

FROM AIR TO GROUND – RESILIENCE STRATEGIES AND INNOVATION ACROSS CRITICAL INFRASTRUCTURES

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Abstract

We compare strategies and tactics for increasing resilience in three critical domains: aviation, healthcare, and energy. We explore similarities and differences addressing the following questions: What does resilience look like in everyday operations in an air traffic control center, a power plant control room and an acute care hospital? How does each setting anticipate, prepare and respond to surprising and novel events? Are there strategies that are uniquely suited to each domain, and why? Which strategies would work across domains? Which would not and why? The authors disclose a self-serving motive of learning from each other thereby building a richer toolbox for resilience engineering practitioners. The themes will consider the challenge of implementation and thus be paired with innovation techniques that could be used to co-create robust solutions with end-users. This creates an opportunity for innovative thinking at all levels of the organization with respect to preparing for, and responding to novel and surprising events. Management innovation to mature resilience concepts gives room for unique and unorthodox approaches to unleash people's thinking and attitudes; where everybody is pushed to consider useful solutions.

1 INTRODUCTION

Demographic and socio-economic changes, globalization, fast-paced technological innovation with an increasing reliance on automation and access to digital data, all have a significant impact on the way that people think about and perform their work. How does the workplace reconfigure itself to respond to these changes to ensure continuous operation and provision of essential functions and services? We start with the underlying theme that systems today are very complex, and yet both management and frontline staff can be resilient and adaptive to the dynamic and often unpredictable nature of everyday work. Our challenge is to understand the resilient and adaptive capacity of high-risk, complex workplace environments, with the overall goal of developing a platform to enable resilient and adaptive capacity. We begin by highlighting the complex nature of three risk critical industries and then we describe what is currently understood about the key features of resilient teams. Following this, we explore the potential of applying innovation management and innovation games to enable resilient and adaptive capacity in the workplaces.

2 COMPLEX ADAPTIVE SYSTEMS AND WORKPLACES

Air traffic management is an example of a complex system. It is a formal system, with clear roles and responsibilities defined by international rules, regulations, manuals and procedures adapted to different aerodromes. Air Traffic Controllers have a range of responsibilities, including providing air-space control and guidance to the aircraft under varying conditions e.g. seasonal, weather, interactions with other air traffic management units as well as coordination with other organizations such as ground services and airline companies. Cyber-physical systems and increase of automation are transforming operational concepts and ways of working towards highly networked systems-of-systems. An example is remote tower operations.

Modern power plants epitomize complex systems and variable work. "Everyday work" in power plants has been disrupted with the increase in renewable power, plants that were once "base-loaded" (running constantly) are now starting and shutting down daily; work happens on elevated platforms, in all kinds of weather, in hot, enclosed spaces, and everything in between. One mechanic described routine work as "It's different every time." Complexity comes from the many, interconnected and interrelated systems that make

up a power plant with critical, tight operating parameters and little margin for error.

The delivery of healthcare is also marked by complexity and unpredictability. Diversity is a key feature of health care delivery – diversity of patients, diversity of clinical specialization and support staff, diverse and often complex care pathways, and the trajectory of patient care often involves a range of locations with substantial variation of the clinical layout and care environment. The social context of healthcare is also complex, as patients are inherently vulnerable and there are a myriad number of relationships to manage – between patients, healthcare providers, support staff, family members and community agencies. There is rapid implementation of new technologies. In healthcare, work situations are always underspecified (i.e. the conditions of work frequently do not match what has been specified or prescribed), and thus when unpredictable components or dynamics arise within the system, adaptation is often necessary. Performance variability is both a normal and necessary feature of the healthcare setting.

3 CURRENT AND EMERGING RESILIENCE THEMES (“PRIMER FOR RE NOVICE”)

3.1 Resilience Organizational Characteristics

Drawing from bodies of knowledge in Resilience Engineering (RE), Highly Reliable Organizing (HRO), and our own experiences, we paint a picture of “ideal” resilient teams, they:

- *Are prepared to be surprised. Point of view: surprise will happen.* They notice and manage small signals, emerging risks, and uncertainty. They practice making decisions when uncertainty is high. They look for how they will be or have been surprised. They prepare for the general shape of risk.
- *Hold a constant sense of unease. Point of view: past performance is not an indicator of future success.* Remaining sensitive to the possibility of failure or opportunity is recognised as important both within High Reliability Organizational (HRO) theory and RE (adapted from Hollnagel, Nemeth & Dekker, 2008).
- *Are flexible, adaptable, and gracefully extensible (positive capability to stretch near and beyond boundaries when surprise occurs). Point of view: change is constant.* They develop adaptive capacity (ability or potential to adjust activities, resources, tactics, and strategies in the face of different kinds of events, variations, demands, and uncertainty) to regulate processes relative to targets and constraints. This is a simple extension of an old definition for skill and expertise, the ability to adapt behaviour in changing circumstances to pursue goals (Woods lecture on Resilience Engineering, 2015). They prepare both static (margin) and dynamic (capacity) slack, defined as available, spare resources of any sort which can be called on in times of need (Freyer, 2004). They manage differently when close to boundaries. Systems and organizations need graceful extensibility as a separate kind of capacity to our everyday performances when the system is far from the boundary conditions (Woods, 2015). *Sustained adaptability* offers new ways to manage interdependencies across scales. It refers to the ability to manage adaptive capacities of systems (organizations) that are part of a layered network (Woods, 2017 in preparation).
- *Learn on a routine basis from every day activities, threats as well as opportunities. Point of view: Important lessons are in the 99% of work that goes well.* Learning focuses on frequency, performance variability and performance adjustments during every day work. They also learn from situations where something unexpected happened, uncertainty was high, operating close to boundaries, or running out of margin to respond through assessing how well and quickly they dealt with the situation.
- *Are empowered at local level with humble leadership. Point of view: workers are local experts.* Organizing for resilience requires a balance between local and central governance. Through humble leadership and empowering people with necessary expertise to solve the situation at hand, resilient organizations provide space for creative problem solving. Leaders leave rank at the door and commonly offer help to the frontlines.
- *Understand the distance between work as imagined (WAI) and work as done (WAD). Point of view: work is variable.* Conditions related to the work, worker, and workplace are always changing. Workers are afforded freedom and flexibility to get their job done, guided by commander’s intent. Routine work is approached looking for what’s different today. The people who write the rules and procedures make the effort to understand the challenges faced by the front line.
- *Value different points of view and are collaborative, cooperative. Point of view: it takes variety to manage variety.* They build capabilities to manage responses within work units and across different levels of the organization. They create opportunities to build relationships and offer help across organization boundaries. They create insight into each other’s responsibilities, challenges, and goals. They employ practices to look from different perspectives (more experienced-less experienced, challenger, outsider,

and details-big picture). During shift changes, trouble shooting, and assessing risks, there's a lot of back and forth engagement wherein they invite cross checks and ask clarifying questions. (Rayo et al, 2013)

- *Pay attention to the system within its boundary and its environment. Point of view: the system is complex, interconnected, and interdependent.* They plan how to handle relationships, interactions, different tempos, non-linear dynamics, and hidden dependencies; "thinking outside the box" (strategic foresight) is key. They study and plan how they'll handle failure patterns or opportunities. They look for tight couplings that increase brittleness then loosen or de-link, if possible.
- *Use safety models that fit complex socio-technical systems. Point of view: focus on the presence, not the absence, of safety.* A possibility is to analyse functions of how organisations work (e.g. FRAM, Hollnagel, 2017) to change focus from individuals towards resilience performance. When an event emerges, they seek to understand the perspective of those involved and the conditions that existed; moving away from linear, cause and effect models. The interest is to capture, understand and the way systems work when challenging changes occur. It also considers set of organizational aspects: formal systems; technology; values and knowledge in the organization; interactions; and social relations (e.g. Pentagon Model, Schiefloe et al., 2005).

3.2 Why innovation as enabler for resilience management?

We've just described significant changes in perspective from traditional safety programs. We suggest that it takes innovation to successfully implement the non-traditional ideas that RE brings. Innovation management can support the creation of something that is both novel and useful when established rules and procedures no longer apply. In this section, we offer ideas on applying innovation management which have been applied in different European projects.

Innovation can be large or incremental (Mckeown, 2014; Hill, et al, 2014). We relate this innovation process to graceful extensibility, as it can be a new process or a new way of organizing or a creative solution to solve the problem or opportunity at hand.

Today's complex adaptive systems (CAS) require a multidisciplinary problem solving approach where decision-making is deferred to expertise (Dekker, 2014); Weick & Sutcliffe, 2007). Engaging team members with relevant expertise that includes knowledge about operational processes and sensitivity to how work gets done on the frontlines is a critical feature of managing threats and opportunities. The challenge is to how to successfully engage team members in this process. Each person in the team contains a relevant expertise that need to be collected, combined and converted into viable solutions. We see innovation as a core process which needs to be organized and managed to enable renewal of an organization. The concern is not to build a strong innovation management capability but to acknowledge the challenge to create a learning and adaptive approach which constantly upgrades the dynamic resilience capabilities associated with survival and growth (adapted from Tidd and Bessant, 2009). We use innovation management practices and innovation games to create space where people are willing to collaborate, experiment and integrate ideas and co-create solutions. Specifically, we establish shared values amongst team members and this create an environment where people is willing to collaborate and co-create solutions (Hill et al, 2014). These values are as: (1) To address complex challenges, foster experimentation, learning, improvisation and structure; (2) Collaboration of diverse people, with the involvement of end users (operational, maintenance personnel and managers) who interact closely, consolidate ideas and make integrative decisions; and (3) Learning through collaboration and discovery, encouraging diverse and even conflicting views.

