishes the times and locations at which access will be granted for engineering work.
- Possession planning: consists on the integration of different work items to be carried out at a given time and location, within common protection arrangements. These arrangements essentially aim to isolate the areas of track on which engineering work will be undertaken from any part of the railway remaining open to regular train traffic.
- Worksite planning: this stage is partly developed in parallel with possession planning and it consists on the scheduling and sequencing of all aspects of work delivery.

The infrastructure manager has ownership of this process and is responsible for its entire development. However, it relies on critical input from other industry stakeholders, both from within and outside the organisation. Aiming to optimise resource allocation (e.g. machinery, haulage, staff and access), the planning process must request as much information as possible from stakeholders (contractors, maintenance units) regarding the engineering work to be carried out, in order to establish priorities and ensure the safety and reliability of access and work on the rail infrastructure. Within this context, planning must be capable of negotiating priorities and allocating access and other critical resources in the most efficient way, whilst ensuring the conditions necessary to safely deliver reliable engineering work.

3 THE CASE STUDY

The events described took place around the period of Christmas 2007, during which several major renewals and enhancement projects were planned for completion, nationally. The reduction in passenger numbers that is normally experienced between Christmas and New Year makes this period a favourable time for the delivery of work that requires significant disruptions of timetable train services. In 2007, the weeks leading up to the Christmas period were marked by an increasing pressure to complete several work programmes that were critical for an enhanced train timetable to become effective in January 2008. This was later described as the most intensive period of engineering work in the history of the UK rail network since its privatisation. The following facts and figures demonstrate the scale and complexity of this national plan:

- Between 24 December 2007 and 2 January 2008 more than 1000 pieces of work were delivered.
- More than 123 million pounds were invested.
- 414 possessions and 2300 worksites were being delivered.
- Over 1.2 million man hours were worked, which amounts to 5000 people working on the railway at any time in a 24-hour period.

Throughout this period and amongst all the work planned and delivered across the entire network, only one minor accident occurred. However, three major possession overruns occurred, causing serious disruptions to train services. These major overruns occurred at Rugby, Liverpool Street (London) and Shields Junction (Glasgow).

Evidence from investigations into events (ORR 2008) suggested that at different stages of the planning decision making process, the pressure to trade-off business objectives against safety and reliability needs, led to a work delivery scenario that greatly exceeded the available capacities of the system. In particular, during work around the area of Rugby station, numerous accumulated delays and minor incidents (as described below) caused the work programme to drift beyond the planned schedule. Mainly due to inaccurate delivery reports and poor site supervision, the seriousness of such drift went undetected up until the point where the work programme had already extended 14 hours beyond the planned completion time. Only then a serious loss of control over the work delivery was recognised. The work programme at Rugby area overran for nearly four extra days, causing serious disruptions to normal train operations. The complexity and volume of work within the Christmas period, at several locations nationwide, proved to dramatically exceed resource availability and management capabilities.

The study carried out by Ferreira (2011) consisted mainly on the analysis of archival data regarding work delivery within the Christmas period and during the previous weeks (when parts of the work programme were already being carried out), as well as planning records. The main aspects of the Rugby overrun can be summarised as follows:

- Apart from the infrastructure manager as the owner of the project, many other stakeholders were involved in the planning and delivery of the Rugby project, as well as the remaining ones across the network (train operating companies, engineering consultants, contractors, and staff agencies, among others).
- An initial scheme from 2002/2003 consisted on demolishing and relocating Rugby station. In 2004 this was replaced by a less costly scheme that worked around the current location to rebuild the station and reconfigure track layouts. Despite reducing costs, this new project introduced technical challenges with a degree of complexity never before experienced by the team responsible for the modernisation programme.
- In mid December 2007 the infrastructure manager announced that it was extending the planned possession at Rugby by an additional day (31 December). This was in response to the loss of various preliminary works on three preceding weekends, which represented an accumulated delay of the modernisation programme to be completed by January 2008. As an additional contingency, lower priority work planned for other parts of the country was deferred in order to reallocate more resources to the Rugby Christmas possessions.
- The Rugby possession itself then overran badly, until 4 January 2008. The main reason was a severe shortage of skilled and supervisory overhead line electrification engineers. Although the infrastructure manager had identified this as a critical resource and, in an unusual step, had obtained the names of rostered individuals from its contractors in advance, many named individuals failed to turn up and many of those who did arrive worked fewer hours than planned.
- Several unexpected events took place throughout delivery, such as the discovery of buried services in the station area and the derailment of an engineering train. Although these events required minor re-planning and the deployment of contingencies, the testimonies gathered during the investigations refute these events as causes for the overrun, as each of them was considered manageable under normal delivery circumstances.
- Information provided to management by the engineering contractors during the works was badly inaccurate, partly as a result of the shortage of skilled staff. As a result managers did not appreciate that the work was running into serious difficulty until well after this should have been apparent. Under the circumstances, it may not have been possible to avoid an overrun entirely, but because of the delays in communication, effective actions to mitigate an overrun were taken too late. Train operators were not warned that an overrun was likely until the afternoon of 31 December, and accurate information about the duration was not provided until 2 January 2008. This exacerbated the disruption to rail users.

As foreseen within the planning process, deliverability risk assessments were undertaken, through which several critical aspects were identified, including the sequential nature of the work programmes and the overhead line electrification staff and resources. Mitigation measures were planned and later deployed, as delivery problems emerged (as previously mentioned). However, these measures rapidly became insufficient to recover “normal performance” in work delivery. This indicates that, not only planning may have underestimated deliverability risks, but also that mitigation actions may have been inappropriate or insufficient in view of the existing risks. Only after the deployment of management and control measures equal to those of a state of emergency (e.g. implementation of a “Gold Command”), recovery and conclusion of work was possible.

Evidence documented in Ferreira (2011) points towards the fact that the underestimation of risks was mainly motivated by the poor quality of data supplied to the team responsible for the work programme. The information that was needed depended on a large number of stakeholders and each one of them was producing delivery details for which they were responsible for at different timings. This created severe difficulties for the project team in developing an accurate and up-to-date scenario for work delivery.

Throughout the investigation reports (ORR 2008), there are several references to poor communication and difficulties in obtaining up-to-date information. There is evidence to suggest that the inter-organisational structure for the engineering work was too fragmented to respond to such demands. The scope of the Rugby project and its ambitious targets would seem to require a much more cohesive and dynamic system in order to support the complex interactions between all stakeholders that were involved and indeed necessary to successfully deliver the precise sequence of work that was planned.

4 DISCUSSION

In line with concept introduced by Pinedo (2009), engineering planning can be described as a complex decision making process, ranging from high level strategic business decisions down to the definition and scheduling of work details and its delivery on the rail infrastructure. This means that planning teams are considerably exposed to several sources of pressure, namely business and strategic targets, as well as operational and safety requirements. In hindsight, it is clear that the pressures to deliver an enhanced rail capacity by the New Year were of such degree that they encouraged the development of work plans for the Christmas 2007 period, which traded-off in favour of a maximised resource utilisation, with detriment to a more balanced and safer usage.

Regarding the unexpected events during delivery, although it was mentioned that these were considered to be within the operational capacity (ORR 2008), they required the full attention of site engineers. Being mobilised by the need to solve arising problems, site engineers were unable to properly monitor the work development and its drift away from project targets. In light of resilience engineering literature and in particular the concept of functional resonance (Hollnagel 2012), this can be interpreted as a sequence of normal (manageable) events that generated a degree of operational variability that exceeded the ability of the system to adapt.

Overall, the engineering planning function was unable to accurately estimate resource availability at national and local level, but also, planning decision making and risk assessment was supported by poor information regarding the actual development of the work programmes during the weeks leading up to the critical work period of the Christmas time. This suggests that reliable planning needs to be supported by a close contact with engineering work delivery. Such contact appears to be a fundamental support to understanding the operational settings and to be able to anticipate resource needs, in view of the established objectives. The close interaction between planning and work delivery also appears to provide the means necessary for the development and deployment of appropriate and effective contingencies and the readjustment of plans, as unexpected events arise.

These findings are similar to those observed by McCarthy & Wilson (2001) in relation to manufacturing industry contexts, where the physical and organisational proximity of planning with the shop floor can significantly contribute to the efficiency and reliability of planning activities. However, the large geographical and time scale of rail engineering planning, as well as its complex organisational structure, may render this close interaction simultaneously more essential and difficult to implement. As noted by Ferreira (2011), the fact that planning teams normally work according to regular office hours while engineering teams mainly work on night shifts (the large majority of engineering work can only be delivered during night time), already constitutes a considerable obstacle, among many other technical, organisational and human factors.

5 CONCLUSIONS

The Christmas 2007 overruns illustrate the critical role of planning in overall system performance. They also underline the nature of planning as a decision making process, throughout which the impacts of uncertainty and variability resulting from high system complexity, become apparent. As operational and business pressures lead the system to explore the limits of its resource availability, many forms of "ETTOing" (Hollnagel 2009) emerge at the core of this complex decision making process. Many factors, other than those directly related to planning, have contributed to the loss of control over work delivery at Rugby, in particular those related to on-site management of work delivery. Nevertheless, it is clear that planning ETTOing created the settings that escalated towards delivery failure.

In view of the four cornerstones of resilience (Hollnagel et al 2011), planning may be considered as an essential support to the ability to anticipate both the critical and the potential. It therefore becomes essential to identify how lack of visibility over resource availability may emerge and understand how it may hinder planning performance and the way in which it provides reliable support to engineering work delivery. Planning can also constitute an important support to the ability to learn. In many ways, planning establishes what is expected in terms of system performance. It therefore defines what the system envisages as successful performance. Hence, planning may also represent an important support to the development of an ability to learn through success, rather than through failure, as it provides a basis on which to measure success.

Operations planning and engineering planning compete for the same primary resource (access to the infrastructure), but these two types of planning tend to be approached as independent processes. This competition ultimately results in a critical trade-off between maximising operational efficiency and thorough maintenance of the rail infrastructure. Therefore, it can be argued that a closer interaction between these two sides of planning may contribute an improved balance between two fundamental but opposing needs of the rail industry, hence contributing to enhanced system resilience.

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Resilience in ATM operations: Incorporating Robustness and Resilience in Safety Assessment

Rogier Woltjer[1], Jonas Haraldsson[1], Ella Pinska-Chauvin[2],
Tom Laursen[3], Billy Josefsson[4]
[1] Swedish Defence Research Agency FOI, Linköping, Sweden
rogier.woltjer@foi.se, jonas.haraldsson@foi.se
[2] EUROCONTROL, Brétigny-sur-Orge, France
ella.pinska-chauvin@eurocontrol.int
[3] IFATCA & NAVIAIR, Denmark
mettom@private.dk
[4] NORACON/LFV, Norrköping, Sweden
billy.josefsson@lfv.se

Abstract

The paper describes the approach taken to analyse air traffic operations and develop robustness and resilience guidance, with a focus on resilience. It summarizes the main principles of robustness and resilience applied to ATC/ATM as developed in the SESAR JU 16.01.02 project. The on-going project aims to incorporate these principles as part of safety assessment guidance into the SESAR Safety Reference Material and formulate the principles for ATM concept design. Specifically, the following resilience aspects are discussed in detail: actual practice, procedures and techniques of all actors, goal trade-offs, adaptive capacity, human performance, capacity near margins, buffers and tolerances, coordination, complexity, coupling, interactions, tractability, cascading, control time scales, timing, pacing, and synchronization, under-specification and approximate adjustments. Operational examples to illustrate some of these principles are provided.

1 INTRODUCTION

Air Traffic Management (ATM) safety is usually addressed in safety assessment and design by means of minimizing negative outcomes through attempting to eliminate hazards, preventing adverse events, setting constraints, or protecting/mitigating against adverse consequences. However, considering the actual number of incidents of about one in 10.000 non-incident events, understanding safety cannot be based exclusively on incidents (EUROCONTROL, 2009). Thus, new perspectives focusing on understanding everyday operations are necessary. The perspectives of Resilience Engineering (Hollnagel et al., 2006; 2011) and Safety-II (Hollnagel, 2012a) aim to understand why everyday performance succeeds. In this context, safety is understood as the ability to succeed under varying conditions (Hollnagel, 2011b).

As part of the Single European Sky (SES) initiative of the European Commission, the SESAR (Single European Sky ATM Research, see www.sesarju.eu) programme is designing new ATM concepts with the aims of improving fuel efficiency, cost efficiency, safety, and airspace capacity. A large number of technical and operational projects aim to develop concepts (technology and working methods) towards these goals, meaning that new trade-offs between safety, efficiency, and capacity will likely need to be found for future operations. Functional changes and new trade-offs have the potential to make socio-technical systems brittle (Hoffman & Woods, 2011; Woods & Branlat, 2011) emphasizing the need for Resilience Engineering and Safety-II concepts in ATM.

The concepts and perspectives from the new Resilience Engineering discipline have as yet hardly made their way into Air Navigation Service Providers (safety) management processes. SESAR Project P16.01.02 "Ensuring ATM with SESAR is kept resilient" described here aims to do a step in that direction. The SESAR Safety Reference Material (SRM) (Fowler, Perrin, & Pierce, 2011) is the process by which operational and technical projects assess safety of the concepts they develop. There are a suite of research projects (e.g., P16.01.02) looking to explore how novel approaches to safety can be delivered into SESAR. Their vehicle to do this is via the SRM, as technical annexes. Thus, P16.01.02 has been assigned by SESAR Joint Undertaking to develop guidance for resilience to be part of the SRM, as well as general resilience design guidelines for ATM.

Based on the resilience literature the following working definition for resilience was derived for the 16.01.02 project. The working definition of robustness was derived from the definition of resilience focusing on anticipation and handling expected disturbances, in its scope closer to a Safety-I (Hollnagel, 2012a) approach.

Robustness is the ability of the ATM system to anticipate and handle expected disturbances, whilst sustaining required operations.

Resilience is the ability of the ATM system “to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions” (Hollnagel, 2011b, p. xxxvi).

A two-fold approach was chosen for this study with robustness interpreted as a first step towards the broader and more encompassing emergent property of resilience.

2 MEtHOD

2.1 Robustness: Incident data

In the initial phase an incident analysis template was developed, for incident analysis from both robustness and resilience perspectives, with a focus on robustness.

The robustness part of the template was developed by simplifying HERA-SMART (Pariès et al., 2003), a method derived from Reason’s Swiss Cheese metaphor (Reason, Hollnagel, & Pariès, 2006) adopted to ATM, asking questions on prevention, recovery, and mitigation, regarding events in the incidents. The analysis took place during two one-week workshops involving staff from the Air Navigation Service Providers (ANSPs) utilizing their knowledge of the operational environment where the data were collected from. This analysis included 15 incidents from two European ANSPs and was used to develop Robustness Principles for ATM.

2.2 Resilience: Everyday operations data

As the second stage of the project a series of observations, interviews and workshops addressing everyday operations at Air Traffic Service Units were conducted with a focus on resilience. Observations were focused on 3 operational units (control towers) with a diverse mix of traffic types. Workshops and interviews were conducted with air traffic controllers, managers, and safety personnel from several other towers, area control centres, and terminal area control units, as well as ANSP headquarters. Data was gathered and analysed using concepts described in the emerging Resilience Engineering literature (e.g., Hoffman & Woods, 2011; Hollnagel, 2004; 2009; 2011a; 2011b; 2012a; 2012b; Hollnagel et al., 2006; 2011), and Resilience Principles for ATM were developed.

The resilience part of the incident analysis template (see Section 2.1) was developed by including selected questions from the newly proposed Resilience Engineering method Resilience Assessment Grid (RAG; Hollnagel, 2011a) as well as other questions derived from the Resilience Engineering literature. The resilience analysis of the incidents was included in the generation of the Resilience Principles.

3 RESULTS

3.1 Robustness Principles

The Robustness Principles include the following subjects:

- varying conditions,
- predictability, usability,
- actual practice, procedures, and techniques,
- human performance,
- signals and cues,
- control time scales,
- technical transparency,
- controlling practice or “defensive” controlling,
- communication aspects,
- airspace/airport design,
- ATC-cockpit interactions,
- stepwise implementation,
- automation.

There are similarities and links between the Robustness and Resilience Principles, due to the project approach of using robustness as a first step towards resilience. Robustness and Resilience Guidance merged towards the end of the project. The focus of the remainder of this paper is on the Resilience Principles for ATM.

3.2 Resilience Principles

The Resilience Principles (numbered ResP*nn*) include the following subjects:

- actual practice, procedures and techniques of all actors,
- complexity, coupling, interactions, tractability, cascading,
- goal trade-offs,
- control time scales,
- human performance,
- timing, pacing, and synchronization,
- capacity near margins, buffers and tolerances,
- coordination,
- under-specification and approximate adjustments.

ResP01: Actual practice, procedures and techniques of all actors. Safety assessments should be sensitive to actual everyday operator performance, and to specific conditions of operational environments and tools, and how these interact with each other and with ATM changes. Rather than labelling these as “human errors” or “deviations” from procedures or training, Resilience Engineering aims to gain a deeper understanding and appreciation of performance variability (Hollnagel, 2004). This includes operators’ techniques to handle situations beyond what is addressed in procedures or training. With operators we mean not only controllers but also stakeholder and actors (in)directly interacting with ATC, including pilots, airline operations centres, ground vehicle operators, maintenance personnel, military airspace users, etc. “Techniques” refer to the ways operators use procedures and other working methods, strategies and practices to achieve safety and efficiency.

ResP02: Goal trade-offs. The recognition of the effects of multiple goals is critical for understanding the variability that arises in daily operations (see Hollnagel, 2009; Hoffman & Woods, 2011). In SESAR terms, Key Performance Areas (KPAs) such as Safety, Security, Environmental Sustainability, Cost Effectiveness, Capacity, Efficiency, Flexibility, and Predictability are often tightly coupled and related in that optimising or prioritising one may affect others. In that sense a design of an operational ATM functional system is by necessity sacrificing all KPAs to some extent, and some more than others. Furthermore one may identify conflicts within and between these KPAs, such as long-term versus short term goals, goals from different functional systems or stakeholders’ perspectives (e.g. ANSPs versus other actors on and around the airport). Anticipating how a design and its associated operational performance can strike an appropriate trade-off is essential from a Resilience Engineering perspective.

Example 1: Techniques & trade-offs. Capacity goals may have been optimized and set in a manner to satisfy safety goals, while leaving little margin for variations in behaviour. For example, the capacity for landings per hour may be set to a certain (high) number meaning that in peak traffic hours the traffic has to be separated at the minimum separation (and exceptions may have been approved that enable separating below the standard separation, further decreasing margins). Ways of performing the function Sequencing & Spacing to meet these capacity goals may be highly reliant on physical solutions (e.g. high speed runway exits) and predictability in conditions (e.g. visibility, winds), possibilities of controlling traffic (e.g. actively controlling approach speed of aircraft, which makes the performance of the approach more brittle from a pilot’s perspective) and skill (controllers having developed techniques through training and experience on safely controlling with little margin).

Example 2: Techniques & trade-offs. APP controllers performing the function Sequencing & Spacing, may be currently doing radar vectoring from the feeder fix to runway threshold in order to take into account unexpected flights entering the sequence late, avoid adverse weather (e.g., CB), vector other traffic around unexpected aircraft movements, handle emergencies, etc., while maintaining a high runway capacity and high service level for airspace users. How this vectoring is done is a technique not specified in detail in the procedures. Change of new scheduling concepts and technology using for example points further or closer from the threshold or at the threshold, would change the ability for the ATM system to provide the Sequencing & Spacing function flexibly and effectively, and would change the ability to handle unexpected events. This technique therefore needs to be considered when making AMAN scheduling changes and thereby changing the Sequencing & Spacing function in the TMA.

ResP03: Adaptive capacity. The effects of many conditions can to a certain extent be anticipated analytically or through simulation, and mitigated as part of design, development and safety assessment. This preparation forms the *base* adaptive capacity of the ATM functional system, including training, procedures, HMI and technical capabilities, and degraded modes and contingency plans. The Resilience Engineering perspective recognises that one will (as a consequence of complexity and dynamics) never be able to go through the full range of possible operational scenarios that will occur during the operational lifetime of a technical system, operational concept, or ATM unit. Unexpected events will occur at some point, which don't quite match the conditions for triggering the planned responses. Adjustments, adaptations, flexibility, and/or improvisation are necessary to a varying degree, based on experience (see also Hollnagel, 2009; Woods & Branlat, 2011).

ResP04: Human performance. Most of the adaptive capacity that goes beyond the base adaptive capacity of the ATM functional system is based on operators' exclusively human capabilities (especially attention management, problem detection, adaptation to situational circumstances, ability to achieve goals using different means and methods). This human (or team) ability of providing resilience can only be preserved if the conditions and information necessary for operators to be in control and adapt (through processes of anticipating, monitoring, and responding) are acknowledged.

ResP05: Buffering capacity near margins, and tolerance. In order to meet the challenges of the inescapable nature of unexpected events and adjusting the base and beyond-base adaptive capacity, several characteristics of resilient systems can be engineered into the functional system to improve the ability to anticipate when the system should adapt and providing it with a readiness to respond and meet changing demands before hazardous situations occur. Several such systemic characteristics have been identified, such as buffering capacity, margins, tolerance, and flexibility (Woods, 2006).

Example 3: Margins. Alternate airports and fuel levels and margins seem to be handled differently today by flight crews and airlines than some years ago. Functional changes to the ATM system (e.g. tools and working methods) that pertain to approach should acknowledge the way flight crews handle fuel margins and in various circumstances.

ResP06: Coordination. The ability to flexibly coordinate between ATCOs, pilots, and all other actors and stakeholders when the situation demands this is a major source of resilience that needs to be addressed explicitly in safety assessment for ATM changes. Human operators rely to a significant extent on flexible and improvised use of coordination and communication content (what is said) and channels (who to contact and how) in order to solve challenging situations that go beyond the base adaptive capacity to handle varying conditions. Technology-based functional changes such as automated communication and information sharing will thus likely affect the ability to cope with unexpected challenges and disruptions, which need to be assessed.

ResP07: Complexity, coupling, interactions, tractability, cascading. Central to Resilience Engineering for ATM is an understanding that the ATM functional system should be regarded as a network of nodes where functions are performed in a distributed manner. Properties (cf. KPAs) such as efficiency, capacity, flexibility, safety, and resilience are dynamic and cannot be attributed to static properties of components but emerge out of the joint behaviour of the nodes in a distributed air traffic system. More complexity and less tractability typically lead to higher demands on human operators and human-technology-systems in unanticipated situations, and typically increase the risk for small variations cascading (unpredicted and undetected) into hazardous situations, resulting in a more brittle (less resilient) system.

Example 4. Complexity and tractability. In one of the incidents studied, an inactivated flight was manually activated in an unexpected manner (the activation looked solved for that ATCO and sector perspective). The flight activation however was sent to the previous rather than the next sector. Underlying technical system logic turned out to be incompatible with actual ATCO problem solving methods leading to a brittle system.

ResP08: Control time scales. Critical aspects of resilience are the timing aspects of synchronisation and the pacing of tasks. Effects at different time scales should be considered in assessing resilience as for example carry-over effects from strategic to pre-tactical to tactical operations across various stakeholders as they may cascade into non-linear effects (see also Woods, 2006).

ResP09: Timing, pacing, and synchronization. The dynamics of the ATM system are critical to understand when assessing which aspects of a change make the functional system resilient and which make it brittle, especially in human-automation joint systems (DSB, 2012). Time may in many cases be the aspect providing buffer capacity.

***ResP10: Under-specification and approximate adjustments*.** Under-specification means that descriptions of procedures and the use of technical systems are not fully specified for the actual situations that will be met during everyday operations, because the conditions of work cannot be fully specified. Thus operators necessarily have to make approximate adjustments of their performance to the context, and their performance has to be variable, to be able to cope with unexpected situations and conditions (Hollnagel, 2004, 2009, 2012b). From a safety assessment perspective it should be recognized and anticipated to the highest extent possible that SOPs and tools will be used in different ways than exactly as-designed, to meet varying demands.

4 CONCLUSIONS

The paper describes the approach taken to analyse air traffic operations and develop robustness and resilience guidance, with a focus on resilience. It summarizes the main principles of robustness and resilience applied to ATC/ATM as developed in the SESAR JU 16.01.02 project. Operational examples to illustrate some of these principles have been provided.

Based on these principles, preliminary SRM Robustness and Resilience Guidance has been derived. On-going continuation of this development includes validation of the guidance on SESAR R&D projects and refining the guidance to fit into the SRM, as well as validating the principles as design guidelines for ATM. Ideas for future research in the ATM industry include extending the Safety-II and Resilience Engineering approach into ATM management beyond the established safety assessment and human performance assessment processes.

Acknowledgment

The project work presented in this paper is part of the SESAR Joint Undertaking P16.01.02 and we gratefully acknowledge the contribution of project-external informants and the project members from the SJU P16.01.02 project partners: NORACON, EUROCONTROL, NATS, AENA, ENAV, INDRA, and AIRBUS. Opinions in this publication are the authors' and are not intended to represent the positions of SESAR JU or its project member organisations.

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"Staying ahead of the aircraft" and Managing Surprise in Modern Airliners

Amy Rankin [1], Rogier Woltjer [2] Joris Field[3], David Woods[4]
[1,2] Linköping University, Linköping, Sweden
[1]amy.rankin, [2]rogier.woltjer@liu.se
[3] NLR, Amsterdam, The Netherlands
joris.field@nlr.nl
[4] Ohio State University, USA
woods.2@osu.edu

Abstract

The pilot's task in commercial aircraft operations has changed from flying the aircraft by means of manual control, to increased monitoring of the cockpit. The increase of automation provides a high level of stability and reduces variations and disturbances, leaving crews with little exposure to surprise. Current training programs are similarly focused on dealing with anticipated problems and pre-determined responses, provide little opportunity to prepare for the unexpected and unforeseen. In this paper we frame the research agenda for investigating how pilots cope with surprise and confusion in modern aircraft. An interview study with pilots has been carried out, identifying areas for further investigation regarding manual control, procedure applicability, system knowledge and training for unexpected events. A crew-aircraft control model has been developed to frame the functions and processes to be further investigated.

1 INTRODUCTION

The current generation of commercial aircraft are designed with highly automated and reliable systems, a development that has many safety benefits. However, as the cockpit operations grow increasingly stable, the amount of variations and disturbances decrease, leaving the crew with little exposure to surprises and unforeseen situations. The effects on the operational work environment are not well understood, since the crew's ability to deal with the unexpected has received less attention in the aviation industry. Crew training, for instance, is primarily focused on dealing with specific anticipated problems, and dealing with unexpected events is not explicitly addressed. Similarly, potential disruptions and faults during operation are anticipated and addressed through systems design and procedures.

A resilience engineering approach to complex and dynamic systems, such as commercial aviation, recognises that operational life contains fluctuations, unexpected events and disturbances that do not always fit the textbook examples and trained scenarios (e.g., Dekker & Lundström, 2006; Loukopoulos, Dismukes, & Barshi, 2009). To be resilient it is necessary to be well-prepared for anticipated failures, but also to be "prepared to be unprepared" (Paries, 2011). Recent aviation accidents demonstrate the necessity of crew abilities to cope with situations beyond the procedures and standard crew training. Examples include, for instance, the ditching of the US Airways A320 in the Hudson River after an unlucky bird strike (NTSB, 2010) and the successful management of the Qantas A380 engine explosion leading to a series of events and faults (ATSB, 2010). Although the initial threats of these events were anticipated, the full consequences of the failures, given the situational circumstances were not, leaving the crew to rely on their individual experience and expertise.

This paper structures the initial findings, main issues and questions identified at an early stage of the EU-FP7 research project Manual Operations of 4th Generation Airliners (Man4Gen) from the theoretical perspectives of cognitive systems engineering (Hollnagel & Woods, 2005; Woods & Hollnagel, 2006), sensemaking (Weick, Sutcliffe, & Obstfeld, 2005) which is one of the macrocognitive functions described by Klein, Klein, Hoffman, & Hollnagel (2003), and resilience engineering (Hollnagel et al., 2011). It thereby defines a research agenda for tackling the problem of preparing flight crews of highly automated airliners to cope with the unexpected. Results from a pilot interview study and descriptive modelling attempts are presented to scope and frame the research area to be investigated in the project. The focus is twofold: (1) what is required to "stay ahead of the aircraft" while "flying as usual" to minimise and prepare for surprise and (2) what strategies pilots use to deal with surprise and confusion. The focus and term descriptions are presented below in Section 1.1 and further illustrated in the crew-aircraft model in Section 2.1.

1.1 "Staying ahead", Surprise and Confusion

The terms "staying ahead", "surprise" and "confusion" have been used by the industry and academic partners in the Man4Gen project to focus and discuss the problem area to be investigated. Below we describe what the terms from a sensemaking perspective.

The expression of *"staying ahead of the aircraft"* has been used within the project to describe the crew's current "awareness" (of e.g., the aircraft systems, environment), their expectations and their ability to anticipate and respond to future events. In sensemaking "staying ahead" can be described as the retrospective and prospective processes of data framing, re-framing and anticipatory thinking (Klein, Snowden & Pin, 2010; Klein, Wiggins, & Dominguez, 2010; Weick et al., 2005). Sensemaking involves the continuous process of fitting the data (what we observe) into a frame and fitting a frame around the data (what we expect) (Klein, Wiggins, & Dominguez, 2010). To "stay ahead" further requires the prospective process of anticipatory thinking. Recognising and preparing for difficult challenges is directed by where we focus our attention, which is based on our expectations. This is a highly contextualised process where responses are simultaneously being identified based on the constraints of the situation (Klein, Snowden & Pin 2010).

A *surprise* occurs when a mismatch between what is observed and what is expected is detected. Hence, a surprise from a sensemaking perspective is when what is observed does not fit the current frame (organising of data), requiring an elaboration or a re-framing of the data (Klein, Wiggins, & Dominguez, 2010). Surprise is thus not only about interpreting data after-the-fact but also closely related to our expectations (anticipatory thinking). Woods & Hollnagel (2006) define surprise (with a focus on automation surprises) as the "miscommunication and misassessment between the user and the automation which leads to a gap between the users understanding of what the automated systems are set up to do, what they are doing, and what they are going to do" (pp 120-121). It is when the mismatch, or gap, is detected that the surprise occurs. If the mismatch cannot be fitted to the current frame there will be recovery interval, or a re-framing process, to fill the gap; a process which in everyday terms could be referred to as c*onfusion* and problem solving. Lanir (1986) makes a distinction between situational surprise, i.e., a surprise that can be fitted into our current frame and a fundamental surprise, i.e., a surprise that challenges our basic assumptions of the situation and requires a new frame. The process of re-framing to fit the current situation in complex environments (Klein, Wiggins, & Dominguez, 2010) may be challenging, due to, for example, fixation problems (De Keyser & Woods, 1990) and organisational barriers (Klein, Snowden & Pin, 2010). The inability to identify the mismatch and fill "the gap" may have disastrous effects. However, it is not always necessary to fully understand the situation in order to respond sufficiently, as is discussed in section 2.

2 RESULTS

Results from an interview study with 20 participants, including pilots, instructors, examiners, and industry experts provide insights into the current issues and challenges of flying modern airliners. The interview questions were based on findings from academic and industry studies and working groups (e.g. ICAO, 2006; Holder, 2012; ICAO, 2013) and highlighted the topics of surprise, confusion and problem solving, automation and system knowledge, manual operation, training, procedures and communication. The interviewees ranged from low-experience first officers, to experienced captains, flight instructors and training and safety managers. Overall there were more experienced crew in the group; 14 out of 20 participants were instructors and examiners and only 2 were first officers. The average number of flight hours of the participants was 10892 and the average age 49. There were 5 interviewers performing the interviews, and at least 2 were present during each interview. The interviews were recorded, transcribed and categorised according to the topics listed above. The iterative analysis process further allowed the identification of sub-categories as they emerged from the data.

Results show that both automation (e.g. sensor failures) and operational factors (e.g. ATC communication) are more common sources of surprise. A surprise or an unexpected situation is however not necessarily a significant threat, although confusion resulting from a surprise may be. On the other hand, it was also mentioned that it is not always necessary to fully understand the problem to cope with the situation successfully. For example, a common strategy mentioned to deal with confusion was "if confused about the automation, take over and fly manually". Other strategies to cope with surprise and confusion mentioned were to "sit on your hands", i.e., evaluate the situation before acting and to "stay ahead of the aircraft" to minimise surprise.

The examples and strategies outlined by the interviewees demonstrated potentially conflicting coping mechanisms to deal with unexpected situations in modern airliners today. An example is deciding when to disengage automated systems and take over manual control. As mentioned, manual control should be resumed when confused about what the automation is doing. However, airline operators and manufacturers recommend using automation as much as possible and many pilots also identified that ”automation could make confusing situations safer if you know how to make the automation do what you want it to do”. Further, several respondents mentioned that manual flying takes effort (particularly if not well trained), and that this may degrade other abilities important in difficult situations, such as communication.

Varying views on the required level of system knowledge also highlights the challenge faced in modern airliners today. On the one hand a deeper understanding for systems and their interconnectedness may be useful to deal with surprises, but on the other hand ”pilots sometimes put too much effort into identifying what is wrong with the system instead of flying the aircraft”. Similarly, procedures were seen as one of the safest ways to get out of confusing situations. However, it is important not to follow procedures blindly and sometimes it is necessary to deviate from them, while it is not always obvious when to do so. The interviewees did not think that training today sufficiently provide challenging situations that can help prepare crew for surprise (e.g., situations with no clear procedures or multiple inter-system failures).

The interview results are not conclusive as the study only covered a small sample of pilots. However, the ambiguities and trade-offs regarding manual control, procedure applicability, system knowledge and training for challenging situations are in line with the conclusions from earlier studies (e.g. ICAO, 2006; Holder, 2012; ICAO, 2013) and demonstrate that further investigation is needed. Areas highlighted are:

- How can (do) pilots “stay ahead” of the aircraft to minimise surprise?
- Which strategies do pilots use in dealing with confusion and when are these (not) helpful?
- What are the criteria that lead pilots to adjust or disregard the execution of procedures?
- What is the effect of system knowledge on staying ahead of the aircraft and dealing with confusion?

2.1 The Crew-Aircraft Contextual Control Model

The crew-aircraft model (Figure 1) is an initial modelling attempt to focus the core concepts to be investigated and scope the sensemaking research strand within the project. The control model described here is one part of the analysis of pilot-aircraft functions which “serves as an archetypical pattern and narrative generator that guides how specific stories can play out in multiple situations and settings” (Woods & Hollnagel, 2006, p. 21). The model is adapted from Hollnagel & Woods (2005) Contextual Control Model (COCOM) to fit the crew-aircraft context and concepts used to frame the problem.

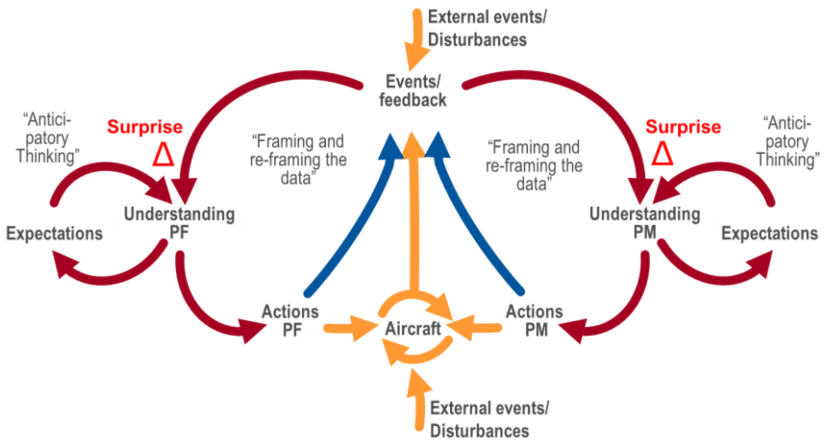

***Figure 1**. The crew-aircraft contextual control loop*

Several interconnected loops represent the dynamics between the two crew members (Pilot Flying (PF) and Pilot Monitoring (PM)) and the aircraft. The two main simultaneous processes of sensemaking as described by Klein and colleagues: anticipatory thinking (Klein, Snowden & Pin, 2010) and framing and re-framing the data (Klein, Wiggins, & Dominguez, 2010), which together serve the purpose of ascribing both meaning and action (Weick et al., 2005) are depicted in the two main loops for each crew member. Red and blue arrows for both PF and PM (jointly and in an iterative and looping manner) represent macrocognitive functions and processes (as described by Klein et al., (2003)). Yellow arrows describe aircraft processes and external events and disturbances.

Events and Feedback from the process to be controlled modify the Understanding (by PF and PM) of the situation, in a process of (re-)framing the data. This part of the loop focuses on macrocognitive functions of situation assessment and problem detection, and macrocognitive processes of attention management and developing mental models. At the same time, both pilots engage in a loop of anticipatory thinking, which focuses on macrocognitive functions and processes of (re-)planning and mental simulation, generating Expectations based on their Understanding. Expectations reciprocally affect Understanding in that they affect attention management and mental models and thus the way in which pilots seek information. Coordination and maintaining common ground is done through communication in the cockpit (blue arrow), which also enables both loops of reframing the data and anticipatory thinking to be a crew effort.

The crew's current Understanding of the situation leads to Actions by PF and PM through macrocognitive functions and processes of (re-)planning, generation of courses of action, and (naturalistic) decision making. Actions consist of (a) actions on Aircraft controls and displays (yellow arrows from Actions PF/PM to Aircraft) and (b) communications, verbal and non-verbal, to the other pilot or to external actors such as ATC or airline operations (blue arrows from Actions PF/PM to Events/Feedback). Note that not acting on automated process or not communicating are also important to include in the model to guide observation. The strategy to "sit on your hands", is an example that can in some situations be useful. Not communicating, as when pilots are too occupied with other tasks to communicate, and it gets "quiet in the cockpit" is an example that some pilots suggested could be indicative of crew struggling with confusion. Aircraft actions result from pilot Actions, and processes including various automated, autoflight, and envelope protection processes (represented by the yellow Aircraft loop). Aircraft processes, PF/PM Actions, and External events and Disturbances together produce Events in and Feedback on the process to be controlled (converging at the top of the figure). These include communication events, data being shown on displays, movement of the aircraft, etc. This mix of various events/feedback (through processes of attention management) modifies the Understanding of the situation and Expectations (as described above), and the loop continues.

The macrocognitive process of uncertainty management relates to the core concepts of surprise and confusion. As described previously, surprise arises when Expectations do not match the interpretation of Events and Feedback. The surprise may result in a quick modification of the current Understanding (for example in a situational surprise (Lanir, 1986)), or in a fundamental surprise (Lanir, 1986) which may result in a longer process of questioning the frame, elaborating the frame, and reframing the data (Klein et al, 2010), which in everyday language may be called confusion and problem solving. Taking Action (for example going to lower degrees of automation closer to "manual control") changing the Aircraft processes may also help the return to a situation where Expectations match situation assessment while trying to form an Understanding of the situation.

The goals of the process to be controlled can be described in several ways: Getting the airplane from gate to gate, from waypoint to waypoint, keeping the aircraft within the flight envelope, avoiding collisions with the ground, obstacles and other aircraft, following the cleared trajectory or heading, etc. This suggests that anticipatory and compensatory control loops with different time horizons can be used to describe the process in more detail, as for example using the Extended Control Model (ECOM). Such modelling attempts will be further explored in next steps of the project.

3 CONCLUSIONS

The different views and challenges identified in the interviews demonstrate trade-offs faced by the aviation industry today, as the system works toward multiple goals. Safety is designed at the blunt-end of the system through increased capability and reliability and organisational demands require continuous advances creating new complexities. The need for flexibility and transparency of aircraft systems in order for the aircraft systems to cooperate as a team player in unexpected events becomes limited as variations are brought to a minimum and responses are pre-determined; or as noted by Paries (2011), flexibility is being traded for efficiency. The interviews suggest that training today does not adequately prepare pilots to cope with surprise, such as by using scenarios with ambiguous and potentially conflicting information. However, the content of training programmes is carefully regulated and under pressure as simulator time is restricted and the numbers of situations pilots can be exposed to are limited and have to be carefully designed. The initial attempts to model the processes to be further investigated in the project helps frame the scope of the research on how to prepare crew's for the unexpected. In the next phase of the project, experiments will be carried out in aircraft simulators to further investigate the problem.

Acknowledgements

The authors would like to thank the organisations and participants involved in the interview studies. This research is funded as part of the FP7 2012 Aeronautics and Air Transport programme under EC contract ACP2-GA-2012-314765-Man4Gen. The views and opinions expressed in this paper are those of the authors and are not intended to represent the position and opinions of the Man4Gen consortium and or any of the individual partner organisations.

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UAS in (Inter) national Airspace: Resilience as a Lever in the Debate Proceedings of the Fifth Resilience Engineering Symposium

Gwendolyn C.H. Bakx MSc[1] and James M. Nyce, PhD[2]
[1] Department of Military Behavioural Science & Philosophy, Netherlands Defence Academy, Breda, The Netherlands
gch.bakx.02@nlda.nl
[2] Department of Anthropology, Ball State University, Muncie, Indiana, USA
jnyce@bsu.edu

Abstract

This paper explores what a particular strategy from the resilience engineering "tool kit" – taking an alternative perspective – can do for "wicked" problems in which often numerous trade-offs have to be made. The Israeli Defence Forces have, as we will illustrate, successfully applied this strategy in their battle of Nablus in 2002. In this paper we attempt to transfer this strategy to the UAS integration debate. This is the debate around the safe introduction of unmanned systems in the current airspace structure along with its current (manned) "inhabitants." Many trade-offs have to be addressed in this debate, some of which will be neglected as long as certain angles to the issue are ignored. It appears that a social science approach – more specifically in this case the ethnicity literature – can strengthen dialogue and discussion. Also, it can provide a more adequate scientific understanding of some socio-technological issues underlying what superficially seems to be a simple case of managing trade-offs for the purpose of safety.

1 INTRODUCTION

How to safely integrate Unmanned Aircraft Systems (UASs) into the (inter)national airspace structure seems to be a "wicked" problem (e.g. Ramalingam, Kalawsky and Noonan, 2011) in which many trade-offs have to be successfully addressed. The debate about integration has some time depth but some issues, especially safety, have not yet been unresolved.

Historically, attempts to integrate UASs in the airspace have taken mainly engineering and technocratic approaches which focus on technological innovation (such as sense/detect-and-avoid technology) and on standardization, policy and regulation efforts (e.g. ICAO, Eurocontrol and EASE in UVS International, 2011; Loh, Bian and Roe, 2009; Cork, Clothier, Gonzales and Walker, 2007). These "conventional" solutions, however, do not always seem to achieve the ends that one desires in these "wicked" cases. To pursue alternative strategies, approaching a topic from an unorthodox direction, can then be helpful. The Israeli Defence Forces (IDF) give us an example of this.

In April 2002 the IDF assaulted the city of Nablus while Palestinian armed organizations barricaded all entries to the old city. Streets and alleys were mined and entrances to buildings were booby-trapped, as were the interiors of strategically important structures. The IDF therefore chose to perform an unconventional manoeuver that they call "inverse geometry" or "walking through walls", part of their more broadly defined "lethal theory":

[In Nablus IDF] soldiers used none of the streets, roads, alleys, or courtyards that constitute the [usual] syntax of the city, and none of the external doors, internal stairwells, and windows that constitute the [normal] order of buildings. [They] rather moved horizontally through party walls, and vertically through holes blasted in ceilings and floors. In fact, after serving their original purpose, the openings forced through the walls [became] part of the [everyday] syntax of the city and [were] not reused for military purposes. (Weizman, 2005)

Since Nablus this IDF manoeuver has been regarded as highly controversial (e.g. Gordon, 2002) but this is not the issue that will be addressed here. The advantage that this strategy gave the IDF in Nablus is taken here as an example of what an alternative viewpoint can achieve. In this paper this has been applied to the introduction of UASs into the national and international airspace structure.

Many trade-offs have to be addressed in this debate, most of them – if not all – affecting the larger system's safety. For some of these issues, standardized solutions are not sufficient. In these cases, unorthodox perspectives can perhaps provide a way in. What we propose here is a kind of a meta resilience engineering: the ability and resilience to deal with the many trade-offs and unknowns in a system before the system has even emerged yet. Like the IDF applied their "lethal theory" in Nablus we will suggest that the UAS integration debate can benefit from approaching this issue from the perspective of ethnicity literature. The issue, we believe, can benefit from this as it takes up the introduction of UAS as a sociological process of acculturation strategies rather than as a process in which it is assumed that "equivalent" levels of safety, for instance, can be arrived with by using or applying some supposed rational and universal standard.

2 RESILIENCE STRATEGY IN WICKED PROBLEMS

Walking through walls is not an obvious strategy. In the case of Nablus, one could say, it was a strategy that was born out of necessity; it provided a means for penetrating a previously "un-penetrable" city. However, choosing such an unorthodox strategy cannot be done without getting past one's current paradigms, here especially about the outside physical world:

This form of movement … sought to redefine inside as outside, and domestic interiors as thoroughfares. Rather than submit to the authority of conventional spatial boundaries and logic, movement became constitutive of space. … The IDF's strategy of "walking through walls" involved a conception of the city as not just the site, but the very medium of warfare. (Weizman, 2005)

With this inverse geometry manoeuvre, the IDF truly crossed both physical and conceptual boundaries. The formulation of high level theories has been very important in the Israeli way of conducting a municipal war:

Theory is important for us in order to articulate the gap between the existing paradigm and where we want to go…. Without theory, we could not make sense of different events that happen around us and that would otherwise seem disconnected…. (Weizman, 2005)

The inverse geometry manoeuver is an example of what Weizman (2005) defined as "Lethal Theory". Although he does not define at length what Lethal Theory is, he seems to means the use of a particular theoretical discourse to aid the development of unorthodox tactics. The theoretical sources were found in poststructuralist schools which favour criticality (criticality attempts to critique and so transcend common assumptions of order, reality and society). The application of this unconventional strategy provided the IDF with a significant strategic advantage in the battle of Nablus.

In this particular case the IDF benefitted from avant-garde urban research conducted in architectural institutions. The point here is that, especially when numerous trade-offs have to be made, a tendency often exists to restrict oneself to a number of "everyday" choices. What the IDF case illustrates, however, is that in those "wicked" cases especially, a resilience engineering strategy (taking an alternative perspective) might be a better choice to provide a way in. Like with the assault of Nablus such a strategy can perhaps be helpful as well in the debate on the integration of UAS in the (inter)national airspace. Approaching the issue from a socio-technological rather than from an engineering or technocratic perspective, for instance, would allow us to look at the role social dynamics (a topic that so far has received little attention) can have in the UAS integration debate. Central to this debate, national and international, seem to be these two main premises:

1. UAS must meet the equivalent levels of safety (ELOS) as manned aircraft, and
2. UAS must be integrated seamlessly in the current air traffic management (ATM) structure

What these two premises imply is that the introduction of UAS integration in non-segregated (inter)national airspace implicitly (or explicitly) is supposed to rest on the capability of the UAS minority to act like the majority of the current airspace users i.e. manned aircraft. The worldwide UN-organization ICAO, in Circular 328 on UAS, expresses this this way: "The goal of ICAO in addressing unmanned aviation is … to underpin routine operation of UAS throughout the world in a safe, harmonized and seamless manner comparable to that of manned operations" (ICAO, 2011). Framing the UAS integration issue like this has much in common with what Berry, a respected scholar in ethnicity research, terms "acculturation strategies": the strategies that people seek in "the dual process of cultural and psychological change that takes place as a result of [prolonged] contact between two or more cultural groups and their individual members" (Berry, 2005).

Bringing acculturation theory to bear on UAS integration could have an effect like lethal theory in the battle of Nablus. Taking an alternative viewpoint, avoiding thereby current paradigms and resultant dead ends, could help clarify what is at stake in the UAS integration debate and result in an understanding and solutions that the current focus on engineering, policy and regulation has so far has not been able to provide. It allows us to look, for instance, at the role that social dynamics in general (a topic that so far has received little attention) can have in this debate. What current debates on UAS integration mask, it seems, is the notion of power.

3 ACCULTURATION IN THE DEBATE ON UAS INTEGRATION

3.1 Integration or Assimilation?

The aim of the various stakeholders in the UAS integration issue is to enable a safe *integration* of UASs in the airspace structure along with all the other users. The word integration, which is used in this debate by both members of the manned and the unmanned sector, deserves some exploration. Integration, for instance, is one of the eight key strategies that Berry identified in his bi-dimensional ethnic acculturation model (Fig 1).

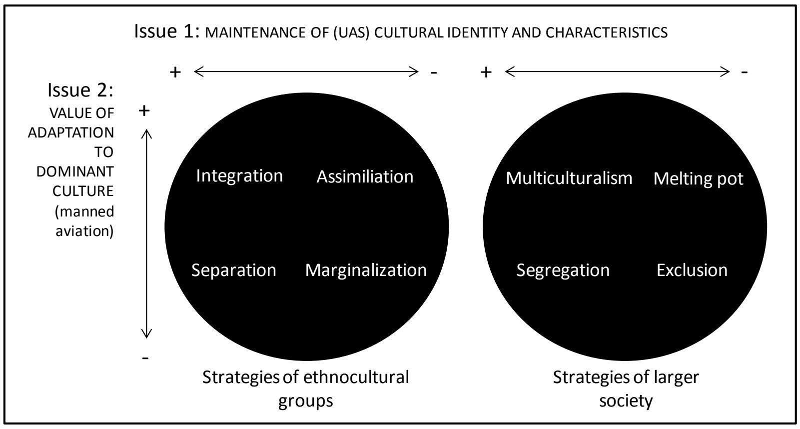

***Figure 1**. Berry's acculturation model (Berry, 2005)*

To integrate, viewed through Berry's model, is a strategy of *non*-dominants to try to maintain the own habits and characteristics while at the same time to seek interaction and exchange with members of the dominant group. The corresponding attitude towards newcomers by *dominants* would be called in Berry's terms multiculturalism. Dominance, by the way, is recognized in most acculturation models but the question of how this dominance is arrived at (except by sheer number) is, also by Berry, seldom directly addressed. Translated to the UASs, nonetheless, integration would thus mean an end-state in which both manned aircraft and UAS can operate in close (even collaborative) conjunction with each other in the same airspace structure while at the same time retaining differences in say technical characteristics and in concepts of operations. This, in no way, however, coincides with the pathway that the various stakeholders seem to have embraced on this issue. After all, the two premises mentioned earlier rather seem to assume and encourage UAS to act exactly like manned aircraft. This resembles the characteristics of a melting pot (~ assimilation) strategy rather than those of integration or multiculturalism. There seems then to be a divide when it comes to the introduction of UASs in the airspace between the intention that is articulated (integration/multiculturalism) and the actions performed or intended (directed towards assimilation/melting pot).

3.2 Or should we consider Fusion?

This belief, that for a safe integration of UASs they should act like manned aircraft, corresponds to what Woods refers to as the "substitution myth". Woods applied this term to engineers' apparent belief that human activities can be substituted by automation activities "without otherwise affecting the operation of the system" (Woods and Christofferson , 2002, p. 3). Such a "substitution", however, actually adds another actor to the system and this is invariably accompanied by a whole rearrangement of tasks, roles, duties and also of responsibilities. What seems to be a simple substitution of one item for another can thus instead, to a greater or lesser extent, impact the system as a whole, resulting at times in a complete different system. Not recognizing this, can weaken discussions on system safety.

The introduction in aviation of a collision avoidance system in aviation at the end of the past century is an example in which this substitution myth was not recognized and had a tragic effect. This Traffic Collision Avoidance System (TCAS) is an on-board system and generates automated air traffic coordination messages. However, it does this within the existing air traffic management (ATM) structure provided by human air traffic controllers on the ground. The introduction of TCAS can thus produce a potential source of ambiguity and thereby can it inadvertently limit or weaken the system as a whole. Indeed in 2002, five years after the introduction of TCAS and just before the aviation industry was ready to call the TCAS system "mature", a Bashkerian Airlines passenger plane collided in the air with a DHL cargo aircraft. In this accident, the directions of the on-board TCAS system conflicted with the air traffic instructions from the ground. The result was to extend the development phase of the TCAS system.