We adapted storytelling and innovation games such as the ones proposed within "gamestorming" (Gray, D. et al., 2010). Stories are defined as "narratives with plots and characters, generating emotion in the narrator and audience, through a poetic elaboration of symbolic material. This material may be a product of fantasy or experience, including an experience from earlier narratives. Story plots entail conflicts, predicaments, trials, coincidences, and crises that call for choices, decisions, actions, interactions, whose actual outcomes are often at odds with the characters intentions and purposes" (Gabriel, 2000). The innovation games enable the creation of "new worlds" exploring everyday operations, challenging situations or introduction of new technologies, analysing systems and organizations opportunities and challenges improving collaboration and generating new insights about the way these "new worlds" works and what kind of possibilities we can find there (Gray, D. et al., 2010). Table 1.0 describes a set of innovation games used in different contexts, highlighting the respective purpose and relation to resilience management.

Table1: Example of innovation games adapted to explore resilience

Method (M) – Game (G)	Purpose	Relation to resilience	Lessons learned
Storytelling (Gabriel, 2000)	Rich source of material, not a reliable source of information but it can be revealing. It reveals that facts cannot reveal, individual, peoples or groups value.	Narratives as way of knowledge sharing	Narrative can lead to discoveries
Affinity Map (G)	Discover patterns and meaning by clustering information into relations	organization practices	Used to understand resilience in action. Participants map concepts to their own stories.
4C (Components, Characteristics, Challenges, Characters) (G)	Rapid way to gather and organize information	operational resilience capabilities	Good to map relevant stakeholders and capabilities at managerial and operational level
The Blind Side (G)	To disclose and uncover unknown information	performance variability	Effective way to gather variables affecting performance
Training for resilience capabilities (TORC) (Grøtan et al, 2016)	To guide operational teams and management teams to recognise and facilitate resilience as a critical capability in the context of compliance	sense making, anticipation, respond and after action review	Potential application areas everyday operations, emergency planning, unexpected situations

Our experience so far shows that storytelling and innovation games are powerful tools allowing all participants to share their views and knowledge. We have so far used them for training, discovery of resilient performance and evaluation. We see future areas of application addressing improvisation and creativity during times of surprise for example adapting the “blind side” game mapping and updating “things we know, we know and things, we do not know” during events, thus creating a window of opportunity for action.

4 CROSS INDUSTRY PRACTICES TO INCREASE RESILIENCE (“HOW TO GUIDE”)

A key idea in RE is the importance of “everyday work” in creating resilience. Below we share practices that support creating resilience.

Table2: Sample practices from each domain featured, arranged according to selected characteristics

Theme	Air Traffic Management (ATM)	Power Plant	Health Care
Are prepared to be surprised.	Update on airport current conditions, update on recent developments before starting work. Do simulations involving surprises as part of certification program.	Pretask briefs: “What’s different that could make it harder or easier?” “When we did this in the past, what surprised us?” After Action Reviews: “What surprised us?”	Change of shift, intensive care units. IDRAW I= identify patient; D= current problems; R=recent changes; A=anticipated changes; W=What to watch for? (i.e. What should I be most worried about?). (Wrae Hill, 2015)
Hold sense of unease : Past performance is not an indicators of future success	Briefings are part of hand-over. Actively, constantly monitoring the situation both within the ATM and its surroundings considering potential bottlenecks or opportunities ahead.	Set tone prior to high risk tasks (ex. rotor lift “if you notice anything, no matter how small – stop. Trust your intuition.”) Plan detailed monitoring when starting up after major overhaul.	Patient safety huddles: mid-shift briefings that create heightened awareness of both staff and patient needs throughout a shift, opportunity to clarify information, anticipate what could go wrong, and manage staffing issues.