Similarly, the impact that the substitution myth can have in the UAS integration debate has gone so far unnoticed. In this debate it is believed that as long as UASs act as any other (piloted) aircraft in the airspace structure, i.e. as long as a melting pot strategy is pursued, it will be safe for UASs to share the airspace structure. It can, however, be argued that UASs can be made to act similarly to manned aircraft, but never exactly alike. In other words, with the introduction of a substantial amount of UASs in the airspace structure, it is inescapable that the airspace system will change as a whole and the operations within it as well. This possibility exceeds, however, Berry's acculturation model which does not seem to allow for an altered system to develop.

A more recent and more applicable acculturation model, therefore, is perhaps the fusion model. In this model the newcomers and the host society are believed to mutually influence each other in such ways that their aggregated acculturation process results in a new society with characteristics that set it apart from the previous one. In the fusion model, the acculturation processes of the two groups *together* thus ultimately creates a whole new structure (e.g. Hermans and Kempen, 1998; for other references for this fusion model, see Coleman, 1995; Padilla, 1995; LaFromboise et al., 1993). When applied to the introduction of UAS in the (inter)national airspace, the fusion model allows a new structure to emerge from the dominants' (conventional aircraft) and the non-dominants' (UAS) behaviour(s). This model therefore seems to fit the issue. Still, the aviation community claims to pursue the *integration* of UAS in the aviation sector. There thus seems to be a gap between the strategy pursued in the UAS debate and that what can be argued reflects the actual situation. The fusion model in particular would therefore perhaps be a better framework for the introduction of UAS in the (inter)national airspace than other models such as the integration model that is currently used.

3.3 Framing

Another issue that we would like to discuss here is the one that brought us to bring ethnicity theory to bear at the introduction of UAS in the airspace to begin with: framing. Safety is a key issue in the debate. No concessions to safety are allowed, no trade-offs for safety. "Thoroughness" (Hollnagel, 2009), so to speak, dominates the discussion. The discussion has, however, been framed such that one of the parties, UAS so it seems, has to argue – or rather to negotiate – in the terms and references of the majority group (manned aircraft). Under the rhetoric of being equal – the basic premise of integration – the arguments pro and con UAS status are thus already "tilted" in the direction of manned aviation. This leads us to challenge whether it is pure safety that is adhered to in the discussions or something else.

4 DISCUSSION

Historically, the aviation sector has been seen by itself and others as a safety conscious domain. It can be argued then that the UAS integration debate has a firm base in safety as well. After all, many of the arguments in the debate – if not all – in the end seem to boil down to arguments after safety. The first premise in the debate, that UASs must meet an equivalent level of safety in the air and for people on the ground as manned aircraft, is perhaps the most obvious one. Inherently to the debate are the many trade-offs that the different stakeholders will have to make in conjunction with each other. These social dynamics (and process) allows a social science or, even better, a socio-technological perspective on the issue.

Like lethal theory for the IDF in Nablus, acculturation theory seems to be able to provide a useful theoretical perspective on the UAS integration issue. It can perhaps bring to the surface some important, but not yet widely acknowledged, issues related to the safe introduction of UAS in the (inter)national airspace structure. The lack of congruence, for instance, between the stakeholders' positions and the acculturation model that seems to interpret actual practice best – the fusion model – can result in both discussions and solutions being less nuanced than they perhaps should be. From a resilience perspective, it is therefore necessary in this debate to consider the acculturation strategies which stakeholders embrace, and to analyse whether they have the potential to improve airspace safety. Neglecting these issues could in fact jeopardize safety in ways that otherwise could be difficult to pinpoint.

What current integration UAS debates mask, for instance, is the notion of power. Rhetorically, the arguments pro and con UAS status are already "tilted", so it seems, in the direction of the dominant party, manned aviation. Perhaps if we can shift the terms away from this notion of integration, we can begin to deal with some of the more difficult but important issues that so far have not surfaced in the UAS airspace debate. What lies behind what seems to be an academic or policy debate about equality seems to be one in which self-interest is at work right across the spectrum from (inter)national concerns to market interests to those at a more micro level (self-interest ranging from (individual) firms, actors and their respective careers and successes).

This paper has focused specifically on the safe introduction of UASs in the current (inter)national airspace. We have proposed to take an alternative perspective on the issue since it appears that taking such an unorthodox approach can be useful in providing empirical data which could help clarify neglected but important safety issues in this debate. Further research from a social science perspective should be performed, however, to find out whether this can also reveal obstacles in a more general sense as well in debates on issues of safety that strictly engineering, management, and policy may not be able to identify or address. Under uncertainty specifically, unorthodoxy seems to have at least the potential to serve as a source of meta resilience in systems engineering in general.

5 CONCLUSION

What we have argued for in this paper is that, especially when numerous trade-offs are to be made, such as in the debate around the introduction of UAS in the airspace structure, a tendency often exists to restrict oneself to the choices already formulated (which often reflect the basic premises in a debate). It is in these instances in particular, it seems, that a specific resilience engineering strategy (taking again an alternative perspective), can provide a way in. Bringing, for instance, acculturation theory to bear on UAS integration, can help clarify what is actually at stake in this debate. While safety is said to prevail at all times (no trade-offs for safety), discussions have been framed such that the minority group (UAS) by definition will be at a disadvantage, regardless how safe they are, since they are forced implicitly to express themselves in the language of safety of the majority manned aviation sector. What this paper does, therefore, is that it acknowledges and illustrates how bringing in an alternative perspective can lay bare hidden assumptions and bias regarding trade-offs, for instance, that otherwise would not be brought to the table.

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Trade-Offs as Symptoms of Mismatches Between Sociotechnical Systems: A Case Study involving Commercial Aviation and Air Traffic Control

David Moriarty[1] and Steve Jarvis[2]
[1] Zeroharm Solutions Ltd, London, UK
d.j.moriarty@hotmail.com
[2] Jarvis Bagshaw Ltd and Cranfield University, Cranfield, UK

Abstract

Trade-offs occur frequently within sociotechnical systems and allow the system to maintain its output in the face of the variable performance of its constituent components. Trade-offs also occur between systems that must interact with each other. Some of these intersystemic tradeoffs may threaten the integrity of one or both systems particularly if the allowable magnitude of the trade-off is not clearly defined. Such unbounded trade-offs are symptomatic of fundamental mismatches between the goals of these interacting systems and represent a risk. These trade-offs can be eliminated by aligning the goals of the systems. In this way the required trade-off is made at the design stage and eliminates the need for the operators to undertake potentially risky trade-offs in dynamic, time-limited conditions.

1 INTRODUCTION

Much of the research undertaken in the field of complex sociotechnical systems explores the dynamics that occur within such systems (*intra*systemic). Far less work has been carried out to look at the interactions *between* such systems (*inter*systemic). The aim of the research on which this paper is based was to look at a safety significant event that occurs in commercial aviation known as the unstable approach.

Despite the high level of safety of commercial aviation relative to other forms of transport, approach and landing remain the phases of flight where accidents are most likely to occur (Civil Aviation Authority, 2008). During these phases of flight, pilot workload is high as it is necessary to change both the vertical and horizontal position of the aircraft whilst reducing its speed and altering its configuration by deploying landing gear and flaps in order to make landing possible (Lee & Liu, 2003).

The high proportion of accidents occurring during this phase of flight led to the Flight Safety Foundation implementing the Approach and Landing Accident Reduction (ALAR) Task Force. The ALAR Task Force found that unstabilised approaches were a causal factor in 66% of 76 approach and landing accidents and serious incidents between 1984 and 1997 (Flight Safety Foundation, 1999).

In order for an approach to be defined as stable, the aircraft must meet a certain set of criteria at a predefined height above the runway (usually 500ft or 1000ft depending on the meteorological conditions). Criteria include being on the correct flight path, speed within plus 20 knots and minus 0 knots of the calculated threshold speed for aircraft weight, landing gear down and flaps in landing position (Flight Safety Foundation, 2000). If an approach is unstable, the pilot must discontinue the approach and go-around (i.e. climb to a safe height and fly a predefined route with the option to return for a second approach). Whilst approaches that were too low or had insufficient speed tended to result in collision with the ground or with other terrain, approaches that were too high (based on distance from the runway) or too fast tended to result in runway overruns and excursions. The report also recognised that flight handling difficulties were often triggered by rushed approaches, adverse wind conditions and attempts to comply with inappropriate air traffic control (ATC) clearances.

The research carried out by the Flight Safety Foundation was undertaken in the 1990s, prior to the emergence of the field of resilience engineering. The research on which this paper is based was designed to take a 'systems perspective' on the phenomenon of unstable approaches in the hope of discovering system-based causes why this safety significant event continues to occur (Moriarty, 2011). The methodology included semi-structured interviews with pilots followed by analysis of the interview transcripts in order to identify how pilots decide when the speed and configuration (landing gear and flaps) of an aircraft should be changed in order to perform a safe approach and landing (i.e. what was the pilot's 'configuration plan'). Only findings relating to the interaction between pilots and air traffic controllers are given here.

2 TRADE-OFFS WITHIN AND BETWEEN SOCIOTECHNICAL SYSTEMS

2.1 General Systems Theory Applicable to Sociotechnical Systems

Von Bertalanffy first identified that mechanical, biological and social systems share some common characteristics that provide a common basis for talking about systems across several scientific fields (Von Bertalanffy, 1950). This position, known as general systems theory, gives rise to some recurring characteristics across systems (Kast & Rosenzweig, 1972) and some of those relevant to sociotechnical systems are given below:

1. Open systems – those which exchange information, energy or material with their surroundings;
2. System boundaries – separate the system from its surroundings. Less well-defined in open systems;
3. Multiple-goal seeking – different system subunits may have different goals;
4. Equifinality – biological and social systems operate differently to mechanical ones because system end-points can be achieved from a variety of different starting conditions using diverse inputs with varying internal activities.

Equifinality in a system suggests that there must be some variation in how components operate in order to achieve the same system output. This 'variability of normal performance' as a feature of system success (and system failure) is fundamental to the concept of safety in complex systems. Hollnagel first alluded to this variability in 2001 (Hollnagel & Amalberti, 2001) and later developed it into the principle of the Efficiency-Thoroughness Trade-Off (ETTO) (Hollnagel, 2002 & 2009). This paper focuses on trade-offs that occur between systems but it is worth briefly summarising why trade-offs occur within systems.

2.2 Intrasystemic Trade-Offs

Whilst variability of normal performance permits equifinality (and success) within a sociotechnical system, it also means that the system may function differently from one day to the next. Components within the system must adapt in order to accommodate variations in how other components are functioning, particularly in tightly coupled systems. In modelling sociotechnical systems, the Functional Resonance Analysis Method (Hollnagel, 2012) recognises that each function/activity has both an input and output as well as a possible time trigger/constraint. If the output of one activity is delayed and this output forms the input to another activity that is time-limited, the operator may have to perform an ETTO in order to preserve overall system function.

Another type of trade-off may occur as a response to an inefficiency in the design of the system. The interaction between two or more functions in the system may be inherently inefficient and so the operators come up with a 'work-around' that becomes a feature of the system, albeit an unofficial one.

2.3 Intersystemic Trade-Offs

Sociotechnical systems rarely operate in complete isolation. At various points along their boundaries, they will have to interact with other systems. Perrow (1984) gives an account of the interaction between two complex systems in his summary of the Lake Peigneur disaster of 1980. The unanticipated interaction between two systems with different goals (a company drilling for oil in Lake Peigneur and a mining company digging for salt beneath it) led to the loss of an oil rig and 3.5 billion gallons of water through a hole drilled into a mineshaft. This case study looked at the unfortunate outcome of an *unanticipated* interaction between two systems. What is of greater interest are the dynamics of *anticipated* system interactions.

3 INTERACTION BETWEEN COMMERCIAL AVIATION AND ATC

3.1 Commercial Aviation and ATC Interactions During the Approach Phase of Flight

When taking a systems perspective on the phenomenon of unstable approaches, one area of interest was the interaction between pilots and ATC. Commercial air transport is a system designed for the safe and efficient carriage of people and cargo by air. ATC is also a complex sociotechnical system, one designed to orchestrate the safe and timely flow of aircraft in and out of a particular volume of airspace. In the majority of cases, the goals of both systems are complimentary. There are cases, however, when the goals of one system may have a negative impact on the goals of the other. In the case of the crash of Southwest Airlines Flight 1455 in Burbank, California, ATC imposed altitude and speed restrictions on the pilots that limited their ability to achieve their goal; a stable approach (National Transportation Safety Board, 2002). In this case, two normally complimentary systems had two different goals that resulted in an accident after the aircraft landed at too high a speed, too far down the runway.

When pilots in the study were asked what lead them to have to change their preferred configuration plan, the most common reason cited was the need to comply with ATC instructions, such as 'maintain 180 knots until 4 miles (from the runway)'. Although it was shown that pilots employed a wide range of tactics in dealing with ATC instructions that were unexpected or unusual, the regulations regarding compliance are quite clear and demonstrate the mismatch between the systems of air transport and ATC.

Regulatory authorities make it the responsibility of the pilot to comply with ATC instructions unless safety is an immediate priority. For example, section 91.123 of the Federal Aviation Regulations (Federal Aviation Administration, 1989) regarding compliance with ATC clearances and instructions states:

"When an ATC clearance has been obtained, no pilot in command may deviate from that clearance unless an amended clearance is obtained, an emergency exists, or the deviation is in response to a traffic alert and collision avoidance system resolution advisory".

However, the Federal Aviation Authority, Order JO 7110.65T (Federal Aviation Administration, 2009), characterises the role of air traffic control services as follows:

"The primary purpose of the ATC system is to prevent a collision between aircraft operating in the system and to organize and expedite the flow of traffic".

These regulations mean that a pilot must comply with ATC instructions that may not be given for the purposes of separation but may instead be given for the purposes of expediency. The regulations do not recognise any requirement for facilitating a stable approach. Although pilots reported that their configuration plan was partly designed to permit an efficient approach, by far the most important influence on their configuration plan was the desire to guarantee a stable approach. The Flight Operations/ATC Operations Working Group of the Global Aviation Information Network undertook a survey of pilots and air traffic controllers regarding what they would like the other group to know about their respective jobs. Pilots responded that they would like controllers to be more aware of the criteria and importance of a stable approach (Global Aviation Information Network Working Group E, 2004).

From a systems perspective, during the approach phase of flight, there are two systems (the air transport system and the ATC system) using the same material (aircraft) in the same physical environment (the approach zone) at the same time to achieve two potentially different outcomes; stability for the pilots and separation/expediency for the air traffic controllers.

Based on interview responses, it is usually the pilot who has to make a trade-off in order to reconcile the mismatch between system goals, normally by modifying his or her normal configuration plan in order to comply with an instruction from ATC. For example, a pilot may normally reduce speed from 180 knots to 160 knots at 6 nautical miles from landing but may be put under pressure to delay this speed reduction until 4 nautical miles from landing at the request of ATC. Pilots also reported that requests from ATC usually came without warning and also came during the high workload phase of the approach. Pilots then have to quickly re-plan how they were going to configure the aircraft without having a clear idea whether these changes would threaten the stability of the approach.

The maximum extent of the trade-off (for example, the latest point at which a pilot could initiate a speed reduction) that would still guarantee stability would not be known to the pilot at the time. It is a function of, amongst other things, aircraft weight, wind conditions, approach angle and technical status of the aircraft. The multitude of variables means that the pilot cannot know for sure what size of trade-off will lead to instability and, in lacking this information, the trade-off they make is unbounded.

3.2 Unbounded Trade-Offs

For the purposes of this paper, an unbounded trade-off can be defined as one where the maximum safe extent of the trade-off is unclear to the operator at the time. If it becomes necessary to make such a trade-off, it may potentially threaten system success if it is too great. Unbounded trade-offs may occur intrasystemically in response to the varying performance of its components and may threaten system output if they are excessive. However, unbounded trade-offs that occur intersystemically may be seen as symptomatic of an inherent problem in how these systems interact rather than being a natural response to varying component performance.

Whilst we might expect there to be some variability in how systems interact with each other from day-to-day (as system outputs may vary slightly), when one system has to adjust its output substantially to satisfy the goals of the other without knowing in advance how much adjustment is safe, there is a risk of system failure. In the case of the interaction between air transport and ATC, there have been multiple occasions where ATC have issued clearances that have lead to pilots changing their approach configuration plan to such an extent that the approach has become unstable and, in some cases, the unstable approach has continued to a landing followed by the aircraft running off the end of the runway.

4 ALIGNING SYSTEM GOALS TO ELIMINATE UNBOUNDED TRADE-OFFS

If unbounded trade-offs are symptomatic of mismatches between the goals of two sociotechnical systems, once they are identified, steps should be taken to eliminate the need for them as they pose a risk to the functioning of one or both systems. When legislation was being drafted to regulate the air transport and ATC systems, it would have been clear to someone with knowledge of both systems that there was a potential mismatch in their goals. Unfortunately, systems tend to be designed by people with an in-depth knowledge of that particular system without full reference to the other systems that it will be interacting with.

One potential way of eliminating the need for an operator to make an unbounded trade-off in dynamic conditions is to make the trade-off *in advance*, at the design stage. If the goals of both systems are aligned so that rather than one system attempting to achieve separation/efficiency and the other trying to achieve stability, both systems aim for a more concrete goal such as getting the aircraft to fixed points along the approach path at predetermined speeds. These points along the approach are designed to guarantee stability and separation whilst still maintaining efficiency.

In this particular case, one concern might be that in changing the goals of the system, ATC might be prevented from maximising runway usage as controllers are adept at orchestrating an efficient flow of traffic to and from and airport. With many airports operating at their top capacity, any measures that would potentially decrease efficiency would need to be carefully weighed against reducing the risk of unstable approaches and the type of accident that results from them. It is worth reiterating that when an aircraft is not stable by a predefined height above the runway it must discontinue the approach and go-around. When we consider the issue of airport efficiency, the data available yields an interesting fact about the current perceived efficiency of the system. Data derived from the KLM fleet suggests the go-around rate is 15 per 1000 approaches and that the rate of go-arounds caused by unstable approaches is 3 per 1000 approaches (Speijker et al., 2000). The DGAC states that the rate of unstable approaches is 30 per 1000 approaches (Direction Générale de l'Aviation Civile, 2006). If pilots did as they were encouraged to and flew a go-around from every unstable approach, the go-around rate would almost triple to 42 per 1000 approaches. This would have a significant impact on ATC as nearly 1 in 20 approaches would result in a go-around. When viewed from this perspective it becomes clear that the current perceived efficiency of the system is predicated on pilots continuing unstable approaches to a landing.

5 CONCLUSIONS

Sociotechnical systems maintain system output (equifinality) partly because of trade-offs that occur between components. In a similar manner to trade-offs between components, trade-offs occur between systems that interact with each other because the system outputs are not always exactly the same. In some cases, trade-offs are made without knowing how large the trade-off can be before it threatens one or both of the systems. These unbounded trade-offs are symptomatic of fundamental mismatches in the goals of both systems and represent a risk.

One explanation for why these trade-offs occur is that each system tends to be designed by people with experience of that type of operation. Designers may be able to identify problem areas within their own system but it is unclear who has the responsibility for identifying problems that may occur *between* systems. Aligning the goals of potentially conflicting systems would eliminate the need for unbounded trade-offs. In essence, the designers of both systems agree the trade-off prior to the systems becoming active and it is then up to the operators to ensure that they commit to the aligned goals in the knowledge that it will deliver both the efficiency and the thoroughness desired by both systems.

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To certify, to investigate or to engineer, that is the question

J.A. Stoop
Lund University, Sweden
Delft University of Technology, faculty of Aerospace Engineering
Kluyverweg 1, 2629 HS Delft, the Netherlands
Stoop@kindunos.nl

Abstract

Several major safety critical events have occurred in aviation in an attempt to make this matured system more efficient, mean and lean. These events have raised questions about their design and operational concepts. Simultaneously, the aviation investigation community reflects on how to cope with the second century of aviation. Events such as the Dreamliner batteries, QF32 and AF 447 have demonstrated how thin the line is between precaution, successful recovery and disaster. Modern socio-technical systems have a very high degree of complexity, dynamics and uncertainty. These uncertainties are dealt with by several professional communities during design, operation and investigation. This contribution elaborates on the potential and opportunities to feed information across these communities by creating communication loops for designing resilient systems in the early phases of systemic adaptation.

1 INTRODUCTION

Historically, safety investigations have seen a development in which a focus on technological failure has been complemented by a focus on human behavior, organizational failure and governance risk decision making. Over times, a more integral safety notion has been created by broadening the scope from pre-accident causation contributing factors towards safety enhancing and recovery factors during rescue and emergency handling in the aftermath of serious events. In the international aviation community, a gradual development took place in incorporating family assistance and victim support in dealing with the aftermath of aviation accident, first in the USA and Canada, later on in Europe (Troadec 2013). Informing the public about major accidents and incidents through independent investigations has become a Citizen's Right and Society's Duty (Van Vollenhoven 2006). Merging these safety aspects into a notion of 'integral safety' has broadened the identification of system deficiencies, which may have their origin before, during and after an occurrence. Consequently, the population at risk involved in the investigation has expanded from crew and passengers to employees at airports, residents in the vicinity of an airport, rescue and emergency services, family and relatives that may encounter traumatic damage due to an air crash.

Characteristics and properties of modern, open, complex systems can be identified and analyzed along the lines of:

- A prospective analysis of the primary processes and relevant actors during design and operation including their safety critical strategic decision making issues. However, an encompassing analysis is not always feasible in practice due to the complexity and dynamic nature of transportation systems.

Therefore, a second retrospective approach is indispensable:

- An in-depth and independent investigation into systemic incidents, accidents and disasters. Such independent investigations may provide a temporary and timely transparency as a starting point for removing inherent deficiencies before they manifest themselves as 'emergent' properties.

Accidents and incidents are the manifestations of such inherent and emergent properties and may provide evidence and explanation through investigations.

2 CASE HISTORIES

2.1 Air France AF447

The BEA report on the AF447 accident demonstrates the complexity and dynamics of man-machine interfacing in which a continuous adaptation to a rapidly changing information display had to be taken into account. The eventual crash results from a succession of events in which (BEA 2012):

- A temporary obstruction of the pitot tubes, created inconsistencies in air speed measurements that caused autopilot disconnection and reconfiguration of normal flight control law mode towards alternate law mode
- Inappropriate pilot input destabilized the flight path
- The lack of linking between loss of indicated airspeed and appropriate crew procedures and the late identification of deviation from the flight path and insufficient correction applied by the PF
- The crew did not identify the approach to stall, their lack of immediate response and exit from the flight envelope and the crew failure to diagnose the stall and lack of inputs to enable a recovery.

In response to the obstruction of the pitot tubes by ice crystals, various monitoring systems triggered almost instantaneously. The crew is only informed of the consequences of the triggering by observing the disconnection of the automated pilot and the automated throttle and the shift to alternate law Electronic Centralized Aircraft Monitoring (ECAM). No failure message is provided that identifies the origin of these failures, in particular the rejection of the ADR's and of the speed measurements. No ECAM message enabled the crew to perform a rapid diagnosis of the situation, initiating the appropriate procedures. However, the crew is trained to read the ECAM as soon as the flight path is controlled, in order to analyze the situation and to organize a course of action to deal with the failures. Between the disconnection of the autopilot and the stall warning, numerous messages were displayed on the ECAM, but none helped the crew to identify the problem with the anomalous airspeed. Furthermore, the rapid change-over of the displayed information which was created by the flight computer in managing the priorities further complicated the crew's analysis and understanding of the situation. The reading of the ECAM by the pilots was time consuming and used up mental resources to the detriment of handling the problem and monitoring the flight path.

The final words of the BEA on the AF447 crash concluded that (Troadec 2013):

- The operating circumstances were only clarified by the flight recorder retrieval
- The occurrence was a consecutive series of critical events, starting with a loss of airspeed indications, followed by the airplane exiting the flight envelope, a loss of situational awareness of the crew, a lack of understanding of the stall situation and absence of recovery manoeuvres
- Such occurrences occurred in both classic and high automation levels of aircraft design
- In which safety depends on adequacy between cognitive capacities and signals provided
- While hypotheses used for safety analysis were not always relevant, procedures not always applied and warning not always perceived
- Improving quality of feedback enables detection of weaknesses in safety models as
- Combination of ergonomics of warning designs, training conditions and recurrent training processes did not generate expected behavior, showing limits of current safety models.

In particular the last item revealed concerns about the basis for designing, manufacturing, simulation, certification, training and investigating human performance in aviation. In particular in emergency and unforeseen situations, human performance modeling proved to be deficient.

2.2 Qantas Flight 32

The accident occurred on the morning of 4 Nov 2010 at 10.01 hrs am by an uncontained failure of the port inboard (Number 2) engine, while en route from Singapore over Batam Island, Indonesia (ATSB 2010).

Debris from the exploding engine punctured part of the wing and damaged the fuel system causing leaks, disabled one hydraulic system and the anti-lock brakes and caused No.1 and No.4 engines to go into a 'degraded' mode, damaged landing flaps and the controls for the outer left No.1 engine.

The crew, after finding the plane controllable, decided to fly a racetrack holding pattern close to Singapore Changi Airport while assessing the status of the aircraft. It took 50 minutes to complete this initial assessment. The First Officer (FO) and Supervising Check Captain (SCC) then input the plane's status to the landing distance performance application (LDPA) for a landing 50 tonnes over maximum landing weight at Changi. Based on these inputs the LDPA could not calculate a landing distance. After discussion the crew elected to remove inputs related to a wet runway, in the knowledge that the runway was dry. The LDPA then returned the information that the landing was feasible with 100 metres of runway remaining. The flight then returned to Singapore Changi Airport, landing safely after the crew extended the landing gear by a gravity drop emergency extension system, at 11:45 hrs am Singapore time. As a result of the aircraft landing 35 knots faster than normal, four tyres were blown.

Upon landing, the crew were unable to shut down the No.1 engine, which had to be doused by emergency crews 3 hours after landing until flame out. The pilots considered whether to evacuate the plane immediately after landing as fuel was leaking from the left wing onto the brakes, which were extremely hot from maximum braking. The SCC pilot noted that in a situation where there is fuel, hot brakes and an engine could not be shut down, the safest place was on board the aircraft until such time as things changed. The cabin crew had an alert phase the whole time through ready to evacuate, open doors, inflate slides at any moment. As time went by, that danger abated and the crew was lucky enough to get everybody off very calmly and very methodically through one set of stairs. The plane was on battery power and had to contend with only one VHF radio to coordinate emergency procedure with the local fire crew.