Theme	Air Traffic Management (ATM)	Power Plant	Health Care
Are flexible, adaptable, gracefully extensible	Support colleagues in case of overload. People available with different competences that can take different roles if required. ATM has many redundant systems	Avoid scheduling critical work during holidays when have fewer people working. Schedule “NASA hold point” near end of difficult maintenance project to re-center and address any issues before hitting “restart” button. Have few redundant systems since risk of equipment tripping is generally accepted.	Prepared to shift people for the “unexpected” such as environmental disasters or threats such as chemical spills or earthquakes, riots, terrorist attacks, epidemics. Overcapacity protocols to manage overcrowding in emergency departments; development of “rapid assessment zones” to reduce overcrowding in emergency departments
Learn on a routine basis	Situations occurred in one site are shared with other sites. Normally focus learning from unwanted situations. Probe where things are going well, ask “where do we never experience (this problem)? Why is that?” (Lundhal, 2016) Do simulations involving surprises as part of certification program.	Share case studies between plants that tell story, from point of view of those involved, to just before revealing what happened, ask: “What would you do? How could this play out? What would you do to avoid...?” Do After Action Reviews when things go well.	Learning through critical incident investigations. Regulatory bodies establish standards and create opportunities for learning. Simulation based learning (artificial representation of a real world process (e.g. clinical scenarios) to achieve educational goals).
Are empowered at local level with humble leadership	Supervisors adapt and reconfigure sectors to shift load... to cope with changing demands and challenging conditions.	Remove symbols of rank (ex. parking places at front, special place at the table). Develop scenario training based on common sacrifice decisions, define acceptable level of risk tolerance. (Crandall, 2000)	Healthcare delivery is strongly hierarchical, and this can be a barrier to effective communication. Leadership can actively work to flatten hierarchy, minimize power distances, and consistently engage all team members.
Understand the distances between work as imagined (WAI) and work as done (WAD)	Air traffic controllers actively monitor each other. Air traffic controllers and supervisors practice “humble inquiry” (Schein, 2013)	Teach value of, and how to ask, open-ended questions. (Schein, 2013) Implement “Learning Teams” wherein you query WAI and WAD (Hollnagel, 2017, Conklin 2012)	Critical incident investigation work that uses a framework based on resilience perspectives. Patient safety senior executive walk-arounds to understand how the work gets done on the frontlines.
Value different points of view, collaborative, cooperative	In the control rooms collaboration between controllers, supervisors and novices is practiced considering the criticality of the operation. This builds trust necessary to perform reconfiguration and adapt to situations.	Purposefully build cross-plant relationships. Drill with all staff to build understanding of each other’s roles and develop trust. Teach collaborative engagement during shift turnover: taking turns, off-	

Theme	Air Traffic Management (ATM)	Power Plant	Health Care
		going invites crosschecks, on-coming actively questions. (Rayo, 2013)	
Pay attention to the system	Operational personnel look to the system and relation to their environment e.g. other actors.	Look for tight couplings and interdependencies, loosen or de-couple (ex. brittleness assessment when planning multiple maintenance outages). Notice patterns, such as a plant trip followed brief lull before 2 nd cascade begins.	Critical incident investigation that understands safety as an emergent property of the system, and seeks to explain the system level contributions to incidents, rather than looking solely at the sharp end of care.
Use safety models that fit complex socio-technical systems : How safety is created is more important than the absence of safety	For new technologies, different safety models are in experimentation. Case studies analyse the impact of new technologies on ways of working (e.g. remote towers). Resilience perspective enables identifying bottlenecks as well as new ways of using technology.	Create safety through learning to notice “stack-up of risks”, recognizing risk and uncertainty through language (ex. “worse than”, “not sure”), and Real Time Risk Assessments for quick response for emergent risks. After an incident, seek to understand conditions, dilemmas, and system view.	Overcapacity protocols to manage overcrowding in emergency departments; the development of “rapid assessment zones” to reduce the potential of overcrowding in emergency departments

5 DISCUSSION

All three domains (ATC, power plants, and healthcare) implement methods to understand incidents from system and 2nd story points of view, consider social aspects of work, such as value of using open ended questions and developing humble leaders and shift people or roles to expand capacity. All prepare for surprise through simulations and drills. ATM is in a high state of alert almost continuously, while power plants and healthcare have specific briefs wherein they question and crosscheck related to higher risk work or patients. ATM develops resilience through many redundant systems (note that redundancy could be more related to robustness than resilience), this is less common in power plants and healthcare.

Opportunities for ATM and healthcare include learning from how they have been surprised on a routine basis. Healthcare has routinized shift handovers to probe where to focus attention for oncoming; this practice would benefit both ATM and power plants.

6 CONCLUSIONS

We presented a set of resilient characteristics relevant to three critical infrastructures. We propose the use of both established organizational methods such as storytelling and unorthodox tools such as innovation games to support identification of these characteristics and resilient practices. We have used our experience to reflect how resilience is part of everyday operation in different domains. This knowledge has been collected through years of practice, interview data, observations, questionnaires, storytelling and application of innovation games. We conclude that both adaptation of existing and innovation management tools support a paradigm shift to a resilience-oriented perspective based on RE and complemented by other relevant fields of research and practice.

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