There were no injuries reported among the 440 passengers and 29 crew on board the plane. Immediately after the accident, shares of the engine manufacturer Rolls-Royce fell 5.5% on the London Stock Exchange. Shares of AEDS, which owns Airbus, also fell. By mid-morning on Nov 8, Rolls-Royce shares had fallen by more than 10% since the accident the previous Thursday.

2.3 The Dreamliner battery case

On January 7th 2013, a B787 Dreamliner of Japan Airlines engaged a fire after landing at Boston USA in its Li-ion battery pack. On January 12th 2013, an All NipponB787 made an emergency landing after a battery fault warning and smoke smell dispersed the aircraft. No passengers were injured and no aircraft were lost. All Nippon shares fell 1.6% in Tokyo, while Boeing shares fell 3.3% in German trading and 1.9% in New York. The battery manufacturers shares fell 4.5%. Fifty jets, each 207 million$, were grounded for almost 4 months, staggering total costs to about 550 million$. NTSB and JTSB started investigating the events, during which also Thales as the designer of the battery management systems, were investigated. The Li-ion batteries were selected for reasons of weight reduction and energy density, although problems with thermal runaway and overheating were previously known. During these investigations, Boeing conducted research to create a simple cooling, fire mitigation and containment solution for the battery package in order to avoid a full time consuming and costly renewed certification process that would delay resuming flights for about one year. During its investigation NTSB was not able to identify the deficiencies on a short notice and shifted its focus on the design assumptions and the certification process as such. According to the NTSB, the direct causes for the overheating may never be found.

The main criticism focused on the assumption that a failure was due in less than one out of 10 million flight hours, while two safety critical events occurred within 52.000 flight hours. The investigations showed that the battery concept was prone to heating, based on the experiences in other applications of Li-ion batteries where fires had been noticed. During the following months, Boeing put pressure on the regulators to resume flying, indicating that the event would not happen again. During the investigation period, news releases indicate that the Federal Aviation Agency certification process relied on engineering design knowledge within the Boeing company. This procedure started in 2005, using approved outsider engineers and continued for years, even as government audits found that these procedure had poor oversight and led to errors, compromising the delegation system. While most countries followed the FAA lead in these regulatory matters, the Canadian Transport safety Board pointed to engineering certification as a possible factor in the crash of Swissair flight 111 in 1998, killing everyone on board. Engineers may have lacked sufficient knowledge of the Boeing MD-11 power grid to provide certification, the TSB found. Between 1998 and 2004, 700 designated engineers were removed from the FAA approval procedure. In several news bulletins a failure to spot certification issues may have been responsible for 70% of the deaths in the past 20 years with US carriers (FSI 2013). This raises the question whether complexity could outpace manufacturing and regulation ability to spot deficiencies in design and certification. Earlier deficiencies in the Boeing 737 rudder actuator inverse functioning, the Boeing 747 explosive fuel tanks and several icing issues with fatal consequences may have been caused by this certification approval procedure, where all designs were certified as fail safe. A mismatch between resources in FAA, lacking sufficient design knowledge, and manufacturers expertise may have created a situation where certification standards and assumptions have not been challenged adequately.

Eventually, public confidence in the aviation system was challenged. The use of Lithium-ion batteries was addressed by a public forum of NTSB on 11-12 April 2013, questioning the principles of industrial self-certification. As FAA announced a return to flight for the Dreamliner on may 13th, ETOPS use was blocked by passenger advocacy groups, requesting flight limitations on the extended use of the Boeing 787. While FAA did not wait for the results of the NTSB investigations, public concern was raised and supported by prominent aviation safety experts in the USA. In conclusion, the strive for recapturing dominance in a world market, competing with Airbus, FAA lost face in public credibility, while Boeing lost about 50 million$ per week due to the grounding. All Nippon Airways had to cancel over 3600 flights for its 17 Boeing 787's, potentially requiring cash refunds from Boeing to compensate for the losses. The Japanese FAA formulated additional and more stringent requirements before resuming flight with the Boeing 787 by requesting monitoring systems on board for the Li-ion batteries.

Failures to spot and anticipate safety flaws during certification of new aircraft have been linked to 70 % of US airline-crash death in the past 70 years (FSI 2013). The Dreamliner lithium-ion battery fires have renewed questions whether complexity and new technologies of new aircraft have outpaced a manufacturers' and regulators' ability to identify deficiencies during design and certification. Although certification standards have preventing fatal US airline crashes since 2001, occasions have occurred where assumptions were incorrect and not conservative enough. The use of 'special conditions' in the absence of regulations for new technologies, as applied in the Dreamliner case, have proven the need to modernize certification processes and standards (FSI 2013).

3 A ROLE FOR ACCIDENT INVESTIGATIONS

There is a specific role for accident investigations as a partner in a more institutionalized network as a prerequisite for a further professional development, sharing professional expertise and participating in knowledge management.

In such a network, safety investigations may serve as:

- A repository for information dissemination and common learning
- A problem provider for knowledge development and systems change
- A public safety assessor and public spokesman beyond and above parties involved.

Safety investigations represent a specific analytic instrument with its own characteristics:

- Independent from blame and vested interests of third parties and stakeholders
- A cased based approach, based on a systems perspective
- Evidence based with respect to its findings and recommendations
- Pro-active learning by developing generic principles, notions and knowledge, combined with dissemination of findings and recommendations on domain and sector specific solutions and change strategies.

Safety investigations serve a triple goal:

- Vision Zero: prevention of fatalities and injuries among the population at risk
- First Time Right and Zero Defects: no socio-economical losses during the introduction of new products and processes that jeopardize business continuity
- A Citizens' Right and Society's' Duty: providing society a timely transparency on the factual functioning of systems.

3.1 A socio-cultural context

However, some safety scientists are critical about the notion of Vision Zero (Hale 2006):

As an objective it seems to be a shining example of altruism and concern for mankind. Being an ideal, it is too far off to be motivating, but more fundamentally, ignores the fact that safety is not an independent property of a system. Claiming zero accidents as a goal denies conflicts and tradeoffs with other goals. Claiming zero accidents is the safety equivalent of the cries of fundamental religious groups, subordinating all other goals to their one vision of the right path to salvation or paradise. Zero accidents is a pure, hard and shining ideal – almost 'one worth dying for' (Hale 2006).

This opinion is not shared by many others. It is possible to establish a School of Thinking in identifying safety deficiencies and system change (Stoop and Dekker 2012). It is possible to reconcile conflicts and to overcome contradictions by establishing independent investigations as a Citizen's Right and Society's Duty (Van Vollenhoven 2006).

It is possible to achieve a safer aviation system than ever before, aiming at the goal of no fatalities and injuries in commercial aviation, where no fatal US air carrier accidents have occurred since 2009 . Such systems represent a separate category of non-plus ultra-safe systems.

The aviation investigation community considers accident investigation a unique incentive for safety changes through the release of reports and recommendations, especially those who deal with systemic and knowledge deficiencies (Arslanian 2011).

Are such trade-offs purely personal or can they be traced back to underlying socio-cultural differences between world regions; are they imposed by higher order social, cultural or economical values? An exemplary discussion is provided by the debate on road safety developments in Europe, with the Vision Zero principle.

In a debate on how far a Vision Zero can be effectuated, differences of opinion on whether such a goal can be achieved, clarify underlying differences in a socio-economical perspective on safety as a social value. While some emphasize the ethical approach to human life in averting fatalities and injuries and addressing responsibilities at a societal level, others emphasize the inevitability to balance safety against other societal values. They emphasize the need to make cost-effective decisions in terms of a rational socio-economical policy and a human desire for fulfillment, where risk of death and serious injury is a matter of degree. At the operational level, such a balancing values dilemma is formulated as the ETTO principle: the Efficiency-Thoroughness-Trade-Off (Hollnagel and Woods 2006). Such differences can be traced back to differences in socio-economical models and the value of life in each of these models.

Three competing socio-economical models exist in the Western hemisphere, which are seldom made explicit in debates on safety culture and organizational culture:

- The Anglo-Saxon model of liberal values, dealing with self-relianceness, private entrepreneurial initiatives, freedom and limited social security, with a dominant position for market mechanisms. In this context, safety and risk are based on cost-effectiveness considerations, taking into account probabilities of occurrences and responsibilities of corporate management
- The Scandinavian model of humanitarian values, where social cohesion, common wealth, human rights, and stability of the economy leave more room for governmental control and participation. Safety and risk in such a model, deals with preserving the unprotected from hazards beyond their control. This includes a Vision Zero regarding inflicting death and injury on road users.
- The Rhineland model, dealing with providing a human face to socio-economical, political and power relations. In this model a role for governmental control and guidance is foreseen, aiming at a welfare state, achieving consensus between social partners, providing stability on a medium and long terms. With respect to safety, continuity on the long term prevails over short term profit and cost-effectiveness and democratic participation in policy making decisions is stimulated.

Unfortunately, subsequent organizational structures and their functioning at an entrepreneurial as well as governmental level, have not yet been studied extensively by scientific research with respect to the safety performance and failure mechanisms of these models.

3.2 Human performance in emergency monitoring

Several major events such as AF447 and QF32 indicate the thin line between successful skilled professional responses and a catastrophic outcome in a Fly By Wire environment. The classic notion of ‘human error’ as undesirable deviation from a normative concept of flight control is predominant among human factor specialists. Human error is commonly accepted among psychologists as the leading artifact in causing accidents. Human error should degrade the system from its optimal performance, creating mishap that could be prevented by safety management interventions. For psychologists, the rejection of the concept of ‘human error’ is difficult to rationalize with the perspective of the system designer employing a formal prediction methodology to help avoid actions that will degrade the system. *When considering human error, first of all pick your perspective then choose your label (Harris 2011, pp 100].*

Consequently, automation would be the solution to human error, resulting in full automated flight. In this concept, there is no space for a critical reflection on the design of a supervisory role and discretionary responsibility of the pilot [7, 9]. Leaving aviation, navigation, communication to automated systems, pilots should restrict themselves to a managerial responsibility, balancing safety against efficiency and costs (Harris 2011). However, such concepts rely on almost flawless automation and extreme low failure probabilities, irrespective of technological imperfections and harsh operating conditions. In practice, such an approach might not be the most appropriate perspective to analyze and understand complex and dynamic interactions between flight management systems and operators (Stoop and Dekker 2012, Stoop 2012). It is a question whether it is possible to incorporate the know-how of operator experience into the design of safer systems (Morel, Amalberti and Chauvin 2008). Such a design could preserve craftsmanship and native resilience of such systems, relying on a high level of adaptability and professional expertise of the operators. These studies indicate potential adverse effects of classical safety interventions in terms of professional reluctance to accept

further automation or through the emergence of new risks (Morel, Amalberti and Chauvin 2008). Constraining operator behavior in order to improve safety makes systems more rigid to the detriment of self-managed safety.
Such a role of the pilot as supervisor with oversight and control over the aircraft fits in well with the delegated responsibility of operators in a global network with distributed control over the primary production processes in a time critical environment, based on good airmanship (Stoop 2012).

In analogy with Paries, three main sources for failure or success can be identified (Paries 2011):

- The available time window to deal with the situations was critical. The AF447 event took only 263 sec from the beginning to the very end, while the QF32 event took 4 hours and 45 minutes before the crew could declare the situation to be safe.
- Understanding the complexity and dynamics of the event consumed many resources. Diagnosing the event was to the detriment of the primary task to control the flight path in the AF447 event, while additional crew resources enabled to a high extend a successful handling of the QF 32 event.
- The availability of resources, redundancy and flexibility in responses determined the outcome of the events to a very high extend. Regaining oversight over the situation by strictly following procedures and check lists on a compliance based level would not have helped an understanding of the situation due to the damage to the Flight Management System and the structural damage to the aircraft or the adherence to quantitative risk analysis standards.

4 RESILIENCE AND INNOVATION

In particular where dealing with innovations is suggested, designs should be based on principles of resilience. Introducing such designs intend to serve flight safety by further development of the flight envelope protection, based on three notions:

- Redundancy. The implementation of a recovery function for pitch control is necessary because of the loss of aerodynamic forces on the aircraft by disruption of the air flow across the wing and empennage. In addition, malfunctioning of the regular control surfaces may occur due to external or internal damage, failure of control actuators or as collateral damage due to other malfunctions such as structural collapse. Such a recovery function focuses on technical redundancy. Additional redundancy is provided by an overlap between technical redundancy and enhanced emergency handling capacity of the pilot in the recovery control mode of the flight management system
- Resilience. The decoupling of a tight relation between the aerodynamic center and center of gravity range of the whole aircraft can create a more flexible range for the aerodynamic center by adding two small eccentric forces, deployed by two small extractable control surfaces. A further optimization of the center of gravity range is possible beyond the conventional cg range, facilitating a more economic and flexible use of the aircraft. This device does not replace the elevators, but reduces their size, reducing weight and parasite trim drag. Such resilience focuses on performance efficiency and eventually may lead to reconfiguration of the aircraft geometry as foreseen in the eu framework program of smart wing development
- Responsive. There is a growing concern in the pilot community with respect to the reduction of flying and emergency handling skills under automated flight conditions and continuing degree of automation. Such a transfer from pilot controlled recovery action to aircraft controlled recovery devices seems the only option for commercial aircraft in the absence of the powerful thrust vectoring which exists in military aviation. In such a strategy, a human centered design in maintaining overall control over the situation seems preferable over a fully automated solution. The focus is on redistribution of the decision authority between aircraft and pilot and requires careful design of the man-machine interfacing. Such a transfer is to be accompanied by a simulator training program. By making the aircraft-pilot interface more responsive to degraded flight conditions and emergency conditions, the aircraft becomes less dependent of fluctuations and unforeseen situations in normal conditions. Such a responsiveness may reduce planning continuation errors and procedural flight performance.

4.1 Reality checks

Safety investigations serve the goal of knowledge deficiency identification. Safety investigations are the problem providers for knowledge development.

Historically, on a case basis, investigations have disclosed failure phenomenon that had not been understood before. Examples in various high-tech industrial sectors provide show cases that have triggered scientific developments, establishing new disciplinarian domains. The De Havilland Comet is associated with metal fatigue in jet engines with pressurized cabins, Tenerife and Harrisburg are related to human error and human resource management issues, while the Challenger is linked to organizational learning.

In their criticism on current practices in accident investigation and risk assessment modeling, scientists link the criticism on models such as FTA, FME, Event trees and others to the conduct of investigating accidents itself, in particular to the investigation of events. The simplicity of analysis, the linear causality, loss of the time as analytic dimension and limited focus on the operational level and role of the operator should make event models inappropriate during investigations. Their descriptive nature and limitation in the number of failure mechanisms they encompass, reduces the usefulness and quality of event investigations (Hollnagel and Woods 2006). The lack of coupling to a systems approach reduces the validity of their findings and consequently, their solution potential.

4.2 Modeling and prediction

This shift from event investigation to event modeling however, is disputed by investigators: accident investigators do not apply models in the fact finding phase of an investigation, they are applied during design of systems and in the analysis phase of investigations. During fact finding and recomposition of the occurrence, forensic principles prevail (Stoop 2012).

During the design, probabilistic models are used in a generic and context free manner to describe a limited set of 'top events' which are allocated a certain frequency of occurrence. The eventual risk should to stay within acceptable limits or risk levels. If such a frequency is very low, such failure mechanisms are considered acceptable and are not designed out of the system. This is based on the assumption that their occurrence will be fed back to designs and certification processes to enable further mitigation. In practice however, such feedback may be absent by a lack of feedback mechanisms, or fade as weak signals in an increasing information noisy environment. Such failure mechanisms may go unnoticed, until an accident occurs. Several accident have demonstrated that there is no guarantee that pilots will detect failure modes in a timely manner that have been overlooked or accepted as negligible during the design and certification process.

As stated by Arslanian: it is not possible to rely only on a predictive approach. Prediction is not a replacement for correction, but prediction and correction are in fact two sides of the same coin. A permanent screening of available data to identify unforeseen hazards or to better assess risks needs feedback data, sometimes from the unpredictable (Arslanian 2013).

5 CONCLUSIONS

In the investigative community, critiques focuses on the practical use of models for investigation purposes, discriminating between their application in the fact-finding phase and analytical phase. For the benefit of collecting and structuring information it is required to apply a specific investigation methodology. An investigation should take into account each of the events as building blocks, sequencing in a temporal and spatial order to create mental representations for investigators in an advancing time frame. This should facilitate a quality control over the reasoning process and inferring logic in the relations between events. Using predefined models in accident investigation deprive an investigator from verifying and falsifying models that have been used in design and certification phases and have proved not to be fail safe in practice (Troadec 2013).

Safety investigations bear the element of *serendipity*; finding something out by accident through an open-minded, systemic and in-depth investigation of unpredicted events. Safety investigations are a reality check since preceding modeling, simulation and systemic decomposition during design, development, testing and certification all have their assumptions and limitations. It is necessary to make capital out of experience, to get feedback from the unpredictable, to learn from what we encounter in the field (Arslanian 2011).

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Cognitive Demands of Staying in Control
on Highly Automated Aircraft When Faced with Surprise

Shawn Pruchnicki [1], David Woods[1]
[1] The Ohio State University, USA
Pruchnicki.4@osu.edu Woods.2@osu.edu

Abstract.

The pilots of today's modern aircraft are much more information and resource managers as opposed to direct controllers of the aircraft. Failures can result in conflicting or erroneous information flowing to automatic systems and flight deck displays complicating control and management tasks. The initiating or triggering event produces a kind of surprise situation where flight crews must recognize that the state of control of the aircraft has changed, scan information sources, understand the changed situation, priortize and decide on new courses of action. It is not well understood how pilots handle such surprises including factors that influence how they recognize the event, update their understanding of the situation and priorities, and develop/revise a course of action. We are interested in cognitive demands and difficulties that arise in the short interval immediately following the symptoms produced by the initiating event. By examining the demands of the tasks that flow from the initiating event -- how it is manifested in instrumentation, how different automated systems respond, and how aircraft behavior changes, how the event changes tempo, how the event changes priorities, and how the event changes what are critical and constructive courses of action -- we can better understand how pilots successfully accomplish this task and risks of breakdowns when these situations arise.

1 INTRODUCTION

In today's modern aircraft, the majority of flight time is spent at cruise where decision making is typically light and flight crew members are interacting with automation in a supervisory mode. That is to say, crew members are watching automation "fly" the aircraft and are adjusting various systems as needed. Additionally, during these times, event tempo is low and crew members have a clear understanding of what to expect next. They have sufficient time to recognize changes, understand the new situation and re-adjust the systems that handle the aircraft. The flight crew has the capability to stay in control of the aircraft and manage the automated systems.

But what happens when an initiating event occur in other phases of flight and when the failures result in conflicting or erroneous information flowing to automatic systems and flight deck displays? The flightcrew as resource manager and supervisor experiences new cognitive demands at the same time that tempo increases and actions become more critical for safety.

The initiating or triggering event produces a kind of surprise situation where, in the short interval immediately following the symptoms produced by the initiating event, flight crews must

- recognize that the state of control of the aircraft has changed,
- scan multiple information sources, and integrate information gathered to understand the changed situation,
- priortize and decide on new courses of action.

We understand too little about pilots' ability to able handle such surprises, the difficulties involved in the cognitive activities, the risks for how tasks could breakdown, and the support mechanisms that ensure the tasks can be done successfully and reliably despite the difficulties and given the criticality (Woods and Sarter, 2000). A variety of factors could influence how flight crews recognize the event, update their understanding of the situation and priorities, and develop/revise a course of action. It is particularly critical to measure the cognitive demands and difficulties that flow from the initiating event -- how it is manifested in instrumentation, how different automated systems respond, and how aircraft behavior changes, how the event changes tempo, how the event changes priorities, and how the event changes what are critical and constructive courses of action.

In this paper we describe a line of research underway to examine the above issues. As a hallmark of resilient systems, we are interested in how flight crews reassess, reconsider and revise their perceptions and understanding following the initiating event. How do they gather and integrate information across multiple data sources to make sense of the situation quickly? How do they decide on decisive and constructive actions despite the time pressure, criticality and uncertainties? The end result of this line of inquiry will contribute to a new kind of assessment of what it means to be in control, including risks and support requirements (Hollnagel, 1993).

2 BEING IN CONTROL

Vignette 1: "My new first officer had been doing a great job flying the jet on previous legs. However, on the next leg as we lifted off the runway to fly a complicated departure procedure, I could see and hear that he was becoming focused solely on aircraft heading to the exclusion of other flight parameters. He was trying to hand fly a departure that not only required a rapid level off, but also a turn to stay within a close by airspace boundary. Additionally, we were assigned an speed well below normal our normal departure airspeed. I could see that because of his narrow focus on aircraft heading, our rapidly increasing airspeed & climb rate would soon result in multiple violations; thus I assumed control to prevent an excursion."

This notional example considers how one person monitors how well another human is controlling a process, anticipates risks of loss of control, and intervenes constructively and decisively before control of the situation deteriorates too far (Woods, 2011; Woods and Branlat, 2011). In this example we see how an experienced Captain stays in control as initial signs of loss of control emerge when she is monitoring the activities of the First Officer as pilot flying, The example illustrates the combination of factors that led the Captain to anticipate the need to intervene and to transfer control bumplessly to avoid difficulties. She considered the difficulty of the task (a complicated departure procedure), workload trend (going up), the difficulties ahead (increasing), and the risks of to task performance. (getting closer to limits on criteria for successful performance), all, relative to the abilities of the First Officer to handle the multiple demands. To consider these factors, she knew what indicators to scan, how to integrate the information she gathered and how to combine them with expectations about to what lay immediately ahead in order (a) to understand the trend on the risk of loss of control and (b) to see how and where to take decisive and constructive action to maintain control.

Vignette 2: "We had the autopilot engaged upon beginning our initial descent towards our crossing restriction. As we were completing the descent checklist, I noticed something flashing while scanning across the displays to ensure ATC path compliance. As I searched the moving map and FMS indications, I recognized that the FMS had gone into dead reckoning mode and the rest of our route had disappeared from the map display. I was puzzled as to what could have produced this change? I soon recognized that this change in mode meant the aircraft was not only drifting off course, but also, that our crossing restriction had been removed. I directed the First Officer to advise ATC, while I quickly inserted the next waypoint, re-established the crossing restriction, and shifted autopilot modes to regain control of the situation."

The second notional example considers how one person monitors how well automated systems are controlling a process. The example illustrates an automation surprise (Woods and Sarter, 2000) triggered by an indirect mode transition (Sarter and Woods, 1995). Whereas in vignette 1 the situation developed rapidly but continuously, in vignette 2 the initiating event introduces a sudden change. The Captain needs to recognize that a change in control has occurred and that the automated systems have changed their configuration, and therefore how they will control the aircraft relative to targets, constraints, and plans has changed. Upon noticing an unexpected indication while scanning the cockpit displays, we can easily imagine the basic questions of an automation surprise (Sarter and Woods, 1995) running through the Captain's head: what just happened, what are the automated systems doing and going to do next, how did we get into that mode. Also note in this example, the absence of an indication provides relevant information, i.e., the absence of route indication, the loss of he crossing restriction.

These situations occur under time pressure, so that scanning displays and integrating data gathered to answer how and why questions is insufficient -- constructive interventions to maintain control are needed. One could spend too much of the limited time available for information processing and decision making answering the questions of how and why did we get into this situation, when staying in control demands timely identification of what to do next and the ability to commit to decisive intervention despite the time pressure (and potentially uncertainty).

The shift to monitoring automated systems for risk of loss of control introduces some differences and new difficulties as contrasted with the human to human case illustrated in vignette 1. The Captain directly can observe directly how well the First Officer is handling demands, and can project how the First Officer will handle upcoming demands based on shared knowledge and experiences as professional pilots. Understanding changes in automation configuration, how the automation will handle the aircraft following the change, projecting how automated systems will behave next, and judging how these changes effect the risk of loss of control is quite different and presents new kinds of difficulties (Sarter and Woods, 2000).

Vignette 3: "We had just lowered the gear and were starting down the nighttime ILS to minimums when I noticed that, despite the auto-throttle being engaged, the airspeed was too fast for lowering final flaps. I still tried to lower flaps but the aircraft's programmed protection refused to comply. I manually extended the spoilers in an attempt to bleed off airspeed so that once corrected we could lower the flaps. With the spoilers extended the aircraft climbed above the glideslope and then surprisingly pitched down. I retracted the spoilers as we descend below the glideslope and the aircraft responded by pitching up and the auto-throttle began to spool up the engines. However, given that the rate of applied thrust was insufficient to regain the lost airspeed, we started to descend further below the glideslope. It almost seemed as if the auto-throttle was not working correctly in conjunction with the autopilot that was flying the ILS. Things were happening very fast. When we received the first "pull-up" terrain warning I took control of the aircraft, turned off the automation and hand flew a missed approach. We still don't understand how we became so unstabilized and why the autopilot could not regain stability and path control after the slight initial airspeed excursion."

The third notional example introduces new complexities as there are interactions across multiple automatic systems, and two automated systems appear to be working at cross-purposes. In this example, time pressure to intervene is high limiting the amount of time available for scanning and interpretation. But uncertainty is high: each action is followed by unexpected behaviors of automated systems and aircraft behavior. Each cycle of information gathering and situation assessment leads to control surface adjustments but instead of improving control of the situation they introduce new demands for information gathering, situation assessment, and intervention. Ultimately, the resolution is to fly a go-around maneuver.

These notional cases illustrate the need to study and model the cognitive demands and risks associated with staying in control on highly automated aircraft. To do this we need to analyze the cognitive processes required while moving through time from initiating event and associated indications, through information search and integration, to committing to new courses of action, and looping through combinations:

- Background: What is the state and trajectory of control just prior to the initiating or surprise event?
- Initiating event and manifestation in displays, alerts, automation system changes and behaviors, and aircraft behavior: How do events change control and change risks of loss of control? How are the events and the change in control signaled to flight crew? Does the event generate conflicting indications or other challenges?
- Scan patterns and information gathering: What are effective scan patterns? What are the costs (e.g., time delays), difficulties (e.g., recognizing the absence of an expected indication; detecting state changes with poor display of events) and risks of breakdown (e.g., fragmented scan pattern; missing indirect mode changes, missing dropped constraints)
- Integration and assessment: What is necessary to resolve uncertainty and conflicts between indications (analysts must be sure to escape from hindsight bias to address this question)? What is needed to anticipate upcoming events and constraints? What are the costs, difficulties (e.g., what is the role of anticipation), and risks of breakdown (e.g., getting stuck on this cognitive activity delaying intervention decisions) associated with integration and assessment?
- Interventions and commitment to course of action: How to identify constructive interventions and commit to a course of action despite uncertainty and risk? How to generate possible approaches? How to focus on key priorities? what are the costs, difficulties (e.g., how to decide on interventions when data conflicts), and risks of breakdown (e.g., over-relying on automated systems to handle non-normal situations; delays due to resolving uncertainties, inability to prioritize, bumpy transfer of control) associated with identifying and committing to constructive interventions?

- Dynamic interplay across these events and activities: how to manage tempo, time pressure, and workload to keep up with the pace of events? What are the costs, difficulties, and risks of breakdown in managing workload in time as a situation threatens to cascade out of control?
- The cognitive demands above can be address by observing how professional crews in advanced turbojet aircraft simulators handle the general challenges imposed by different specific instances of surprise that challenge the ability to stay in control. The data can be analyzed as a process tracing of the detailed cognitive flow as organized around the above points (Woods, 2003). Analysis can extract results on questions such as:
- What factors delay information gathering and integration when the surprise is first manifested or recognized?
- What kinds of scan patterns do pilots use? Are these ad hoc or systematic? Are some scan patterns more useful and robust in these situations?
- How do current displays hinder or facilitate information gathering and integration?
- What factors produce bumpy transfers of control or control conflicts between the interacting automated systems and flight crew?
- How do crews resolve conflicts between data and interpret unexpected automated systems responses?
- How do some failures complicate flight crew control and management tasks when conflicting or erroneous information flows to automatic systems?
- What factors delay or undermine the ability to take decisive and constructive actions despite uncertainty?

The initial model of the cognitive demands of staying in control following a surprise event provides the structure for future data collection and analysis to identify what is particularly difficult, what breakdowns are likely, and what support mechanisms can increase the ability to stay in control in demanding situations.

3 RESILIENCE AND STAYING IN CONTROL

Staying in control in this setting (aviation flight decks), for this joint cognitive system (multiple automated systems and flight crew), and for key dynamics associated with keeping pace with a changing situation represents a kind of natural laboratory (Woods, 2003) for Resilience Engineering to investigate key concepts about how systems respond to challenge situations (Woods and Branlat, 2010).

First, staying in control following a surprise is subject to significant risk of the adaptive system breakdown pattern - decompensation which occurs when challenges grow and cascade faster than responses can be decided on and deployed to effect (Woods and Branlat, 2011). The ability to continue to control saturates so that there is little or no capacity to adapt as challenges cascade and new events occur (Cook and Rasmussen, 2005).

Second, staying in control following a surprise when managing a set of partially autonomous resources (the different parts of flight deck automation) is subject to significant risk of the adaptive system breakdown pattern - working at cross-purposes which occurs when there is inability of different agents at different echelons to coordinate their activities given uncertainty, risk, and the potential for goal conflicts (Woods and Branlat, 2011). Automated systems may work at cross purposes as is indicated in vignette 3, especially following sensor failures, and flight crew and automated systems may and have miscoordinated their activities (Sarter and Woods, 2000; Woods and Sarter, 2000).

Both kinds of breakdowns are risks when flight crews need to stay in control following a surprise, and this risk of a failure to control is captured in the parameter brittleness of a complex adaptive system (Woods and Wreathall, 2008). Estimates of brittleness or change in brittleness can be used to drive investment in training and design improvements.

Staying in control following a surprise represents another kind of opportunity for Resilience Engineering - a potential demonstration of the engineering potential of the field. As specific factors are identified that drive the risk of these breakdowns, specific improvements can be developed and tested. For example, one approach is the development of new training approaches that develop pilot skills to manage surprise events (Dekker and Lundström, 2006). Another is the role of tactile displays which have been shown to improve dramatically pilots' accuracy to recognize relevant indirect mode transitions (Sarter, 2002; Nikolic et al., 2004; Ho, et al., 2004). The data gathered on staying in control following surprise may point to vulnerabilities in different areas with different implications for practical and measurable improvements: if a vulnerability is inconsistent and fragmented scan patterns, then new part-task training programs can be developed to reinforce effective scan patterns; if the vulnerability is inherent difficulties associated with resolving data conflicts, then new heuristic procedures for resolving data conflicts can be innovated (Lipshitz, 1997); if interruptions and multi-tasking are a key vulnerability, then attention directing displays can produce significant performance improvements (Sarter, 2002).

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Applying Robustness Analysis of Dynamic Models to the Problem of Systems Resilience

Hei Chan[1,2] and Katsumi Inoue[2]
[1] ,Transdisciplinary Research Integration Center
2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo 101-8430, JAPAN
hei@nii.ac.jp
[2] National Institute of Informatics
2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo 101-8430, JAPAN
inoue@nii.ac.jp

Abstract

The concept of resilience can be informally defined as the ability ``to maintain its core purpose and integrity in the face of dramatically changed circumstances''. In recent years, many researchers of different fields have recognized the importance of a new research discipline concerning the resilience of complex systems in the face of unexpected events in terms of time and scale (such as the 3.11 earthquake in Japan, the global economic crisis, or a new strain of virus) may cause irreversible damages to the core functionality of these agent systems. In this paper, we introduce a new research topic called ``systems resilience'', to provide a set of unified design principles for building resilient systems, and define a model called the *SR-model*. We will then present our work on applying robustness analysis of dynamic models to the problem of systems resilience. Robustness analysis (also called sensitivity analysis) is the analysis of the relationships between changes in the inputs and the outputs of a mathematical model. In artificial intelligence, uncertain beliefs have often been represented using probabilistic graphical models, such as Bayesian Networks. We will show an example of applying robustness analysis on Bayesian network using a graphical user-interface Bayesian network software tool.

1 INTRODUCTION

The concept of resilience can be informally defined as the ability ``to maintain its core purpose and integrity in the face of dramatically changed circumstances''. In recent years, many researchers of different fields have recognized the importance of a new research discipline concerning the resilience of complex systems in the face of unexpected events in terms of time and scale (such as the 3.11 earthquake in Japan, the global economic crisis, or a new strain of virus) may cause irreversible damages to the core functionality of these agent systems. The goal of resilience research is to provide a set of general principles for building resilient systems in various domains, such that the systems are resistant from large-scale perturbations caused by unexpected events and changes, and if their functionality is lost temporarily due to outside forces, the systems can recover gracefully and quickly to restore their functionality in the long run.

The concept of resilience has appeared in various disciplines such as environmental science, materials science, sociology, ecology, disaster prevention, artificial intelligence, and so on. However, while we have seen many examples of seemingly resilient systems in various fields, researchers have not agreed on a common definition on resilience among the different domains yet.

We have recently developed a new research topic called ``systems resilience'', to provide a set of unified design principles for building resilient systems . Our first step is to define a novel system model called the *SR-model* ([Schwind et al.], which was presented and awarded 3rd place in the Best Challenges and Visions Paper Track in AAMAS 2013).

The significant aspects of our SR-model are as follows. The definition of the SR-model allows the system to change dynamically over time, such that the variables, domains, constraints, and configurations of the system can evolve based on the decisions made by agents and/or outside environmental events. The flexibility of our SR-model allows the modeling of the dynamicity of systems that is required in many domains, and is based on Constraint Satisfaction Problems (CSPs). Our SR-model enables us to measure four important properties that are central to the idea of resilience:

1. **Resistance**: The ability to maintain under a certain ``threshold'', such that the system satisfies certain hard constraints and does not suffer from irreversible damages.

2. **Recoverability**: The ability to recover to a baseline of acceptable quality as quickly and inexpensively as possible.

3. **Functionality**: The ability to provide a guaranteed average degree of quality for a period of time.

4. **Stabilizability**: The ability to avoid undergoing changes that are associated with high transitional costs.

In Figure 1, we show an intuitive example of the SR-model. First, for the property of resistance, the costs of the system at any time (for example, the number of faults) must not exceed a certain threshold (red line of cost = 7), as demonstrated by the system from time t = 1 to 4. Second, for the property of recoverability, the costs of a system should recover as quickly as possible back to an acceptable value (yellow line of cost = 3) if they exceed this value (from t = 1 to t = 2, with the system fully recovered at t = 3, with the recoverability value measured by the "triangular" area above the yellow line) For more thorough definitions of our properties, please see the paper [Schwind et al.].

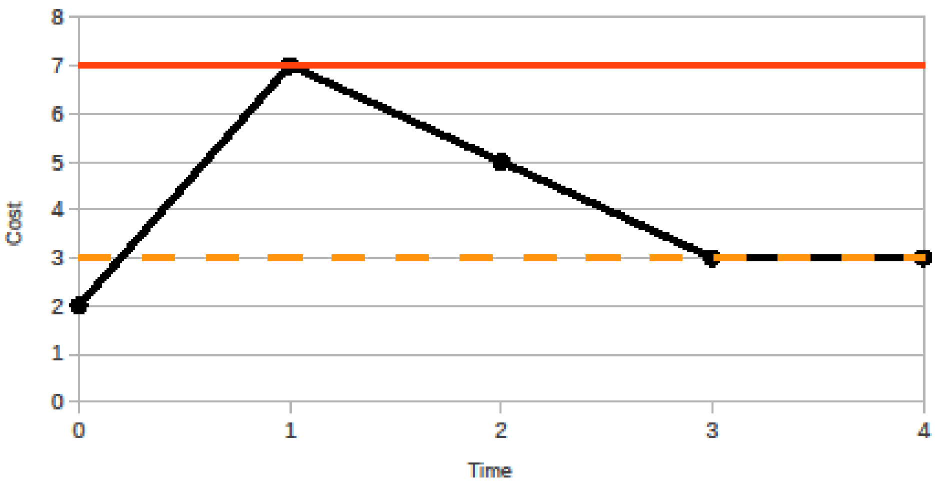

Figure 1. *A graph showing the conceptual idea of resistance and recoverability*

In the current version of our SR-model, we assume that we have a complete knowledge on all past and current configurations of the variables in the dynamic system. However, in reality, we may only have uncertain information on some of these configurations. Therefore, we must incorporate into our models with properties which allow for probabilistic reasoning. In artificial intelligence, uncertain beliefs have often been represented using probabilistic graphical models, such as Bayesian Networks. In a Bayesian Network, the inputs are the network structure, which specify the causal relationships between variables, and the network parameters, which specify the probabilities of local events, while the outputs are the conclusions drawn from performing query inference, such as marginal probabilities.

In this paper, we will present our work on applying robustness analysis of dynamic models to the problem of systems resilience. Robustness analysis (also called sensitivity analysis) is the analysis of the relationships between changes in the inputs and the outputs of a mathematical model. In artificial intelligence, uncertain beliefs have often been represented using probabilistic graphical models, such as Bayesian Networks. In a Bayesian Network, the inputs are the network structure, which specify the causal relationships between variables, and the network parameters, which specify the probabilities of local events, while the outputs are the conclusions drawn from performing query inference, such as marginal probabilities.

2 ROBUSTNESS ANALYSIS

Robustness analysis is an essential tool for checking whether conclusions drawn from model are robust against uncertainty (e.g., estimation errors, environmental changes, unexpected events), and can be used in systems design and model debugging. For example:

- For model builders, who design and debug models
  - What are the "weak" points of model that may contribute to large variations in output?
  - What components we can change to improve model robustness?
- For decision makers, who use and evaluate models
  - What are the causes of certain decisions being made based on the model?
  - How confident are we in the decisions against uncertainty?

Robustness analysis can help researchers and scientists build better models to represent the real world.

The purpose of our research is to develop results for extending the algorithms of robustness analysis to dynamic models such as Dynamic Bayesian Networks, Dynamic Constraint Networks, and Boolean Networks, which evolve over time in a repeated pattern. For example, a Dynamic Bayesian Network can be considered to be the same Bayesian Network repeated over consecutive time slice t = (1, 2, …, T), where the variables at time slice t influence the variables at time slice t+1 (see Figure at the bottom of page). The two types of network parameters, intra-time-slice parameters (within the same time slice t) and inter-time-slice parameters (from time slice t to time slice t+1) are repeated many times within the Dynamic Bayesian Networks. Changing a single value of this parameter means that its copies over multiple time slices also have to be changed. Therefore, the relationship between an output of the Dynamic Bayesian Network (e.g., marginal probability) and a network parameter will be of very high degree (equal to the number of time slices T). This is different from a simple Bayesian Network, where the relationship is of degree one (i.e., linear), and only single-order derivatives are necessary to compute the relationship, and answer the questions we posed earlier. Other dynamic models, such as Dynamic Constraint Networks and Boolean Networks, involve logical relationships between the inputs and outputs. Similarly to Dynamic Bayesian Networks, we will look at how changing an initial input will affect the output of the model over time, or vice versa, how to affect the output of the model by changing some initial input.

To perform robustness analysis of dynamic models, solving for higher-order derivatives are usually involved. This means computation may be expensive complexity-wise. For managing trade-offs between quality of computations and time of computations, we may use many different techniques for approximating results. Below is a list of possible methods of robustness analysis.

- Mathematical methods
    - Derivatives of outputs with respect to parameters at fixed point
    - Bounds of output changes with respect to input changes
    - Robustness intervals or neighborhood regions where decisions remain the same
- Empirical methods
    - Perturbing of model by “small” amount to compute changes in outputs
    - Sampling of variations in a subset of parameters
    - Randomizing changes to check responses in inference results

The significance of applying robustness analysis of dynamic models to the problem of systems resilience is due to the fact that many of these complex systems are dynamic, i.e., they evolve over time based on a set of transition rules. Therefore, they may be represented by dynamic models, where the transition rules are represented by the definition of the models, e.g., in Dynamic Bayesian Networks, transition rules are represented by probabilities, where we have incomplete knowledge of the values of each variable. By performing robustness analysis of these dynamic systems, experts can make guarantees of the resilience of these systems in the face of unexpected events, such that the outputs of the system are robust against any unforeseen perturbations, or whether changes in system design that affects input parameters will consequently affect the current conclusions drawn from the output values.

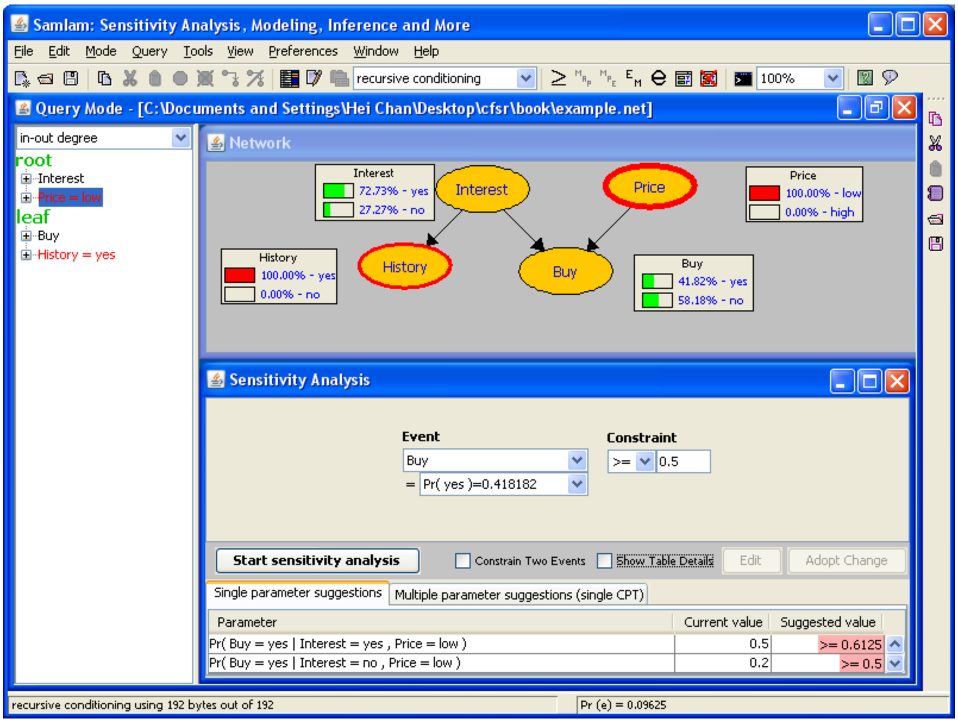

Figure 2. *A screenshot of **Samlam** returning a list of suggestions of single parameter changes for enforcing a user-specified query constraint*

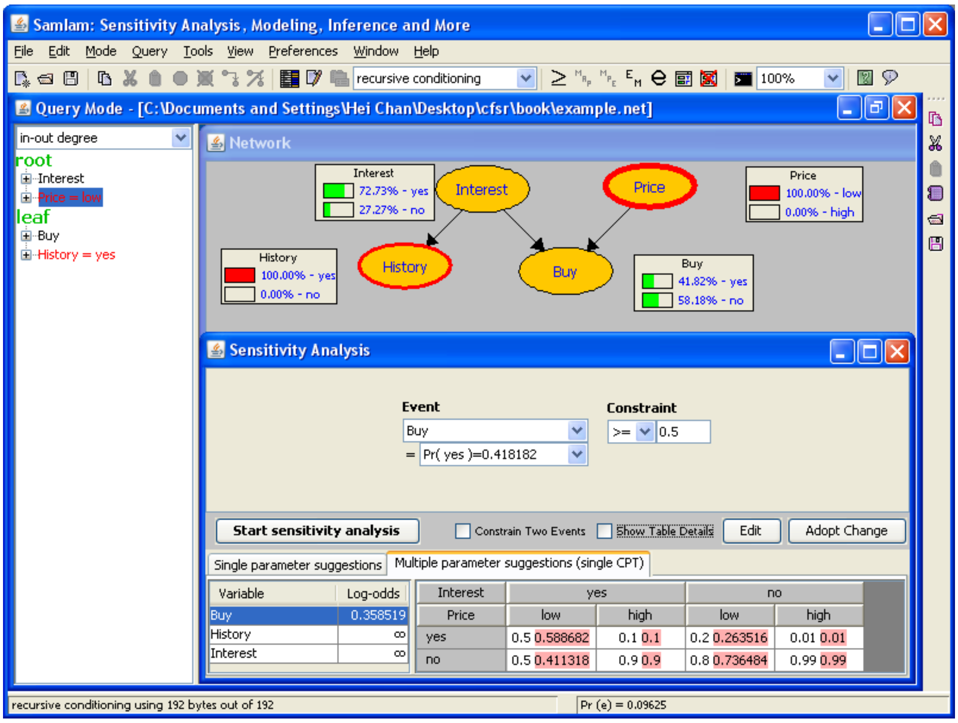

Figure 3. *A screenshot of **Samlam** returning suggestions of multiple parameter changes for enforcing a user-specified query constraint*

3 EXAMPLE OF ROBUSTNESS ANALYSIS

We now show a simple example of performing robustness analysis on a Bayesian network. For an example, we construct a Bayesian network to represent the decision of whether a customer buys a product, with four variables:

- *Interest* represents whether the customer is interested in this type of product.
- *Price* represents whether the price of the product is high or low.
- *History* represents whether the customer has previously bought the same type of product.
- *Buy* represents whether the customer buys the product.

We know that the customer's interest is a factor in determining whether he has previously bought the same type of product, while the price of the product and the customer's interest are both factors in determining whether he will buy this product. Therefore, we can obtain the Bayesian network structure as shown in Figures 2 and 3, and using expert knowledge or statistical data, we can specify the network parameters.

Now we compute query results using this Bayesian network. For example, the probability that a customer will buy the product given that the price is low and he has previously bought the same type of product is Pr(Buy = yes | Price = low, History = yes) = 0.4182.

However, after collecting customer data, we find that at least half of the customers in this case bought the product, so this probability should be higher, and the correct result should be Pr(Buy = yes | Price = low, History = yes) > 0. We now need to update the Bayesian network so that we can get the correct answer. We use ***SamIam***, a Bayesian network software tool developed by the UCLA Automated Reasoning Group (http://reasoning.cs.ucla.edu/samiam/), to find the single parameter changes that can enforce the query constraint Pr(Buy = yes | Price = low, History = yes) > 0.5. Two suggestions of single parameter changes are returned, as shown in Figure 2:

- Increase Pr(Buy = yes | Interest = yes, Price = low) from 0.5 to at least 0.6125.
- Increase Pr(Buy = yes | Interest = no, Price = low) from 0.2 to at least 0.5.

We can choose to adopt either of the above parameter changes to our Bayesian network in order to satisfy our query constraint. From the two suggestions, the first one is close to the correct customer behavior, while the second one is not. So we will choose to adopt the first suggestion, and increase the probability of a customer buying a product given that he is interested in this type of product and the price is low, from 0.5 to at least 0.6125.

We can also ask ***SamIam*** to return multiple parameter changes to enforce the query constraint, as shown in Figure 3. The suggestion returned is to increase both parameters, Pr(Buy = yes | Interest = yes, Price = low) from 0.5 to (at least) 0.5887, and Pr(Buy = yes | Interest = no, Price = low) from 0.2 to (at least) 0.2635. Here, we see that the amount of increase for the parameter Pr(Buy = yes | Interest = yes, Price = low) when we can change multiple parameters is only 0.0887 (from 0.5 to 0.5887), and thus is less than the amount of increase when we can change only single parameters, which is 0.1125 (from 0.5 to 0.6125).

4 FUTURE RESEARCH

The next step of our research of systems resilience is two-fold. From a theoretical aspect, we want to solve some of the open problems of the SR-model, such as complexity results, algorithms to find solutions that guarantee resilience of the system, and incorporating uncertainty into the model. In this process, we aim to use existing robustness analysis techniques, or develop new or improved techniques, that can be applied to other dynamic models that are suitable for modelling different types of real-life systems, such as biological, engineering, and social systems. From a practical aspect, we want to evaluate and apply our theory into solving these domains, and to develop tools and software that allow for better testing and understanding of the research topic of systems resilience.

Acknowlegments

This work is supported by the ``Systems Resilience'' project of the Transdisciplinary Research Integration Center.

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Assessing Rio de Janeiro Municipality's Natural Disaster Prevention Program against the UN's Hyogo Protocol

Armando M. de Souza[1], Paulo Victor R. Carvalho[1,2], Gilbert J. Huber[1], José Orlando Gomes[1]
[1]Graduate Program in Informatics – Federal University of Rio de Janeiro (UFRJ)
armandomartins.souza@gmail.com, paulov@ien.gov.br, gilbert@archive.com.br , joseorlando@nce.ufrj.br

Abstract

There are records of major natural disasters due to heavy rains in the city of Rio de Janeiro since 1711. Due to the recurrence of these disasters, the city government began to seek ways to make the city resilient them. Based on the five (5) actions described in the Hyogo Protocol, a framework used by the UN which adopts a methodology to build resilience with a focus on natural disasters, it has launched the implementation of its Community Rain Alert and Alarm System (referred to as the A2C2 System, due to its acronym in Portuguese), which aims to alert the community to the risk of landslides. This article aims to compare what has been accomplished so far by the municipal government to the UN's protocol for disaster preparedness recommendations.

1 INTRODUCTION

We have records of disasters caused by heavy rains in Rio dating back more than three centuries. During this period, the number of lives lost and financial losses are incalculable. In April 2010, after yet another disaster, the city of Rio, with support from the federal and state governments, began a series of actions to minimize losses due to this type of event and improve the city's infrastructure.

Based on the Hyogo Protocol's priority actions, the city of Rio intensified Geo-Rio's work toward mapping out landslide and slippage risk areas, among other actions, and through its Civil Defense Sub-Department, began implementation of its A2C2 System – Community Rain Alarm and Alert System Project. The principal focus of this project is to provide residents of the areas at risk timely warning of landslide threats due to the amount of rainfall in the region. The system has the support of various municipal agencies, volunteers, and the community.

Our work aims to assess Rio de Janeiro municipality's natural disaster prevention program against the Hyogo Protocol, performing a comparative analysis between actions undertaken by the Municipal Government and the topics set out in the UN Protocol's 5th priority action. The research method adopted is based on conitive task analysis techniques (Crandall et ali, 2006) and used field observation of emergency response exercises in several communities, walkthroughs and talkthroughs with exercise participants on the organization side as well as with people from the community.

This paper is structured as follows: in section 2, we present Rio's history of heavy rain induced natural disasters and related measures adopted, in section 3 we cover the methodology used in our work, in section 4 we discuss our findings, in section 5 we present our conclusions, trying to assess where the city of Rio is relative to the Hyogo Protocol's recommendations, and in section 6 we suggest future work.

2 HISTORY OF NATURAL DISASTERS AND ACTIONS DEVELOPED

According to the City of Rio de Janeiro's Fire Department's website (http://www.cbmerj.rj.gov.br), the first record of a disaster caused by heavy rain in the city was made in September 1711. The first study in search of resilience to this kind of disaster was commissioned by the Prince Regent after the February 1811 disaster known as "waters of the hill". Since then, countless disasters caused by flooding and landslides due to heavy \rain have been recorded, with ever more nefarious consequences for the city's poorer population.

Successive disasters, many lives lost, large financial losses, and yet another disaster in April 2010, with 67 dead besides more financial loss, prodded the city government of Rio de Janeiro to initiate several actions in pursuit of disaster resilience for the city.

Using the priority actions of Hyogo, a global movement concerned with making the world safer regarding natural disasters which began in the late 1980's (UN ISDR, 2010), the municipal government of the city of Rio de Janeiro started a study with the following objectives: (i). disaster response improvement to heavy rains and landslides, (ii). establish a culture of resilience in the population that finds itself within the areas of risk, and (iii). mitigate the effects of such an event.

For these objectives to be achieved, the Hyogo Framework for Action (HFA) identifies five specific priority actions, presented in the table below:

Priority Action	Description
HFA 1	Making disaster risk reduction a priority (political dimension)
HFA 2	Improving risk information and early warning (scientific dimension)
HFA 3	Building a culture of safety and resilience (social dimension)
HFA 4	Reducing the risks in key sectors (vulnerability reduction dimension)
HFA 5	Strengthen disaster preparedness for effective response (preparedness dimension)

The overall goal of the Hyogo Framework for Action is to provide guidelines that enable substantial reductions in loss of life and of social, economic and environmental assets due to disasters triggered by natural hazards by the year 2015.In this context, the actions being developed by the municipal government of Rio de Janeiro are described below.

Action	Description
Rio Operations Center – CO-Rio	Created to follow the city's routine, and monitor and optimize its functioning, Rio Operations Center (CO-Rio) opened in December 2010. It brings together over 30 agencies (municipal, state and utility) and is truly a command and control center for the entire city.
Community Rain Alert and Alarm System – A2C2	A key component of a number of city initiatives underway, it seeks to make the city resilient to heavy rains. Activities include mapping geological risk areas, identification of support facilities (places to serve as temporary shelter during heavy rains, usually churches, schools, kindergartens, etc.), and of safer routes to them, as well as points for the installation of sound alarms (horns or sirens).
Civil Defense Community Center Project – NUDEC Project	A city project undertaken through the city's Civil Defense Sub-Department, focusing on Disaster Risk Reduction, through a process of behavioral change, the implementation of preventive measures, and community training to act in case of disaster.
Field Simulation Exercise	An exercise whose main purpose is to analyze the A2C2 System's mobilization capacity, including: (i). evaluate the command, coordination, and control capacities, (ii). evaluate the ability to activate, in a timely manner, the support facilities, (iii). evaluate the ability to activate and operate the audible alarm, etc.

3 METHODOLOGY

To compare what is being developed and the actions suggested in Hyogo's priority action 5 we plotted the answers provided by experts on a graph depicting the levels which the municipality's disaster prevention program has reached relative to each guiding question. We have added comments where necessary.

3.1. Interviews with experts

The answers to the guiding questions were obtained through interviews with experts from the Civil Defense Department, complemented with document analyses and field observations of the emergency simulation exercises.

4 Results and Discussion

A graph depicting the status of Rio de Janeiro's disaster prevention measures is presented below. The graph's action identification letters refer to the guiding questions for tasks 19 and 20 of Hyogo's Priority Action 5, "Strengthening Disaster Preparadness for Effective Response and Recovery: Being Prepared", which can be found in "A Guide for Implementing the Hyogo Framework for Action by Local Stakeholders" (UN/ISDR, 2008).

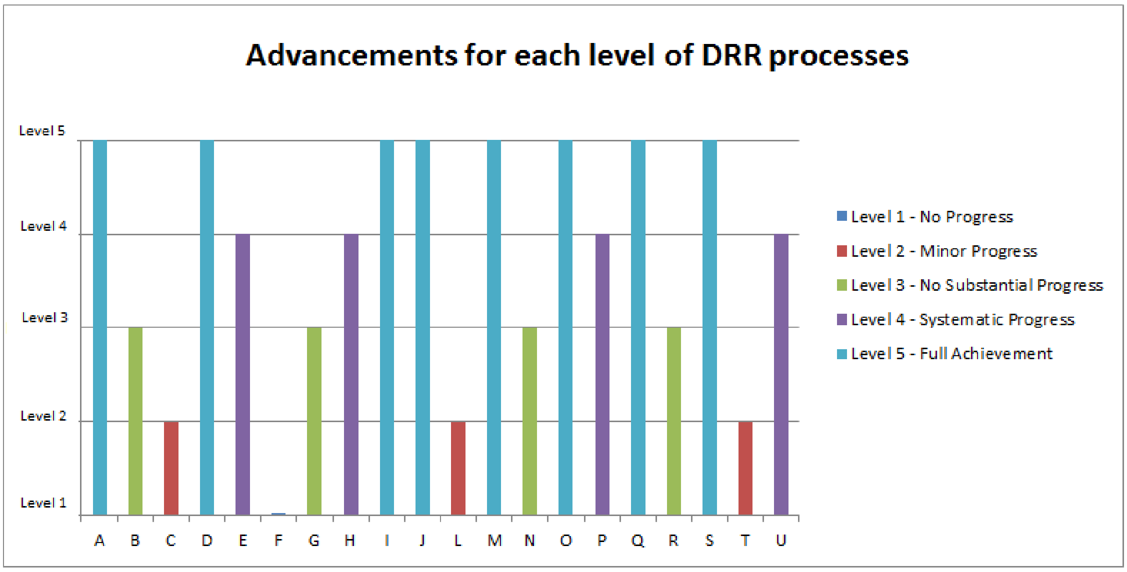

Figure 1. Advancement for each level of DRR process

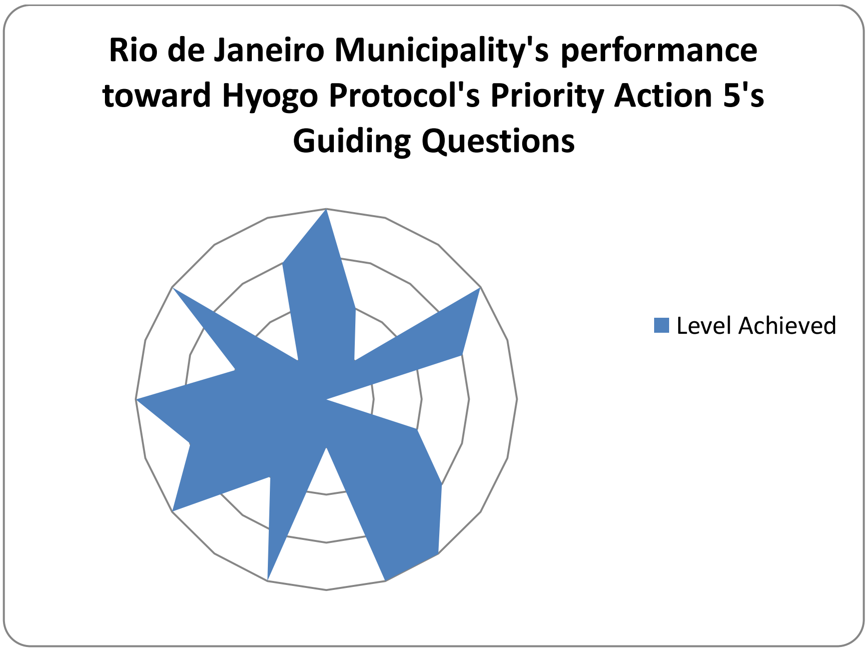

Figure 2. Municipaliy's performance

The guiding questions are divided between the tasks as follows:

Task	Local Indicators	Guiding Questions
19 - Review disaster preparedness capacities and mechanisms	**(i)**.Strong policy, technical, and institutional capacities and mechanisms for disaster risk management at the local/city level	A to G

Task	Local Indicators	Guiding Questions
20 - Strengthen planning and programming for disaster preparedness	**(i)**.Disaster preparedness plans and contingency plans in place at the local/city and community levels, and regular training drills and rehearsals are held to test and develop local/city disaster response programs; **(ii)**. Integration with emergency response and recovery; **(iii)**. Procedures are in place to exchange relevant information during hazard events and disasters and to undertake pos-event reviews; **(iv)**. Local/city government and community have capacity to deal with disaster recovery; **(v)**. The role of communities and volunteers is recognized while principles of accountability of local/city government and other stakeholders are adopted	H to U

The existence of the following resources available to the teams involved in emergency response underpins the maturity levels reported: (i). Task 19 – the City's disaster support plan, its recovery plan, its readiness networks, and its search and rescue equipment; (ii) Task 20 – the readiness for disaster plan, the contingency plan, the emergency simulation exercises, the early warning system, the evacuation procedures, the political financial measures, and the reconstruction and needs assessment plans.

Besides interviewing experts, the research group from the Federal University of Rio de Janeiro participated in the emergency simulation field exercises. During these exercises several important observations were made: (i). during some of the exercises, civil defense agents were dispersive, demonstrating the need for cultural change toward becoming more resilient among them as well as in the communities in the areas at risk, (ii). It was hard to identify the residences involved in the exercises, (iii). disorganization during the arrival of residents in most communities, (iv). in some communities (as yet un-pacified), the atmosphere was tense, due to the presence of drug dealers; (v). lack of joint planning with other municipal government bodies; (vi). there is no database listing residents and informing exactly how many people live in each household, along with their profiles (special needs, elderly, child, etc.); (vii). there is no database with house identification information; (viii). insufficient IT support for the simulation exercise (e.g.: for monitoring or for evaluation purposes).

It is important to note the remarkable efforts of Rio de Janeiro City Government in which are many things in progress and great strides have been made, but much remains to be done to achieve a level of excellence in terms of resilience.

5 CONCLUSION

The municipal government has been following the Hyogo Protocol's recommended actions regarding strengthening its disaster preparedness, but it still has great challenges to overcome, in both the social and the political dimensions (Hyogo's priority actions 3 - culture change, and 1- making disaster risk reduction a priority, respectively).

Note that some measures toward these ends are already underway, such as Emergency Simulation Exercises in Schools, which besides forming aware and prepared future citizens, encourages them to discuss these issues with their families, acting as multipliers at home. Nonetheless, there is still much to be done.

6 FUTURE WORK

The Hyogo Framework for Action is an excellent reference to use to assess any country or city's maturity in disaster preparedness. It is, however, very generic, as it must be to attain the broad reach it seeks, so it is important to create a similar framework geared specifically for Brazilian needs.

Another related research direction is the construction of an information system to support the assessment of simulation exercises within the emergency domain. This system should be based on a framework geared to Brazilian needs, and allow for the identification of shortcomings or possible improvements in the protocols and procedures for emergency situations.

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Organisational Factors FOR EnhancING Train Drivers' Proactive Behaviours to Maintain THE Normal Operation of Railway ServiceS

Hidenori Fujino[1], Tomoko Horishita[1], Tomoyuki Sonda[1], and Hiroyuki Yamaguchi[2]
[1]Safety Research Institute, West Japan Railway Company, 1-2-12, Matsuzaki-cho, Abeno-ku, Osaka, Japan
hidenori-fujino02@westjr.co.jp
[2]Graduate School of Human-Environment Studies, Kyushu University, 6-19-1, Hakozaki, Higashi-ku, Fukuoka, Japan
yamaguch@hes.kyushu-u.ac.jp

Abstract

The aim of this study is to reveal the organisational factors that affect train drivers' motivation to engage in proactive behaviours. Based on participant observation and theoretical considerations gleaned from previous research, the authors constructed a hypothesis regarding the causal factors behind proactive behaviours. The hypothesis was tested using a questionnaire survey. The results show that a driver's *work definition* is a core factor in motivation. Furthermore, positive feedback and workplace atmosphere are important factors in broadening each driver's work definition to promote proactive behaviours.

1 INTRODUCTION

Railway systems have many operational rules (ORs) and standard operating procedures (SOPs), and it is generally believed that railway safety and service quality can be maintained just by observing these ORs and SOPs. However, many train drivers engage in a range of autonomous proactive behaviours, and these behaviours are considered an important part of maintaining the normal operation of railway services. While some drivers follow these behaviours as part of their normal practice, other drivers do not practice such behaviours at all. What factors distinguish the two, and how can managers and organisations promote these proactive behaviours? Revealing the organisational factors related to such behaviours could prove very helpful for managers and organisations. This study aims to reveal these organisational factors.

First, we introduce examples of train drivers' proactive behaviours. We then propose several factors that influence proactive behaviours based on participant observation and on previous studies. Lastly, we examine the results of the questionnaire survey that was used to test our hypothesis.

2 EXAMPLES OF TRAIN DRIVERS' PROACTIVE BEHAVIOURS

As the first step of this study, we observed the actual practices of drivers in one Japanese railway company. We identified certain driver behaviours that can be considered proactive, some of which are described in this section. Such behaviours are not specified in the ORs and SOPs. Furthermore, these behaviours are related to the activities for maintaining resilience (Hollnagel et al., 2011) and threat and error management (Helmrich et al., 1999); all of them include anticipating, preparing for, and managing threats to mitigate the risks of accidents, unsafe incidents, or other undesirable situations.

2.1 Preparing Reminders on Driving Timetable Cards

Drivers in the company are required to put a driving timetable card on the console. Furthermore, drivers have to check the time in various scenes by pointing and calling in order to keep operations running on time. Some drivers write memos on the timetable card with a whiteboard magic pen or a dermatograph pen to remind themselves of important information. Such memos might, for example, refer to the speed limit that is specially set in advance at that driving for any reason; the sign of a stopping point at the station that is distinguished by the number of cars driven at that time; or places where the settings of certain machines need to changed, such as the auto train stopping system, the wireless channel, and so on. The timetable card is covered by a plastic case; therefore, these memos are easily erased. Drivers prepare the memos during break time.

2.2 Whistling Just Before Arriving at Stations

Some stations are located near curves, tunnels, or buildings that obstruct the view. People on the platform might hardly notice a train arriving at such a station. Consequently, there is a danger that passengers will touch the train while it is still running and be injured or, in some unfortunate cases, killed. Normally, station staff announce train arrivals at the station and drivers approaching such a station also will whistle to have them move to safer area when they notice people standing or walking on the edge of the platform. Some drivers whistle in advance, during passing the curves, tunnels, or so on, to alert people at the station that the train will approach soon. While the practice of whistling is not specified in the ORs and SOPs, it is believed to be effective in reducing risks.

2.3 Monitoring Passengers at the Stations from the Driver's Cabin

When a train stops at a station, the conductor, who rides at the back of the train, monitors people on the platform for safety. During that time, the drivers are normally in the driving seat waiting for departure. Some drivers, however, also monitor passengers from the driver's cabin, which is at the front of the train. The driver might, for example, spot a passenger who is caught in a closing door near the front, where there might be a blind spot for the conductor. The driver can then tell the conductor, who operates the door-closing switch, to open the door again. In addition, by showing his or her face through the window of the driver's cabin, passengers can ask the driver questions, enhancing the level of customer service.

2.4 Preparing a Guide for Passengers

While trains are waiting at the platform, passengers sometimes ask drivers questions about the destination or timetable of a train, the most efficient route to their destination, transfers, and so forth. Drivers typically answer these questions by checking the information board on the platform, or they refer the passengers to station staff. Some drivers, however, prepare their own memos with information related to frequently asked questions so they can answer passengers swiftly, confidently, and politely. This behaviour contributes to railway service quality as well.

2.5 Picking Up Garbage

Sometimes bottles or cans are left in the cabins by passengers. It is the cleaners' job to pick these up. Some drivers, however, collect such garbage when they have time. This behaviour is connected to the comfort of the passenger cabins. In addition, bottles and cans can cause train delays or machine troubles when they roll into a door that is closing.

3 FACTORS FOR ENHANCING PROACTIVE BEHAVIOURS

While some drivers engage in most or all of the behaviours described above, others do not follow any of these practices. Here we discuss factors for distinguishing between proactive and nonproactive drivers. These considerations are based on interview data, our observations of the participants, and previous studies on the topic.

3.1 Work Definition, Proactive Behaviour, and the Meaningfulness of Work

One reason for the absence of proactive behaviour is a lack of nontechnical skills. Nontechnical skills involve situational awareness, communication skills, and so forth (Komatsubara, 2011). There is, in fact, an effort to develop a training programme for train drivers to help improve their nontechnical skills (Bonsall-Clarke & Pugh, 2013). However, based on observations of actual driver practices, we believe work motivation is also a major factor in proactive versus nonproactive behaviours.

Work motivation might easily be viewed as an employee's morale, passion, or sincerity in relation to his or her job. That is not correct here. We believe most train drivers are sincere about their work. Therefore, we consider work motivation as dependent on an employee's *work definition*. Drivers who adopt proactive behaviours believe such practices are very natural; the behaviours are ordinary for them, and they consider them part of their work. On the other hand, drivers who do not adopt such practices believe these behaviours are not part of their job. They believe their jobs entail only what is clearly defined by the ORs and SOPs and that proactive behaviours should only be adopted voluntarily since they are not required by the ORs and SOPs. In one instance, a driver was observed going through the passenger cabins from the back end to the front end of train that was in the storage track. The author accompanying the driver noticed a lot of garbage on the floors and on certain seats. The driver, however, passed through as if he did not notice the garbage at all. His behaviour seemed natural, as if he was not bothered by the garbage. This behaviour indicates to us that this driver's work definition did not in any way include the proactive behaviour of picking up garbage.

Drivers are usually not monitored by their managers, and performing alone is a characteristic of job. Therefore, drivers work in a fully autonomous situation. In such situations, employees' behaviours are basically self-regulated. Thus, we believe each member's work definition has to be closed up on a train driver while, for example, CRM skills related to like authority gradients are closed up on an aviation pilot's behaviour.

Interestingly, proactive and nonproactive drivers both have high self-esteem. Both believe they are doing their jobs. In light of the concept of work definition, such thoughts seem very natural. Drivers evaluate their performance based on their own criteria, and those criteria are linked with their individual work definitions. If a behaviour is not included in a driver's work definition, he or she neither adopts that behaviour nor evaluates himself or herself on performing or not performing that behaviour (since the behaviour is not in his or her purview in the first place). When drivers adopt behaviours they think are to be done, their evaluations of themselves are always good since, if they notice they can't perform a given behaviour, they make an effort to complete the behaviour. As stated above, most drivers are sincere and passionate about their work. As a result, they come to believe they can complete the work.

While all drivers have high self-esteem, their feelings of meaningfulness in their work are quite different. Drivers who adopt proactive behaviours feel more strongly that their jobs are meaningful than drivers who don't adopt proactive behaviours. Feelings of meaningfulness in work are thought to result from intuitive evaluations of the social meanings of work. Drivers who adopt proactive behaviours have wider work definitions than drivers who do not. This means that the former's connection to civil society is stronger than the latter's. Thus, feelings for the social meanings of work are stronger for proactive drivers than for nonproactive drivers.

3.2 Factors Affecting Work Definition

Work definition develops according to the various experiences employees have had since becoming train drivers (Wrzesniewski, 2001). Therefore, there are too many factors affecting members' work definitions to list them completely. On this premise, we will discuss some factors related to organisational management.

Self-Consideration. For each member's work definition to become complex, self-consideration is needed. When some drivers were asked whether they had considered why they work or how they would like to be as train drivers, some said they had never considered such a topic. Such drivers were not always the nonproactive ones; some looked more or less proactive. However, such drivers only adopted proactive behaviours because they were told to do so by their licencing trainers or because they emotionally felt the necessity of the behaviour in a given situation. In short word, their behaviour were not autonomous ones. Their work definition is very limited, not constructed by themselves, and not complex. In order to enhance truly autonomous proactive behaviour, it is necessary for organisation to prompt their self-consideration to broaden their work definition.

Communication between Drivers and Managers. As stated above, train drivers can perform their work with no contact with their managers. However, communication between drivers and their managers is necessary for developing more sophisticated work definitions. There are two effects of individual communication between drivers and their managers.

First, drivers can receive various kinds of information through conversation with their managers. This information can pertain to other departments—like station staff, signal controllers, maintenance workers, and management itself—to company philosophy or policies, to competing companies, to financial information, and so forth. While such information might not seem directly connected to the driver's job, it can broaden the driver's perspective and help his or her work definition become more complex.

The second effect is emotional. Work definition pertains to each member's sense of value. One's sense of value develops with the satisfaction of the needs of competence and relatedness, which are considered fundamental human needs (Gange & Deci, 2005). When a person feels competence and relatedness in a community, he or she accepts the sense of value shared among the members of that community. If communication between drivers and managers includes positive feedback, like praise and admiration for the drivers' daily performance, such communication can lead drivers to accept the managers' sense of value in which proactive behaviours are seen as desirable. On the other hand, if drivers feel their managers don't value their work performance, they will reject their managers' sense of value.

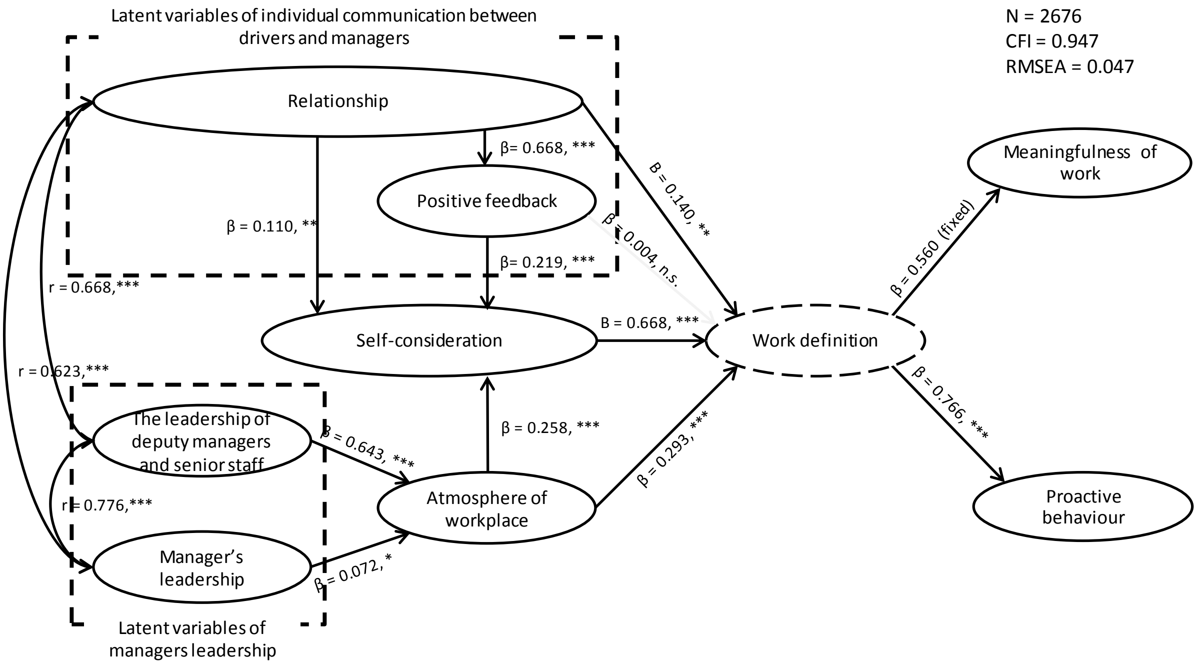
Workplace Atmosphere and Managerial Leadership. Atmosphere is believed to have a strong effect on work definition. People tend to behave according to the atmosphere of their communities. Therefore, if the workplace atmosphere regards the proactive behaviours as things the drivers should do, then individual drivers will follow suit. However, if the atmosphere regards the behaviours as things that don't necessarily have to be done, then drivers will also consider the practices unnecessary. Another important factor concerns whether *the job* is the core of the workplace atmosphere or whether there are other topics. When the authors observed a certain driver's office, they found that most of the daily chatting among drivers was related to their jobs. In such an office, the drivers have to have a broad perspective on their jobs to participate in the daily chatting. This motivation to develop their perspective could also help with developing their work definitions. Furthermore, participating in daily chatting itself could lead to development. Through the process of talking about their jobs, their own positions would become clear, and also with articulating their thoughts, they could recognize their own thoughts that they establish unconsciously in their sense of value. On the other hand, in another certain driver's office, authors felt that there might be a norm members must not talk about any topic positively related to their job in daily chatting. In such an office, developing process of their work definition as stated above would not arise and their work definition would not be broadened so well.

Regarding managerial leadership, we often heard in one office that the atmosphere had improved since the present manager had come to the office. When we asked about the differences in managerial leadership, drivers usually discussed differences in management's passion for their work, their willingness to politely listen to drivers' opinions, and their attitude toward building good relationships with drivers. Thus, managerial leadership affects workplace atmosphere.

4 QUESTIONNAIRE SURVEY

To evaluate whether these factors actually affect each driver's work definition, we administered a questionnaire survey to all drivers in one Japanese railway company except for the drivers of the Shinkansen super express. The number of valid respondents was 2676. Items of questionnaire were answered on a scale of 1–5. The result of our statistical analysis by structure equation modelling is depicted in Figure 1.

The authors' proposed factors affecting drivers' proactive behaviours were mostly supported. In addition, some interesting points are suggested by these results. First, self-consideration strongly regulates work definition in this result. Based on this result, it can be expected that training programmes that facilitate train drivers' self-consideration would be very effective for enhancing proactive behaviours. Second, self-consideration is regulated by positive feedback, while work definition is not regulated by it directly. This suggests that the effect of positive feedback is mediated by self-consideration. That is, even if managers send positive feedback to drivers, there would be little effect on enhancing work definition unless there is attention to self-consideration. On the other hand, this result can also be interpreted as showing that self-consideration would be enhanced by positive feedback. Therefore, in addition to a training programme as described above, positive feedback is required in daily management activity to build a foundation for self-consideration. Third, relationship strongly regulates positive feedback. This result supports previous research (Horishita et al., 2013) and suggests that giving superficial positive feedback without building good relationships has little effect; therefore, it is believed that building good relationships with drivers is also required in managerial practice to make positive feedback more effective.



Note:
- Regarding the lack of a symbol of significance of a coefficient on the path from Work definition to Meaningfulness of work, Work definition is a higher-order latent factor estimated by Meaningfulness of work and Proactive behaviour.
- All β or r values are standardized numbers.

Figure 1. *Model of the structure of train drivers' proactive behaviours*

5 CONCLUSION

In this study, the authors examined causal factors related to train drivers' proactive behaviours, especially factors related to organisational management. We proposed *work definition* as a concept for understanding drivers' proactive behaviours in daily practice and also proposed with quantitative evidence some organisational factors that affect each member's work definition. Work definition pertains to one's sense of value. While we focused only on human relationships in this study, various factors related to management could affect it, such as the information environment surrounding the drivers or the job design itself. In future work, we will attempt to reveal these factors. Furthermore, in addition to a basic study, a practical study is needed to investigate ways to enhance drivers' proactive behaviours, mitigate risks, and prevent accidents or incidents.

As the limitation of this study, we only proposed the model based on the investigations of electric car drivers in one Japanese railway company. Therefore, if we discuss about drivers who work in quite different work situation like steam locomotives which are usually driven by a pair of drivers, their work motivation to proactive behaviour might be different from authors' model proposed in this study. In general, our model is largely depend on the characteristics of job of drivers that is to perform alone and not to be monitored by their supervisors, therefore, proactive behaviour of workers such as aviation pilots or maritime bridge workers who are engaged in their job with other members as a team would not be applicable. On the other hand, workers like one-man bus drivers, whose working situations are similar to train drivers targeted in this study, might be applicable with our proposal models to understand their motivation to proactive behaviour.

Furthermore, this model was tested only by a snapshot investigation in this study. For sufficient evidence, it is required to be tested by longitudinal study.

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A Fuzzy Model to Assess Resilience for Safety Management

Cláudio H. S. Grecco[1], Mario C. R. Vidal[2], Carlos A. N. Cosenza[2], Isaac J. A. L. dos Santos[1] and Paulo V. R. Carvalho[1]

[1] Comissão Nacional de Energia Nuclear/Instituto de Engenharia Nuclear, Cidade Universitária - Ilha do Fundão, Rio de Janeiro, RJ, Brazil,
paulov@ien.gov.br

[2] Universidade Federal do Rio de Janeiro/ Programa de Engenharia de Produção, Cidade Universitária - Ilha do Fundão, Rio de Janeiro, RJ, Brazil,

Abstract

The Most of methods to assess resilience cannot fully solve the subjectivity of resilience evaluation. In order to remedy this deficiency, the aim of this research is to adopt a Fuzzy Set Theory (FST) approach to establish a method for resilience assessment in organizations based on leading safety performance indicators, defined according to the resilience engineering principles. The method uses FST concepts and properties to model the indicators and to assess the results of their application. To exemplify the method we performed an exploratory study at the radiopharmaceuticals dispatch package sector of a radiopharmaceuticals production facility.

1 INTRODUCTION

Contemporary view on safety based on resilience engineering (RE) principles emphasizes that safety critical organizations should be able to proactively evaluate and manage safety of their activities. This new safety paradigm must be endorsed by the organizational safety management to be successful. Therefore we need new methods to measure safety according to RE principles, considering that safety is a phenomenon that is hard to describe measure, confirm, and manage.

Scientists in the field of safety critical organizations state that safety emerges when an organization is willing and capable of working according to the demands of their tasks, and when people understand the changing vulnerabilities of their work activities (Reiman & Odewald, 2007). Thus, safety management relies on a systematic anticipation, monitoring the evolution of trade-offs, in which various safety indicators play a key role in providing information on current organizational safety performance. An increasing emphasis has been placed also on the role of indicators in providing information to be used in anticipation and evolution of organizational performance. These indicators are called leading indicators.

The safety performance indicators that have commonly been used in traditional safety management have often been lagging indicators, measuring outcomes of activities or things and events that have already happened (e.g., injury rates, radiation doses and incidents). These indicators are reasonably objective, easy to quantify, and that they can be used requiring small changes in the existing system. However, it can be questioned whether they really indicate the actual safety of organization processes, because there is no sharp causal link between past events and the current safety performance. Lagging indicators may be more useful to confirm effects after a while, in long term, than to manage immediate changes in dynamic environments. Monitoring should not rely solely on lagging indicators but also on indicators of current activities and the potential of the organization to succeed in the future. To quickly monitor trade-offs, the effects of good work practices, as well as, to anticipate vulnerabilities, the organizations should define leading indicators. Those should be able to grasp organizational practices and processes that lead changes in safety performance of the people in the organization.

Several reasons for using leading indicators are: (a) they provide information on where to focus improvement efforts; (b) they direct attention to proactive measures of safety management rather than reactive follow up of negative occurrences or trending of events; (c) they provide early warning signs on potential weak areas or vulnerabilities in the organizational risk control system or technology; (d) they focus on precursors to undesired events rather than the undesired events themselves; (e) they provide information on the effectiveness of the safety efforts underway; and (f) they tell about the organizational health, not only sickness or absence of it.

The aim of this research is to adopt a Fuzzy Set Theory (FST) approach to establish a method for safety assessment in organizations based on resilience engineering using leading performance indicators, as the basis for a safety management system. To exemplify the method we performed an exploratory case study at the process of radiopharmaceuticals dispatch package in a radiopharmaceuticals production facility.

2 METHOD FOR RESILIENCE ASSESSMENT

The method has the following phases:

1. Selection of the leading indicators;
2. Determination of a resilience ideal pattern;
3. Assessment of the actual resilience level compared with the pattern.

2.1 Selection of leading indicators

Selection of leading indicators should always start from the consideration of what are the key issues to monitor, manage and change (EPRI, 2000). The leading indicators are utilized as part of the resilience management process, not as an independent goal or function as such. The operationalization of an indicator is called "metric". A metric denotes how the indicator is measured, whereas an indicator denotes something that one wishes to measure with the use of one or more metrics. The selection of the resilience themes addressed and leading indicators used in radiopharmaceuticals dispatch package sector was based on previous ergonomic study (Grecco et al., 2010) and are described in table 1.

Table 1. Themes and Leading indicators.

Themes	Indicators	Themes	Indicators
Top-level commitment	1.1 Human resources 1.2 Material resources 1.3 Safety commitment 1.4 Safety policy 1.5 Procedure management 1.6 Training programs 1.7 Competence selection	Awareness	4.1 Reports of problems 4.2 Information security 4.3 Communication 4.4 Team work 4.5 Workload 4.6 People relations 4.7 Tasks and skills 4.8 Awareness of limitations 4.9 Preventive maintenance 4.10 Proactive actions
Learning culture	2.1 Information dissemination 2.2 Information flow 2.3 Work management 2.4 Actual working practices 2.5 Local adaptations 2.6 Content of the documentation 2.7 Availability of the documentation 2.8 Analysis of incidents 2.9 Investigations of incidents and accidents	Just culture	5.1 Reporting of deviations/worries 5.2 Understanding of errors 5.3 Perception of errors 5.4 Actions are not punitive 5.5 Peer assessments 5.6 Professional recognition
Flexibility	3.1 Ability to cope with unexpected 3.2 Capacity for flexibility 3.3 Safe working limits	Preparedness	6.1 Emergency plan 6.2 Identification of risks 6.3 Safety equipments 6.4 Alarm system

Themes	Indicators	Themes	Indicators
	3.4 Reports on adaptations		6.5 Proactive procedures
	3.5 Incorporation of adaptations		6.6 Emergency training

2.2 Resilience ideal pattern

The second phase of the method is to obtain from experts in radiopharmaceuticals production and resilience engineering issues the degree of importance of each indicator metric, so that the organization sector can be considered resilient. This means that the degree of importance assigned to each indicator by the specialist, should show how the sector should be to achieve an ideal resilience level. Thus, it is not evaluating the sector, but the ideal of resilience that it should have. The phase has the following steps: 1) Experts selection, 2) Calculation of each expert relative importance, based on knowledge and experience, 3) Choice of linguistic terms and membership functions, 4) Determination of the importance degree of each indicator, 4) Aggregation of fuzzy opinions, 5) Resilience pattern.

Calculation of experts' relative importance. The relative importance of the expert was calculated on the basis of experts' attributes (experience, knowledge of radiopharmaceuticals production safety and knowledge of the dispatch package radiopharmaceuticals). We used a questionnaire (Q) to identify the profile. Each questionnaire contains information of a single expert. The relative importance (RI) of expert Ei (i = 1, 2, 3, …, n) is a subset µi (k) Є [0,1] defined by equation 1. Referring to equation 1, *tQi*, is the total score of the expert *i*.

$$RI_i = \frac{tQ_i}{\sum_{i=1}^{n} tQ_i} \qquad (1)$$

Choice of linguistic terms and membership functions. Each leading indicator can be seen as a linguistic variable, related to a linguistic terms set associated with membership functions. These linguistic terms are represented by triangular fuzzy numbers to represent the importance degree of each indicator. It is suggested that the experts employ the linguistic terms, U (Unimportant), LI (Little Important), I (Important) and VI (Very Important) to evaluate the importance of each indicator.

Aggregation of the fuzzy opinions. The similarity aggregation method proposed by Hsu and Chen [21] is used to combine the experts' opinions which are represented by triangular fuzzy numbers. The agreement degree (AD) between expert Ei and expert Ej is determined by the proportion of intersection area to total area of the membership functions. The agreement degree (AD) is defined by equation 2.

$$AD = \frac{\int_x \left(\min\{\mu_{\tilde{N}i}(x), \mu_{\tilde{N}j}(x)\}\right)dx}{\int_x \left(\max\{\mu_{\tilde{N}i}(x), \mu_{\tilde{N}j}(x)\}\right)dx} \qquad (2)$$

If two experts have the same estimates, that is, AD =1. In this case, the two experts' estimates are consistent, and then the agreement degree between them is one. If two experts have completely different estimates, the agreement degree is zero. If the initial estimates of some experts have no intersection, then we use Delphi method to adjust the opinion of the experts and to get the common intersection at a fixed α – level cut (Hsu & Chen, 1996). The higher the percentage of overlap, the higher the agreement degree. After all the agreement degrees between the experts are calculated, we can construct an agreement matrix (AM), which give us insight into the agreement between the experts.

$$AM = \begin{bmatrix} 1 & AD_{12} & \cdots & AD_{1j} & \cdots & AD_{1n} \\ \vdots & \vdots & & \vdots & \vdots & \\ AD_{i1} & AD_{i2} & \cdots & AD_{ij} & \cdots & AD_{in} \\ \vdots & \vdots & & \vdots & \vdots & \\ AD_{n1} & AD_{n2} & \cdots & AD_{nj} & \cdots & 1 \end{bmatrix}$$

The relative agreement (RA) of expert Ei (i = 1, 2, 3, …, n) is given by equation 3.

$$RA_i = \sqrt{\frac{1}{n-1} \cdot \sum_{j=1}^{n} (AD_{ij})^2} \qquad (3)$$

Then we calculate the relative agreement degree (RAD) of expert Ei (i = 1, 2, 3, …, n) by equation 4 and the consensus coefficient (CC) of expert Ei (i = 1, 2, 3, …, n) by equation 5.

$$RAD_i = \frac{RA_i}{\sum_{i=1}^{n} RA_i} \qquad (4) \qquad CC_i = \frac{RAD_i \cdot RI_i}{\sum_{i=1}^{n} (RAD_i \cdot RI_i)} \qquad (5)$$

Let Ñ be a fuzzy number of combining expert's opinions. So, Ñ is the fuzzy value of each leading indicator which is also triangular fuzzy number. By definition of the consensus coefficient (CC) of expert Ei (i = 1, 2, 3, …, n), Ñ can be defined by equation 6. Referring to equation 6, ñi, is the triangular fuzzy number relating to the linguistic terms, U (Unimportant), LI (Little Important), I (Important) and VI (Very Important).

$$\tilde{N} = \sum_{i=1}^{n} (CC_i \cdot \tilde{n}_i) \qquad (6)$$

Resilience pattern. The resilience pattern as a reference for assessing organizational resilience of the is established by calculating the normalized importance degree (NID) of each leading indicator that make up each property relevant to resilient organizations. The normalized importance degree (NID) of each leading indicator is given by deffuzification of its triangular fuzzy number Ñ (ai, bi, ci), where bi represents the importance degree. Then, NID can be defined by equation 7.

$$NID_i = \frac{NID_i}{high \quad value \quad of \quad b_i} \qquad (7)$$

2.3 Resilience assessment

This third phase of the method is to assess resilience level compared to the resilience pattern. In this phase, the linguistic values are used to assess the attendance degrees of the leading indicators to the radiopharmaceuticals dispatch package sector given by workers. It is suggested that the workers employ the linguistic terms, SD (Strongly Disagree), PD (Partially Disagree), NAND (Neither Agree Nor Disagree), PA (Partially Agree), SA (Strongly Agree). Table 4 shows the attendance degrees and triangular fuzzy numbers for linguistic terms. Using center of area defuzzification method we calculate the attendance degree (AD) to the resilience pattern by equation 8. Referring to equation 8, adj, is the attendance degree of the leading indicator j of the theme i in the dispatch package radiopharmaceuticals sector.

$$ADi = \frac{\sum_{j=1}^{k} NID_j . ad_j}{\sum_{j=1}^{k} NID_j} \qquad (8)$$

3 RESULTS

The resilience assessment of the radiopharmaceuticals dispatch package sector was performed by seven workers and results are presented in figure 1. The average evaluation of the resilience based on each indicator was computed and showed in figure 2. We consider satisfactory an attendance degree greater than or equal to 0.6. The result of the average evaluation showed that the radiopharmaceuticals dispatch package sector presented satisfactory learning culture, flexibility awareness, just culture and preparedness. However, this sector presented problems related to the top-level commitment.

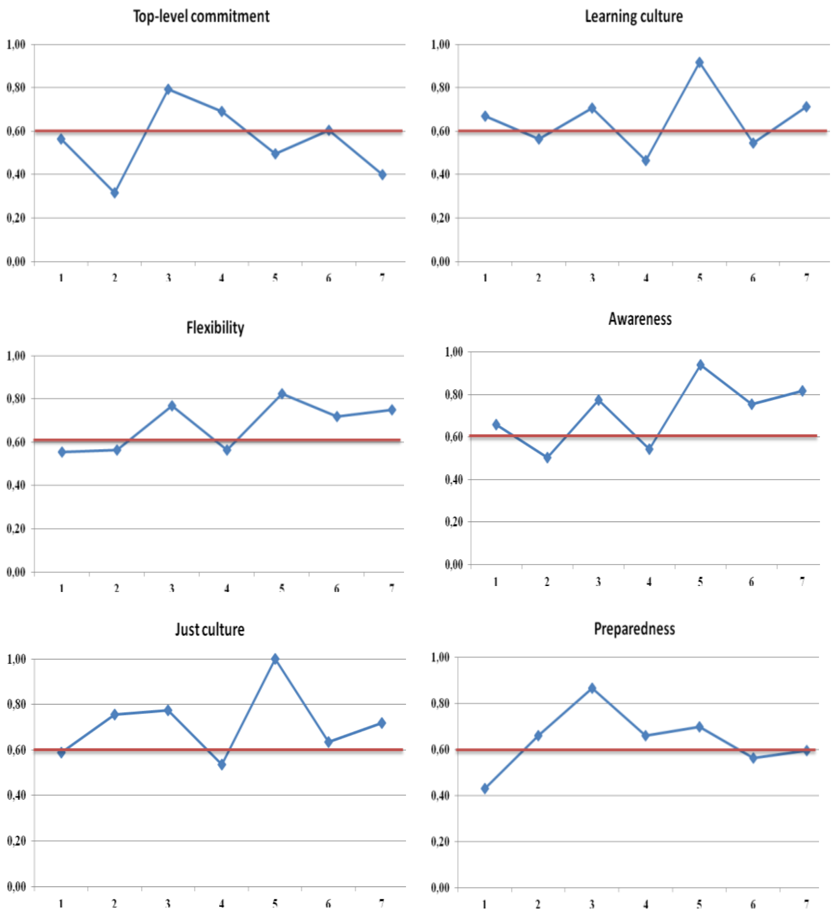

Figure 1*. Result of the evaluation of the resilience by the seven workers.*

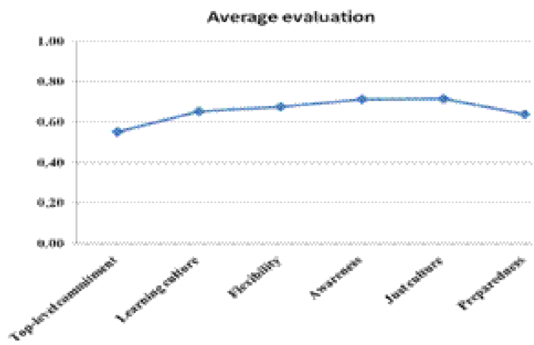

Figure 2. *Average evaluation of the resilience performed by the seven workers.*

4 CONCLUSIONS

In this paper we described a method for organizational resilience assessment was used. We proposed a method that uses leading indicators and concepts and properties of Fuzzy Sets Theory. We develop a resilience pattern using a similarity aggregation method to aggregate fuzzy individual opinions, considering the difference of importance of each expert. A pilot study in the radiopharmaceuticals production facility shows that this method based on leading indicators and fuzzy logic offers interesting perspectives for the implementation of resilience engineering principles. This assessment method can be a proactive tool to provide a basis for action without waiting for events. Through the use of the method we identify problems related to leading indicator metrics of the top-level commitment theme. These problems can be investigated in order to implement actions to make the process of radiopharmaceuticals dispatch package more efficient and secure besides to improve the resilience in this sector.

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Customer Satisfaction Plays an Important Role: A Model to Improve Resiliency of ICT Service Maintainers

Chihiro Takayama[1] and Momoko Nakatani[1] and Takehiko Ohno[1]
and Akinori Komatsubara[2]
[1] NTT Service Laboratories, 1-1 Hikari-no-oka, Yokosuka-shi, Kanagawa, Japan
{takayama.chihiro, nakatani.momoko, ohno.takehiko}@lab.ntt.co.jp
[2] Waseda University, 3-4-1, Ohkubo, Shinjyuku-ku, Tokyo, Japan
komatsubara.ak@waseda.jp

Abstract

We propose a model of resilient response in ICT (Information Communication Technology) maintenance and address the importance of non-technical skill. ICT Services, such as the Internet, are socio-technical systems and must be repaired quickly after failures. These systems are so sophisticated that the ICT maintainers have to deal with a great variety of failure situations. Our response was to conduct an ethnographic study of ICT maintainers who troubleshoot home networks to find out how they achieved resilient response in the face of such variety. As a result, we found that customer satisfaction plays a key role in troubleshooting. When the customer is dissatisfied, the maintainer cannot get much information or even start repairs. The proposed model combines Situation awareness, Managing relationship, Repairs, Explanation, and Learn. In this model, Situation awareness and Managing relationship are the most important activities. To perform these activities, the maintainer needs not only technical skill for failure recovery but also non-technical skills to build good customer relationships.

1 INTRODUCTION

ICT Services, such as the Internet, are indispensable for society and for personal life, and so are called socio-technical systems. However, since their malfunction or failure can never be completely prevented, the maintenance service person (maintainer) must recover the ICT service quickly after a failure.

A key goal of maintainers is resilient response because they have to manage various failure situations and to satisfy the customers, as we discuss later. Poor customer satisfaction threatens the company's safe operation, and so is actually a business risk. Thus it is critical to ensure that all maintainers offer resilient response. The purpose of this study is to examine maintainer behaviour, identify the components of resilient response, and develop and model suitable for training.

2 PRECEDING STUDY

Repairing an ICT service, called troubleshooting, is a kind of problem solving and is common in daily life. Troubleshooting is defined as detecting the system malfunction and its cause, repairing it, and recovering the normal state from the abnormal state (Jonassen, 2000).

In the research field of troubleshooting, many studies have targeted the knowledge and the cognitive ability of maintainers (Morris Rouse, 1985) (Perez , 1991). Schaasfstal et al. analysed the maintainers' thinking process while troubleshooting military equipment by using protocol analysis (Schaasfstal et al., 2000). They found that the troubleshooting process can be divided into four subtasks. First, a maintainer must determine what is wrong and right with the system. (Formulate Problem Description). Second, they create hypotheses (Generate Cause). Third, they test all hypotheses (Test). Finally, they repair the malfunction and evaluate if the system works normally (Repair and Evaluate). With this categorization, they built an efficient training course.

In the field of Resilience Engineering (RE), there are four abilities that yield resiliency: Anticipation, Monitoring, Responding, and Learning (Hollangel, 2011). In troubleshooting, the maintainer needs a flexible and resilient response to cope with various problems and changes of the system's function to adjust to disturbances. To improve resilient ability, it is essential to create programs that teach resilient response.

The goal of this paper is to introduce an initial resilient response guide. To this end, we propose a resilient response model of maintenance and analyse the model to find out the key issues associated with resiliency.

3 FEATURES OF NETWORK MAINTENACE SERVICE

We conducted empirical research on maintainers who had to repair the Internet service used in home networks. They mainly manage metallic and photonic cables between the nearest telephone pole and the house, modems, ONU (Optical Network Unit), routers, and sometimes telephones and PCs and other electronic devices attached to the router.

The current troubleshooting approach to those networks and devices is as follows: First, when a network service experiences trouble, the customer calls the call centre and an operator tries to solve the problem. If it is difficult to solve the problem over the line, the operator dispatches a maintainer to the customer's home. The Maintainer detects and eliminates the malfunction by reviewing the failure history, interviewing the customer, and making some tests.

This network service has so many failure modes that the maintainer must respond with high flexibility. The difficulties posed by home network troubleshooting are detailed below.

3.1 Many Topologies

Connection technologies are becoming more sophisticated and diversified, such as Ethernet, Wireless LAN, and PLC (Power Line Communication). There are also many sophisticated devices in the house, such as home information appliances, STBs (Set-top Box), and Tablets. A home network is expected to handle this huge variety of technologies. This means that the home network maintainer has to deal with far more varieties of troubles than is true with other devices.

3.2 Affected by External Environment

A home network is constructed with and without physical cables, such as GE-PON (Gigabit Ethernet-Passive Optical Network), xDSL (x-Digital Subscriber Line), and Wireless LAN. These communication technologies are affected by environmental changes, such as temperature changes, and interference from other systems. This means that maintainer has to consider not only the devices and media forming the home network, but also the environment in which the system exists. This difficulty is only strengthened as the number of technologies in the home network increases.

In addition, the failures caused by environmental factors tend to have poor repeatability. They may not reoccur if even one environment condition differs from the set of conditions that triggered the failure. For example, on cold winter mornings, optical connectors can become temporarily disconnected due shrinkage of the optical fibre. This trouble may disappear before the maintainer arrives, since the temperature has increased. In this case, the failure situation is no longer available for the maintainer to inspect. S/he can only interview the customer and guess the cause with little information.

3.3 Best Effort Service

Different from a leased line, the home network service is often “a best effort service”. There is no strict service quality level, such as network speed or latency. To deal with a user's complaint about network quality, the maintainer has to consider both the user's demands and the facilities impacting the service level. S/he also must be extremely flexible in negotiating with and explaining the situation to the customer.

4 ETHNOGRAPHIC STUDY

To clarify how ICT service maintainers currently manage these difficulties, we conducted an ethnographic study. We accompanied several maintainers, noted what they did, and interviewed them.

From this study, we found three points. First, it is impossible to provide perfect recovery in some cases because of the intractability of legacy facilities. In these cases, the maintainer tries to repair with supportive care instead of making a complete recovery.

Second, the maintainer changes his/her troubleshooting approach according to not only device status, but also the customer relationship. For example, if the customer is cooperative, the maintainer seeks out the root cause and repairs the fault while offering the customer full support. On the other hand, if the customer is angry, the maintainer tends to go outside first to search for possible failure points, which may allow the customer to calm down.

Third, we found that the maintainer often continues troubleshooting until the customer is satisfied. Even if the failure cause is detected quickly, s/he sometimes checks other devices. Many maintainers noted that they continued troubleshooting until the customer was satisfied.

Summarizing these results, we found that the maintainer's goal was not just to eliminate the malfunction, as might be thought, but to sustain or improve customer satisfaction. Even if the maintainer effects a perfect technical recovery, the response is deemed a failure if the customer remains or becomes dissatisfied. Even partial service recovery (say 60%) can be deemed a success if the customer is satisfied with the maintainer's service behaviour. That is to say, the fault and the customer are equally important to the maintainer.

5 RESILIENT RESPONSE MODEL FOR MAINTENANCE SERVICE

Based on the study results, we developed a model to explain how the maintainer should behave to sustain or improve customer satisfaction. We categorized the maintainers' activities by their purpose, as is written below (see Figure 1)

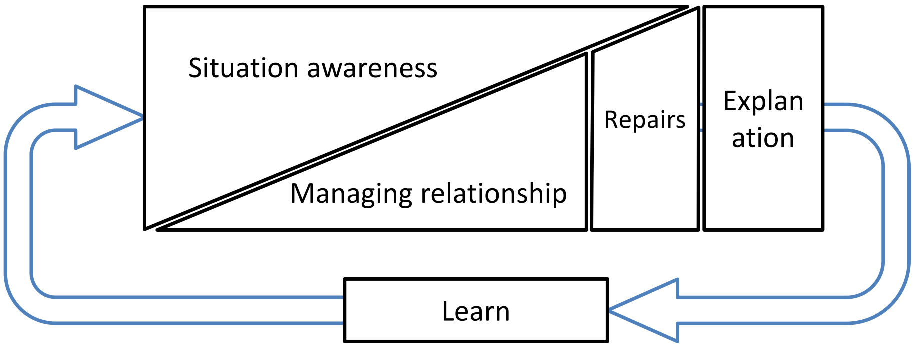

Figure1. *Resilient response model of ICT maintenance service.*

5.1 Situation Awareness

The maintainer finds out not only the situation as regards the failure, but also the mood of the customer, which corresponds to Monitoring in RE. S/he understands the failure using information from logs of devices, system tests, and the attitude of the customer with regard to the failure history. The maintainer chats to discover the customer's personality. This overlaps the process of managing the relationship.

5.2 Managing Relationship

The maintainer manages the relationship with the customer, who is often irritated by the failure. A good relationship enhances the acquisition of information about the failure, and improves the effectiveness of the explanation. Most maintainers were careful about their appearance and were polite in conversation. Sometimes they examined devices not directly related to the fault so as to improve the relationship. This process and the following two correspond to Responding in RE.

5.3 Repairs

The maintainer identifies the failure cause from the information collected and rectifies the problem. Devices may be replaced or settings changed.

5.4 Explanation

The maintainer reassures the customer by explaining what the problem was and what corrections were made. The level of detail is changed to suit the level of ICT literacy or knowledge of the customer. Sometimes briefing material/notes were given to the customer so the customer could understand the failure and the maintenance result easily

5.5 Learn

The maintainer strengthens personal knowledge from the troubleshooting events. Sometimes maintainers will exchange their experiences and know-how if an unusual situation is encountered. This process matches the Learn ability in RE.

6 DISCUSSION

6.1 Interpretation of the Model

In our model, situation recognition, which includes understanding the customer, is the most important activity since it impacts the relationship created with the customer and repair efficiency. As there are great disparities in the situations encountered, the maintainer needs a lot of skill to recognize or diagnosis the situation correctly.

The second most important activity is managing the relationship. If the maintainer cannot build a good relationship with the customer, s/he cannot find out about the situation from the customer and may wastes time, or even makes the situation worse. As mentioned above, customer satisfaction is more dependent on good relationship than on technical skill.

This model fires after the maintainer gets a maintenance order. Because we focused on the activities after the dispatch, this model does not contain Anticipating in RE. However, the maintainers inherently have some anticipation before the dispatch. For example, they anticipate external connection troubles in the rainy season. After receiving an order, they anticipate the trouble type from the information of the failure history. This anticipation will guide them in monitoring the situation in the customer's home, making a diagnosis and repairing the fault. Likewise, they anticipate the customer type, confirm the type, and decide the response.

If they get the wrong failure history or encounter a new case, they cannot anticipate the trouble nor have good foresight in monitoring, and may fail to respond properly.

These trends have parallels in other activities, e.g. medical diagnoses. The physician may know of a specific flue that is currently active. S/he anticipates the disease through this prior information, monitors the patient, and decides the treatment options.

6.2 Data Collection Approach

To make guidelines that can improve the ability of resiliency, we must first tackle the issue of gathering information that permits identification of the key issues.

Since in our case satisfying the customer is the key goal, as is represented by Situation awareness, Managing relationship and Explanation in our model, we cannot be assured that semi-structured interviews and protocol analysis will gather sufficient information. This important point was found in our in-field study of on-site maintainers.

Our ethnographic study was critical to finding what was done and what was important in advancing their work. This approach is suitable for collect various cases and context data in natural settings (Stanton et al., 2005). In this study, we accompanied the maintainers and could directly gather their behaviour in the customer's house, which is impossible to reproduce in the laboratory.

On the other hand, the ethnographic approach cannot clarify cognitive processes, nor compare individual performance in the same context. These goals are best addressed by conducting semi-structured interviews and protocol analyses (Schaafstal et al., 1992).

We believe that it is important to identify the key points with ethnographical studies, and then clarify the practical knowledge with experiments in the laboratory or focused interviews.

7 CONCLUSION

The most important result of this study is that maintenance service personnel need not only technical skill to recover failures but also non-technical skills to build a good relationship with the customer. It is this latter point that we need to emphasize in training.

We conducted additional interviews of experts and focused on the non-technical skills. From these interviews, guidelines that will greatly improve the resilient response of novices are being made. We aim to raise the level of such skills and supress personal variation to create much better service.

This study will contribute to improving the methodology that enhances staff resiliency which is necessary in all service activities connected with human beings or customers, such as healthcare or medicine.

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Actions Contributed to Disaster Level Reduction of the Fukushima Accident

Makoto Takahashi [1] and Masaharu Kitamura [2]
[1] I Department of Quantum Science and Energy Engineering, Tohoku University, 6-6-01 Aza-Aoba, Aoba-ku, Sendai 980-8579, Japan
makoto.takahashi@qse.tohoku.ac.jp
[2] Research Institute for Technology Management Strategy (TeMS), 6-6-40-403, Aza-Aoba, Aoba-ku, Sendai 980-8579, Japan
kitamura@temst.jp

Abstract

In this paper, the actions less known but contributed to mitigate outcome of Fukushima accident in the light of the concept of resilience engineering are described with the emphasis on the human positive contributions. Although accident reports already published mainly focuses on finding persons to be blamed and on finding root causes, there were judgments and actions that reduced the disaster level of the accidents after the tsunami hit the plant and lost almost all methods to save the plant. In this paper, the positive aspects of the efforts made by the TEPCO has been focused and discussed.

1 INTRODUCTION

The accident of Fukushima Daiichi Nuclear Power Plant after the Great East Japan earthquake has caused huge and tragic influences on the people living not only in Fukushima but also on the people living in nearby prefectures by the uncontrolled release of radioactive materials. Although four accident reports already published and the details of accidents have become open, main focus of the reports (except the one by TEPCO) is on finding a person or a company to be blamed and to take responsibility for the disaster (NAIIC,2012) (ICAFNP-TEPCO,2012) (IICFNA,2011)（TEPCO,2012）. Generally speaking, the purpose of an accident investigation should be to reveal the sequences of events and identify the cause of the accident. In the framework of the Resilience Engineering (RE), however, the mechanisms of causing failure are considered to be same as the ones leading to success and the cause of the accident cannot be attributed to a single root cause. In this paper, the focus has been set on the actions less known but contributed to mitigate outcome of Fukushima accident in the light of the concept of RE.

2 HISTORICAL VIEW OF TEPCO

As far as authors know TEPCO as one of the leading company in Japan, they have paid enough attention on the safety of the nuclear power plant after so called TEPCO problem in which it was exposed as falsifying safety data, including Fukushima Daiichi facility. After this scandal, TEPCO took serious actions against such wrongdoings and became more concerned about the organizational safety.

In the field of human factors, TEPCO had been leading other utilities and had been very positive to take actions for the enhancement of the safety concerning human factors. In terms of regulations, TEPCO had followed all of the rules and regulations instructed by NISA. It seems that it is not fair to claim that TEPCO was the company that kept the nuclear power plant danger and uncontrolled situations by breaking regulatory rules and pursued their own profit. What TEPCO did to enhance the safety of nuclear power plant seemed quite reasonable within the range of common sense. It is easy to blame TEPCO based on the hindsight thought. What decision had been made at stockholders meeting, we wonder, if someone made proposal to build a breakwater against tsunami by spending ten billion JPY before 3.11.

Still, we have to face the fact that terrible accident did occur at Fukushima Daiichi Nuclear Stations, in which the core melt had occurred and huge amount of radioactive materials has released. Hollnagel pointed out the inadequate engineering anticipation or risk assessment during the design phase, in combination with inadequate response capabilities precipitated the disaster (Hollnagel, 2013). Authors totally agree in that overconfidence in the expert anticipation of what might go wrong limited the ability to monitor and respond. However, authors also believe that there were judgments and actions that reduced the disaster level of the accidents after the tsunami hit the plant and lost almost all methods to save the plant. In this paper, the positive aspects of the efforts made by the TEPCO has been focused and discussed.

The state of the plant had drifted toward safety boundary and they could not be aware of the distance to the dangerous region. One possible reason of this unawareness of the danger may be the biased attention on the problem of earthquake and its countermeasures. TEPCO experienced large earthquake that hit another nuclear power station at Kashiwazaki-Kariwa in 2007. The earthquake caused fire at one of the transformers in Unit 3 and gave general public negative impression on the safety of nuclear power plant. Since then, TEPCO had been busy to restart the plants by taking measures to deal with the situations. The countermeasures against earthquake itself had been paid more attentions when the Great East Japan earthquake occurred. NISA ordered all utility companies to prepare revised measures against earthquake and utilities mainly spent their resources on this issue. Although TEPCO may have been aware of the necessity of any countermeasures against possible huge tsunami, the priority was on the earthquake and the countermeasures against tsunami was postposed before 3.11,2011. The situation of regulatory body had been the same and they also had focused their attention mainly on the earthquake, partly because the social atmosphere required it. Although this kind of cognitive bias is characteristics of human beings, it made the recognition of distance to failure more and more difficult.

3 REVIEW OF FUKUSHIMA ACCIDENTS

As stated in the previous section, the critics described in the accident reports seem to be unable escape from the hindsight and focus mainly on what went wrong and also on why it happened by finding out flaws in the actions taken in the desperate effort to save the plant. The basic concept in RE insists that the mechanism underlying failure and success is the same and we have to pay more attention on why things go well. It is rather easy to criticize flaws in the actions after we know the overall situations. However, the positive contributions of human actions to mitigate the severe accident should be more emphasized in order to prevent similar accident to happen again. Although there were some problems to be blamed concerning the basic design of safety system and system layout, preparedness against the loss of all external power supply, etc., it should be noted here that the accident had been far more disastrous without the positive contribution of the people who fought against the unbelievable damage caused by tsunami. Several examples of this positive contribution are described in the following.

The Fukushima accident can be categorized into the Irregular Threat, which is quite challenging and unexpected situations with no previous experiences and predefined procedures to cope with. Although there is a discussion whether the possibility of tsunami huge enough to cause critical damage to a nuclear reactor had been recognized by the board of directors of TEPCO, the event happened on 3.11 was totally unexpected from the viewpoint of plant personnel working then. The book written based on the interview of Masao Yoshida, Head Of Fukushima Daiichi Power Plant has revealed the important facts that have not been addressed in any of the previous accidents reports (Kadoma, 2012). Some of the examples of human positive contribution to mitigate outcome are described below.

Just after the huge tsunami hit the plant and lost all of power supply including emergency diesel generators (except one in unit 6), Mr. Yoshida made direction to examine the availability of the fire engine in the power station and asked the head office to arrange fire engines to be sent to Fukushima Daiichi Plant as early as possible, recognizing the possibility of situation in which fire engines were required to inject water into reactor. Although the use of fire engine has been assumed in the Severe Accident procedure, this decision should be appreciated considering the battlefield situation he faced then.

Second example of human positive contribution is the success of line-up of waterline from a fire engine into the reactor of Unit 1 before the radiation level of containment became critically high. It should be noted here that the decision to perform this action was made by the operators of Unit 1 without the top-down directions from emergency management room dealing with all units in Fukushima Daiichi Nuclear Station. If they had failed to line-up this waterline on this limited opportunity, there was no method left to inject water into the reactor vessel, which may have resulted in far more disastrous situation.

Third example is the successful escape of a tanker landing heavy oil. A tanker was at the site port and was landing heavy oil at the moment of earthquake. When tsunami alert came, operators followed the emergency procedure to stop landing and made narrow escape from the site port before tsunami came. They intentionally cut the oil fence to shorten the time required to escape. If they had failed to escape from site port before tsunami, the ship may have crashed against the reactor building and the leaked oil may have caused uncontrollable fire, which would have made the situation more and more disastrous.

4 DISCUSSIONS AND CONCLUSIONS

From the view point of RE, the plant personnel definitely knew what to do by using the limited resources remained. They made desperate effort to take emergency measures against all odds. Also, they knew what to monitor and how to monitor, but there were no way left to measure important parameters in the control room because of the total loss of sensing capability. (Later, they succeeded in reviving limited sensing capability by using battery taken from cars.) Under such hopeless situations, they knew what the consequences would be and tried to take possible actions to mitigate the outcome of accidents. Although TEPCO may have lacked in the resilient characteristics in the long-term perspectives, the people in sharp-end, who dealt with totally irregular threats and managed to avoid worst possible plant situation, should be appreciated for having higher resilience.

It should be noted here that there are many “should-have’s” in the accident reports based on hindsight. The focus of the accident reports is biased against people who actually made considerable effort and succeeded in avoiding worst possible situation. Lessons learned from such hindsight thought may not contribute to enhance safety in the future. We should pay more attentions on the human positive contribution to mitigate outcome of the accidents and on why things went well.

The present paper focuses on the two important aspects in resilience engineering. One is the difficulty in recognizing distance to the safety edge when organization seemed to pay attention to safety extensively. The questions; why we could not insist the risk of tsunami and why we overlooked the risk in the face of the evidence; these are the questions we have to find the answer for.

The other is the human positive contribution to mitigate the consequences of the disaster. The detailed analysis considering the human cognitive characteristics has been performed to find that there were many human actions to be praised considering limited resources and psychological conditions as well as negative ones emphasized in the accident reports.

In this paper, the trade-offs in long-term and short-term perspectives have been focused concerning the Fukushima accident. For long-term perspective, the difficulty in decision of prioritization in selecting required countermeasures against possible threats under the trade-off situations has been emphasized. It is pointed out that the existence of cognitive biases in recognizing risk had misled the decision to put the priority more on the countermeasures for enhancing structural tolerance for earthquake while the countermeasure for tsunami left untouched.

For short-term perspectives, the difficulty in managing simultaneous events under the limited resource situation is described with the emphasis on the appreciated actions that contributed to the mitigation of the disaster. The focus has been set on the successes in dealing with trade-offs among required actions under severe and desperate situation.

What TEPCO learned from this accident is quite important to judge the level of resilience after the accident. As stated earlier, we have to admit that the long-term resilience of TEPCO had degraded gradually and the sensitivity for distance to the safety edge was not high enough to prevent the disaster. When we consider the possibilities of an operation of nuclear power plant in the future, the one of the essential characteristics of resilience, that is, learning capability of TEPCO should be evaluated cautiously. TEPCO already took actions to prepare hardware to prevent similar accident to happen. Furthermore, they established "Nuclear Reform Special Task Force" led by their president in order to reform TEPCO's safety culture, safety measures, disaster prevention measures, risk/crisis control protocol, information disclosure, and risk communication methods. The important point here is that they sincerely admitted that the accident is attributable to their lack of proper risk perception and also to the overconfidence in their safety culture. Authors believe that TEPCO learned much from this disastrous accident and they will continue to make efforts for enhancing safety and to maintain higher level of resilience in the future.

Acknowledgement

This work was supported by JSPS KAKENHI Grant Number 25289347.

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The Management and Evaluation of Change

Nick McDonald
Centre for Innovative Human Systems, Trinity College Dublin. Ireland
nick.mcdonald@tcd.ie

Abstract

Understanding the functionality of how a socio-technical system works is the key to managing more effectively, and to comprehending how it is possible to change to achieve better outcomes. But this understanding is not well supported in social and technical theories. Change is as likely to fail as to succeed and cycles of stability are the norm. A theory of the mechanisms of organizational change is proposed based on the tension between the functional requirements of operational processes and the social relations that are necessary to support them. Cycles of knowledge and information mediate between these and provide opportunities for intervention. This theory is being tested in a number of case studies supported by such interventions. These concern the change of a small regional airport from a public body to a thriving business concern; the introduction of collaborative decision making at a major international airport and the introduction of safety management system at a major airline. Criteria for assessment include functional effectiveness of the future process, consensus for change and capability to implement change.

1 THE CHALLENGE OF SYSTEM CHANGE

The world of operational systems and services is changing not only because of relentless commercial pressures to cut cost but also because the deployment of new technologies creates unprecedented opportunities to reorganize even quite remote relationships in the system. This change is accompanied by pressure for new types of regulation, and new ways of organizing the business space between manufacture and operations. A number of tendencies can be discerned: leaner processes with less redundancy and tighter coupling; greater system integration with changed roles and relationships; joined-up management systems that deliver, in an integrated manner, improved quality, safety, cost, efficiency, and lower environmental impact; being able to measure system performance, both under normal and abnormal conditions so as to provide a reliable evidence basis for policy, development and change; being able to manage system change and improvement taking account of both cultural and technological aspects, so as to develop resilient, adaptable socio-technical systems.

Understanding the **functionality** of how such a system works is the key to managing the system more effectively, and to comprehending how it is possible to change the system to achieve better outcomes, or to how to design a future system to operate in a way that transcends current practice. Understanding and managing the complexities and risks of operational systems, being able to achieve change and to design future systems are the core capabilities to meet the challenges outlined above. Paradoxically it is just those conceptual and methodological tools that could help us understand that functionality that are missing from most approaches to social and technical systems. Human Factors and Ergonomics are too local in their approach despite having aspirations to being a system science (IEA, 2010); organizational psychology addresses just about every aspect of organizations except the functionality of the production system; business process modelling and engineering, which does address those functional relationships is very light on the human and social components; theories of knowledge management (Brown and Duguid, 2001; Nonaka, 2002) largely eschew an analysis of the content of that knowledge.

This is rather unfortunate because the literature on organisational change demonstrates that, against different criteria and outcomes, only a minority of major change initiatives (typically between 30 and 50 percent) have a positive outcome (e.g. Dent and Powley, 2001; Kotter, 1995). From some of the few longitudinal studies of change, Pettigrew shows how change is complex, frequently opportunistic, and depends on the balance of capacity within the organisation with the opportunity that the organisation's environment brings (Pettigrew, 1985, Pettigrew and Whipp, 1991). Just as major organizational change initiatives are prone to failure, so to the failure rate of IT projects can be as high as 60-70% (IT-cortex, 2010). However more recent evidence suggest that the failure rate may be as low as 30%, when more flexible criteria are applied (Sauer et al. 2007). While size is a key predictor of failure rate it is becoming increasingly recognized that organisational and management factors are critical to new IT interventions – not just the technical quality of the product or the development process itself. End-user involvement in design as well as project management and resources in the implementation phase are all critical factors.

These difficulties have led some theorists to emphasise the emergent features of change – those that come from the complex interactions of organisational structures and forces that are difficult, often impossible, for managers to control effectively – as compared to viewing change as a rational process subject to effective planning and managed implementation. However, and this is the knub of the matter, what does emergent mean? Is it possible to understand the relationships between local interactions and dynamic charactieristics of the system? Thus, can our theories be relevant to solving this problem? If this is possible, then can the theory give leverage by helping to derive interventions that can be demonstrated to be effective?

1.1 Organisational change

Much of the energy of social systems works to maintain and reproduce a stable social system, and that stability, the ability to reproduce again and again the same activity and outcome is what is highly valued in productive organisations. Change should not be considered easy, but the difficulties are often underestimated because the powerful mechanisms that assure stability are part of the unacknowledged background of an organisation's continued existence. Even where change would seem to be a compelling option (as when there are serious safety failures), it seems that cycles of stability are more the norm than the exception – where the organization expends a large amount of effort to address a problem, but the outcome is stasis. There are many examples of such cycles of stability. Underlying many failures experienced is a lack of an effective organizational process for solving problems and implementing solutions. The required understanding or competence to deal with issues concerning people in processes is often lacking amongst the people in a position to intervene through different roles.

On the other hand change can be successful. Ward et al. (2010) report on just such a successful initiative that addressed and overcame a long history of relative failure in change. It showed how process improvement, through removing 'blockers' to working effectively, resulted in a very profitable series of maintenance checks for a maintenance company, delivered on-time performance for its customer airline, and removed a lot of frustration for the workforce. Collaborative process modeling created a consensus about how the operation really worked and what needed to change; a strong local improvement team and a management process delivered effective solutions to problems; the development of trust and the measurement of progress began to transform the organisation's culture. The improvement program increased reporting, identification and mitigation of hazards. Despite a competitive contract, the airline and the maintenance company were able to collaborate to share information, manage risk and improve both safety and commercial outcomes for both companies.

2 A THEORY FOR UNDERSTANDING THE LOGIC OF CHANGE

For a theory to provide leverage it has to move from being mainly descriptive of aspects that are relevant to change to providing a functional model of some of the dynamic relationships that can explain the mechanisms of organisational change. The proposed approach is based on the functional requirements of the operational process, social relations and the role of knowledge & information cycles mediating between these. This model attempts to answer the questions – How does the system work? What & how to change? This approach links the analysis to the opportunities for intervention, primarily concerning knowledge and information cycles. Hence the new theoretical framework provides a strong basis for planning, evaluating and providing support to change initiatives.

Change evaluation criteria are based on Dawson's (1996) analysis of change. Loosely interpreted, her criteria for successful change pose the following questions:

- Can the to-be functional process deliver the required outcomes?
- Is there sufficient consensus & common understanding to support the change?
- Is there capability to deliver what is needed to implement the change?

Dawson concluded that 'These conditions [….] are rarely achieved; to believe that they are achievable is dangerous' (p. 261). While agreeing with Dawson that total consensus at all stages or overwhelming power, complete knowledge of all cause and effect relationships, and control over all intervening variables is an impossible dream, it is important to strive to improve understanding and control over precisely these dimensions in order to reduce the variance and failure rate in change. A theoretical account of resilience of complex socio-technical systems needs to treat system properties like emergence and resonance as being amenable to an analysis of cause and influence. To manage change effectively requires understanding of the fundamental functional characteristics of social systems in order to maximise the opportunities for leverage over them. The theoretical framework proposed comprises three totally interlocking, interpenetrated systems, each one organized according a particular logic, each logic delivering a particular value. Each has a basic organising principle, a mode of creating value, a timescale and a role.

2.1 System 1 – Process functionality

The basic organizing principle of this system is sequence, not necessarily in a simple linear fashion, but encompassing parallel activities, feed-back loops and iterations. Value creation is through transformation of resources through tasks into outcomes that have transactional value. The timescale is real time (especially for services which do not have the buffer of product warehousing and inventory). Value is defined by the customer and delivered to the customer by the supplier through the co-ordination of resources and tasks (including the management of all related inter-dependencies) to produce an outcome meeting the customer's requirements. Resources can comprise material, people and information. The role of co-ordination is to manage the inter-dependencies between diverse tasks and resources, within and between processes, to ensure the delivery of the outcome. The successful delivery of a process outcome depends on only three basic types of causal relations – the supply of resources; their transformation through tasks; and the co-ordination or management of associated dependencies. Every process can be analysed in terms of the uncertainty in each of these three types of causal/functional relation that arises from its fundamental causal model. Every process conforms to a fundamental logic or basic causal model related to the dominant source of the uncertainty that has to be managed. For example, it is proposed that the dominant (though, of course, not exclusive) uncertainty in aircraft base maintenance concerns resources, in flight operations concerns task vulnerability, and in an aircraft turn-around at an airport concerns co-ordination. It is argued below that the dominant form of uncertainty in change and design processes concerns the outcome of the process.

2.2 System 2 – Social system

The basic organizing principle of social systems is reciprocal complementary relations. Social capital adds value through stable relationships that support the reliability of transactional value generation. They are relatively stable over time. The slow process of consolidation of culture and social system implies a 'décalage' or time-lag/misalignment between the contemporaneous requirements of the functional process and the way in which it is supported in social relations and represented in culture. People operate as part of a social system, managing the dependencies within the process system. Thus the social system is as much a part of overall system functionality as any other part. Where the system requirements (from the technical, economic, competitive point of view) are changing, this creates tension and strain.

2.3 System 3 – Information & Knowledge Cycles

The basic organizing principle concerns circular or cyclical relations - knowledge in use seeks to be validated (e.g. through feedback). Sense-making drives action to meet (or not) functional requirements of the system. The system (potentially) generates data that feed knowledge about the what and the how of system activity. Value creation operates through two processes that manage different types of knowledge – a tacit-explicit process that is socially driven and a data-information-knowledge process that is technologically driven. The transformation of tacit operational know-how to explicit functional knowledge enables future design. Functional knowledge is used to select data representative of system functions, to organize those data into information and to use that information to understand system performance. It is the management of knowledge through these two processes that gives leverage over system design and change. The timescale reconciles past, present and future, dealing with history, current problems and expectations, in iterative cycles. However, underlying this is the possibility for an enduring capability to manage these knowledge cycles, creating a long-term cycle of growth and development.

3 DESIGN AND CHANGE AS PROCESSES

Design and change processes differ from routine operational processes, because the precise outcome is uncertain. Because design and change processes seek to produce something new, the precise requirements for success may not be known at the beginning of the process. These requirements may only emerge as the process develops, through making and learning from mistakes (the wrong action creates the conditions for the right action). This is in direct contrast to the 'right first time' philosophy that is a characteristic ideal of routine operational processes. The consequence of this is that design and change processes need to be iterative with updateable plans, models and analyses. This is in line with Zizek's (2012) analysis of radical change, for example: "The first choice has to be the wrong choice [because] the wrong choice creates the conditions for the right choice". Radical change "retroactively posits its own presuppositions". However these quotes reflect the point of view of post-hoc reflection – having acted we now understand better the preconditions of our action, precisely because we can now see the consequences of our action. But we are always in the position of having to choose how to act and this needs to be planned and executed in the light of the (pragmatically) best possible evidence and analysis. Action creates three outcomes: new 'facts on the ground' of the action and its consequences; the possibility to engage dialogically with all relevant stakeholders in that new situation; and the opportunity to reinterpret the past ("retroactively posit … [better understood] presuppositions") and project a better model of the future. In managing change, all these opportunities need to be taken, iteratively building a case for change through action, working forward, looking back. This is maybe a key way of addressing the 'emergent' aspects of change. "Emergence" therefore becomes something that needs to be understood and managed rather than something that defies comprehension.

4 THE EVALUATION OF CHANGE

A general assessment of change adopts a basic sequence of change process stages (identification of needs and goals; planning and preparation; execution and monitoring; review and reinforcement), while acknowledging that these phases are often iterative, and any change initiative may be at different phases in relation to different levels and different aspects. It builds on prior analysis of the operational process that defines the functionality of the current and future process. For core task groups as well as the wider process group, the integration and alignment of the group as a functional unit is defined in terms of the characteristics that define a team. Specific functional characteristics of the operational situation identify the potential for trust. The knowledge cycle is assessed in terms of the challenges and opportunities in creating common understanding and values concerning the change proposed. The analysis of the information cycle concerns knowledge about how the system functions and the outcomes that it delivers. These are the factors that need to be managed in order to steer the change initiative in a positive direction. The evaluation strategy is to consolidate this assessment of status at the various stages and compare it with the eventual outcomes. This framework is part of the development, support and evaluation of a set of actual change case studies. These case studies include the following:

A comprehensive set of Safety Performance Indicators have been incorporated in a Safety Management System as a way of identifying and driving improvements in a major airline. This is part of a long evolution of the organisation's safety management system through periods of consolidation, integration and radical change to the organization. It involves challenging demands to develop a common safety and risk framework across different departments, to develop common performance management approaches between safety and other goals and to link safety with lean change initiatives.

A holistic performance management approach has been developed and is being implemented in a small regional airport. This is part of a major strategy to create a more business-oriented framework which is critical to the organisation's survival. It has involved developing a new software system based on process mapping to support a daily activity journal, reporting of operational anomalies and identifying hazards.

Airport Collaborative Decision Making is being implemented in a major airport. Like many airports, this has a wide variety of independent ground handling companies and airlines. One challenge is in aligning local goals for a more global objective, and the sharing of data across different stakeholders - Handling, Airport, Airline, ATM. One of the contributions of the MASCA project has been the development and use of a serious game, based on the airport turnaround process that seeks to demonstrate the value of collaboration amongst competing partners.

These case studies, amongst others, will form test beds for the development of a change evaluation framework. All involve coordination and cooperation across boundaries and between members of different organizations. This is part of a long-term strategy to develop a more powerful model of change evaluation by progressively testing predictions against actual outcomes of change initiatives. The initial step is to force the change analyst to think about the causes and consequences of each element of the change process (this is not easy). For each change initiative it is necessary to project an endpoint of the process, when it will be possible to measure the outcomes at that stage. This will allow the comparison of outcomes against goals, and test predictions against outcomes. If repeated for many initiatives, it will be possible to revise the model and theory accordingly.

5 CONCLUSION

Resilience describes some properties of the functional mechanisms of a system that makes it more adaptable and more capable of responding to adverse circumstances and hence more likely to survive. One of these properties concerns the ability of an organisation to develop and use its knowledge and information resources to foster both a common understanding of both what needs to be done and how to do it, fully taking into account the stake and role that each one has in the system and its outcomes. Perhaps this give the best chance to sustain a momentum of change, despite the natural inertia of organisations and external events and influences that normally divert and derail such processes. Whether and how this happens is open to empirical verification by carefully studying the process and outcomes of change initiatives.

Acknowledgements

This work was supported by the European Commission FP7 MASCA project (MAnaging System Change in Aviation) Grant agreement n° 266423. It is based on the work of colleagues and partners in this project whose contribution is hereby acknowledged.

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